Fishery Data Series No. 08-54

Restratification of the Red King Crab Stock Assessment Survey in Southeast Alaska

by

John E. Clark

November 2008

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

Symbols and Abbreviations

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Weights and measures (metric)

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

Weights and measures (English)

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

Time and temperature

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

Physics and chemistry

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

General

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

Measures (fisheries)

fork length	FL
mideye to fork	MEF
mideye to tail fork	METF
standard length	SL
total length	TL

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

FISHERY DATA SERIES NO. 08-54

RESTRATIFICATION OF THE RED KING CRAB STOCK ASSESSMENT SURVEY IN SOUTHEAST ALASKA

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November 2008

Development and publication of this manuscript is partially funded by grants from the Federally Funded Nearshore Marine Research VI.

ADF&G Fishery Data Series was established in 1987 for the publication of Division of Sport Fish technically oriented results for a single project or group of closely related projects, and in 2004 became a joint divisional series with the Division of Commercial Fisheries. Fishery Data Series reports are intended for fishery and other technical professionals and are available through the Alaska State Library and on the Internet: http://www.sf.adfg.state.ak.us/statewide/divreports/html/intersearch.cfm This publication has undergone editorial and peer review.

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This document should be cited as:
Clark, J. E. 2008. Restratification of the red king crab stock assessment survey in Southeast Alaska. Alaska Department of Fish and Game, Fishery Data Series No. 08-54, Anchorage.

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ABSTRACT

The Southeast Alaska red king crab stock assessment survey provides an annual estimate of abundance and overall health of these stocks. The survey has historically sampled strata which are a mixture of both good and poor habitat, compromising the ability of directing pots to high abundance and variability strata. This study uses geostatistical analyses to revise area stratification, based on the geographic distribution of previous survey catches, bathymetric data, and long-standing experience of industry. Nine survey areas were restratified into 5 abundance-based strata; Holkham Bay was restratified into 3 strata. From 22.4% to 44.0% of each survey area was designated as low abundance strata, averaging 30.4%. A very small abundance of crab was expected in these strata. The remaining abundance estimates were assigned to the remaining four strata. Approximately 20%, 18%, 15% and 14% of each area was designated as medium low, medium, medium high, high abundance respectively.

Restratification of the survey areas improved the precision of catch rate estimates in 2005 for all areas except Juneau Area. The number of pots that caught no red king crab decreased from 43% in the 2002 to 2004 average, to 26% in 2005. The coefficients of variation in catch estimates decreased an average of 29% for female and juvenile male catch, and 24% for mature male catch. The areas showing the largest improvement in precision were Pybus Bay, Seymour Canal, and Deadman Reach.

The pilot sidescan sonar project accurately differentiated mud and mud/cobble habitat, as verified by video samples. Comparison of pot catches in areas classified to habitat type demonstrates the association of crab abundance with habitat type. Catches of red king crab were 2 to 5 times greater in mud substrate and catches of Tanner crab were 5 to 7 times greater in mud substrate compared to hard substrate.

Key words: Red king crab, *Paralithodes camtschaticus*, Geostatistical Analysis, Survey Design, Crab Habitat

INTRODUCTION

Red king crab (*Paralithodes camtschaticus*) stocks in Southeast Alaska are harvested in both commercial and personal use fisheries. Total ex-vessel value in the commercial fishery averages over one million dollars U.S. annually. Personal use catches are rapidly approaching those of the commercial fishery (Hebert et al 2005). However, recent declines in crab abundance in areas which have historically been major contributors to commercial catches have resulted in area-wide closures of the commercial fishery and local closures of personal use fisheries. These estimates of abundance and overall health of the king crab resource depend extensively on the annual red king crab stock assessment survey.

Red king crab stock assessment surveys have been conducted in a number of locations since 1978. At present, 10 areas are surveyed annually (Figure 1) although, historically, a total of 21 different locations have been surveyed 5 or more years. An area is defined as either a single bay or a collection of waters in nearby bays and adjacent shorelines of straits and sounds. The sizes of the survey areas range from 6.4 km^2 for Barlow Cove to 320.0 km^2 for the Juneau area, and totals 763 km^2 (Table 1). Currently, Alaska Department of Fish and Game (ADF&G) deploys almost 500 pots annually to estimate the average catch rate (catch per pot day) of several sex and size components of the crab populations, and collect information on the reproductive health, growth, and other fundamental biological measurements of overall health of the resource (Clark et al 2003). ADF&G requires accurate assessments of the overall state of red king crab stocks, to properly manage this resource, monitor changes in biological condition, and maintain the confidence and support of resource users (Quinn et al 2006).

One way to improve survey results is to reduce the variability in pot catches, so that the average catch of pots randomly placed in sampling strata better represents the underlying abundance of the survey area as a whole. There is large amount of variability in pot catches, with over 40% of all pots catching no red king crab and a small number of pots catching large numbers of crab

(Clark et al 2002). The survey is based on a stratified sampling design (Cochran 1997; Thompson 1992). In 1986, the survey areas were subdivided into survey sampling strata, based on bathymetry, catch history, and geographic characteristics. Pots are allocated to these strata according to a Neyman allocation scheme (Cochran 1997) which minimizes the variance of abundance estimates. However, these sampling strata include a mixture of poor abundance regions and high abundance regions, thereby reducing the effectiveness of allocating pots to strata of high variability in catch. Revision of survey area stratification may improve precision of catch rate estimates. For example, restratification of the Deadman Reach area resulted in a significant reduction in variability of average catch rate estimates (Clark et al 2002).

The study of benthic habitat composition and structure provides another source of information which is essential in understanding the abundance and distribution of commercially important marine shellfish resources. The use of sidescan sonar provides an economical means to map large areas of marine benthic habitats. Sidescan sonar can very effectively image large areas of benthic substrate, delineating small changes in sediment deposition, inclines and depressions, or changes in bottom structure (Fish and Carr 1990). However, the ability to differentiate between different substrates will depend on the amount of backscatter, which develops from a dynamic between sonar frequency, bottom roughness, and angle of incidence (Mazel 1985). A pilot sidescan sonar survey was conducted to establish optimum survey protocol (frequency and range of sonar and length and overlap in survey transects), evaluate the ability of sidescan sonar to discern differences in substrate type, and assess the potential of integrating habitat type into crab stock assessment survey design.

This paper documents the restratification of 9 survey areas in Southeast Alaska. Holkham Bay was also stratified, although the lack of a long history of survey information precluded a detailed analysis of spatial patterns in catches. A pilot study was also conducted using sidescan sonar and video samples to describe the benthic habitat in a section of the Juneau survey area. The ability of habitat information to further improve survey design was investigated. Many of the details of the analyses are contained in the accompanying tables and figures, which are summarized in the text but not discussed in detail. The majority of this work was conducted under the Nearshore Marine Research VI grant from the National Oceanic and Atmospheric Administration (NOAA).

METHODS

SURVEY METHODS

Surveys from 1978 to 2004

Over 10,000 pots have been set and retrieved from 1978 through 2004. Although the type of pot and pot placement methods have changed over the years (see Clark et al 2003 for a more detailed description of changes in survey methods), there are only minor differences in catchability of pots (*unpubished analysis*). Some of the 1978 through 1985 pots sets were well outside of the current boundaries of the these 10 areas, or were deemed compromised due to broken webbing, unsecured pot door, or no bait in pot and were not included in this study. Data from pots set in fall surveys (September and October) were also excluded due to potential differences in crab spatial distribution between summer and fall surveys.

Pot catches were converted to a catch rate, by dividing total catch by the fraction of a day the pot was deployed. Generally, pots are in the water for about 18 hours, although some soak times have been as short as 12 hours or over 24 hours. Soak times greater than 1.5 days were set at 1.5

day soak time since recruitment into the pot is likely insignificant after this time. The abundance of crab varies widely from year to year (Clark et al 2003). To standardize the annual survey catch from an area, individual pot catches were divided by the estimated weighted average pot catch. Thus a catch of 0.50 normalized catch signifies a catch which is 50% of the average catch in a specific area and year.

Catch of red king crab is divided into two classes: mature male red king crab (male king crab over 129 mm carapace length), and female and juvenile male red king crab. Management bases guideline harvest levels on the abundance of mature male crab, although the abundance and condition of the female and juvenile male segments of the population may be used as a rationale to modify harvest rates by survey area. Because the abundance of the mature male component of the population is so prominent in the decision process, the overall total catch of red king crab in a pot is weighted more towards the mature component by the following formula:

Total Crab =0.75 (Mature males) + 0.25 (females and juvenile male crab). (1)

DATA PROPERTIES

Optimum sampling design depends on allocating more pots to strata with higher variability in catch rates. Because individual pots do not provide an estimate of variability in catch rate for that pot, we consider the actual weighted catch of each pot to be a surrogate for the variability of catch at that location. The relationship between mean abundance and variability in measurements of that abundance are well established for many populations (Taylor 1961). This also holds true for red king crab catches, with a significant positive correlation between average survey catch by substratum and standard deviation of this catch (Figure 2). Thus estimates of areas of relatively high abundance will also likely indicate areas of high variability in catch, whereas areas of low (or no) abundance will be characterized by low variability in catch.

Another property of the catch data is its highly skewed distribution (Figure 3). A total of 42% of all pots in the analysis caught no red king crab, while 5% of the pots have catches exceeding 5 times the overall mean catch rate for each bay and year. This type of data is common for stock assessment surveys, but creates challenges in geostatistical analyses. A number of data transformation techniques to reduce the skewness of the measurements have been suggested in other studies. Creating indicator variables (Journel 1983), removal of outliers (Rufino et al 2005); using ranked values of measurements (Petitgas 1998); log-transformation of data (Cressie 1993; Rivoirard et al 2000); and step-wise analysis of modeling the zero observations first then analyzing the remaining observations (Jardim and Ribeiro Jr. *in press*) have been recommended as means to normalize the data. In this study, a square-root transformation was used for total crab catch data. This is a transformation that maintains the order of the measurements and is robust enough to apply to data from all bays.

BATHYMETRY DATA

Bathymetry measurements were obtained from the NOAA National Geophysical Data Center's GEODAS database at http://www.ngdc.noaa.gov/mgg/geodas/geodas.html (accessed 11/2008). This website provides hydrographic survey data for most Southeast Alaska waters, including all of the red king crab survey areas. All available soundings were acquired from the GEODAS database in the xyz format (latitude and longitude in decimal degrees, and depth in meters). Depth is relative to mean lower low water. All depth readings in the survey areas, in shallow waters shoreward of the survey area, and approximately 0.5 km outside of the survey area boundary were obtained and put into ASCII data files.

A 50 m grid of locations was generated for each survey area. The NOAA bathymetric data was used to estimate the depth, local variability in depths, slope, and relative depth at each grid location, and for each pot location. For each location, the estimated depth was calculated based on the average depth of all NOAA bathymetric measurements within 50 m of the grid or pot location. Longitudinal distance was calculated using the cosine of the location latitude times the difference between longitudes. The standard deviation of each location was estimated as the standard deviation of NOAA depths within 100 m of the location. The slope was estimated as the average change in depth in meters divided by the distance between NOAA depth locations in km (i.e. slope units are meters per kilometer). The slope was calculated using multiple regression analysis as,

$$Depth = \alpha + \beta_1(\Delta Latitude) + \beta_2(\Delta Longitude), \quad (2)$$

where Depth is the measured NOAA depth, ΔLatitude is the latitudinal distance between the NOAA location and the pot or 50 m grid location (north is positive direction), and ΔLongitude is the longitudinal distance between the NOAA location and the pot or 50 m grid location (east is positive direction). The β_1 and β_2 are slope estimates in the north-south and east-west direction and α is an estimate of the depth at the pot or 50 m grid location. The absolute slope was estimated as,

$$Slope = \sqrt{(\beta_1^2 + \beta_2^2)} \ . \quad (3)$$

Note that the slope is positive, indicating that there is no direction associated with the slope.

A relative depth was also estimated. The relative depth is the average depth of NOAA measurements within 100 m of the grid or pot location, minus the average depth of NOAA measurements within 50 m of the grid or pot location. A negative value indicates that the sea bottom in the vicinity of the grid or pot location is deeper than the surrounding sea bottom (a depression), while a positive value indicates a relative rise in the marine topology at the grid or pot location.

GEOSTATISTICAL ANALYSIS

Geostatistical techniques have been developed and used to answer a number of marine fishery problems related to the design of optimal sampling schemes, spatial prediction of abundances, spatial distribution of resources, and development and evaluation of management actions (Booth 2000; Harbitz and Aschan 2003; Morsan 2003; Petitgas 1998; Petitgas 2001; Simard et al 1992, and others). These studies were often designed to estimate abundance in a given time frame, and especially to provide an estimate of the associated variance utilizing the geographical information intrinsic to the data. Often a random sampling design cannot be used, requiring a model-based variance estimate (Petigas 2001). In our study, we attempted to create high resolution maps of the historical average distribution of red king crab, to both optimize the sampling design of the stock assessment survey, and to provide management with spatial features of different biological categories of crab (i.e. Lembo et al. 2000).

Because the goals of the project involved estimating the distribution of red king crab in 9 different areas and stratifying these areas to optimize sampling allocation, we could not make a detailed analysis of any one area. We therefore simplified the analysis for all areas by making a number of assumptions. First we assumed that the covariance function is isotropic, and not a function of the geographic orientation of differences in distance between pots. Also Euclidean distances were calculated as the distance between pots, although Little et al (1977) and Rathbun (1998), suggested that a landscape-based distance metric that measures distances between sample points through the water might be more appropriate). Stationarity was also assumed when we calculated the covariograms. Although some studies have divided study areas up into subareas to better meet this assumption (Vining et al 2001), such a detailed analysis was not feasible in this study.

There are 3 steps in geostatistical analyses: calculating experimental covariances; fitting an empirical model to the covariances, and using this model to estimate abundances at given locations (see Thompson 1992 for a good summary).

The experimental covariance between individual pots was calculated as,

$$Cov(\Delta Depth_i, \Delta Distance_j, \Delta Year_k) = \frac{\sum_{h=1}^{n_{ijk}} (c_{h_{ijk}} - \bar{c}_{ijk})(C_{h_{ijk}} - \bar{C}_{ijk})}{n_{ijk}} \quad , \qquad (4)$$

where $c_{h_{ijk}}$ and $C_{h_{ijk}}$ are the normalized combined square-root catch of each pair of pots located ΔDepth$_i$, ΔDistance$_j$ and ΔYear$_k$ from each other, $\bar{c}_{ijk}$ and $\bar{C}_{ijk}$ are the average catch of all pairs, and n_{ijk} is the number of such pairs. The differences in depth were grouped by 10 m increments, the differences in distance by 0.1 km, and the differences in year were grouped as either in the same year or in different years. For example, the term Cov(ΔDepth = 10-20, ΔDistance = 0.1-0.2 and ΔYear = 1) designates the covariance of catches between pots which are 0.1 to 0.2 km distance apart, 10 to 20 m difference in depth, and in different years. There were few or often no paired catches when ΔDistance was small (0.0 to 0.2 km) and ΔYear is 0 (i.e. when pots were set very close to each other in the same year), or when ΔDistance is small (0.0 to 0.2 km) and ΔDepth is large (pots were set close to each other but the differences in depth was large). However, most covariance estimates had over 100 n_{ijk} values for paired catches in the same year, and several thousand n_{ijk} values for paired catches in different years.

Benthic topology may also play a role in better estimating the abundance of crab at grid locations. In order to take into account differences in the overall benthic character of each survey area, pot locations were ranked by depth, standard deviation of depth, slope, and relative depth in each area and normalized catches were averaged for each 10% interval of these ranked characteristics. Thus, the normalized catches from the shallowest 10% of pot locations were averaged and assigned to the 0-10% interval. The next shallowest 10% of pot locations were subsequently grouped and normalized catches from these pots were averaged. This results in the benthic characteristics of each survey area being relative to each other and not absolute measurements.

The covariances were fitted to an exponential model that predicts covariances that are relatively large between catches at the same location, year, and depth, and exponentially decrease with increasing distance between pot locations, differences in depth and different years. The following model was used:

$$Cov(\Delta Depth, \Delta Distance, \Delta Year) = \alpha e^{\beta_1 \Delta Depth + \beta_2 \Delta Distance + \beta_3 \Delta Year} . \quad (5)$$

When the difference in depth, year, and distance between pots equals zero, the α parameter is an estimate of the variance in catches at any location. As the differences and distance increase, the covariance in catches between pots decreases, as estimated by the β parameters, which should be negative. Eventually, the experimental covariances will be zero (or vary about zero values). The distance and depth at which the covariance values approach zero is termed the 'range'. The covariances were fitted to this model by weighted least squares minimization (Cressie 1993).

Kriging is a linear interpolation method that estimates the catch at a given location from observed catches within the range of spatial influence. This is achieved by selecting a subset of catches that are close to the given location in distance and depth, creating a matrix of estimated covariances between the catch at this location and the subset of selected catches using the covariance model, and then solving the linear system of equations to obtain weighting values used in obtaining a weighted average of the subset of catches according to the following equations.

If **C** is the covariance matrix of c_{ij}'s, which are the estimated covariances between catches used to estimate the abundance (A), then,

$$\mathbf{C} = \begin{pmatrix} c_{11}\ c_{12} \ldots c_{1n} & 1 \\ \ldots\ \ldots\ \ldots\ \ldots & 1 \\ c_{n1}\ c_{n2} \ldots c_{nn} & 1 \\ 1\ \ 1\ \ldots\ 1 & 0 \end{pmatrix}, \quad (6)$$

and the estimated covariance vector between the site and catches used to estimate A,

$$\mathbf{G} = \begin{pmatrix} c_{10} \\ \ldots \\ c_{n0} \\ 1 \end{pmatrix}, \quad (7)$$

then the vector of the weights applied to the catches is estimated as $\mathbf{W} = \mathbf{C}^{-1}\mathbf{G}$, where

$$\mathbf{W} = \begin{pmatrix} w_1 \\ w_2 \\ \ldots \\ w_n \\ m \end{pmatrix}, \quad (8)$$

and the estimate of the abundance, A_h, at site h is $A_h = \sum_{i=1}^{n} w_i r_i$. (9)

where r_i is the observed catch at location i.

The 50 m grid of location sites was created within the existing sampling boundaries for each area. A relative weighted abundance was estimated using kriging techniques for each site in the grid. Because of computational limitations, a maximum of 50 observed catches were used to estimate the catch for each site. The selected samples were those that had been estimated to have the highest covariance with each site, corresponding generally with samples taken near to the generated site and at similar depths. Also associated with each location in the grid is a depth, variance in depth, slope, and relative depth.

Each site in the 50 m grid was assigned to 1 of 5 abundance strata, based on the estimated abundance at that site. These strata were designated as low, medium low, medium, medium high and high abundance. The grouping of the estimated abundances into these stratum designations was based on frequency distribution graphs. Sites where the abundance was estimated as zero were designated as low abundance. The remaining estimates were assigned to the remaining abundance strata. The proportion of habitat assigned to each stratum was approximately the same to a slight weighting towards lower abundance strata

The designation of strata was further modified using the estimated depth, standard deviation of depth, and relative depth, to assign a location to either a more abundant or a less abundant stratum. All waters less than 20 m deep were excluded from the survey area. Sites with estimated high levels of variability (20 m or greater standard deviation in depth), or with a large positive relative depth (10 m or greater), were reassigned to a stratum of lower abundance. Sites with large negative relative depth values (-10m or less) were reassigned to strata of higher abundance. Strata were also modified based on conversations with fishermen that had years of commercial fishing experience in the survey areas.

The grids of abundances for each area were imported into ArcGIS to obtain contours of abundance and define the areas of each abundance stratum. This was accomplished by using the spatial analyst programming in ArcGIS. XY data were interpolated to a Raster image, reclassified, and then converted from raster to features. The file was then reclassed from graduated color to grid code. In the toolbox/analysis tools/extract/clip, the abundance strata shape file was delineated by the polygon that defines the boundaries of the survey area to obtain the shape file of abundance stratum boundaries in each survey area.

EVALUATION OF RESTRATIFICATION AND 2005 SURVEY DESIGN

In the 2005 red king crab stock assessment survey design, pots were allocated to the new strata based on a Neyman allocation scheme (Cochran 1997; Clark et al 2003). We used several different criteria to evaluate the effectiveness of the restratification used in the 2005 survey. The simplest analysis was to ascertain whether the 2005 survey had fewer pots with no crab than previous surveys. Although large decreases in crab abundance in an area would also result in an increased number of pots with no crab, even in medium and high abundance strata, areas with small changes in abundance should still see reduced numbers of pots with no crab, since the intent of restratification is to direct pots to areas of higher crab abundance. Another way to evaluate the impact of restratification on survey results is to see if low numbers of crab and small variability in catches were characteristic of areas designated as low abundance, while higher catches and larger variability in catches were characteristic of areas designated as high abundance. A third method of evaluating the success of restratification efforts is to compare the variability in average catch estimates for each of the survey areas using the new strata with the corresponding variance of estimates using the prior stratification design. The old strata are composed of segments of the new strata, and pots randomly located in the new strata would likewise be randomly located in the segments of the new strata combined to reconstitute the old strata. Therefore, estimation of the variability of catches in the entire survey area is simply a matter of reweighting the variances in each segment of the new strata, combined to reconstitute the old strata.

PILOT SIDESCAN SONAR

There were 4 different types of activities planned for this survey: 1) setting empty cone crab pots as index markers for sonar towfish location calibration; 2) conducting 5 sonar transects using different frequencies, ranges, and transect overlap and direction; 3) taking substrate samples using the benthic dredge; and 4) deploying a submersible video camera and frame to videotape the benthic environment. The sonar frequencies were 150 and 600 kHz and ranges began at 500 m for the right and left channel, but were quickly reduced to 300 m with a 50% overlap. Twenty-one sites were sampled with the video camera and 5 sites with the benthic dredge. The layout of the transects, the video camera sites and sites for the cone crab pots are shown in Figure 4.

RESULTS

SURVEY AND BATHYMETRIC DATA

The number of pots included in this analysis summed to 9,097 pots (Table 2). Only 5 years of survey data existed for Holkham Bay, resulting in 248 pots with catch information, while at least 21 years of survey data existed for all other bays. Juneau area, Seymour Canal and Pybus Bay all had over 1,000 pot sets with usable data. A total of 746,523 bathymetric measurements were used to estimate the overall bathymetry for all survey areas (Table 3). The number of locations in the 50 m grid used to estimate bathymetry and abundance in each survey area ranged from about 2,500 for Barlow Cove, to 138,000 for the Juneau Area. On average, 2.2% of the total survey area was excluded because water depth was less than 20 m. Seymour Canal had the highest excluded percentage, 4.5% (Table 4). The overall average depth of surveyed waters is 86.7 m and the average by survey area ranges from 60.2 m to 126.9 m. Waters included in the average do not include shallow waters less than 20 m in depth which are not surveyed.

Normalized catches were highly variable, but some general trends were observed. Mature males tended to be found at deeper depths, with average normalized catches increasing from 0.5 to 1.5 normalized catch when progressing from shallow to deep areas (Figure 5). In contrast, female and juvenile male catches show no obvious pattern of catches with depth. All classes of red king crab are caught in higher numbers in benthic habitats with relatively flat profiles (i.e. small variability in bottom depths and little slope, Figures 6 and 7). The relative depth showed little relationship with crab catch, except at depths which were shallower than surrounding waters (Figure 8). Pots located on these ‘peaks’ in bottom topography caught fewer crabs than pots located in other areas.

GEOSTATISTICAL ANALYSIS

The average covariances by distance between pots (distance), difference in depth between pots (depth) and either same or different year for all areas are shown in Figures 9 to 17. For most areas, the covariances quickly decreased as the distance and difference in depth between pots increased. The range in distance varied from 1.0 km for Pybus Bay, to 8.0 km for Excursion Inlet

(Figures 9 to 15). For Excursion Inlet, the covariances decreased as the distances increased, but remained positive for all distances less than or equal to 8.0 km. The covariances also decreased as the differences in depth increased, with the range in differences in depth varying from 10 to 50 m for all areas except Juneau Area, Lynn Canal, and Excursion Inlet. The covariances for these three areas tended to decrease with increasing differences in depth between pots. All difference measurements were used to estimate the regression coefficients (Table 5). The covariances were greater for catches from pots set in the same year, compared to pots set in different years for all survey areas.

Frequency plots of the estimated relative abundances (note that these relative abundances are square-root transformed) are detailed in Figures 18 to 26. Most distributions were highly skewed, with a large number of sites estimated to have zero abundance. Over 20% of the sites in Pybus Bay, Seymour Canal and Excursion Inlet were estimated to have no red king crab. However, sites in the Juneau Area and Barlow Cove tended to have a more even distribution of crab abundance, with less than 1% of the sites estimated to have no crab. A majority of the survey areas also had strata with relatively large estimated abundances; in Pybus Bay, Gambier Bay, Excursion Inlet, Port Frederick, and Deadman Reach, more than 5% of the estimated abundance being greater than 1.60 normalized catch of all crabs.

The percentage of the habitat assigned to low abundance strata ranged from 22.4% (Juneau Area) to 44.0% (Seymour Canal), with an overall average of 30.4%. On average, approximately 20% of the areas were categorized as medium low abundance, 18% as medium abundance, 15% as medium high abundance, and 14% as high abundance.

RESTRATIFICATION

The strata that were created from the geostatistical analysis, and subsequent treatment in ArcGIS are shown in Figures 27 to 36. Overall, most survey areas had obvious sites of high abundance, sites of low abundance, some sites with a mixture of both high and low abundance and transition sites. A number of high abundance sites are located near the heads of bays or in trenches which lead into the inner waters of an area. Although low abundance sites may also be located anywhere in a bay, they were often also located in the outside waters of a bay as the bay transitions into a major strait or canal.

Pybus Bay had two prominent areas of high abundance: the outer east bay and the inner west bay (Figure 27). The channels leading into the inner west bay also had areas of high abundance. Large areas of small or no crab abundance were located at the entrance to the west channel, central waters of the east bay, and the headwaters of the northeast part of the bay.

Both high and low abundance strata were distributed throughout the western part of Gambier Bay, with generally low abundance sites in the eastern channels leading into Gambier Bay, except in the deep trench located along the northern mouth of Gambier Bay and the headwaters of the northeast cove (Figure 28). High abundance sites were especially prevalent in waters of Snug Cove (the southern most cove in central Gambier Bay) and to the northeast.

The areas of highest abundance in Seymour Canal included the channel northeast of Tiedeman Island (the large long island in north-central Seymour Canal) and waters northwest of Tiedeman Island (Figure 29). Fishermen also identified the waters east of central Tiedeman Island as a site with high abundance crab. Very few crabs have been caught in the southern part of the Seymour Canal survey area.

There were four areas of high abundance mapped in the Holkham Bay survey area: the waters of the northern entrance to Holkam Bay, which follow the 100-fathom (fm) chart contour into the bay; the waters both east and west of Harbor Island (the prominent centrally-located island in the bay), in which large catches of red king crab have been obtained in the survey; and waters leading into the southern part of the bay which generally follow the 100-fathom then 50-fathom chart contour. Other sites within the Holkham Bay area were a mixture of medium and low abundance sites (Figure 30).

The headwaters of the Barlow Cove survey area contained the highest abundance of crab (Figure 31). The sites of low abundance were generally nearer the shoreline than sites of higher abundance.

The Juneau Area is the largest and most diverse survey area, being 320 km^2 in size (Figure 32). The survey area is comprised of a varied collection of submarine basins, trenches, and local bathymetric features which provide a number of habitat types for benthic organisms and contains a number of broad patches of high and low red king crab abundance. At the mouth of Oliver's Inlet, near the southern boundary of the Juneau Area, a high abundance site was surrounded by a mixture of high and low abundance sites. A large site of low abundance was located in the passage between Douglas Island and Admiralty Island, with sites of high and medium high abundance in Admiralty Cove. Large sites of high abundance were found in the central part of the survey area: Auke Bay, Fritz Cove, and surrounding Portland Island. Nearby sites of low abundance included south Shelter Island and east-central Shelter Island. High abundance sites were located adjacent to Eagle River and south to Pearl Harbor (the northeast part of the survey area). A large site of very low abundance was located to the west of this area.

The Lynn Canal survey area is comprised of the waters of St. James Bay and offshore areas south of St. James Bay to Lynn Sisters Islands (Figure 33). The highest abundance of crab was found inside St. James Bay, especially in the channel that extends down the center of the bay. Most of the area south of St. James Bay and east to the boundary of the survey area had a very low abundance of crab, although a small site of high abundance exists at the southern end of the survey area, just south of Lynn Sisters Islands.

The inner waters of the Excursion Inlet survey area were characterized by a high abundance of all age and sex segments of the red king crab population (Figure 34). Both the east and west fork of the headwaters of Excursion Inlet had a high abundance of crab, in addition to the deeper waters in front of the cannery (central part of survey area). The mouth of Excursion Inlet contains a diversity of abundance strata. Areas of low abundance are estimated for waters in the southwest part of the survey area.

The Port Frederick survey area, located across Icy Strait from Excursion Inlet also contained high abundance sites in the inner waters of the bay (Figure 35). Both Eight Fathom Bight and Salt Lake Bay (located at near southern head of Port Frederick) contained a high abundance of crab, while the corridor leading into these waters is a mixture of abundance sites. High abundances of crab have also been observed in the waters at the mouth of Neka Bay and in the mid-channel waters west of Hoonah. Although there were high abundance sites at the northern boundary of the survey area, pots located north of the survey area which had been set in early surveys, found no crab outside of the survey boundaries.

The Deadman Reach survey area has been well surveyed over the years, resulting in well-defined abundance strata (Figure 36). Initial efforts at restratification focused on this area with promising results (Clark et al 2002). The high abundance strata were located in two general areas; northwest of the Deadman Reach beach (southeast section of survey area), and at the mouth of and inside Ushk Bay (northwest section of survey area). No crabs are generally found near the northeast and western boundaries of the survey area.

EVALUATION OF RESTRATIFICATION AND 2005 SURVEY DESIGN

The total number of pots and pots assigned to each survey area were similar to past years. However, the number of pots allocated to the new strata within each survey area was very different than in previous surveys (Table 6). Because both historical abundance and variability were much smaller in geographical areas of low abundance, we allocated small numbers of pots to low abundance strata. Historically, an average of 12 pots was set in waters lying in the low abundance stratum in each survey area. In 2005, an average of 2.4 pots was set in low abundance strata. The largest change in the number of pots being allocated to the low abundance stratum was in the Juneau Area; only 2 pots were allocated to the low abundance stratum in 2005, compared to almost 21 pots allocated from 1993 to 2003. However, there were almost no changes in pot allocation in Barlow Cove. The high abundance strata were characterized by large increases in the number of pots, with an average of 21 pots allocated to this stratum in each area in 2005, compared to an average of less than 9 pots from 1993 through 2004. The largest increase in pots occurred for the high abundance stratum in the Juneau area.

The first criterion in the analysis was whether the 2005 survey had fewer pots with no red king crab than previous surveys. The overall number of pots set in the nine restratified survey areas that caught no red king crab in 2005 was 125 pots or 26% of the total number of pots set. This compares to an average of 43% of the pots set in 2002 to 2004. The abundance of all segments of the red king crab population in Seymour Canal has drastically declined since 2000, resulting in very few pots catching any crab, even in areas historically renowned for large abundances of crab. When Seymour Canal is removed from the analysis, only 69 of 410 pots, or 17%, caught no red king crab (Figure 37). Comparison of the percent of pots that did not catch female and juvenile male, mature male, or any red king crab from the 1978 through 2005 surveys finds that more than 50% of the pots caught no crab in the early to mid 1980s, when abundance was low. From 1993 through 1999, an average of 29% of the pots caught no crab, even with overall high abundance during these years. Thus, the observed reduction in pots with no crab catch is clearly a result of allocating fewer pots to areas of low crab abundance.

The second criterion used to evaluate the restratification results was to see if low numbers of crab and small variability in catches were characteristic of areas designated as low abundance, while higher catches and larger variability in catches were characteristic of areas designated as high abundance. Figures 38 to 43 compared the catch and standard deviation of catches in the new strata. For juvenile male and female crab, the highest catches in general occurred in the high abundance strata, with 6 of the 9 survey areas having the largest catches in the high abundance strata. In Lynn Canal, the largest juvenile male and female crab catches occurred in the medium high abundance stratum, while the largest catches occurred in the medium low abundance strata for Juneau and Excursion Inlet survey areas. No juvenile male and female crabs were caught in the low abundance strata for 7 of the 9 areas. The average catch of mature male crabs tended to be in either the high or medium high abundance strata, although the highest catches for the Juneau and Lynn Canal areas were in the medium low strata. No mature male crabs were caught in the low abundance strata for 5 of the 9 survey areas; only Barlow Cove had relatively modest catches in the low abundance stratum. Overall, the total catch of red king crab was highest in the high abundance strata for 7 of the 9 survey areas, and lowest in the low abundance strata for 8 of the 9 survey areas.

The distribution of variability in catches over the abundance strata was similar to the results from the average catches. The standard deviation in catches was highest in 6 of the 9 high abundance strata and lowest in all of the low abundance strata for juvenile male and female crab. For mature male crab, standard deviation in catches was highest in 4 high abundance strata and lowest in 6 of the 9 low abundance strata. For total catch of red king crab, standard deviation was highest in 5 high abundance strata, and lowest in 8 of 9 low abundance strata. The Juneau Area and Excursion Inlet survey areas displayed the most discrepancy in catches and stratum designation. High catches and high standard deviations occurred in the medium low abundance strata for both these areas.

A comparison of the coefficient of variation of average catches from early surveys through 2005 demonstrates that the variability in average catch in 2005 is similar in magnitude to the average variability from 1993 through 2004, and significantly smaller than the coefficients of variations from 1978 through 1989 (Figures 44 to 52). In 5 of the 9 survey areas, the coefficient of variation of the average mature male catch was lowest for 2005, when compared to the average coefficients of variations for 1978 to1989, and 1993 to 2004. For juvenile male and female crab catches, 4 of the 9 survey areas had the smallest coefficient of variation for 2005. Overall, the coefficient of variations average about 25% for mature male catch estimates and 34% for juvenile male and female catch estimates.

A comparison of the restratified coefficient of variations for juvenile male and female, mature male, and total red king crab catches for the 9 survey areas is shown in Figures 53 to 55. The coefficient of variation for juvenile male and female crab catches was 29% lower for the restratified catch estimates, compared to the expected coefficient of variation using the prior strata. The greatest improvement in precision was for the Lynn Canal survey area, which had a reduction in coefficient of variation from 18% to 6%. Only the Juneau survey area had an increase in the coefficient of variation, which was primarily due to one pot in a medium low abundance stratum that had a catch of 104 juvenile male and females crab. Similar results were obtained for the catches of mature male crab. The overall reduction in coefficient of variation averaged 24% from prior strata estimates to restratified estimates. The coefficient of variation for the restratified estimates was almost 1/2 that of the prior strata estimates for Pybus Bay, Seymour Canal, and Deadman Reach. The Juneau area was the only survey area that had an increase in the coefficient of variation from the prior strata estimates to the restratified estimates, increasing from 30% to 37%. This, again, was primarily due to 1 pot in a medium low abundance stratum that had a catch of 84 mature male crabs. The overall improvement of estimated catch of all red king crab from the prior stratification to the restratified estimates was 25%. It is estimated that to achieve this level of precision under the old stratification design, the number of pots would need to be increased from the 482 pots deployed in restratified areas in 2005 to 1,218 pots, or more than 2 1/2 times the 2005 survey effort.

PILOT SIDESCAN SONAR STUDY

The sidescan sonar was able to differentiate easily between hard cobble/mud bottoms and softer mud and mud/silt bottoms. The boundary demarcating the hard and soft substrates was well defined by sonar returns (Figure 56). The type of benthic habitat was verified by camera images collected in sites identified as hard or soft bottom. Camera images collected on areas preliminary identified as soft bottom showed a smooth substrate without any rocks and often with trails generally believed to be from snails (Figure 57a). Camera images collected on areas preliminary identified as hard bottom showed much more texture from cobble (rocks about 0.2 m in diameter) overlaid with silt and mud (Figure 57b).

A mosaic was constructed using the 76 image files obtained from sonar returns. A 200 m lay back was used to position the bottom returns in relationship to the boat. This lay back visually matched up the boundaries between hard and soft bottoms in areas of transects that overlapped. The mosaic then visually allowed the area surveyed to be designated as soft (or mud) habitat and hard (or rock) habitat (Figure 58).

Catches of red king crab juvenile male and female, red king crab mature male, Tanner crab juvenile male and female, and Tanner crab mature male catches obtained in both the red king crab and Tanner crab surveys were depicted in the vicinity of the sonar survey area (Figures 59 to 62). The habitat identified as hard substrate had relatively lower catches of all size and sex categories of both Tanner and red king crab (Figure 63). The largest difference between catches was in the juvenile male and female components of the populations, with catches of juvenile male and female Tanner crab being 7 times greater in the mud habitat. However, even the catch of mature male red king crab, which showed the smallest difference between mud and rock habitat, had twice the catch per pot in mud habitat. Catch rates outside of the sonar survey area suggestede that a soft mud habitat likely predominates the areas inside of Youngs Bay, while a harder rock habitat is likely in the areas southeast of the survey area between Douglas Island and Admiralty Island.

DISCUSSION

Geostatistical analysis has been used to both evaluate and improve survey design and to improve statistical properties of estimates when spatial correlation between sampling sites is unavoidable (Harbitz and Aschan 2003; Petitgas 1998; Petitgas 2001; Simard et al 1992; Jardim and Ribeiro Jr. *in press*). Some studies have advocated a geostatistical model-based approach over that of random or systematic sampling (Aubry and Debouzie 2000). Fletcher and Sumner (1999) used the results of geostatistical analysis to define the size of patches of sardine eggs and larvae, identified as the range of the variogram, and recommended that sampling intervals should be smaller than the diameter of these patches. Recommendations on transect spacing reduction was also based on geostatistical patch size estimates for anchovy surveys (Barange and Hampton 1997) and for clam populations (Morsan 2003). The range of the covariograms of the red king crab survey were 1 km and greater for distance between pots and 20 m and greater for differences in depth. Each survey sets a number of pots within these distances, suggesting that patches of red king crab have historically been adequately sampled with several pots. Lunsford et al. (2001) also found that a stratified sampling plan improved the survey design over a random sampling design by 62%, although most of the improvement was due to allocation of survey effort and not the strata boundaries. However, the Gulf of Alaska trawl survey strata may not be optimally partitioned, due to heterogeneity of habitat for Pacific ocean perch (*Sebastes alutus*) in existing strata.

Geostatistical techniques can also be used to differentiate between the spatial distributions of different segments of populations, different years and variation in abundance levels. Lembo et al (2000) used geostatistical analysis to define nursery areas of shrimp and provide management with options for diverting effort from these areas. The distribution of blue crab was found to vary between years and abundance levels (Vining 2001). Blue crab tended to aggregate in smaller areas in years of lower abundance, resulting in greater potential for overharvesting (Jensen and Miller 2005). However, Petitgas (1998), using geostatistical analysis, found that for young hake, the density by area does change, but the area occupied by these fish doesn't change. However at very low abundances, the area was reduced along with densities.

Spatial analysis has also been integrated into stock assessment models and incorporated into the development and evaluation of management actions (Booth 1998; Bello et al 2005). The spatial distribution of a harvested resource is crucial to understanding catch statistics gathered from harvest data and in forming management actions. Changes in distribution may result in changes in vulnerability to exploitation (Jensen and Miller 2005). Design of marine conservation areas and assessment of potential impacts of habitat disturbances also rely on knowledge about spatial distribution of stocks.

This study did not use geostatistical analysis to estimate population size, but rather to define areas of low and high abundance in survey areas. This information could then be used to improve survey design and increase accuracy of overall density estimates of both mature male and non-targeted juvenile and female red king crab. The survey remains a designed-based stratified random survey with the statistical analysis based on simple random sampling.

The patchiness of crab survey catches, and its impact on accurate assessment of crab abundance and subsequent management decisions is well recognized. In the Bering Sea, red king crab demonstrates the highest degree of variability in survey catch rates, compared to other major crab and fish species (Dew and Austring 2007). This may relate to differences in management success with these stocks and possibly the fact that red king crab are designated as overfished.

The use of sonar data, verified with camera and site specific benthic samples, to identify benthic habitats shows tremendous promise in improving survey design, identifying areas of particular management concern, and differentiating the spatial distribution of key age and sex segments of crab populations. However associating distinctly different epibenthic communities with specific habitats is difficult. Hewitt et al (2004) recommends identifying individual communities and subsequently determining what acoustic data is particular to each community (bottom up approach). The pilot sonar project tended to use a top down approach, which identifies differences in acoustic returns, then associates a habitat type and community with these returns. In general, many studies have found a close association between marine habitats and classification of sonar returns (Anderson 2001).

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TABLES

Table 1.–Summary of bathymetry and geography variables of the 10 areas in the red king crab survey presently sampled. Averages are estimated from bathymetric data obtained from NOAA hydrographic surveys.

Bay Name	Area (km^2)	Average Depth (m)	Std. Dev. of Average Depth	Average Slope (m/km)
Pybus Bay	35.8	61.0	9.8	80.3
Gambier Bay	39.8	75.2	13.0	108.5
Holkham Bay	43.8	112.8	14.9	103.3
Seymour Canal	95.7	76.6	10.7	93.9
Barlow Cove	6.4	126.9	10.5	194.8
Juneau Area	320.0	77.6	8.3	68.9
Lynn Canal	31.0	92.1	16.0	112.2
Excursion Inlet	79.2	93.8	9.6	73.9
Port Frederick	66.7	91.0	9.6	85.0
Deadman Reach	44.3	60.2	6.0	52.9
Grand Total	762.7	86.7	10.8	97.4

Table 2.–Summary of survey effort and sampling distribution in the 10 areas currently being sampled in the red king crab survey.

Bay Name	Years of Survey Effort	Total Number of Pot Sets	Average Distance Between Adjacent Pots (m)	Average Depth of Pot (m)	Maximum Depth of Pot (m)
Pybus Bay	23	1,003	101	63.6	128.0
Gambier Bay	23	972	87	88.8	310.9
Holkham Bay	5	248	351	109.3	248.2
Seymour Canal	22	1,182	124	57.6	186.5
Barlow Cove	24	561	51	124.3	203.0
Juneau Area	22	1,445	211	79.0	237.7
Lynn Canal	21	792	91	76.5	292.6
Excursion Inlet	23	923	125	96.9	186.5
Port Frederick	22	804	128	91.0	168.3
Deadman Reach	23	1,167	89	61.9	117.0
Grand Total		9,097			

Table 3.–Summary of the NOAA bathymetric data used in the analysis. Data were obtained through the website**, http://www.ngdc.noaa.gov/mgg/geodas/geodas.html**

Bay Name	Area (km2)	Number of NOAA Bathymetric Measurements	Number of Locations in 50 mGrid Inside Area Boundary
Pybus Bay	35.8	60,518	15,417
Gambier Bay	39.8	51,654	16,009
Holkham Bay	43.8	34,130	16,956
Seymour Canal	95.7	32,744	39,915
Barlow Cove	6.4	23,773	2,497
Juneau Area	320.0	327,487	137,979
Lynn Canal	31.0	59,962	11,933
Excursion Inlet	79.2	54,736	31,035
Port Frederick	66.7	58,238	26,315
Deadman Reach	44.3	43,281	17,518
Grand Total	762.7	746,523	315,574

Table 4.–Location of survey areas, percent of survey area allocated to individual strata, and upper and lower confidence interval bounds, for estimated relative abundance of red king crab in 2005, based on 50 m grid.

Location / Parameters	Depths Less Than 20 m	Sampling Strata for 2005 Survey				
		Low	Medium-Low	Medium	Medium-High	High
Pybus Bay						
Percent of Area	0.9%	35.7%	18.3%	14.4%	16.7%	14.0%
Rel. Abundance Est. Lower Bound.	–	0	>.05	>.25	>.55	>1.15
Rel. Abundance Est. Upper Bound.	–	0.05	0.25	0.55	1.15	4.14
Gambier Bay						
Percent of Area	3.0%	27.0%	21.3%	16.9%	16.1%	15.8%
Rel. Abundance Est. Lower Bound.	–	0	>.25	>.65	>.95	>1.25
Rel. Abundance Est. Upper Bound.	–	0.25	0.65	0.95	1.25	3.46
Seymour Canal						
Percent of Area	4.5%	44.0%	15.7%	12.9%	9.4%	13.5%
Rel. Abundance Est. Lower Bound.	–	0	>.05	>.15	>.35	>.75
Rel. Abundance Est. Upper Bound.	–	0.05	0.15	0.35	0.75	5.06
Barlow Cove						
Percent of Area	0.0%	23.9%	24.1%	22.1%	19.1%	10.8%
Rel. Abundance Est. Lower Bound.	–	0	>.45	>.65	>.85	>1.15
Rel. Abundance Est. Upper Bound.	–	0.45	0.65	0.85	1.15	2.44
Juneau Area						
Percent of Area	2.8%	22.4%	21.7%	16.4%	21.6%	15.1%
Rel. Abundance Est. Lower Bound.	–	0	>.35	>.65	>.85	>1.15
Rel. Abundance Est. Upper Bound.	–	0.35	0.65	0.85	1.15	4.20
Lynn Canal						
Percent of Area	4.1%	30.8%	18.3%	19.5%	14.1%	13.2%
Rel. Abundance Est. Lower Bound.	–	0	>.25	>.55	>.95	>1.25
Rel. Abundance Est. Upper Bound.	–	0.25	0.55	0.95	1.25	3.16
Excursion Inlet						
Percent of Area	2.3%	31.0%	16.1%	23.0%	10.8%	16.7%
Rel. Abundance Est. Lower Bound.	–	0	>.05	>.25	>.75	>1.15
Rel. Abundance Est. Upper Bound.	–	0.05	0.25	0.75	1.15	2.00
Port Frederick						
Percent of Area	1.0%	28.3%	24.5%	16.4%	16.6%	13.2%
Rel. Abundance Est. Lower Bound.	–	0	>.25	>.55	>.75	>1.15
Rel. Abundance Est. Upper Bound.	–	0.25	0.55	0.75	1.15	4.48
Deadman Reach						
Percent of Area	1.0%	30.5%	19.0%	22.6%	11.7%	15.2%
Rel. Abundance Est. Lower Bound.	–	0	>.15	>.45	>.95	>1.25
Rel. Abundance Est. Upper Bound.	–	0.15	0.45	0.95	1.25	3.60
Average Percent	2.2%	30.4%	19.9%	18.2%	15.1%	14.2%

Table 5.–Summary of parameter estimates for the exponential model used to describe the covariances between pot catches in 2005.

Regression Parameter	Pybus Bay	Gambier Bay	Seymour Canal	Barlow Cove	Juneau Area	Lynn Canal	Excursion Inlet	Port Frederick	Deadman Reach
Intercept (α)	1.636	0.452	0.578	4.946	0.682	2.660	0.742	0.939	0.808
Depth (β1)	-0.081	-0.027	-0.063	-0.555	-0.025	-0.481	-0.010	-0.022	-0.085
Distance (β2)	-1.620	-0.933	-0.831	-2.003	-1.399	-0.720	-0.238	-1.554	-0.685
Year (β3)	-1.315	-1.040	-0.407	-0.582	-0.179	-0.362	-0.177	-1.614	-0.161
Distance Range (km)	1.0	2.5	3.0	1.0	3.0	6.0	All Distance Differences	2.0	3.0
Depth Range (m)	20	30	30	50	All Depth Differences	All Depth Differences	All Depth Differences	50	20

Table 6.–Pot allocations for the 2005 red king crab survey in Southeast Alaska. Allocations are based on Neyman allocation scheme. Averages and standard deviations are calculated from the 1993 to 2004 surveys. Pots are allocated according to a weighted standard deviation of mature male (carapace width > 129 mm) catches, and juvenile male plus female catches.

Survey Area / Sampling Stratum	Area (km2)	Mature Male		Juvenile/Female		Number of Pots	Sq. Km. Per Pot	1993-2004 Avg. No. Pots	Comments
		Avg.	Std. Dev.	Avg.	Std. Dev.				
Pybus Bay									
Low/Zero	12.1	0.01	0.02	0.02	0.09	2	6.0	13.3	Based on 30 mature males and 10 females/juveniles
Medium-Low	7.6	0.16	0.50	0.28	0.69	2	3.8	8.3	
Medium	5.4	1.56	2.06	2.99	5.72	4	1.4	5.8	
Medium-High	6.4	8.22	9.03	9.57	13.74	15	0.4	7.4	
High	4.2	25.38	20.82	30.92	32.65	24	0.2	7.0	
Average / Total	35.7					47	0.8	41.8	
Gambier Bay									
Low/Zero	9.8	0.8	1.5	1.4	3.3	3	3.3	10.3	Based on 30 mature males and 10 females/juveniles
Medium-Low	9.7	3.3	4.4	5.2	8.9	7	1.4	11.3	
Medium	8.1	7.1	6.6	13.1	17.5	9	0.9	8.8	
Medium-High	7.3	14.8	11.6	24.9	35.2	15	0.5	11.1	
High	4.4	17.2	14.0	55.3	42.5	12	0.4	5.6	
Average / Total	39.3					46	0.9	47.1	
Seymour Canal									
Low/Zero	39.9	0.1	0.2	0.3	0.6	2	19.9	16.8	Based on 50 mature males and 20 females/juveniles
Medium-Low	23.3	0.9	2.2	1.7	4.9	11	2.1	13.3	
Medium	13.9	3.0	5.2	4.9	10.2	15	0.9	9.8	
Medium-High	9.3	3.6	4.5	6.2	10.7	9	1.0	11.2	
High	10.6	12.2	12.4	35.8	53.8	35	0.3	13.8	
Average / Total	86.3					72	1.2	51.0	
Deadman Reach									
Low/Zero	12.1	0.4	0.8	0.9	2.6	4	3.0	15.4	Based on 45 mature males and 15 females/juveniles
Medium-Low	11.6	1.5	2.2	5.2	9.5	10	1.2	12.9	
Medium	8.1	2.4	3.2	17.2	18.0	10	0.8	11.7	
Medium-High	7.2	5.4	5.9	32.7	29.9	17	0.4	12.3	
High	5.4	12.8	11.6	74.7	51.3	24	0.2	10.5	
Rodman Bay	19.1					22			
Average / Total	63.4					87	0.7	62.8	

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Table 6.–Page 2 of 3.

Survey Area / Sampling Stratum	Area (km2)	Mature Male		Juvenile/Female		Number of Pots	Sq. Km. Per Pot	1993-2004 Avg. No. Pots	Comments
		Avg.	Std. Dev.	Avg.	Std. Dev.				
Port Frederick									
Low/Zero	18.2	0.1	0.2	0.4	1.0	2	9.1	9.3	Based on 30 mature males and 10 females/juveniles
Medium-Low	17.4	1.7	1.7	1.9	2.8	5	3.5	7.6	
Medium	12.2	4.1	3.5	5.0	5.4	7	1.7	6.4	
Medium-High	10.8	7.1	5.3	11.7	14.4	12	0.9	6.7	
High	8.1	13.1	10.4	59.4	53.5	20	0.4	5.3	
Average / Total	66.7					46	1.4	35.3	
Excursion Inlet									
Low/Zero	22.6	0.10	0.22	0.05	0.11	2	11.3	10.9	Based on 30 mature males and 10 females/juveniles
Medium-Low	15.9	0.85	1.56	5.18	13.69	5	3.2	6.6	
Medium	17.0	3.00	3.54	11.01	19.61	10	1.7	5.8	
Medium-High	10.7	7.72	7.12	32.02	40.89	13	0.8	12.3	
High	11.5	11.34	8.24	73.27	55.23	16	0.7	5.3	
Average / Total	77.6					46	1.7	40.9	
Holkam Bay									
Low/Zero	14.2	0.21	0.53	0.00	0.00	2	7.1	12	
Medium	20.7	1.98	3.14	0.82	1.75	20	1.0	9	
High	8.4	5.73	9.51	1.94	6.11	24	0.4	12	
Average / Total	43.3					46	0.9	32.7	
Lynn Canal									
Low/Zero	7.1	0.8	1.5	0.8	2.5	3	2.4	9.1	Based on 35 mature males and 15 females/juveniles
Medium-Low	5.7	3.6	4.1	3.2	7.3	7	0.8	9.8	
Medium	6.9	4.3	5.1	6.9	15.3	12	0.6	11.3	
Medium-High	6.5	7.4	6.8	20.1	27.2	15	0.4	12.4	
High	3.9	9.9	7.5	22.7	26.3	11	0.4	6.7	
Average / Total	30.2					48	0.6	49.3	

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Table 6.–Page 3 of 3.

Survey Area / Sampling Stratum	Area (km2)	Mature Male		Juvenile/Female		Number of Pots	Sq. Km. Per Pot	1993-2004 Avg. No. Pots	Comments
		Avg.	Std. Dev.	Avg.	Std. Dev.				
Barlow Cove									
Low/Zero	0.6	6.5	4.5	2.6	1.8	2	0.32	2.8	Based on 15 mature
Medium-Low	2.1	8.0	7.2	31.6	37.8	7	0.31	5.9	males and 5
Medium	2.3	11.7	8.8	83.6	78.1	9	0.26	6.6	females/juveniles
Medium-High	1.1	11.4	6.1	114.8	68.8	4	0.27	4.0	
High	0.2	10.6	10.3	223.5	79.8	2	0.09	2.6	
Average / Total	**6.4**					**24**	**0.27**	**21.9**	
Juneau Area									
Low/Zero	71.9	0.2	0.6	0.2	0.7	2	35.94	20.6	Based on 60 mature
Medium-Low	66.6	3.4	3.1	2.9	5.3	10	6.66	14.7	males and 30
Medium	54.1	7.3	4.5	6.2	8.4	12	4.51	14.0	females/juveniles
Medium-High	73.9	12.1	7.3	13.3	18.5	29	2.55	21.8	
High	48.8	22.2	15.7	50.2	61.3	47	1.04	20.9	
Average / Total	**315.2**					**100**	**3.2**	**92.0**	
Grand Total for Survey	**764.1**					**562**	**11.7**	**474.7**	

FIGURES

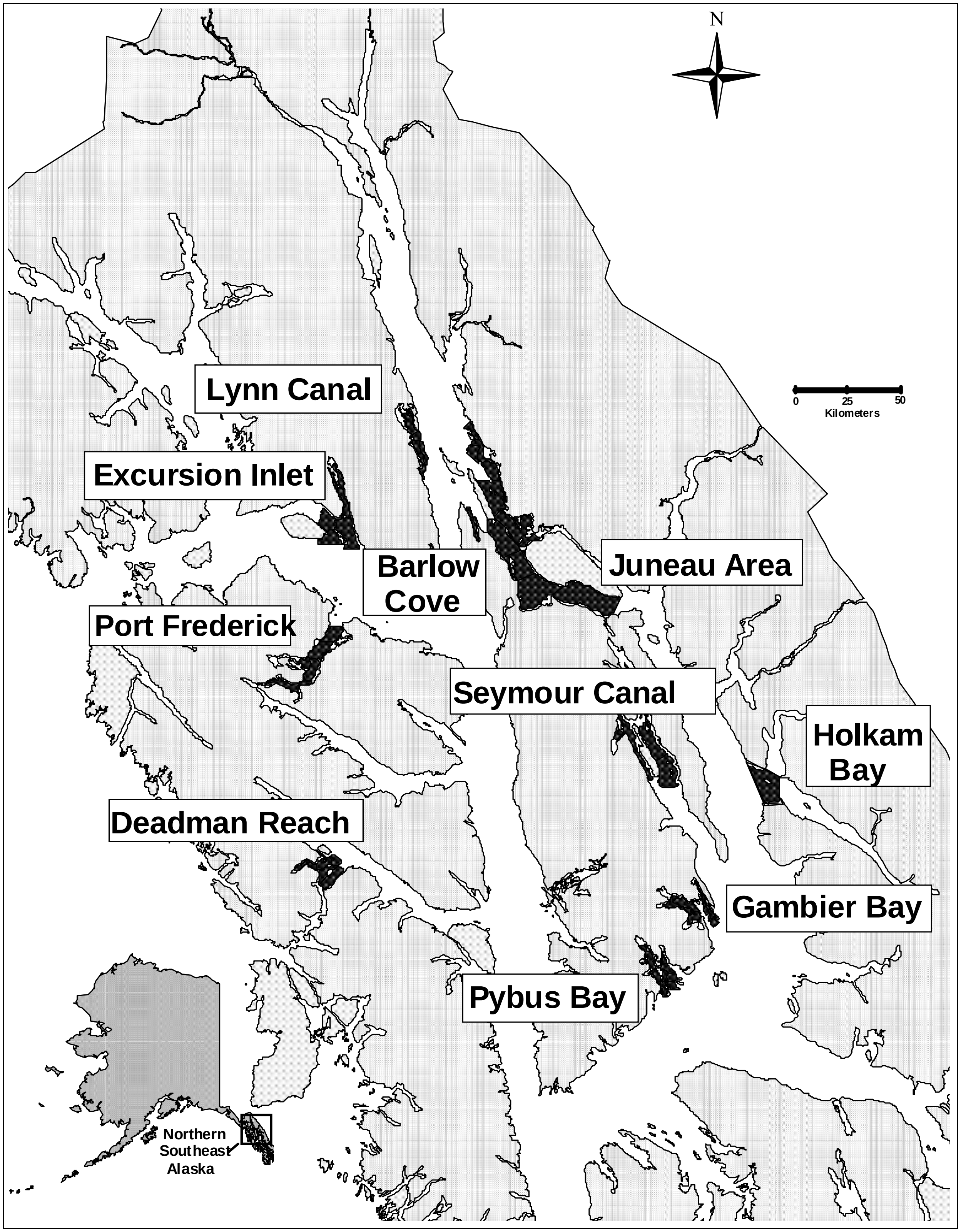


Figure 1.–Red king crab survey areas in Southeast Alaska that were restratified.

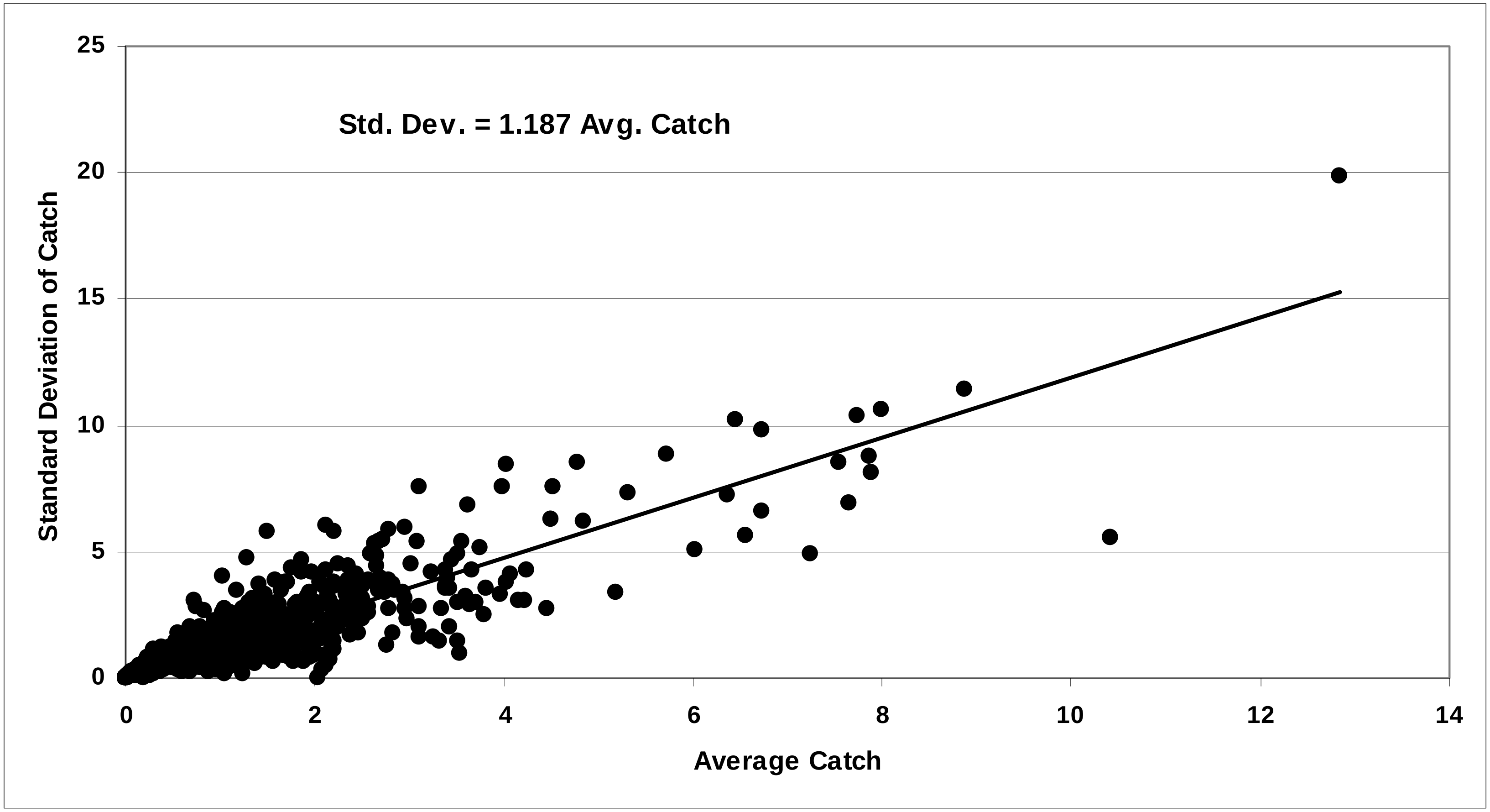


Figure 2.–Relationship between average normalized combined catch by strata, survey, and year and the standard deviation of catches in the same strata, survey area and year.

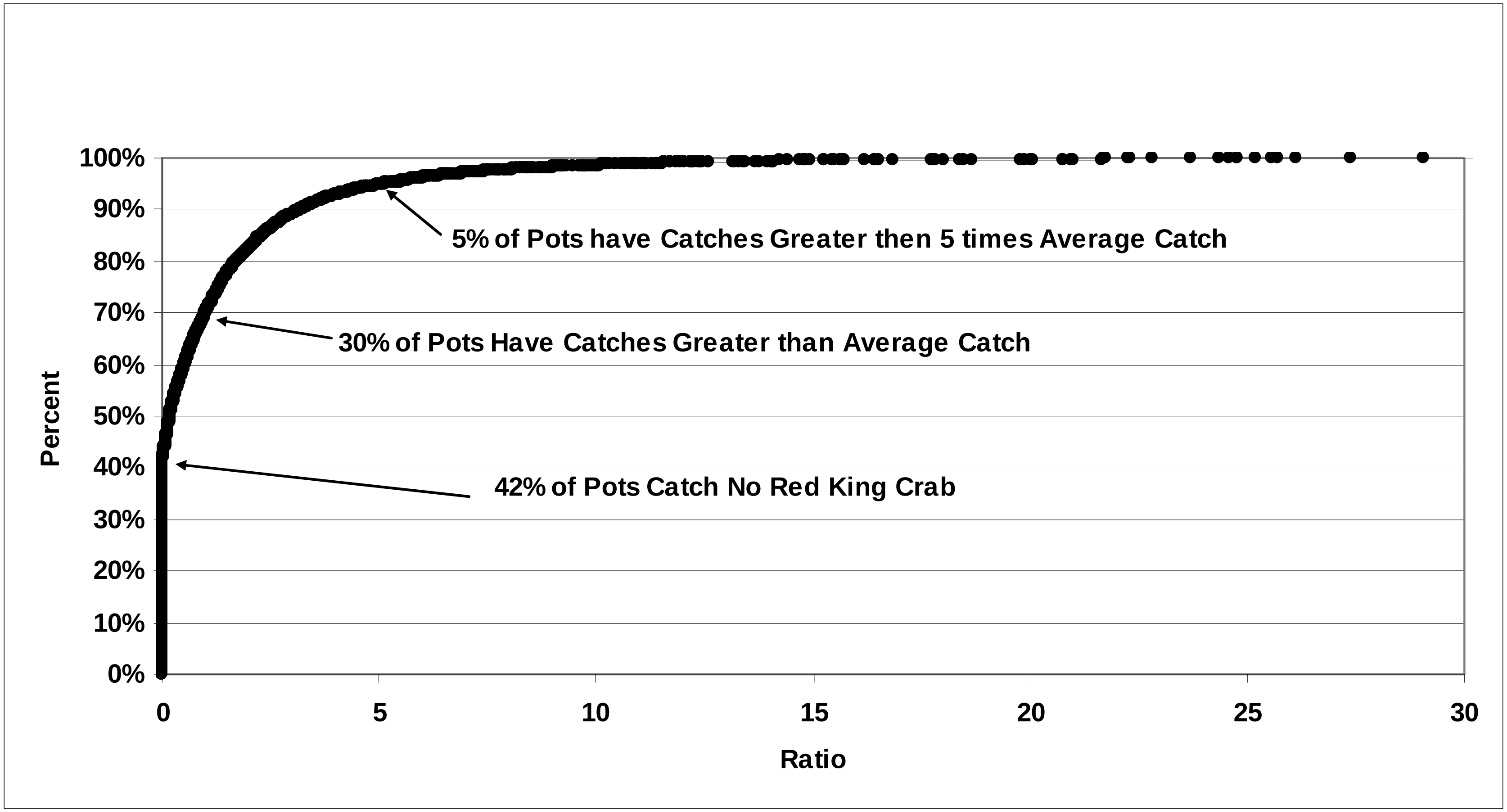


Figure 3.–Cumulative frequency distribution of catch expressed as the ratio of individual pot catch per day to the weighted average catch by survey area and year.

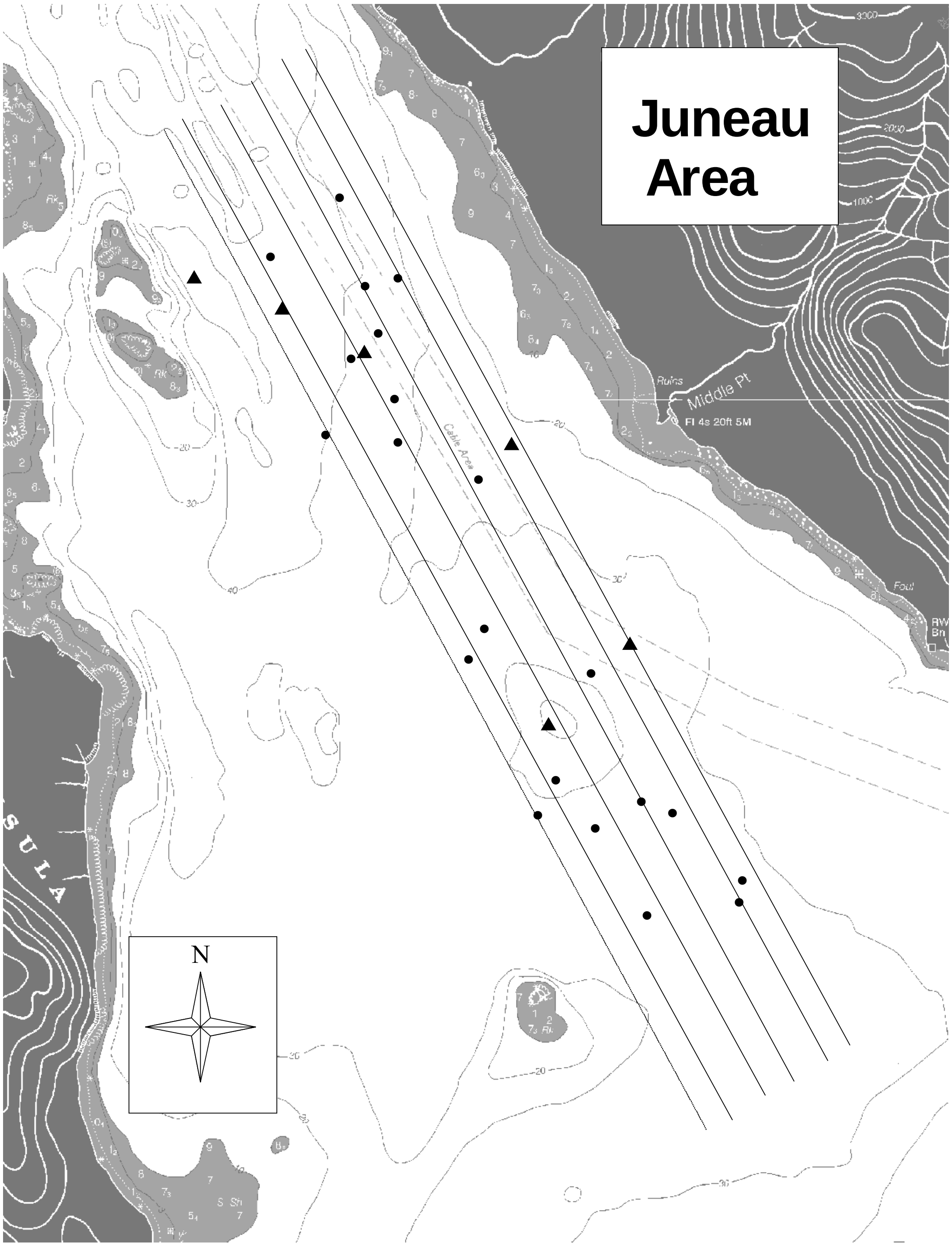
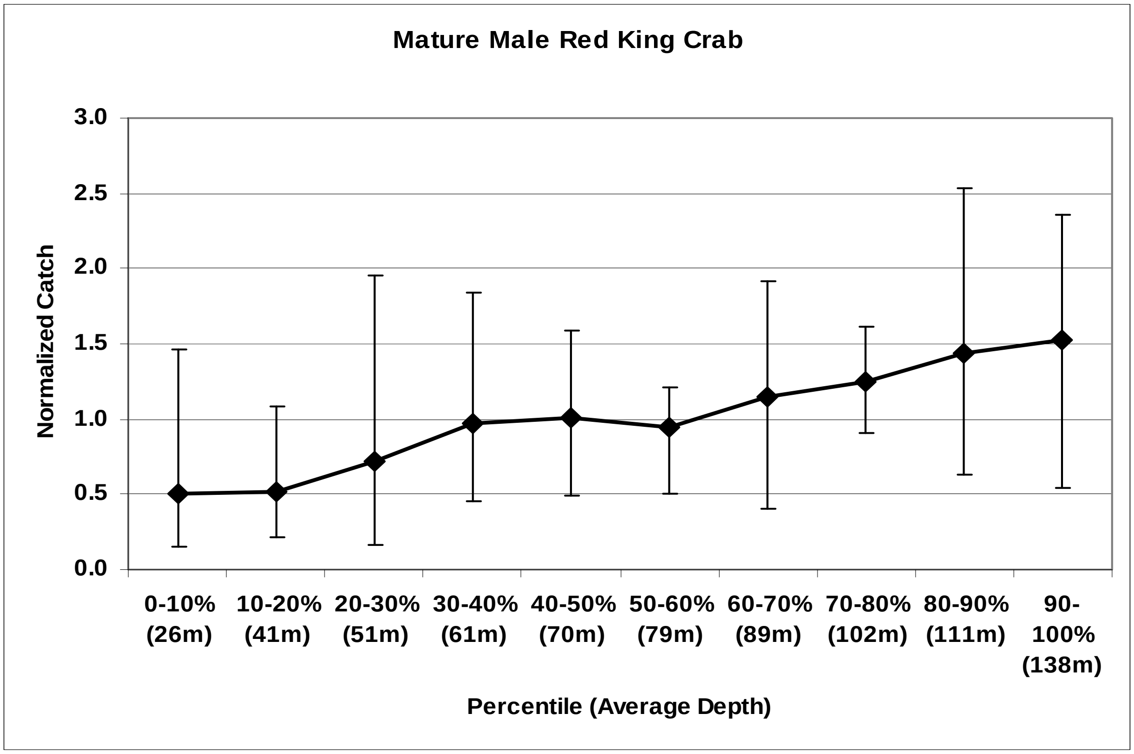


Figure 4.–Sidescan sonar transect locations for the Juneau Area. Solid lines indicate the center of each 600 m wide sonar transects; dotted lines to each side indicate the boundaries of the first and last transect sonar return. Circles indicate camera image samples and triangles indicate pot locations.



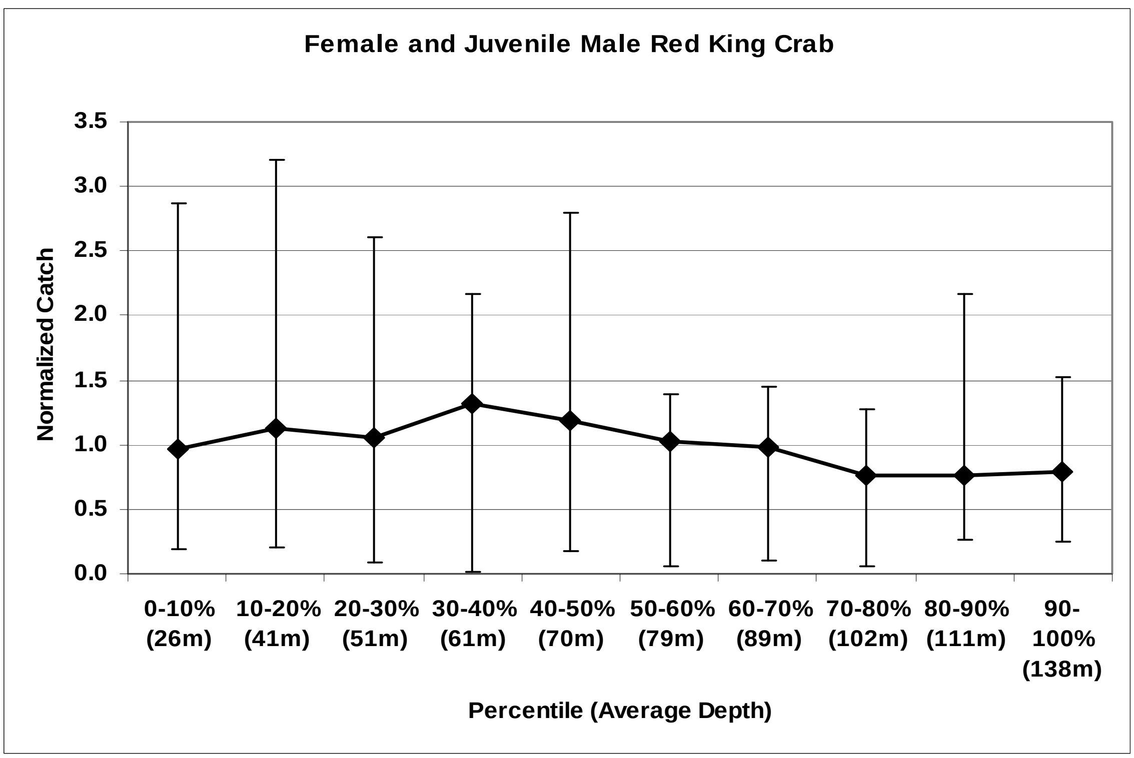
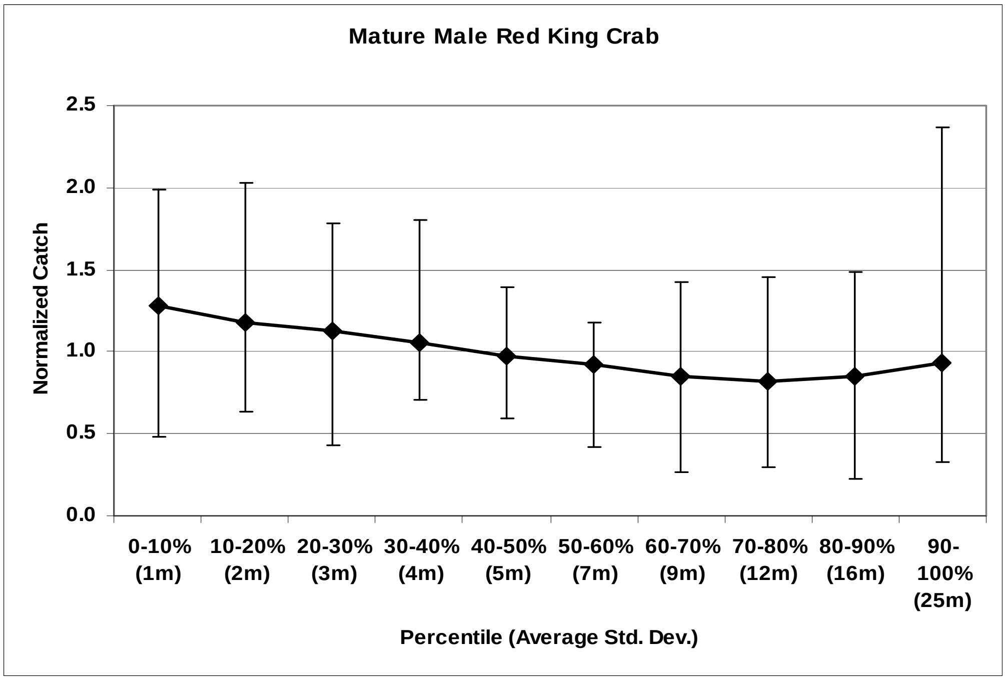


Figure 5.–Average normalized catch for all survey areas (error bars indicate maximum and minimum of individual survey areas) by percentile depth and size and sex categories. For example, the 0-10% percentile average is the average normalized catch of the shallowest 10% of the pots in each survey area.



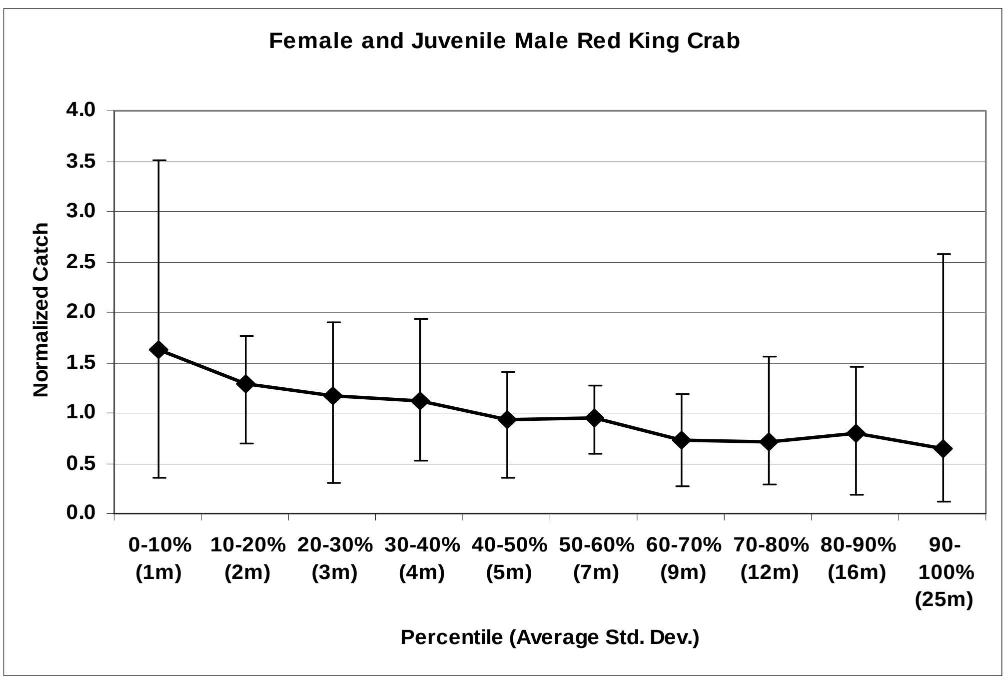
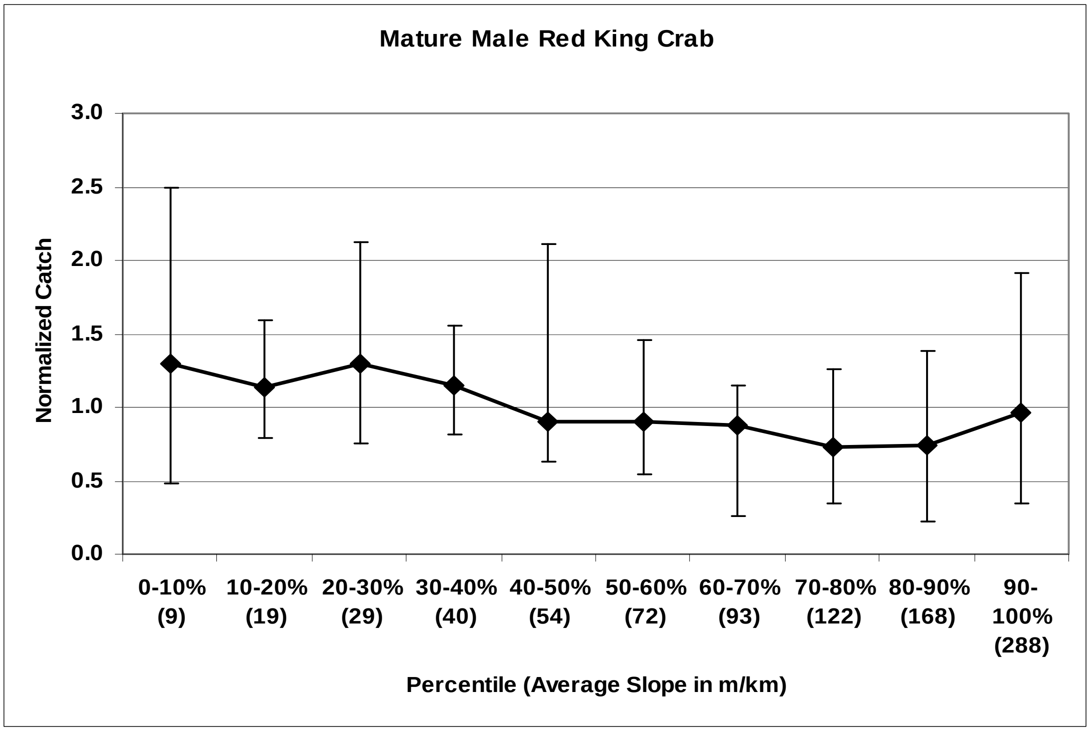


Figure 6.–Average normalized catch for all survey areas (error bars indicate maximum and minimum of individual survey areas) by percentile standard deviation and size and sex categories. For example, the 0-10% percentile average is the average normalized catch of the least variable in depth 10% of the pots in each survey area.



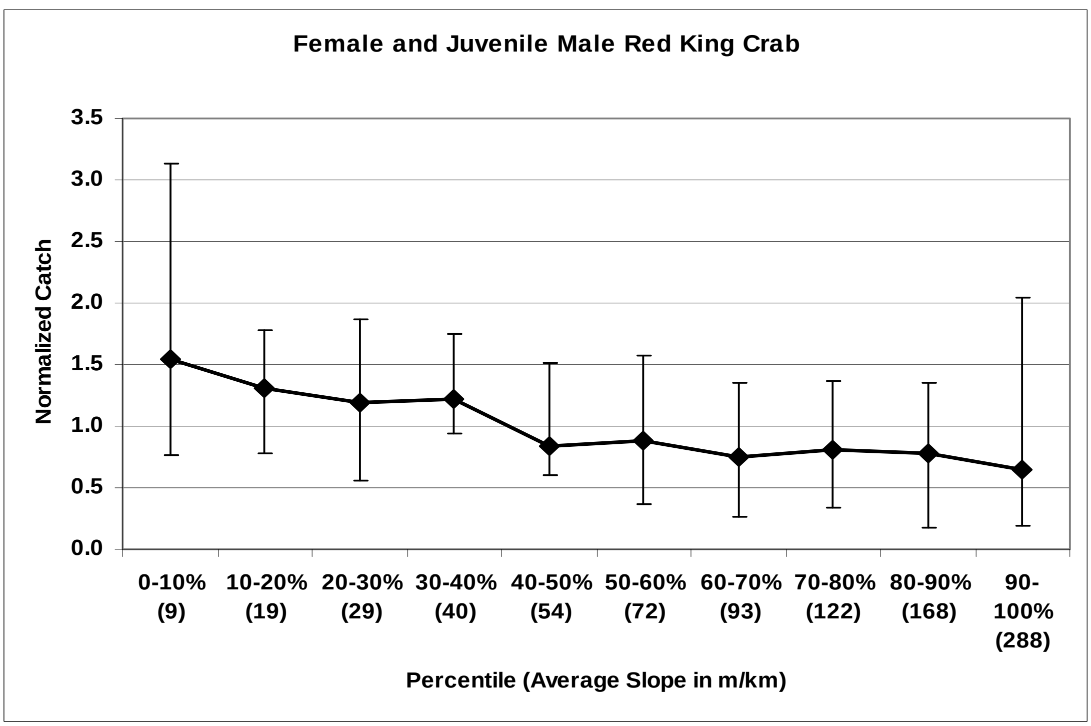
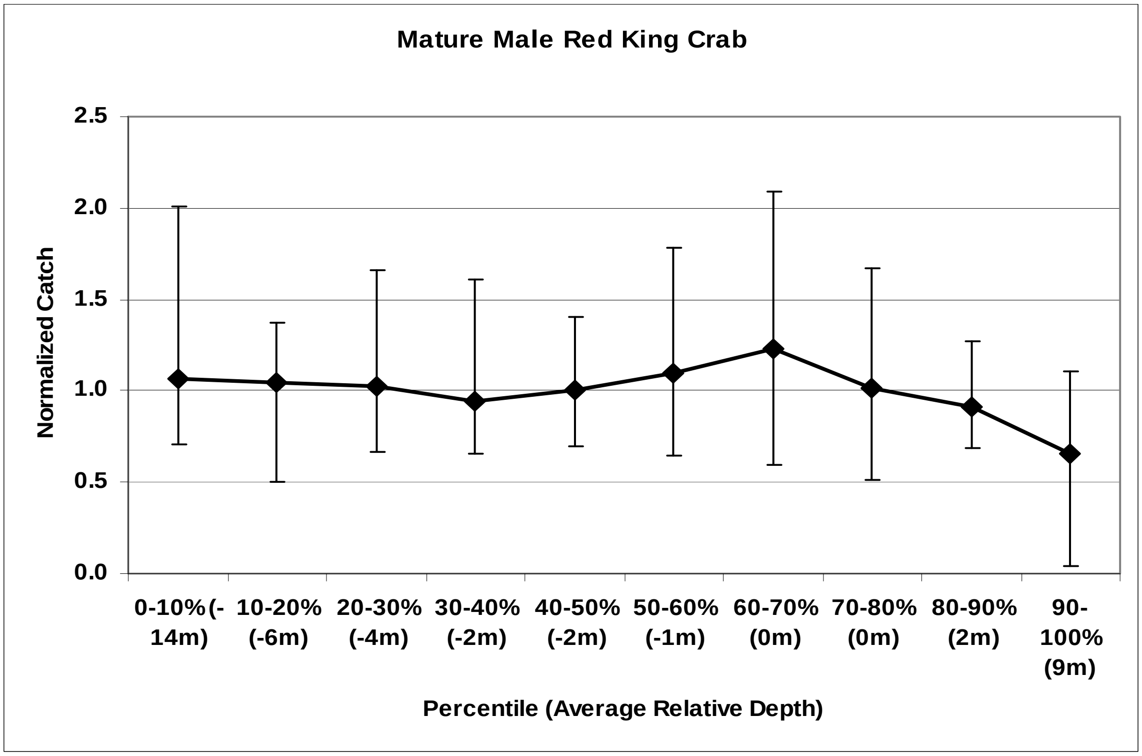


Figure 7.–Average normalized catch for all survey areas (error bars indicate maximum and minimum of individual survey areas) by percentile slope of bottom and size and sex categories. For example, the 0-10% percentile average is the average normalized catch of the 10% of pots with the smallest slope in benthic topography in each survey area.



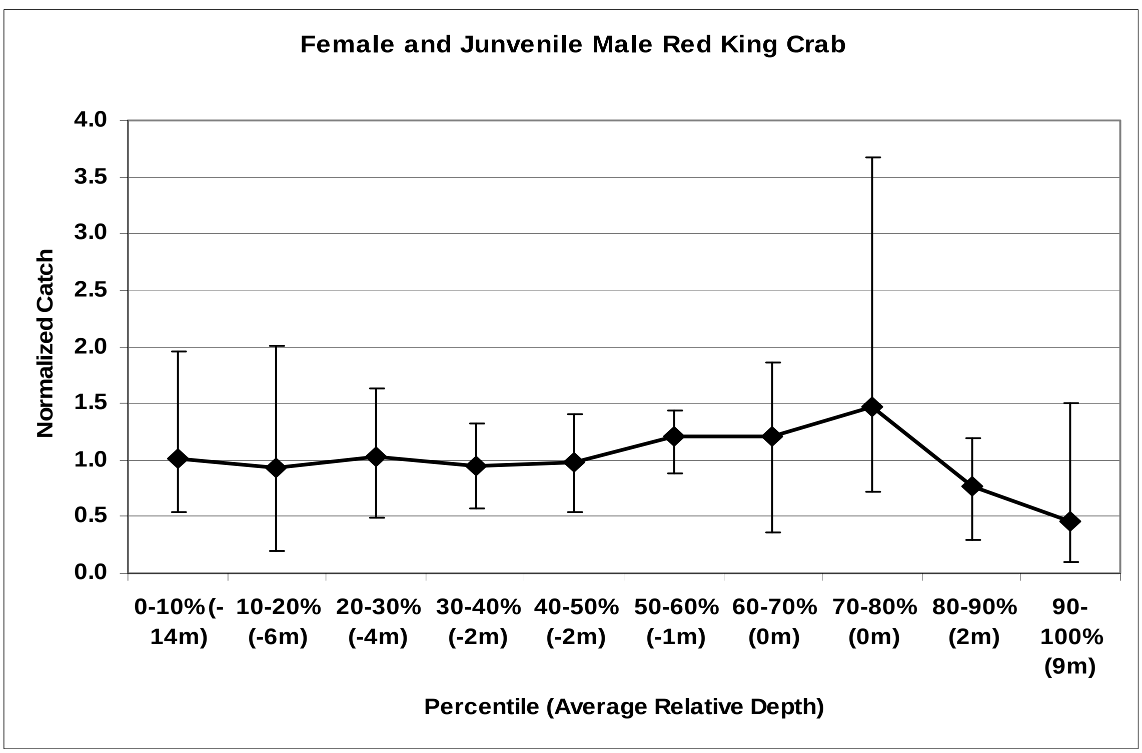


Figure 8.–Average normalized catch for all survey areas, by percentile of relative depth and size and sex categories. Error bars indicate maximum and minimum of individual survey areas. For example, the 0-10% percentile average is the average normalized catch of the 10% of pots with the smallest relative depth in each survey area.

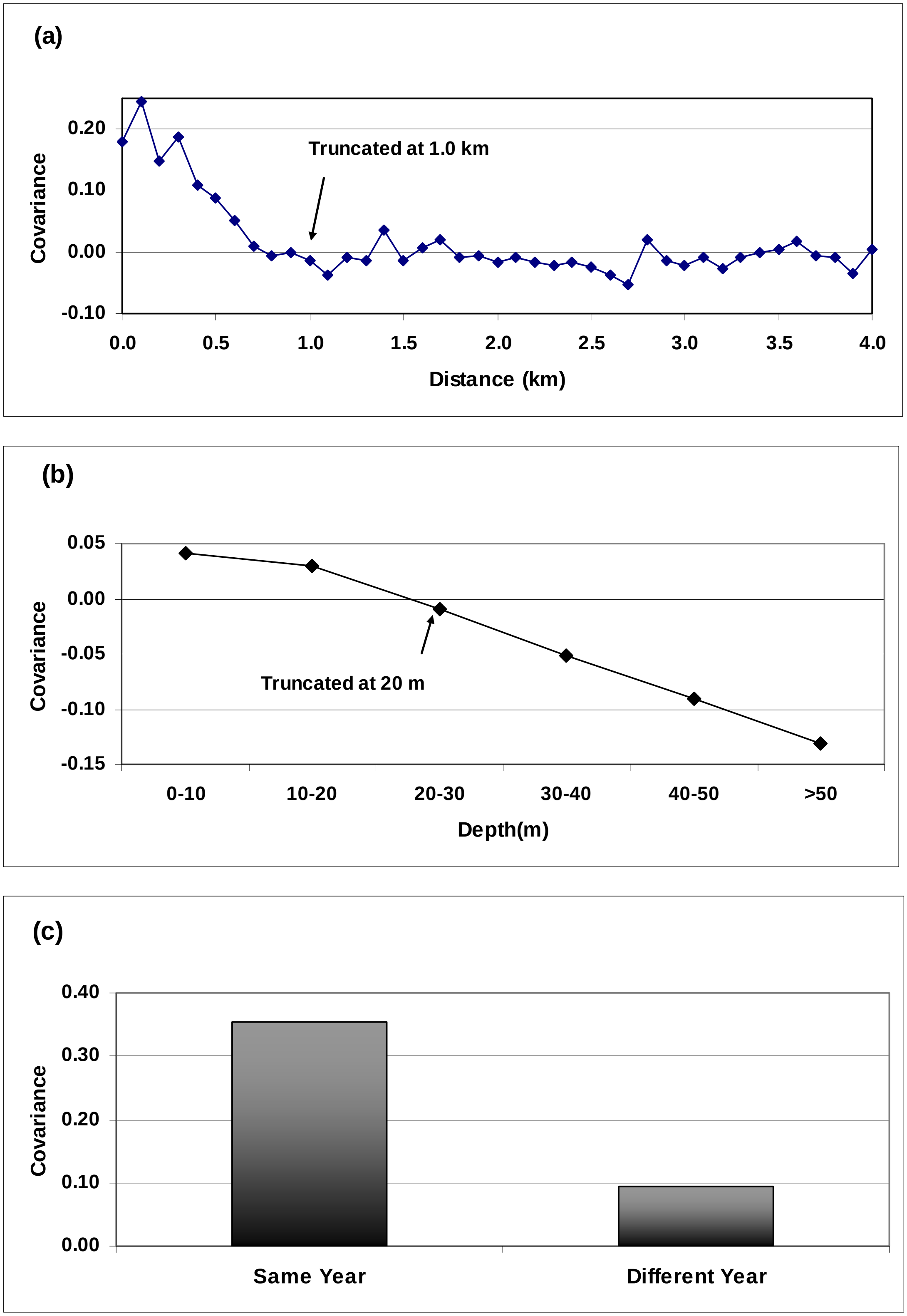


Figure 9.–Weighed average covariances of normalized catches for Pybus Bay, between pots located at (a) different distances, (b) different depths, and (c) within the same year or different years.

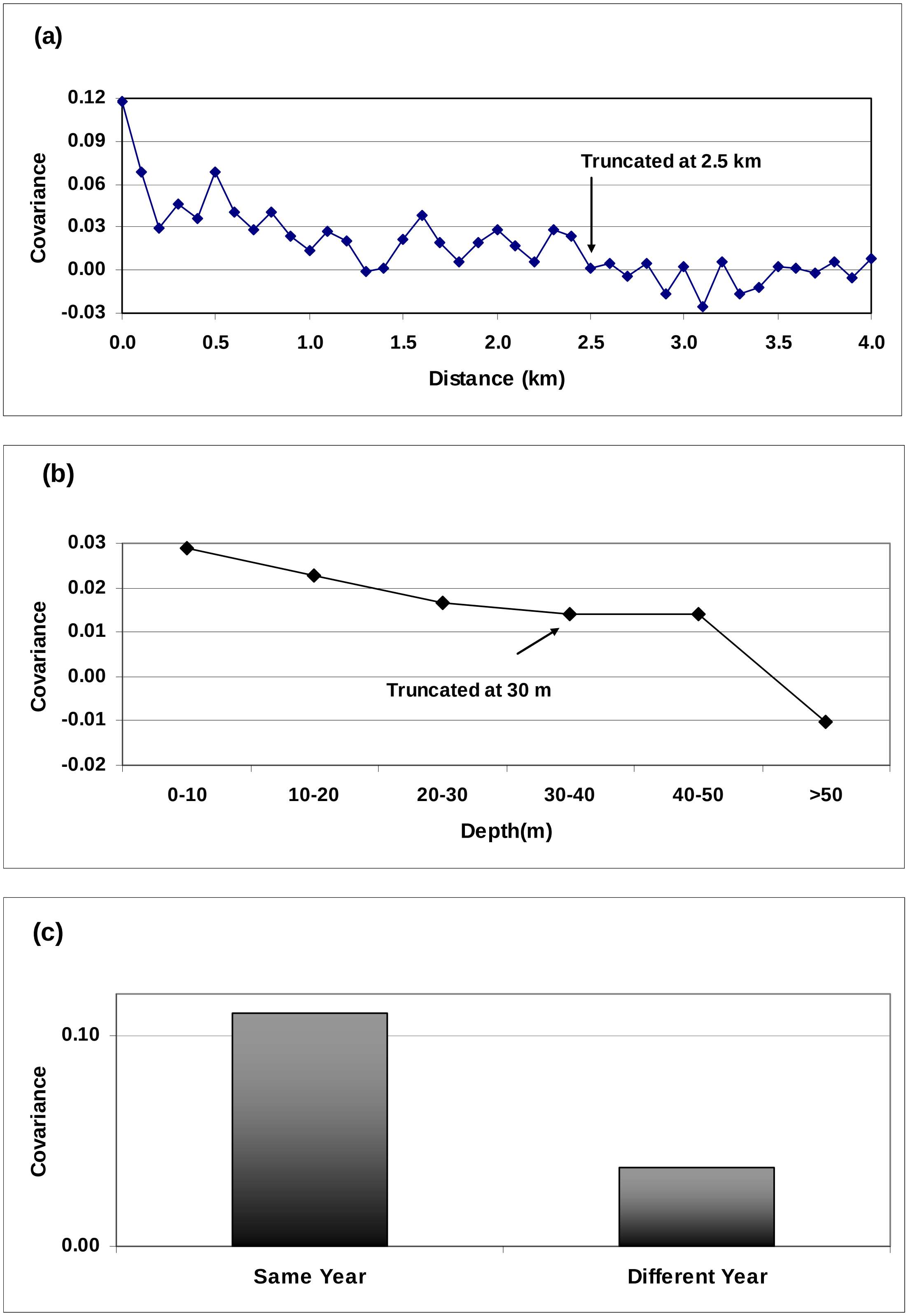


Figure 10.–Weighed average covariances of normalized catches for Gambier Bay, between pots located at (a) different distances, (b) different depths, and (c) within the same year or different years.

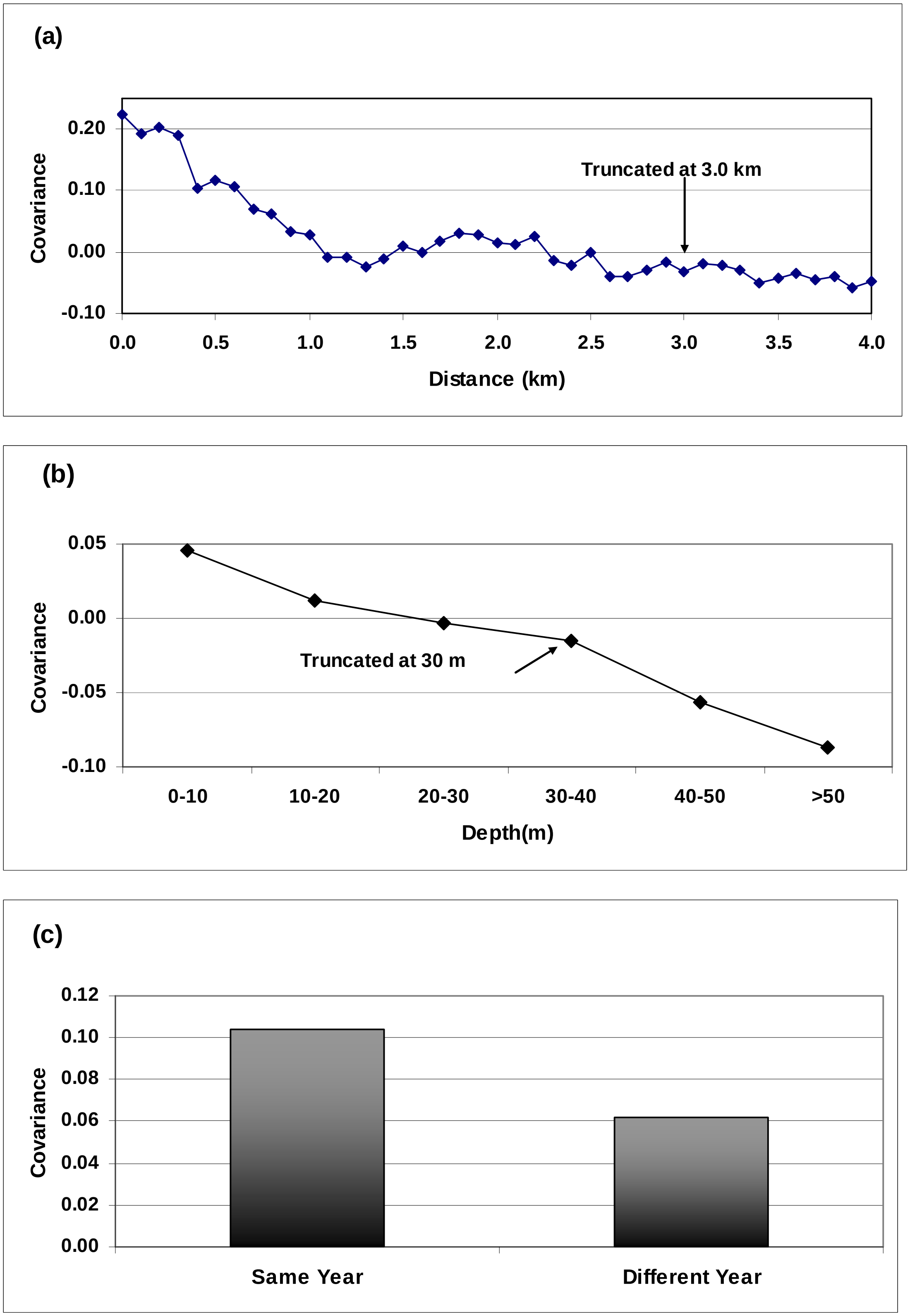


Figure 11.–Weighed average covariances of normalized catches for Seymour Canal, between pots located at (a) different distances, (b) different depths, and (c) within the same year or different years.

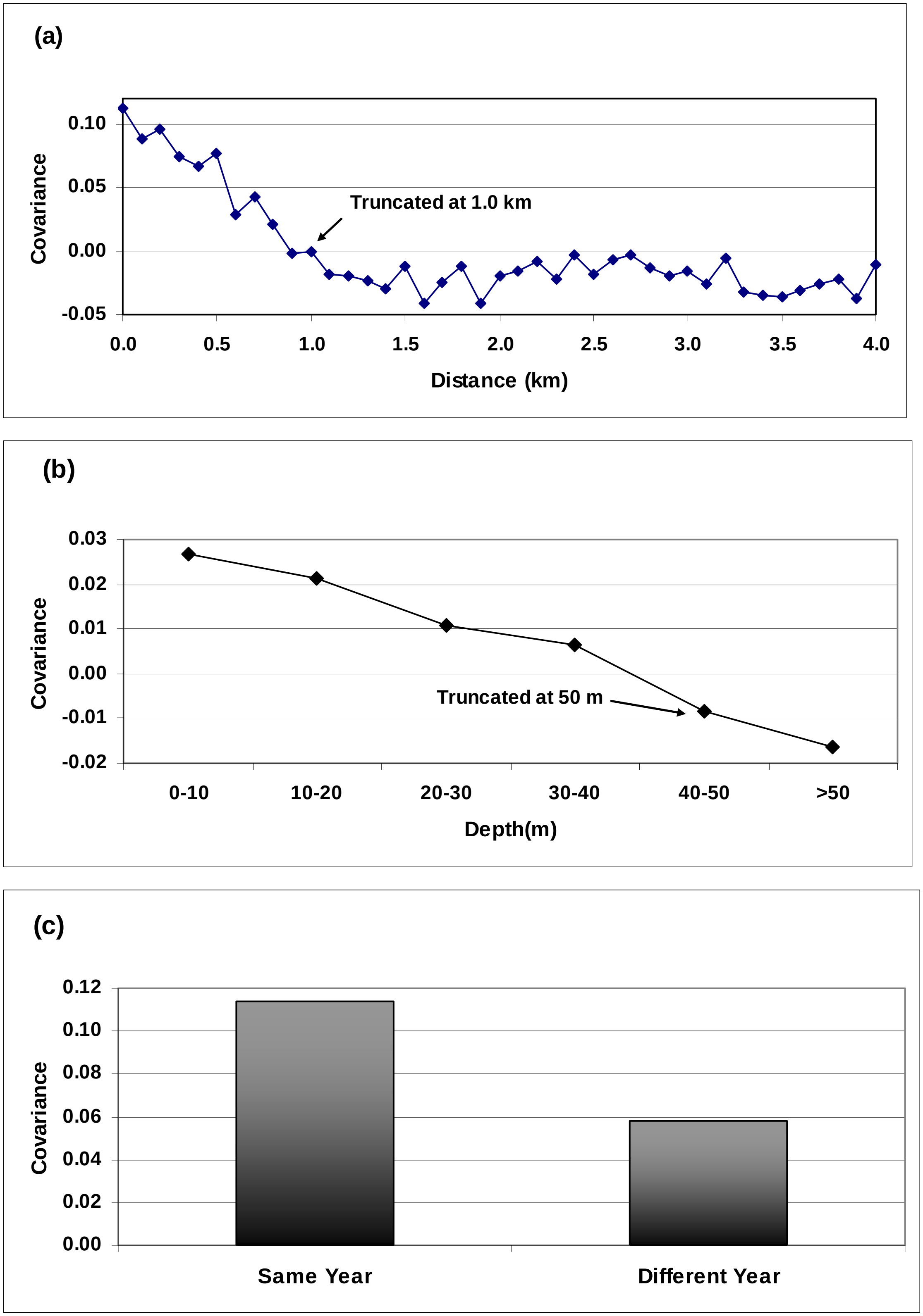


Figure 12.–Weighed average covariances of normalized catches for Barlow Cove, between pots located at (a) different distances, (b) different depths, and (c) within the same year or different years.

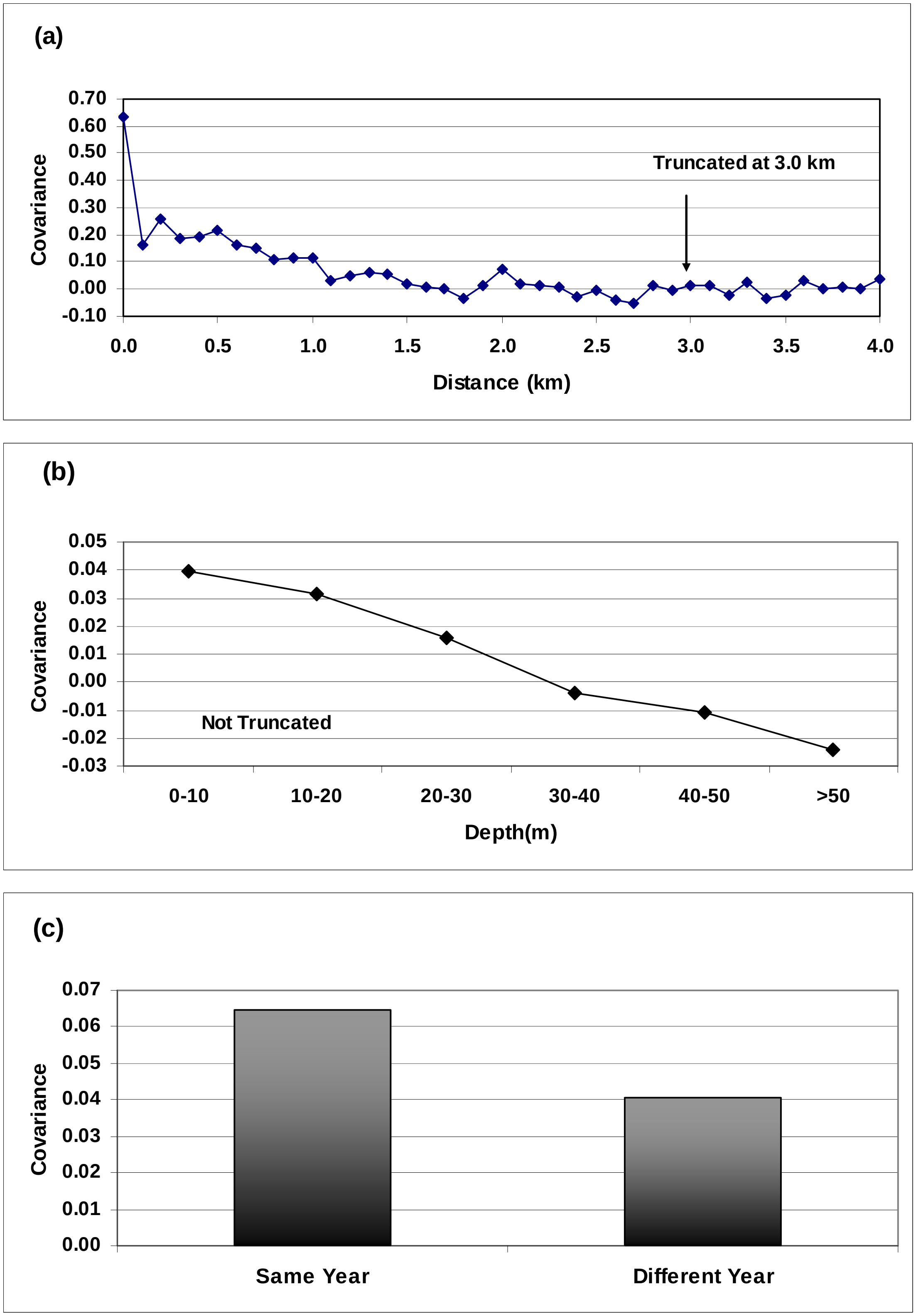


Figure 13.–Weighed average covariances of normalized catches for Juneau Area, between pots located at (a) different distances, (b) different depths, and (c) within the same year or different years.

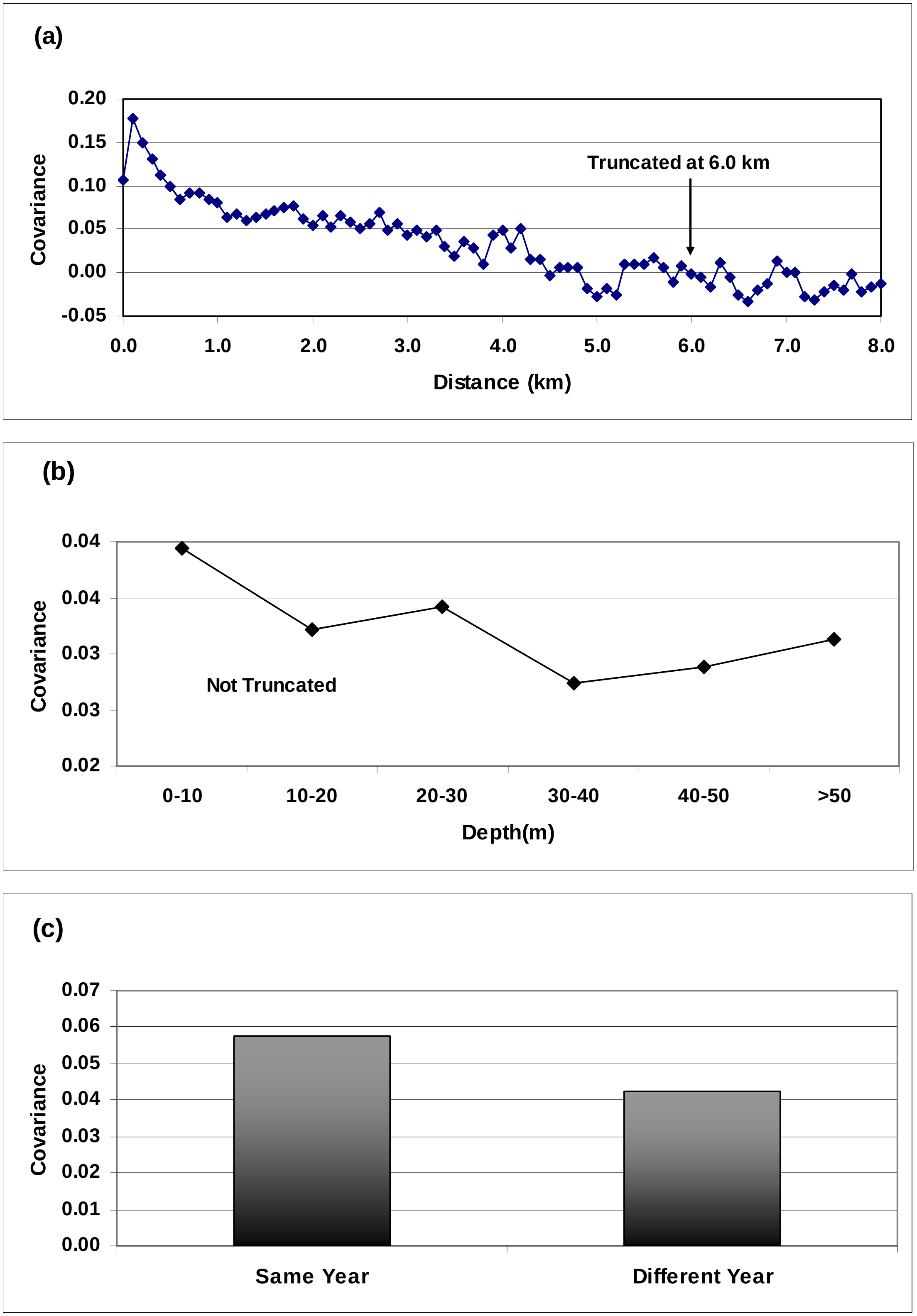


Figure 14.–Weighed average covariances of normalized catches for Lynn Canal, between pots located at (a) different distances, (b) different depths, and (c) within the same year or different years.

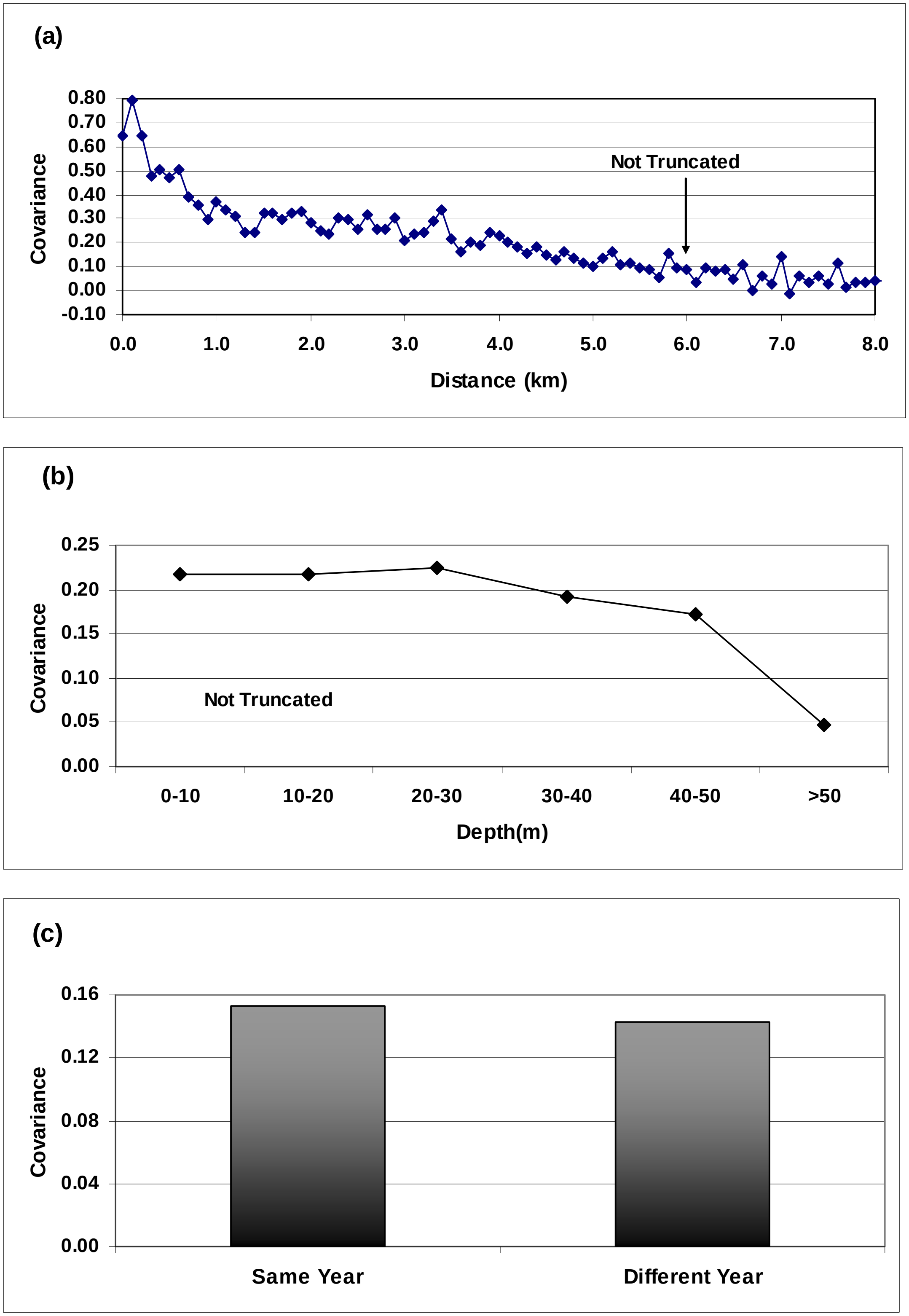


Figure 15.–Weighed average covariances of normalized catches for Excursion Inlet, between pots located at (a) different distances, (b) different depths, and (c) within the same year or different years.

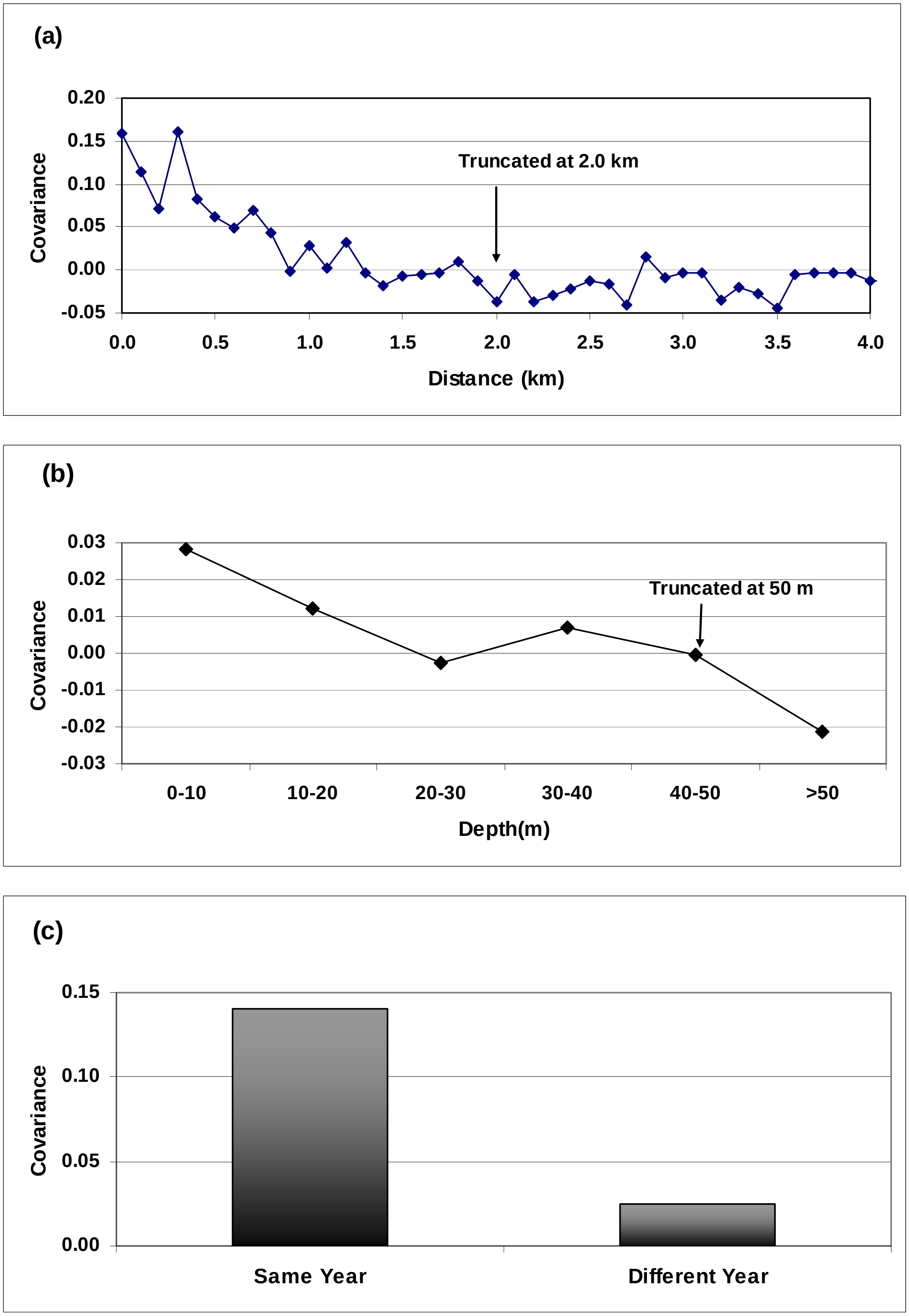


Figure 16.–Weighed average covariances of normalized catches for Port Frederick, between pots located at (a) different distances, (b) different depths, and (c) within the same year or different years.

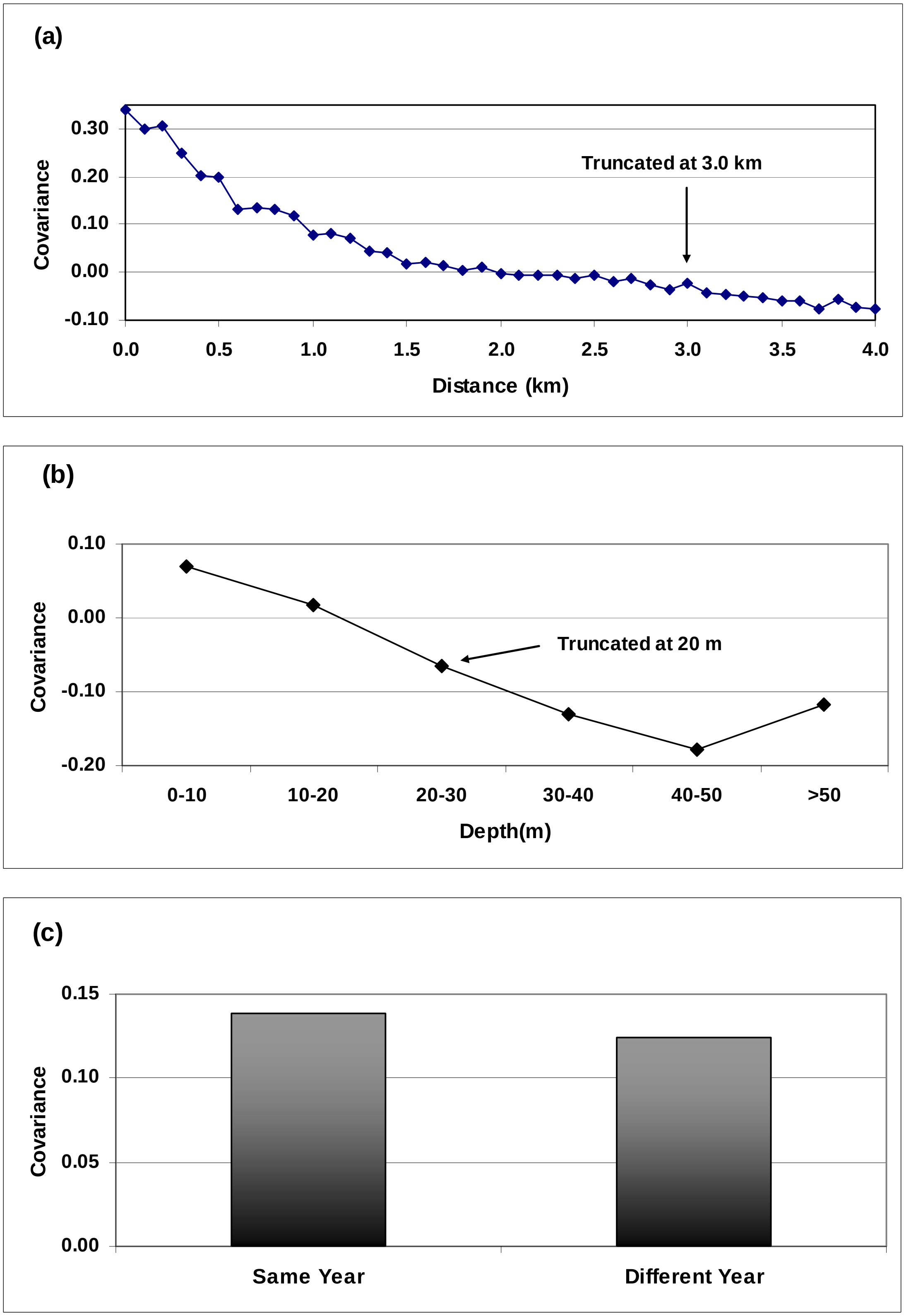
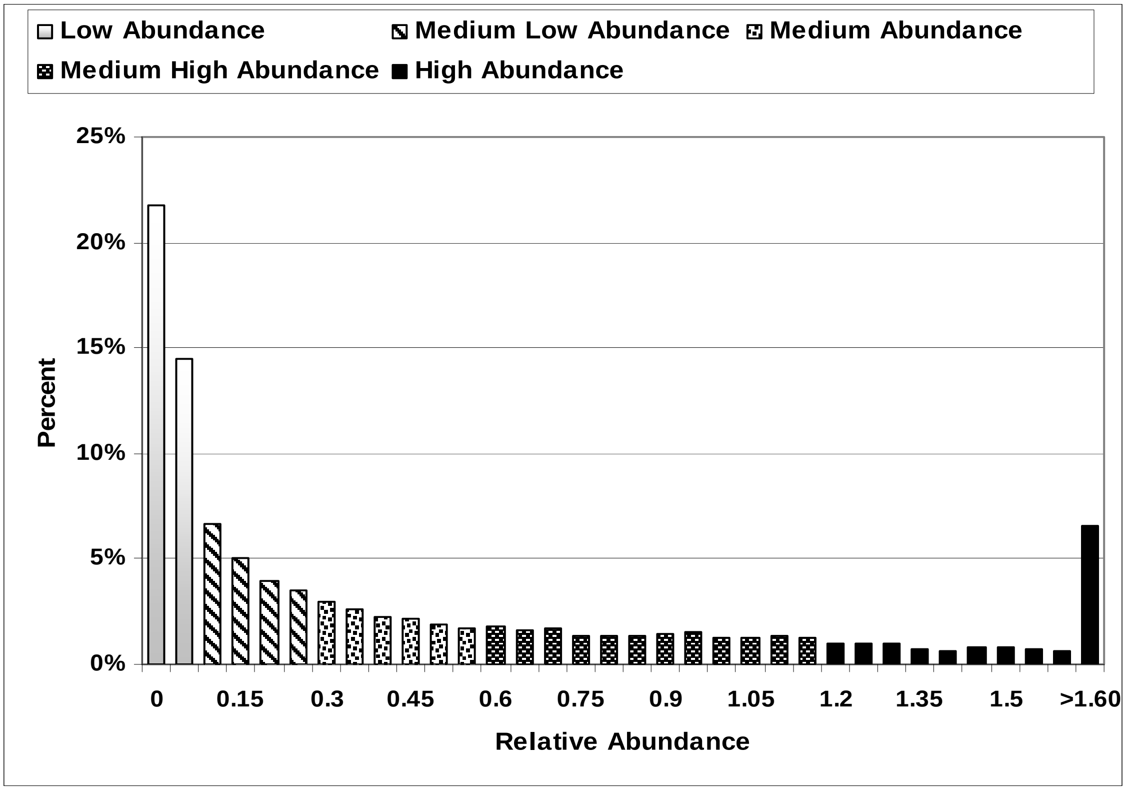


Figure 17.–Weighed average covariances of normalized catches for Deadman Reach, between pots located at, (a) different distances, (b) different depths, and (c) within the same year or different years.



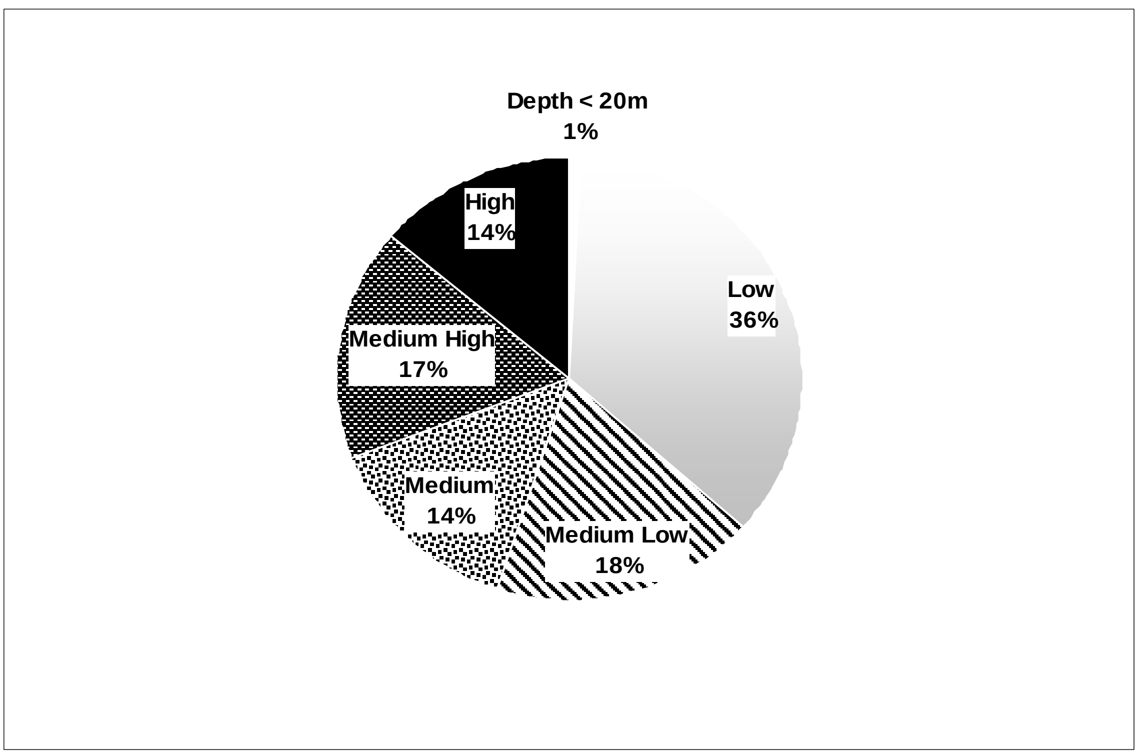


Figure 18.–Percent distribution of relative abundance estimated for the 15,416 grid locations in Pybus Bay, the assigned stratum designation for each relative abundance, and the percent of the Pybus Bay area allocated to each stratum.

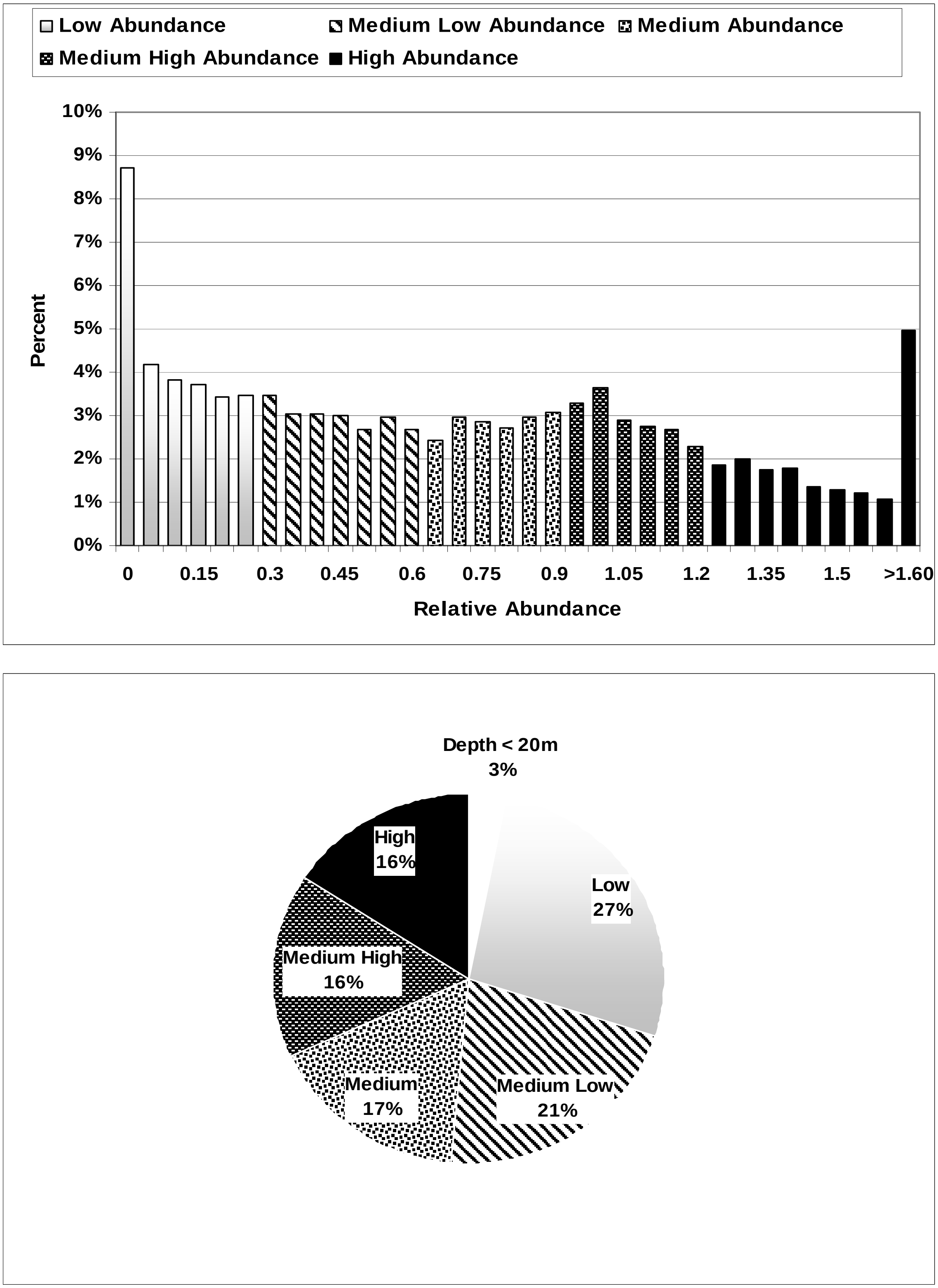
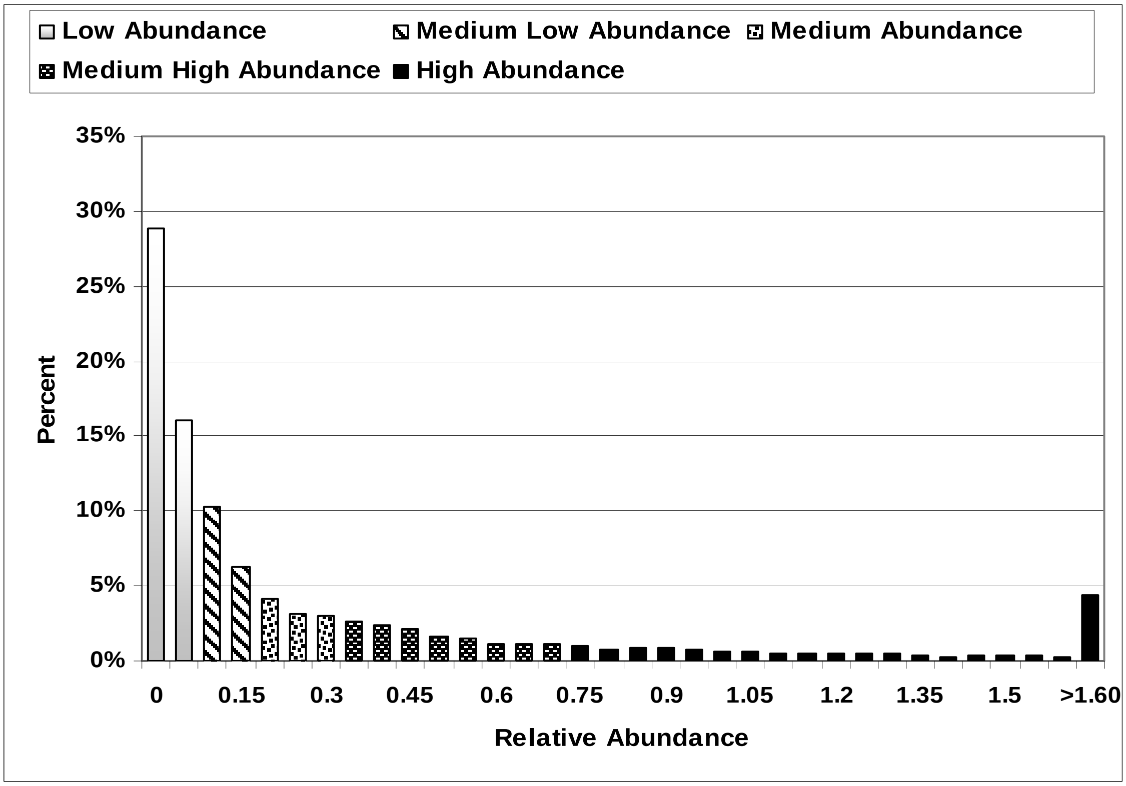


Figure 19.–Percent distribution of relative abundance estimated for the 16,008 grid locations in Gambier Bay, the assigned stratum designation for each relative abundance, and the percent of the Gambier Bay area allocated to each stratum.



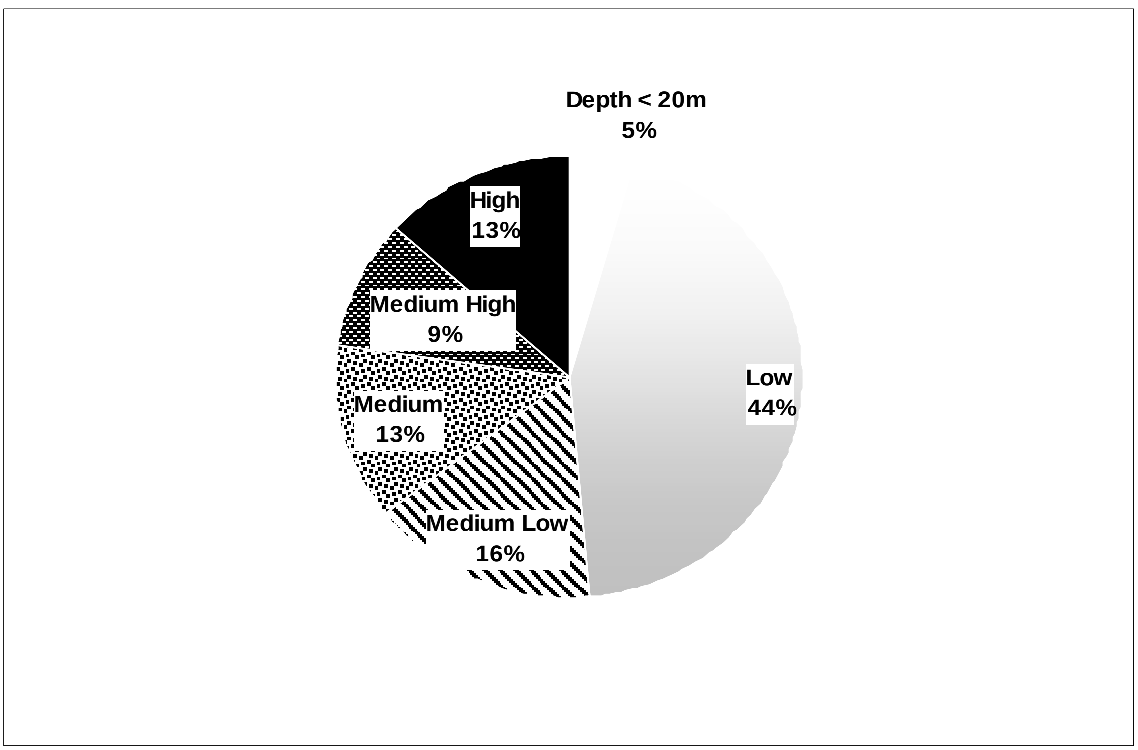
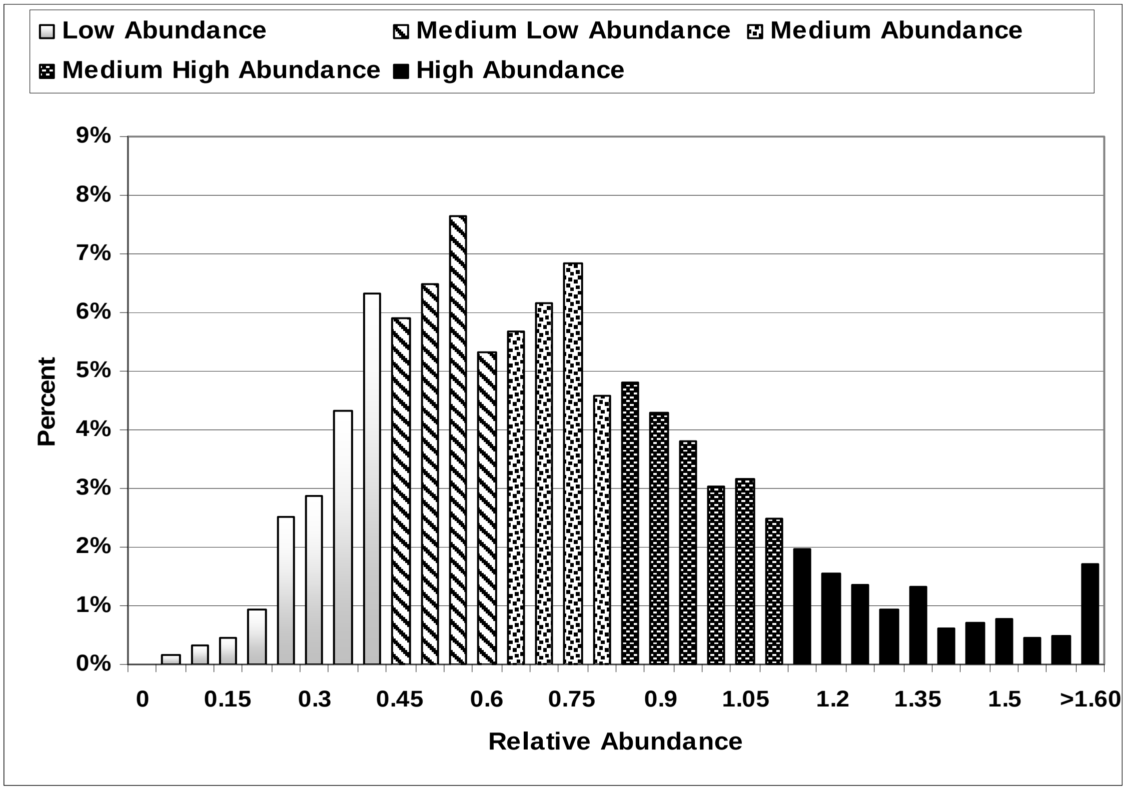


Figure 20.–Percent distribution of relative abundance estimated for the 39,915 grid locations in Seymour Canal, the assigned stratum designation for each relative abundance, and, the percent of the Seymour Canal area allocated to each stratum.



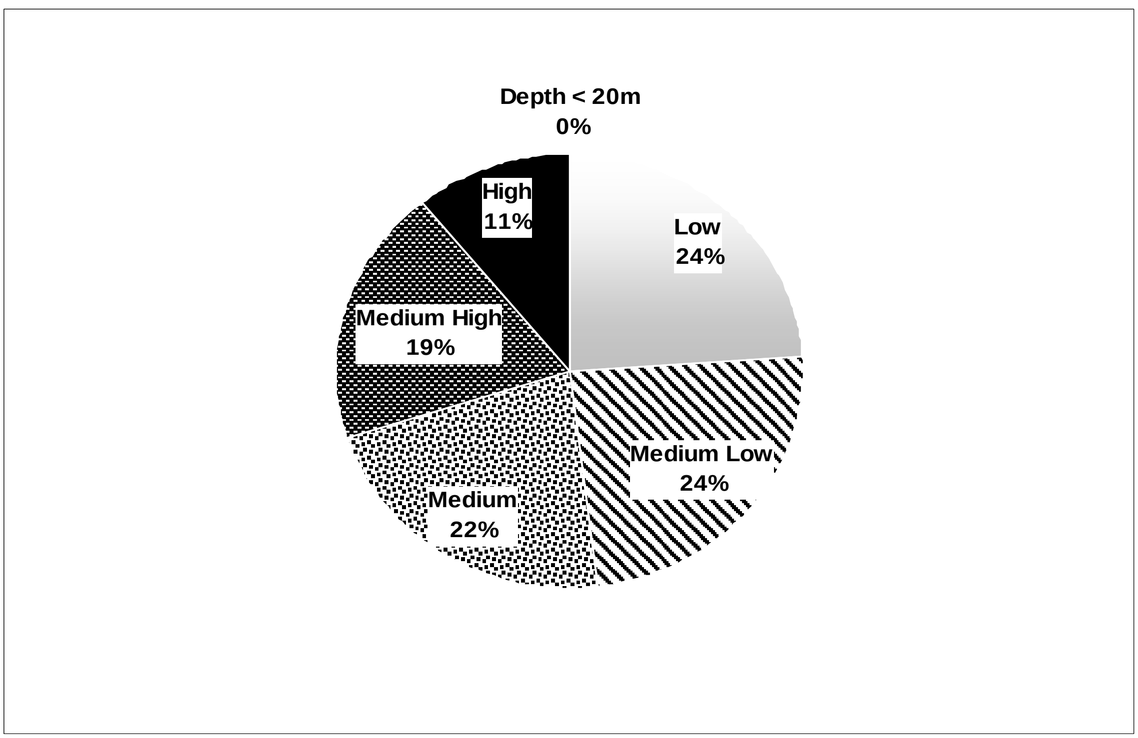
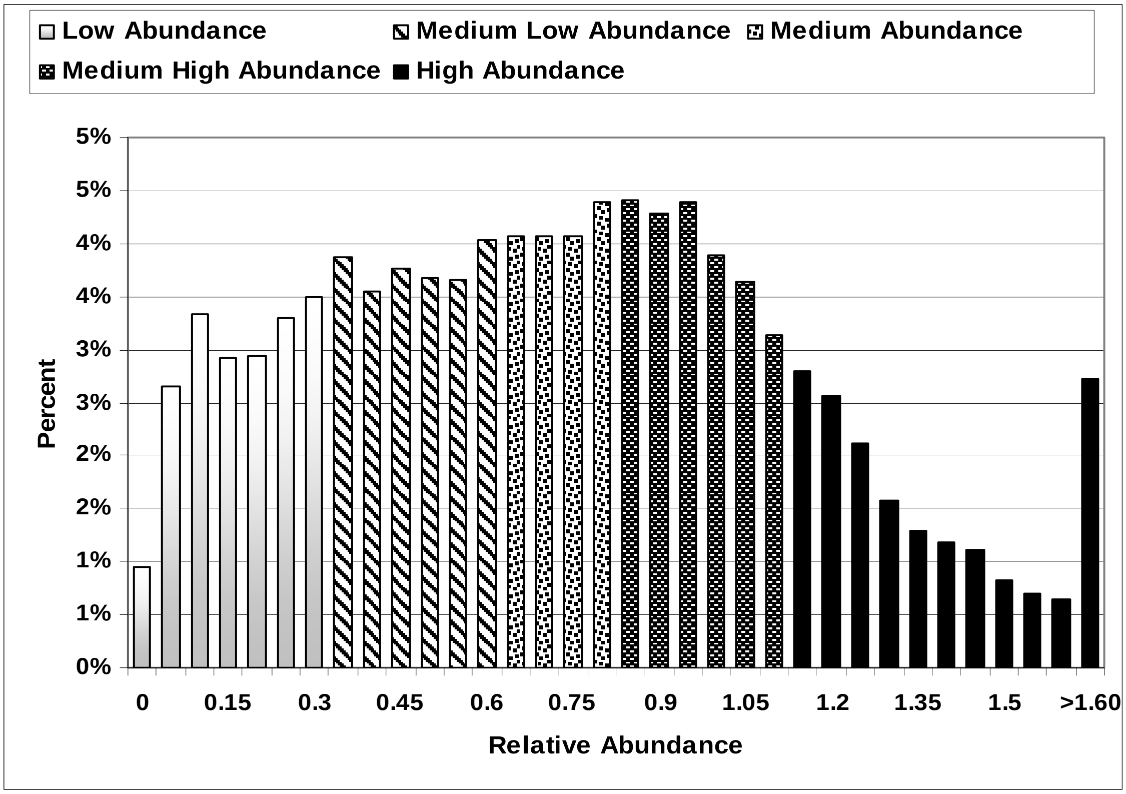


Figure 21.–Percent distribution of relative abundance estimated for the 2,496 grid locations in Barlow Cove, the assigned stratum designation for each relative abundance, and, the percent of the Barlow Cove area allocated to each stratum.



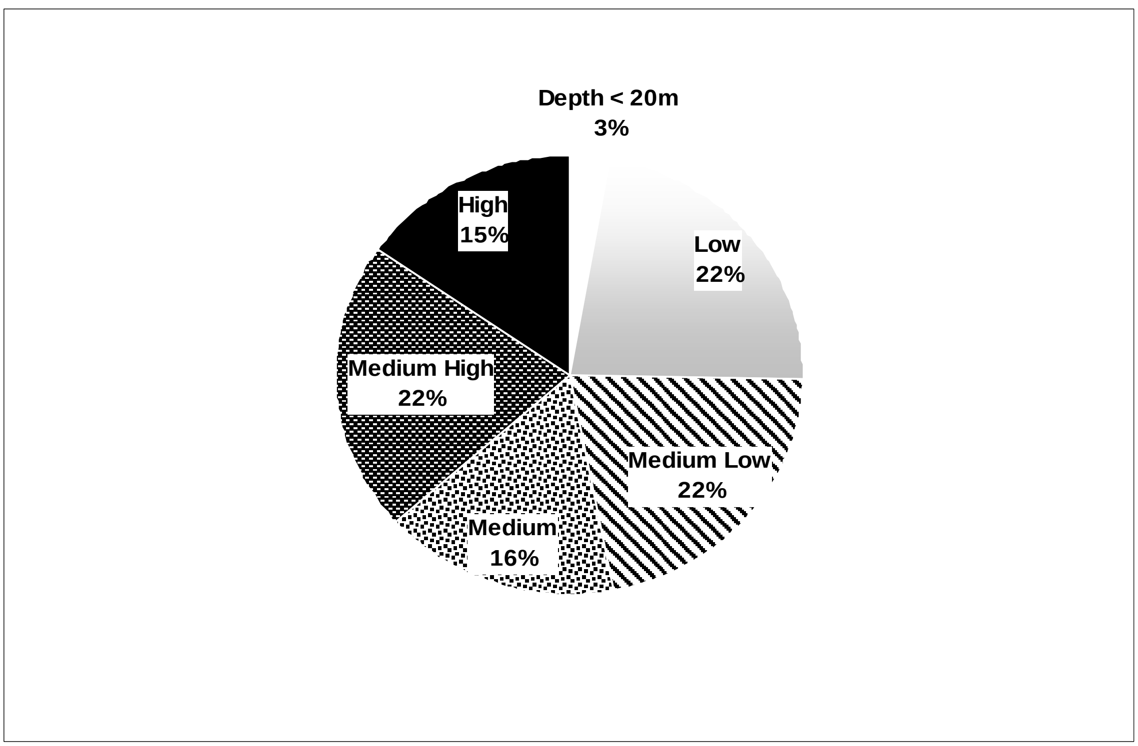
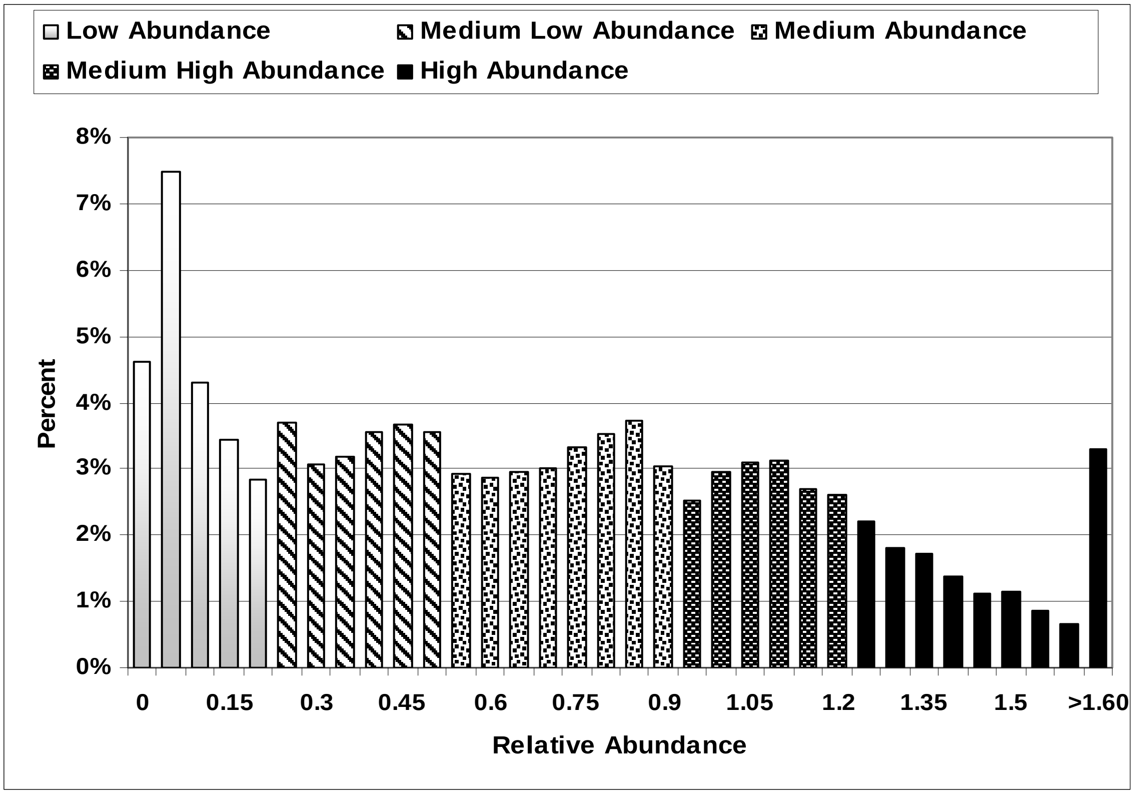


Figure 22.–Percent distribution of relative abundance estimated for the 137,977 grid locations in Juneau Area, the assigned stratum designation for each relative abundance, and, the percent of the Juneau Area allocated to each stratum.



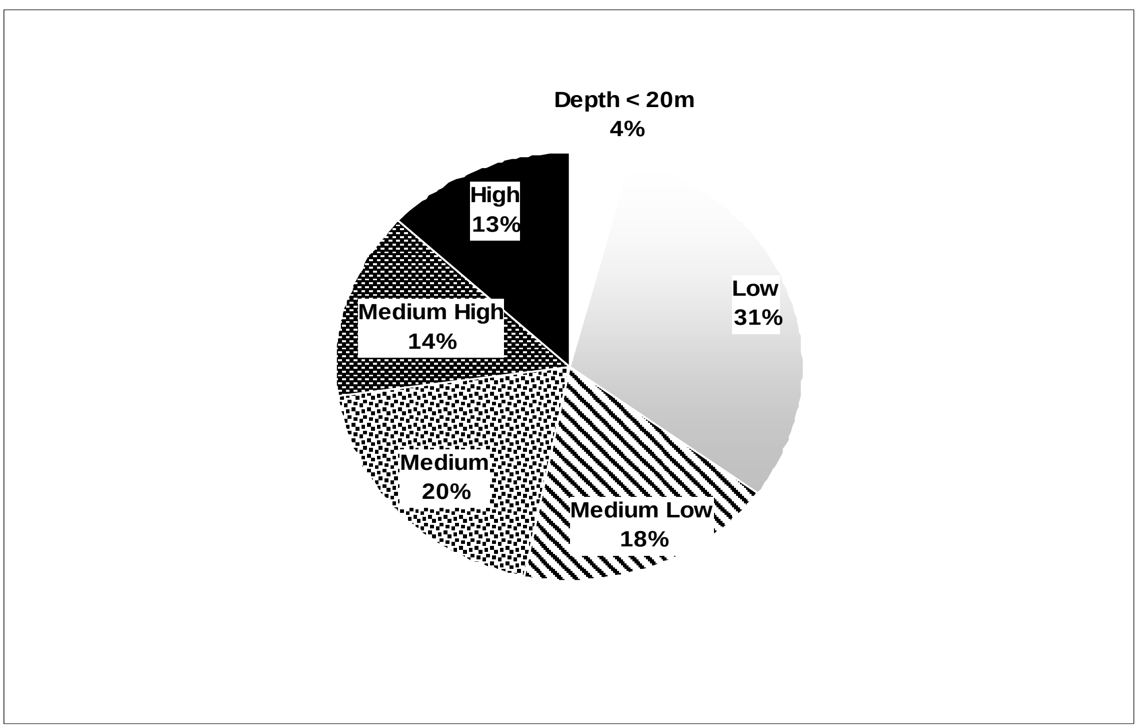
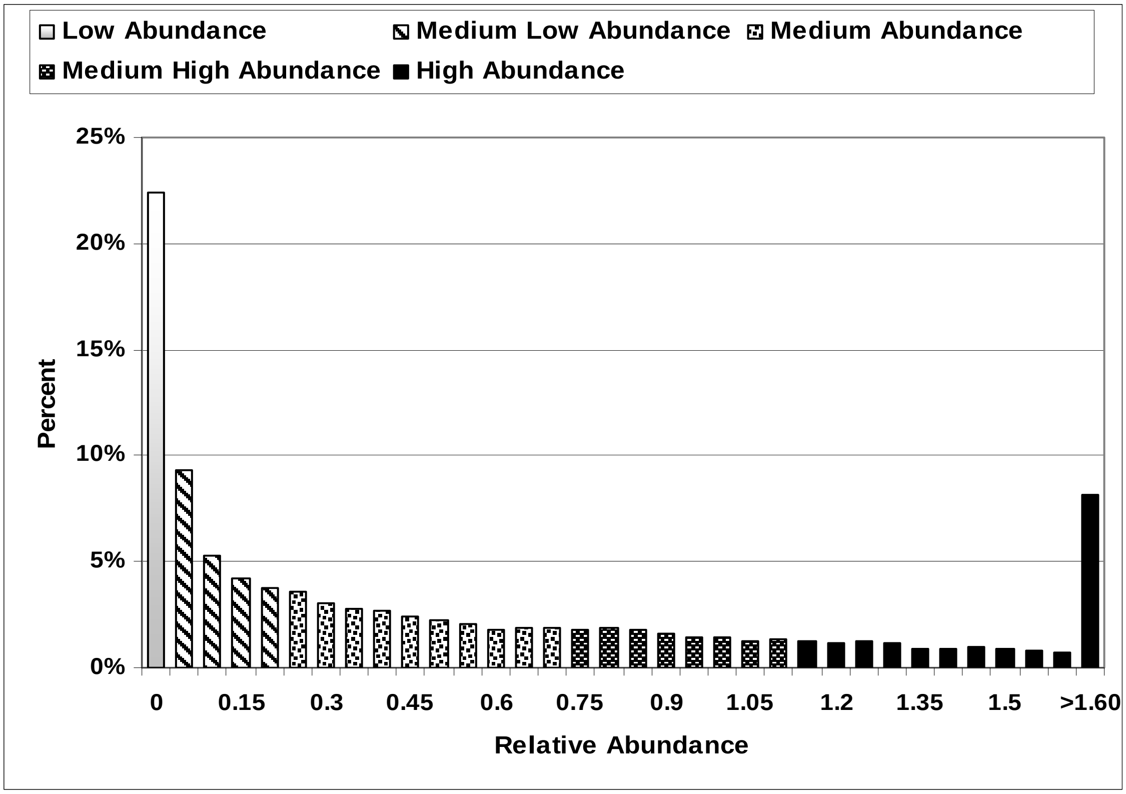


Figure 23.–Percent distribution of relative abundance estimated for the 11,932 grid locations in Lynn Canal, the assigned stratum designation for each relative abundance, and, the percent of the Lynn Canal area allocated to each stratum.



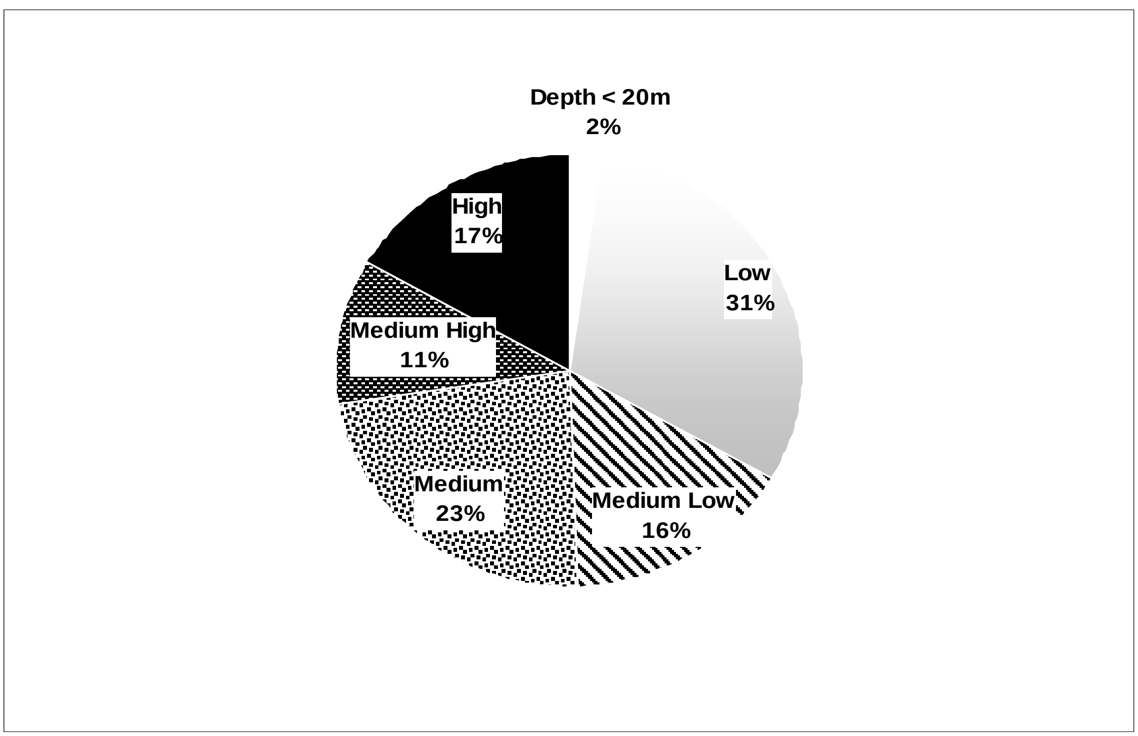
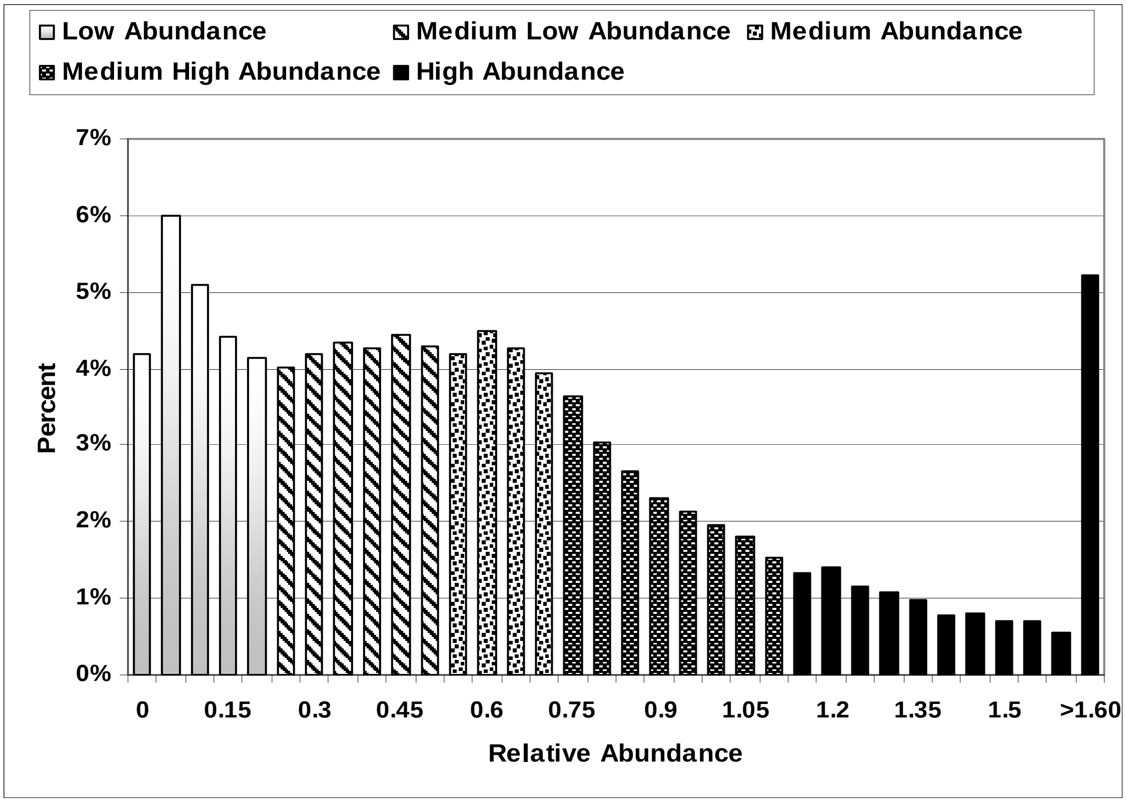


Figure 24.–Percent distribution of relative abundance estimated for the 31,034 grid locations in Excursion Inlet, the assigned stratum designation for each relative abundance, and. the percent of the Excursion Inlet area allocated to each stratum.



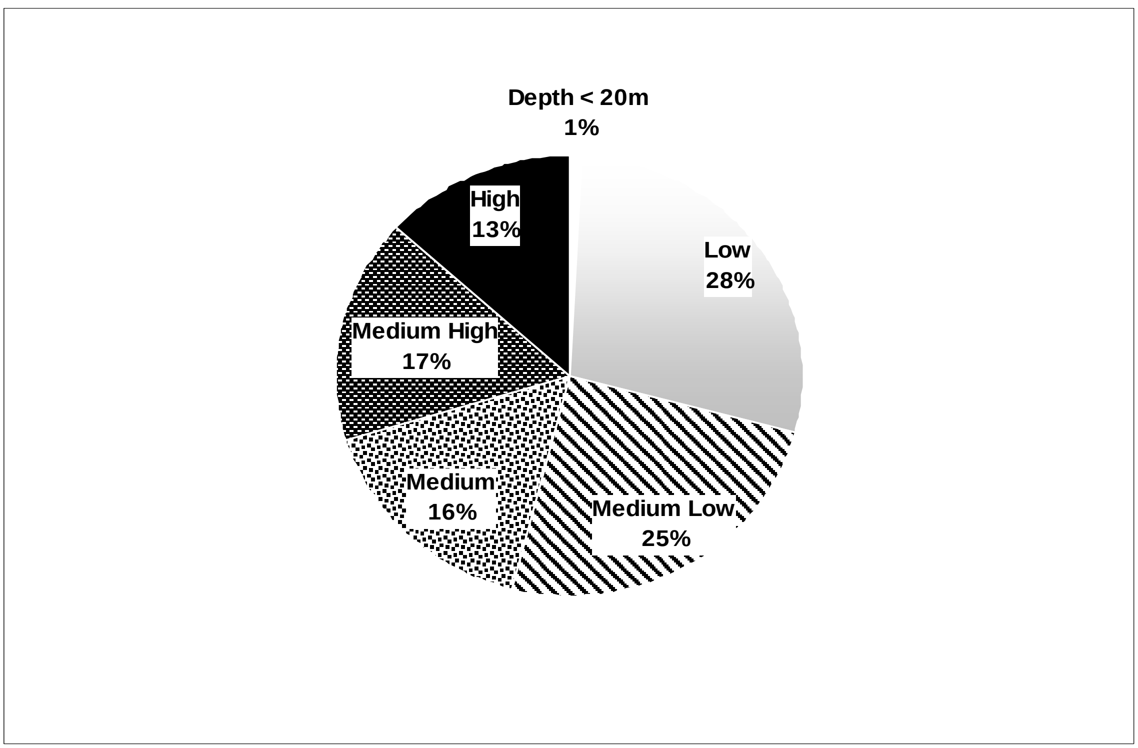
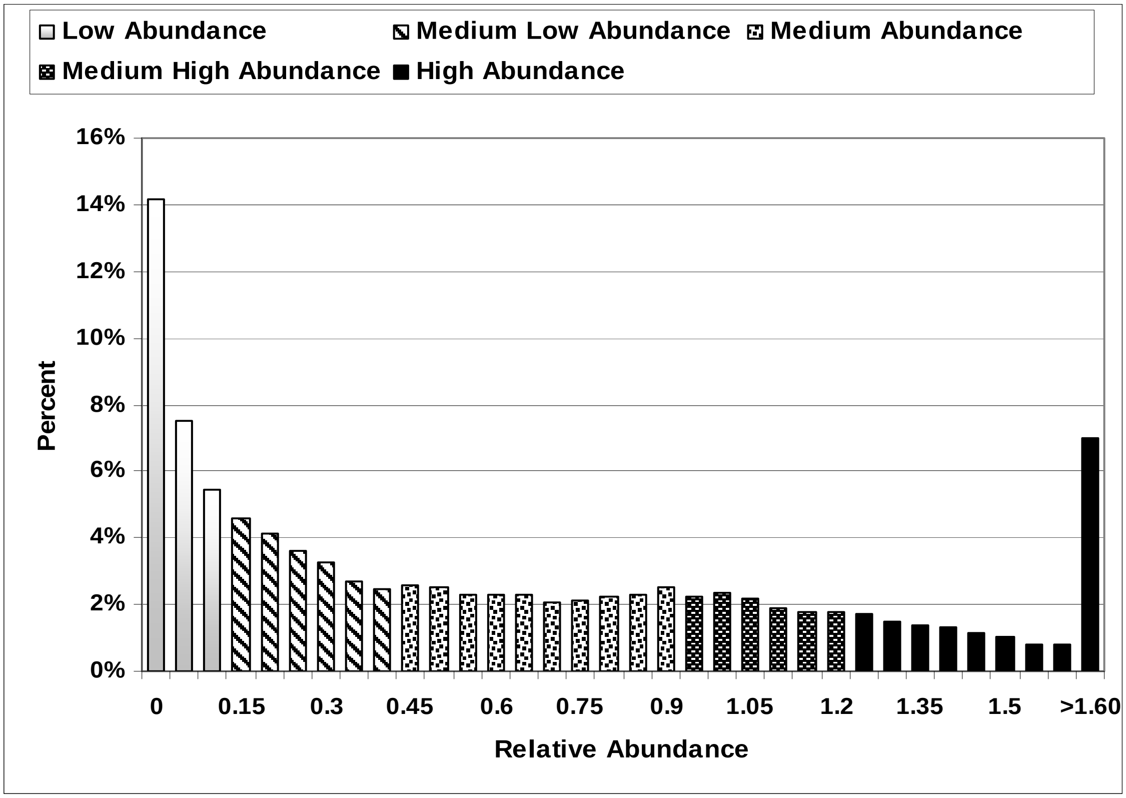


Figure 25.–Percent distribution of relative abundance estimated for the 26,350 grid locations in Port Frederick, the assigned stratum designation for each relative abundance, and, the percent of the Port Frederick area allocated to each stratum.



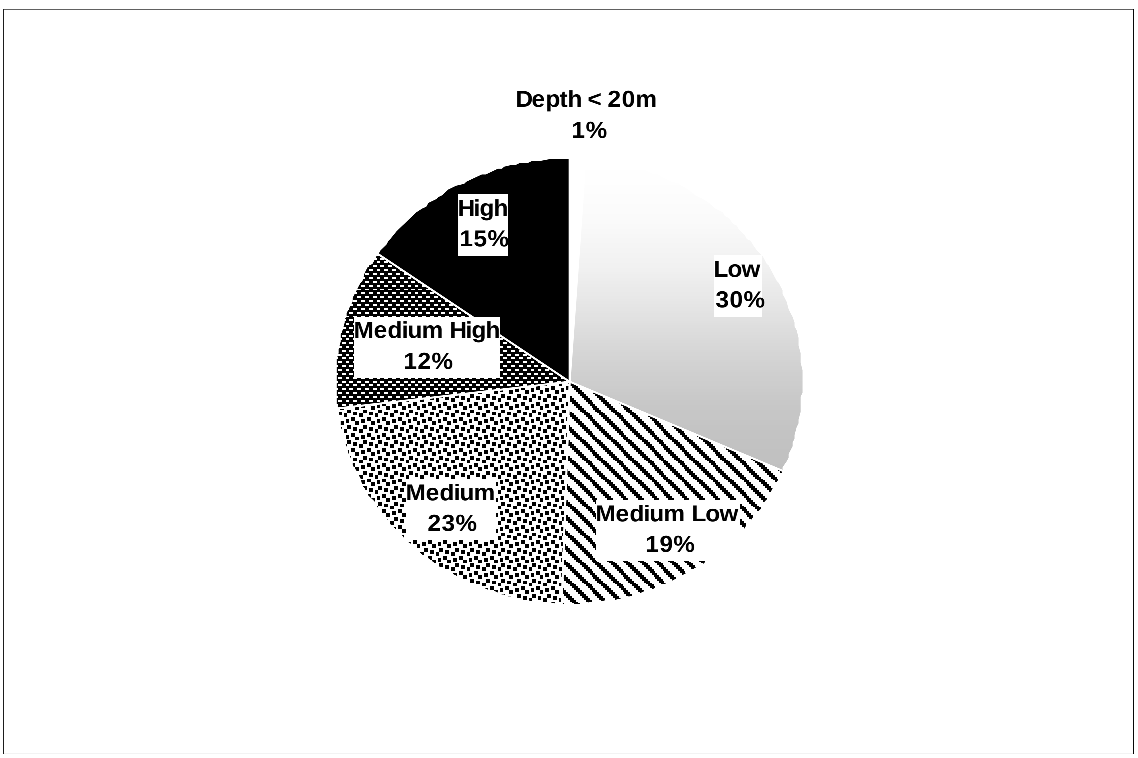


Figure 26.–Percent distribution of relative abundance estimated for the 17,517 grid locations in Deadman Reach, the assigned stratum designation for each relative abundance, and, the percent of the Deadman Reach area allocated to each stratum.

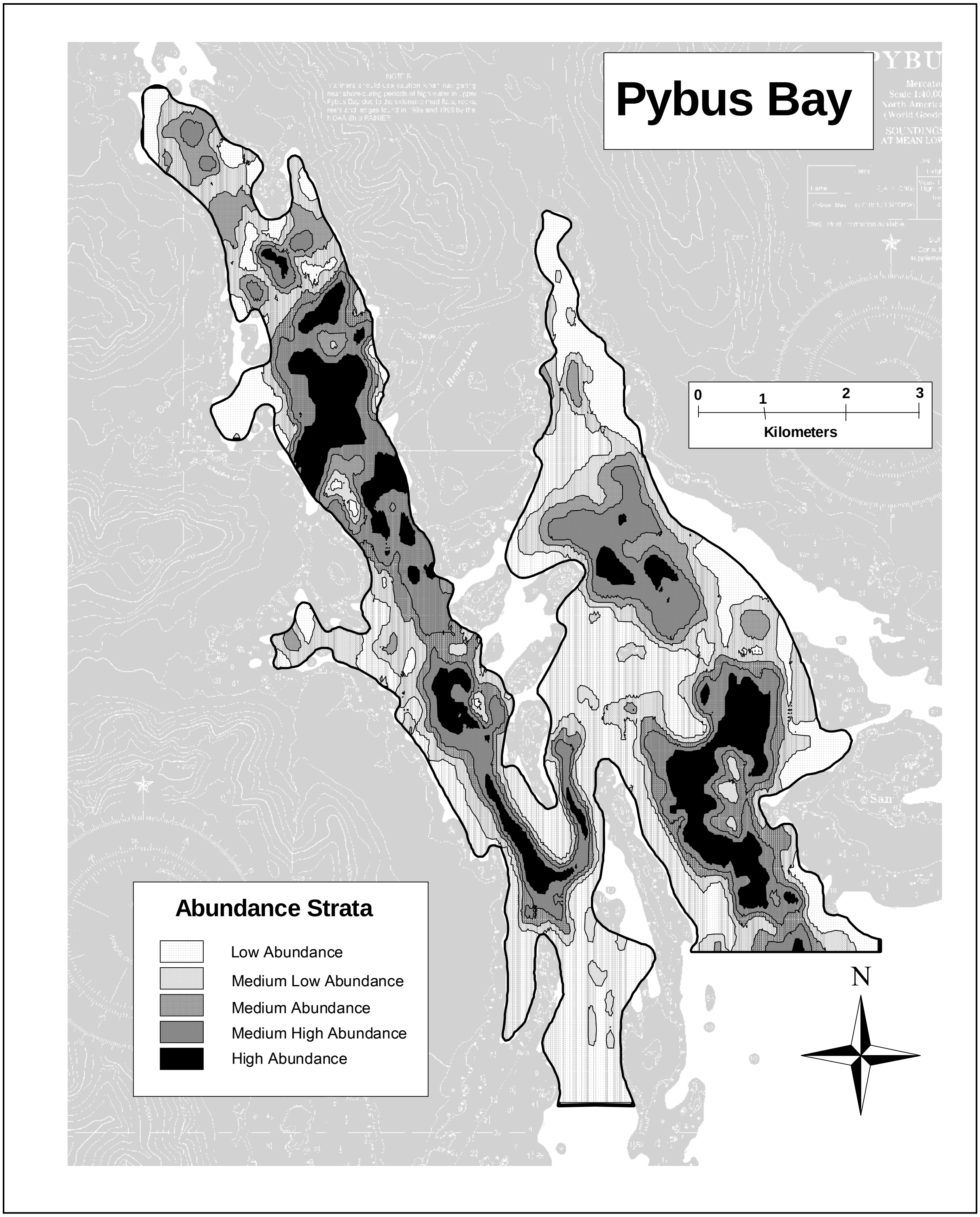


Figure 27.–New stratification designation for Pybus Bay.

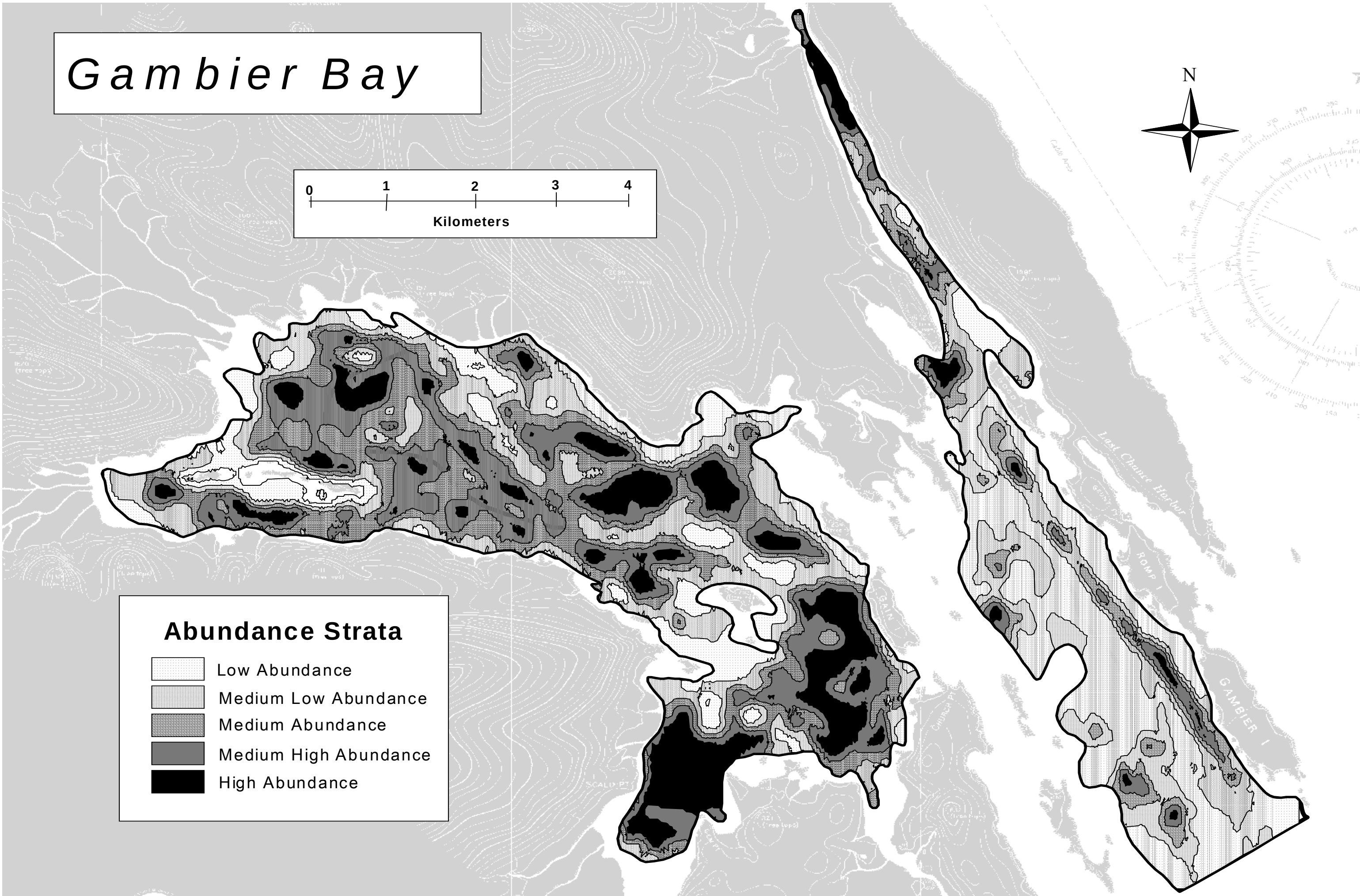


Figure 28.–New Stratification designation for Gambier Bay.

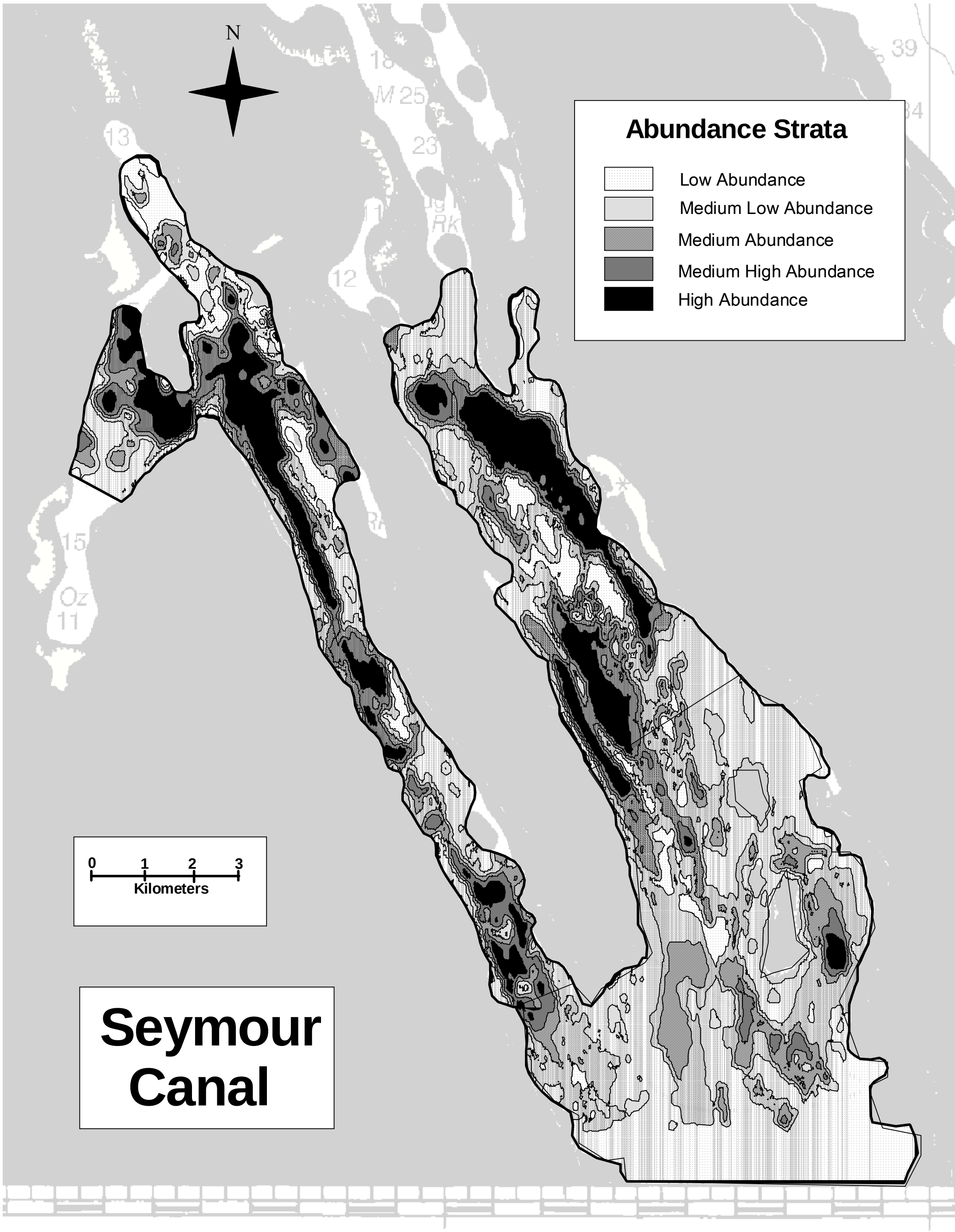


Figure 29.–New stratification designation for Seymour Canal.

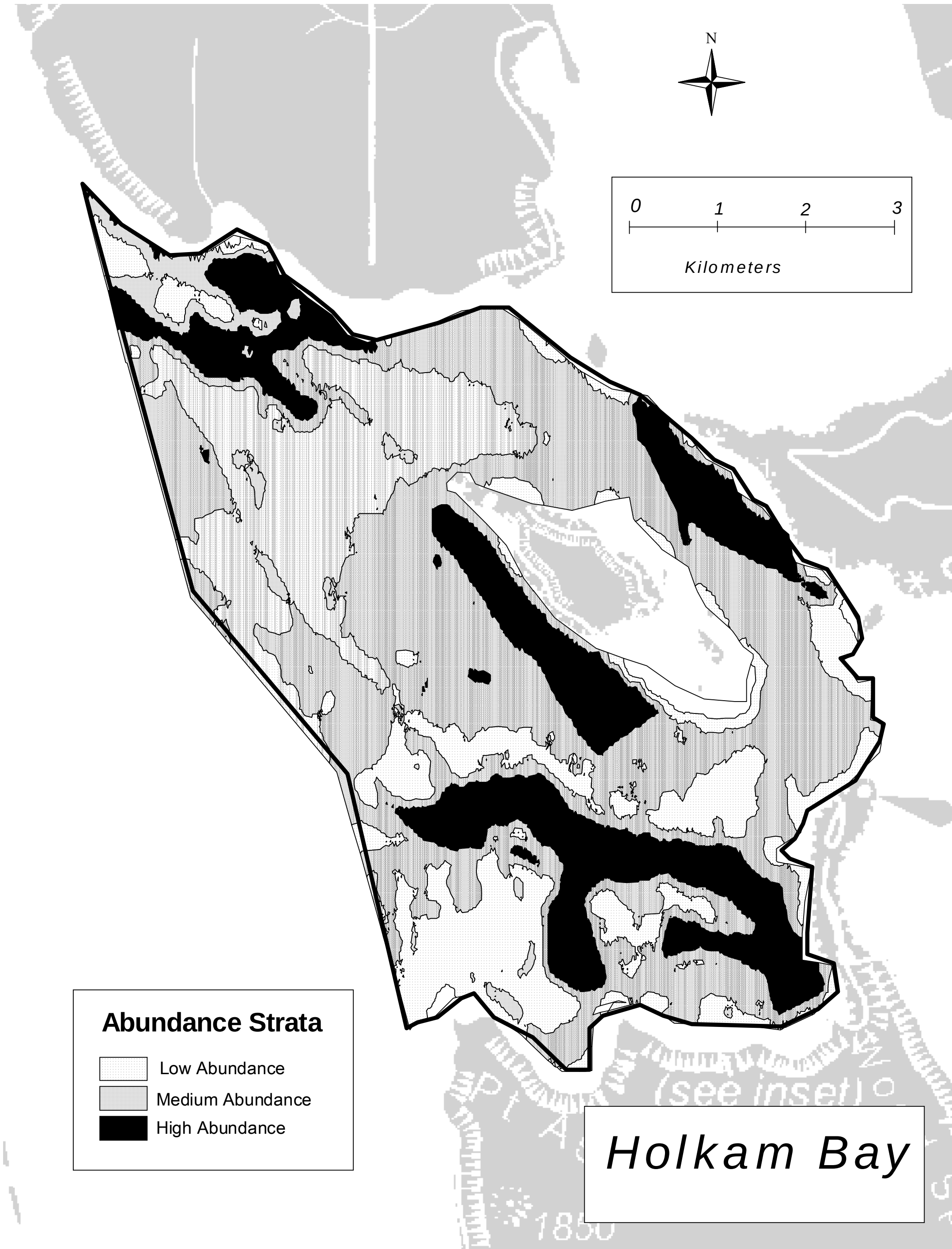


Figure 30.–New stratification for Holkam Bay.

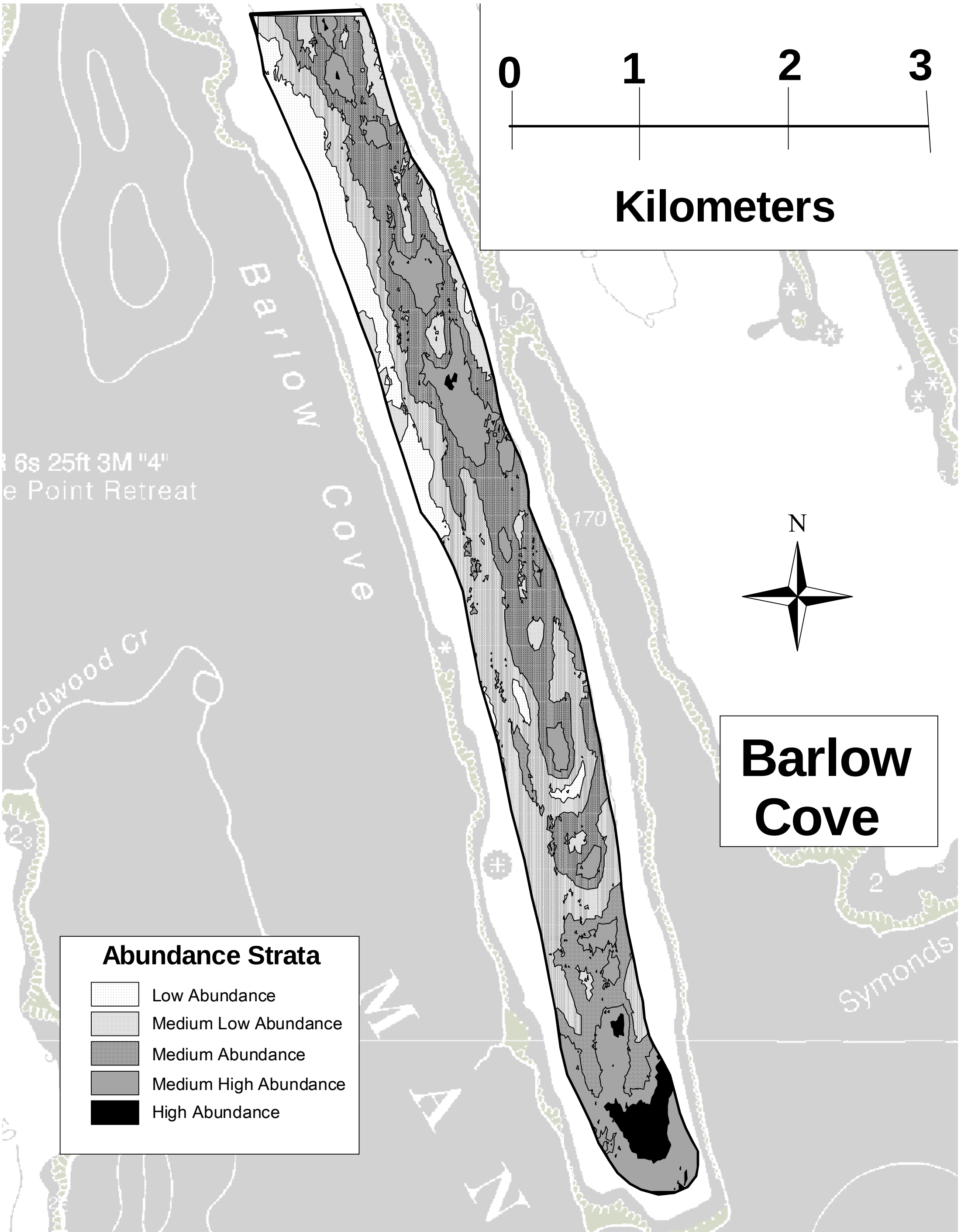


Figure 31.–New stratification designation for Barlow Cove.

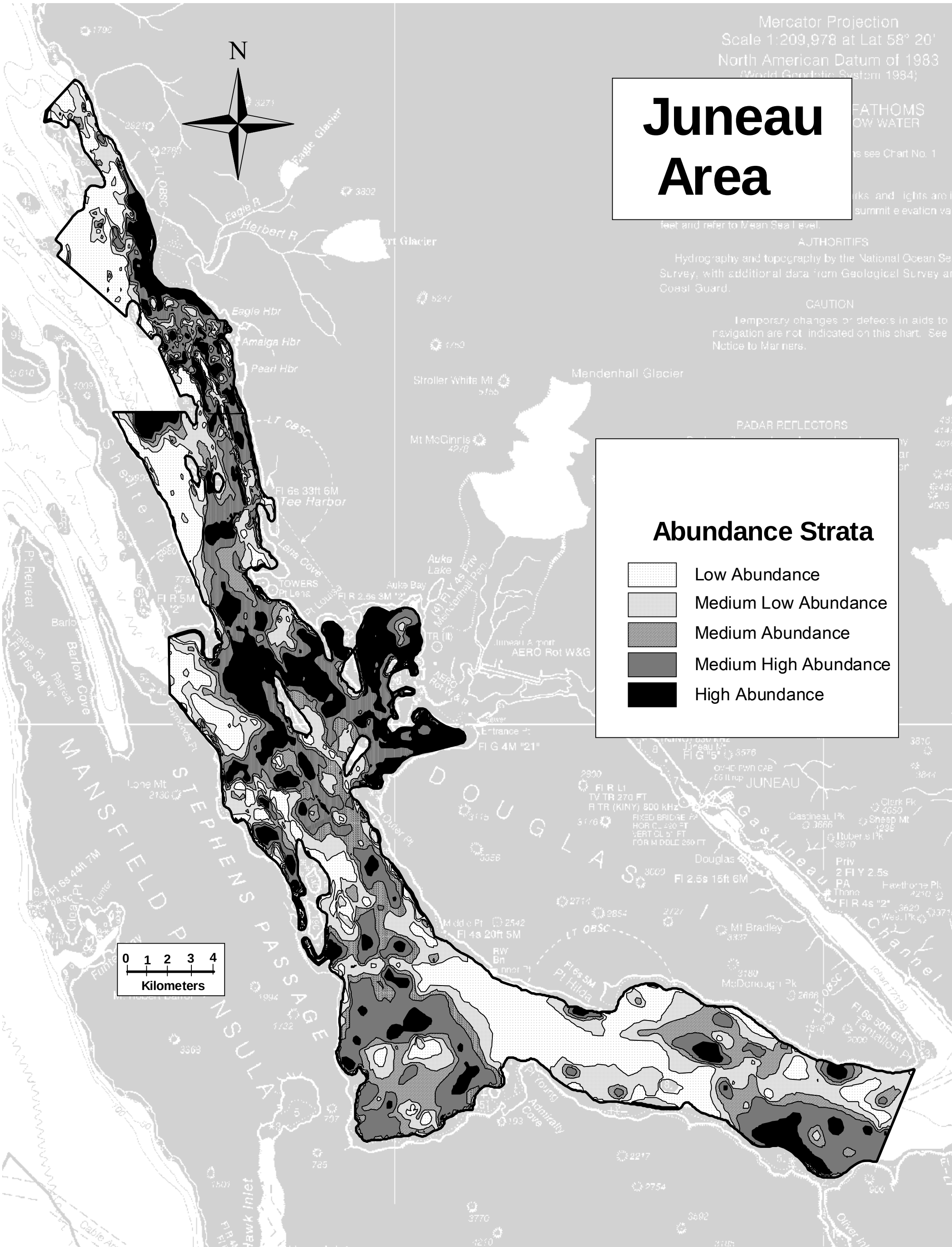


Figure 32.–New stratification designation for Juneau Area.

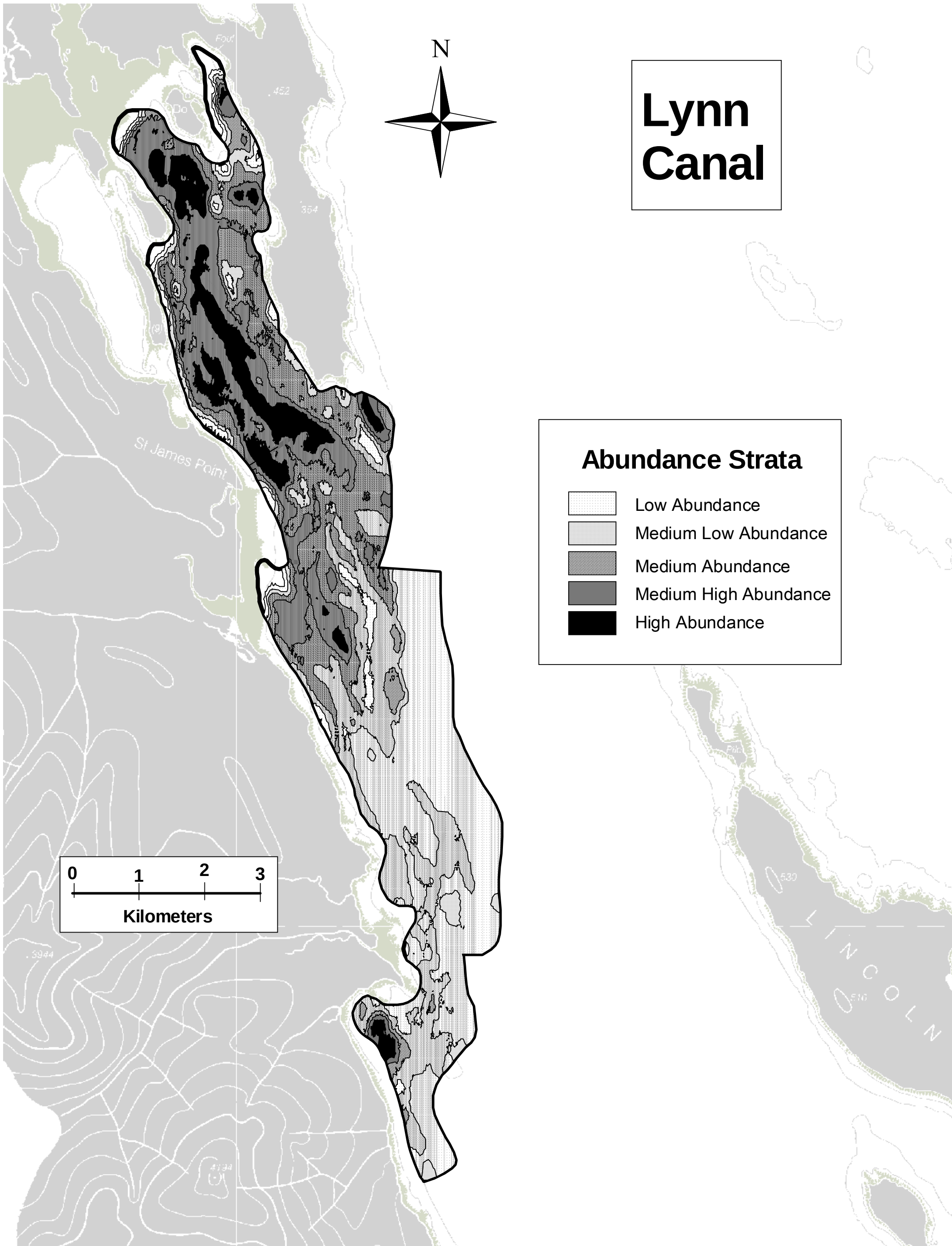


Figure 33.–New stratification designation for Lynn Canal.

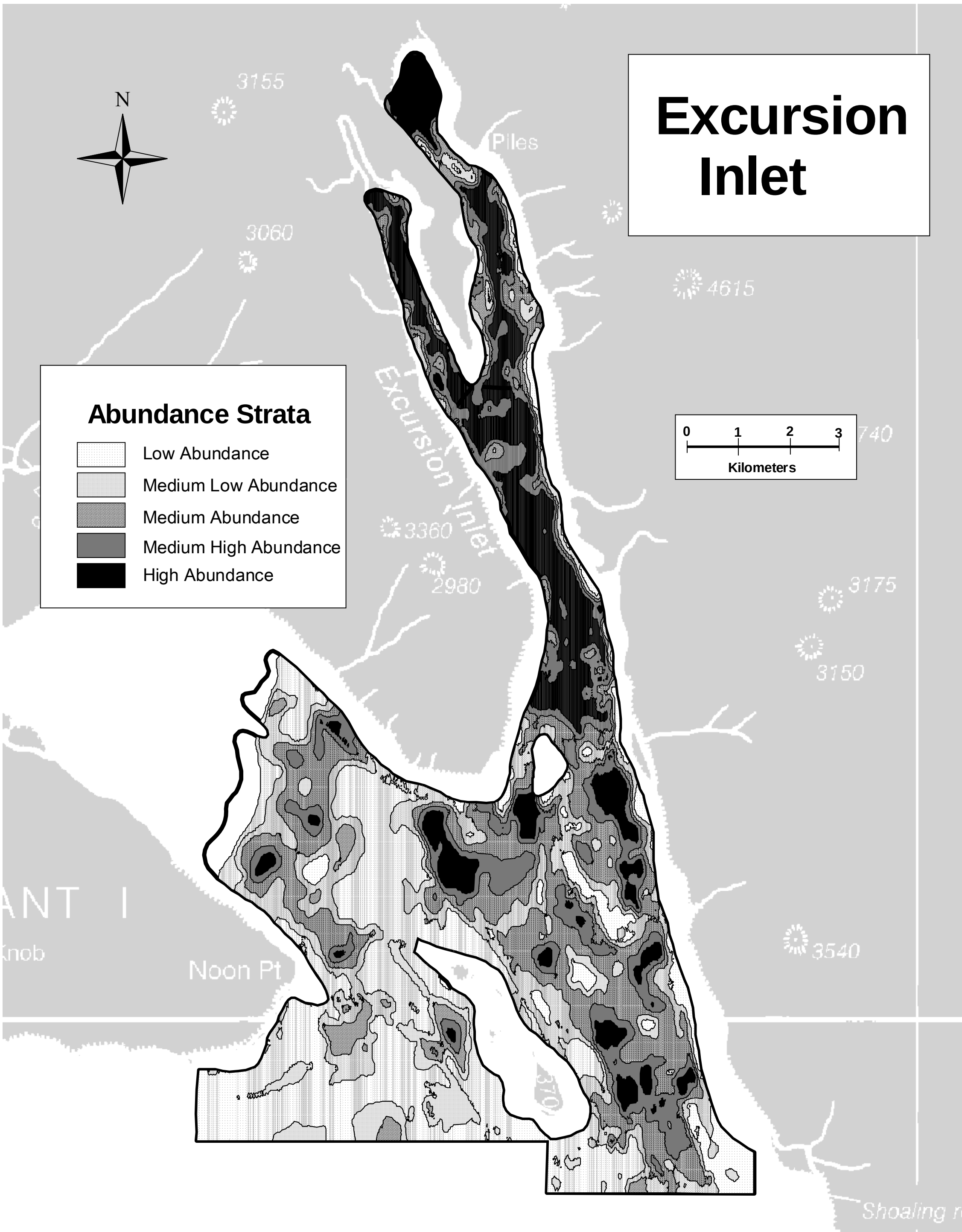


Figure 34.–New stratification designation for Excursion Inlet.

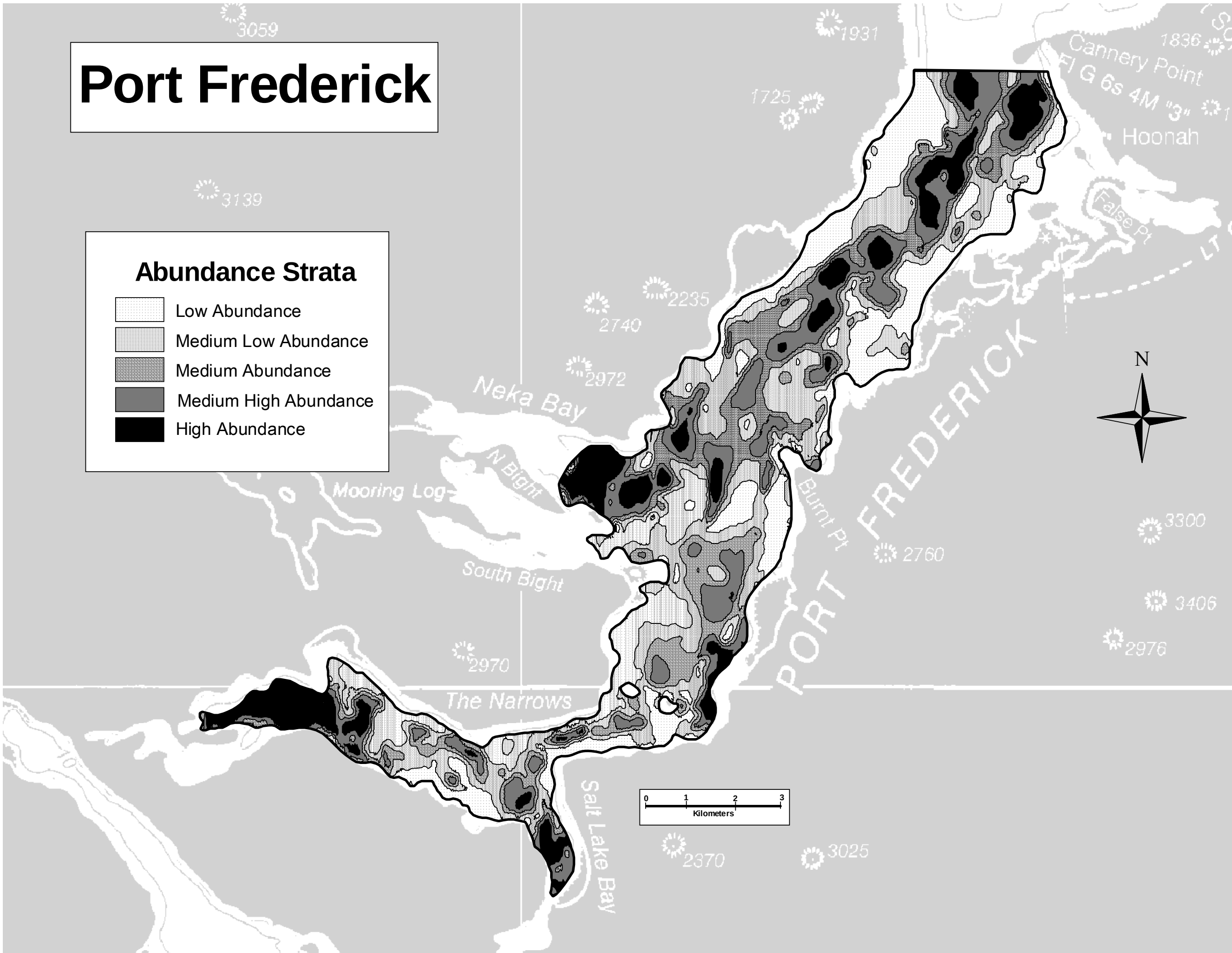


Figure 35.–New stratification designation for Port Frederick.

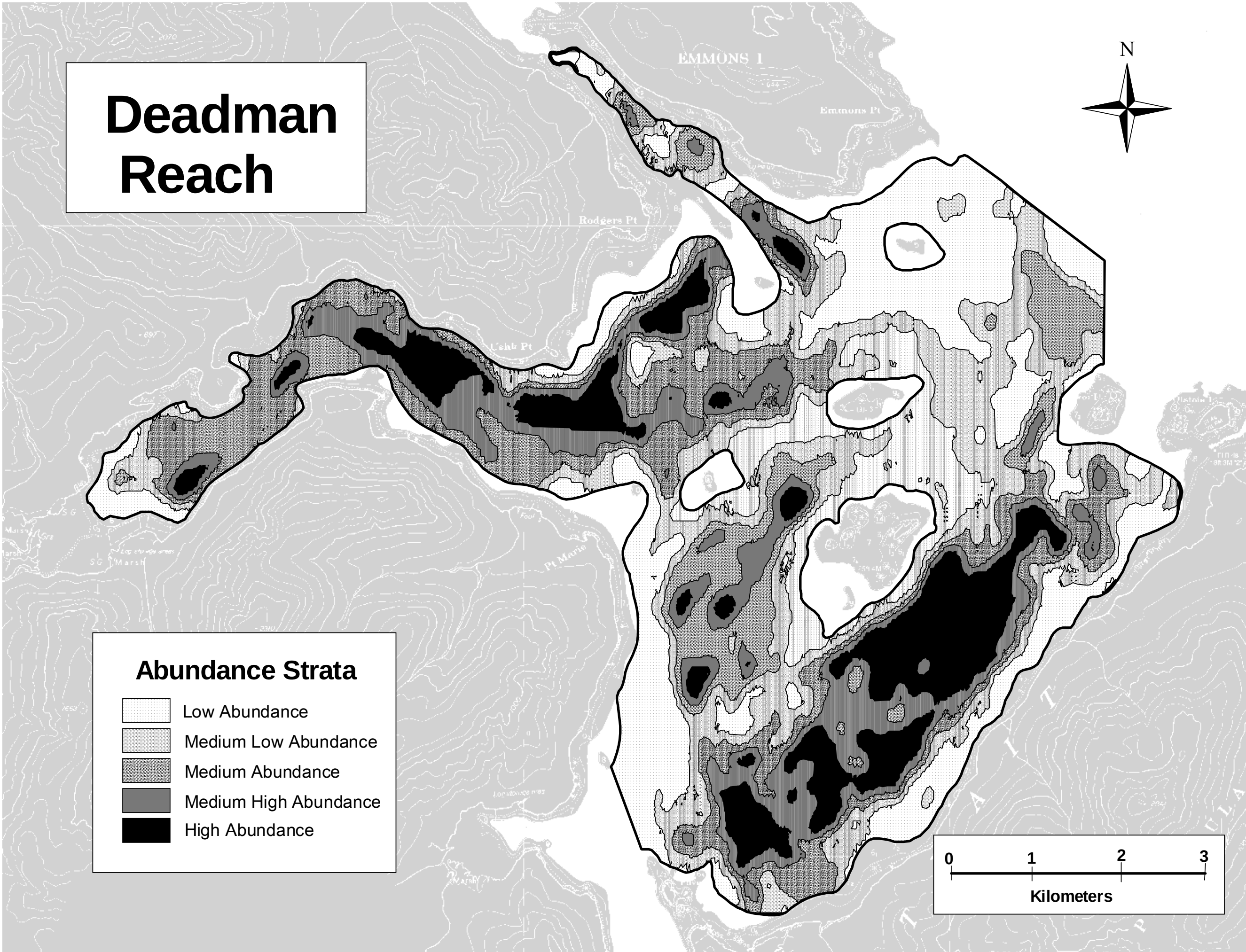


Figure 36.–New stratification designation for Deadman Reach.

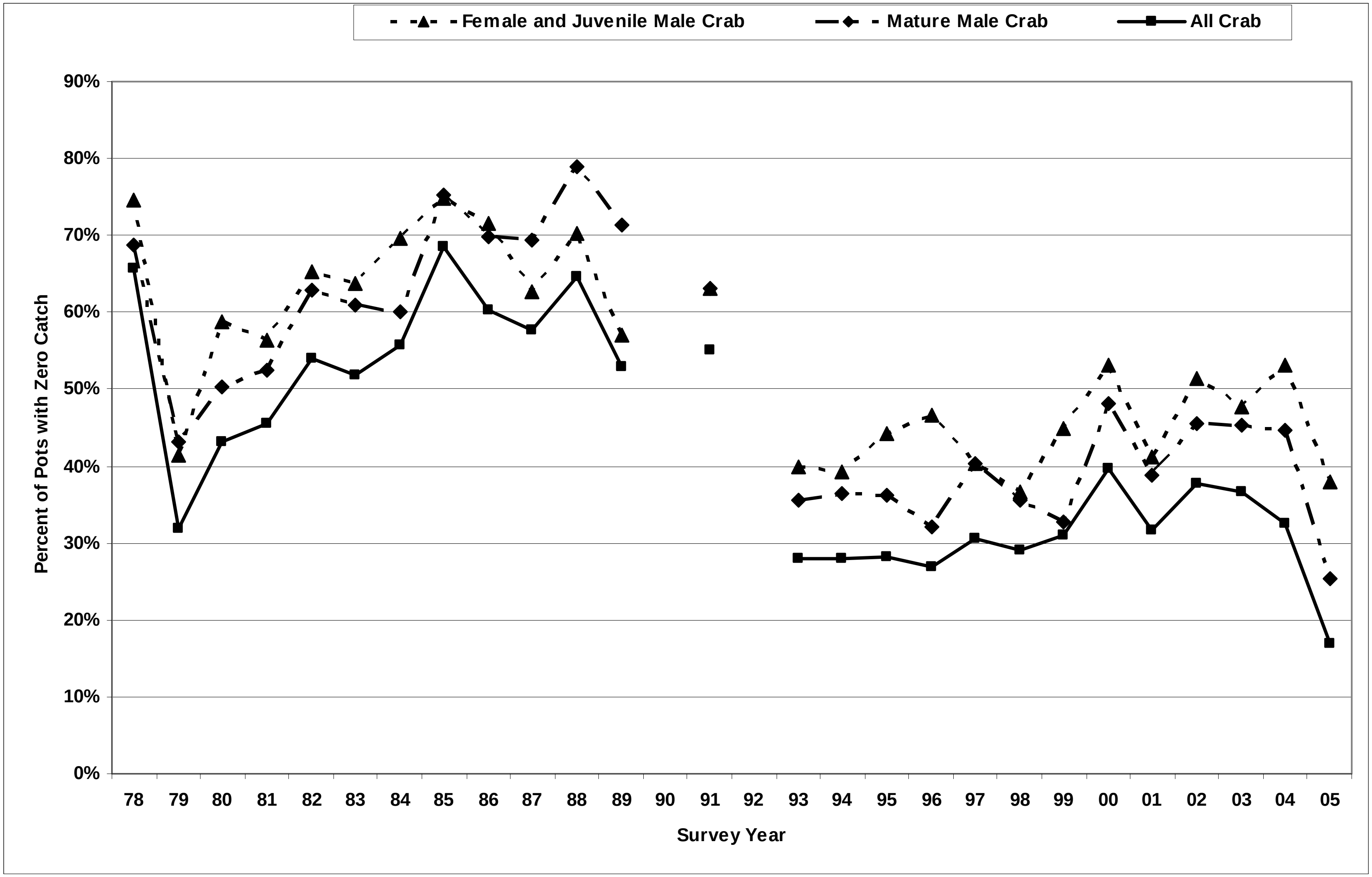


Figure 37.–Percent of pots that caught no red king crab in the stock assessment surveys. Survey areas do not include Seymour Canal.

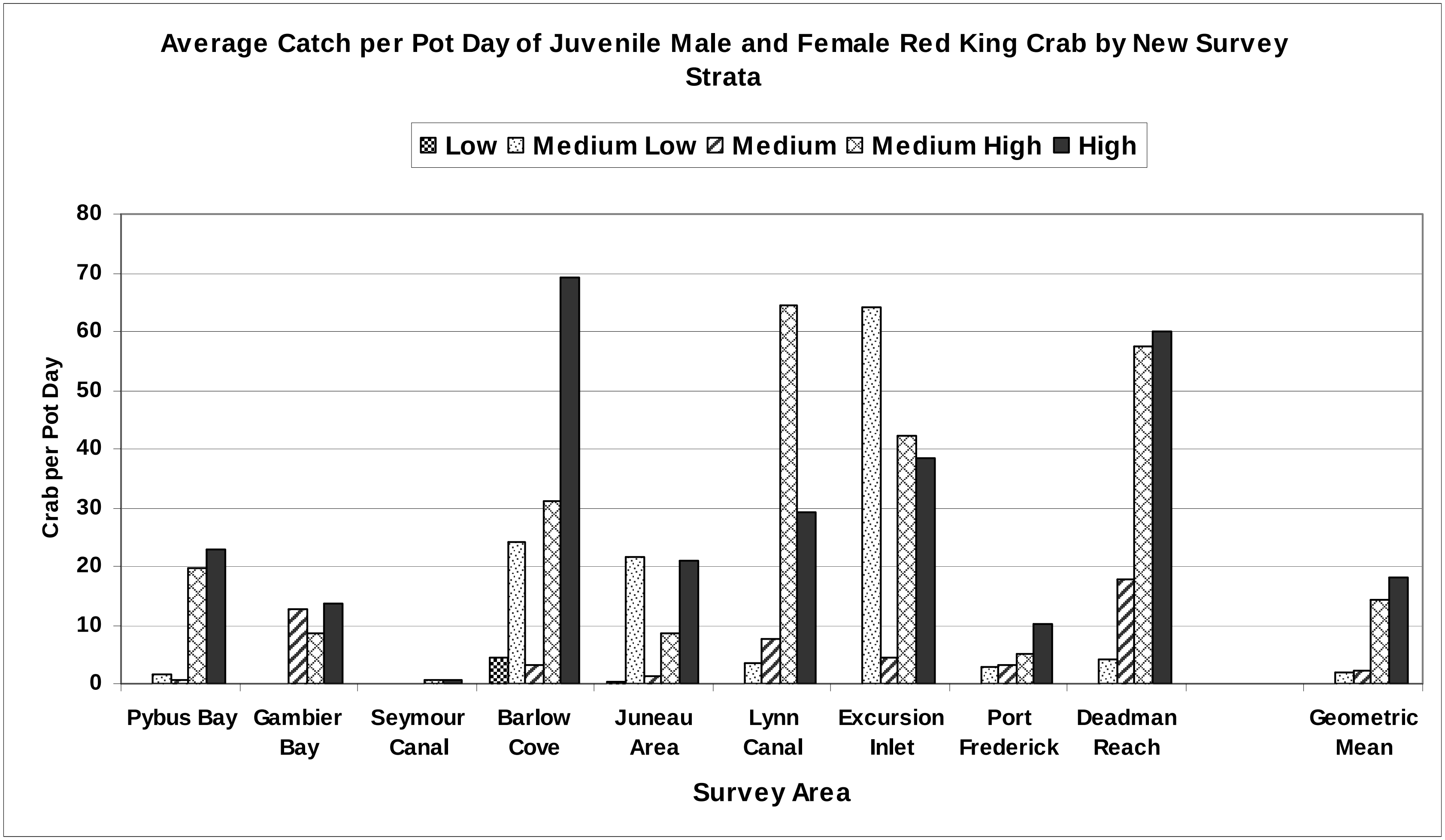


Figure 38.–Average catch per pot day of female and juvenile male red king crab stocks by survey area and new stratum designations.

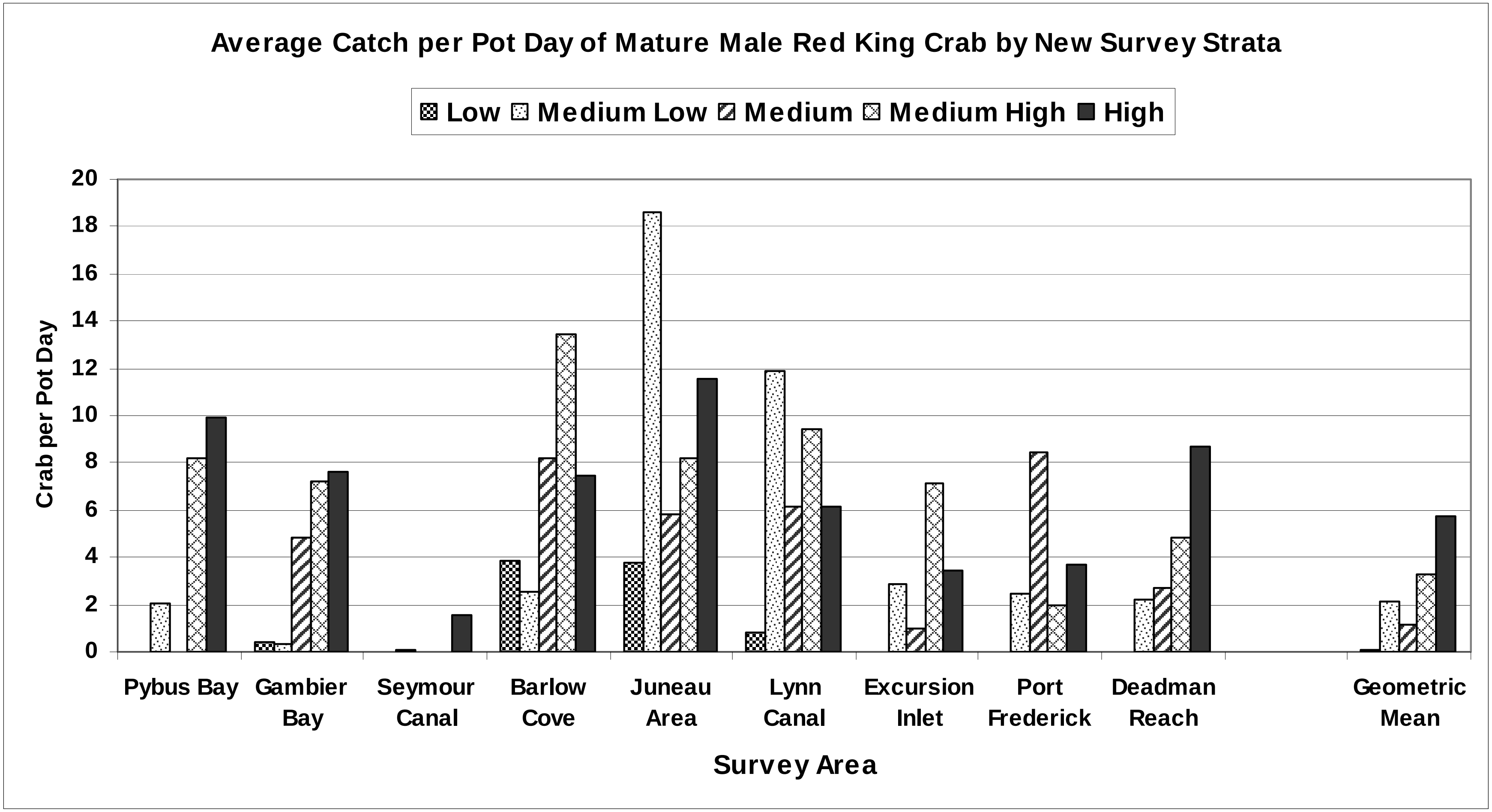


Figure 39.–Average catch per pot day of mature male red king crab stocks by survey area and new stratum designations.

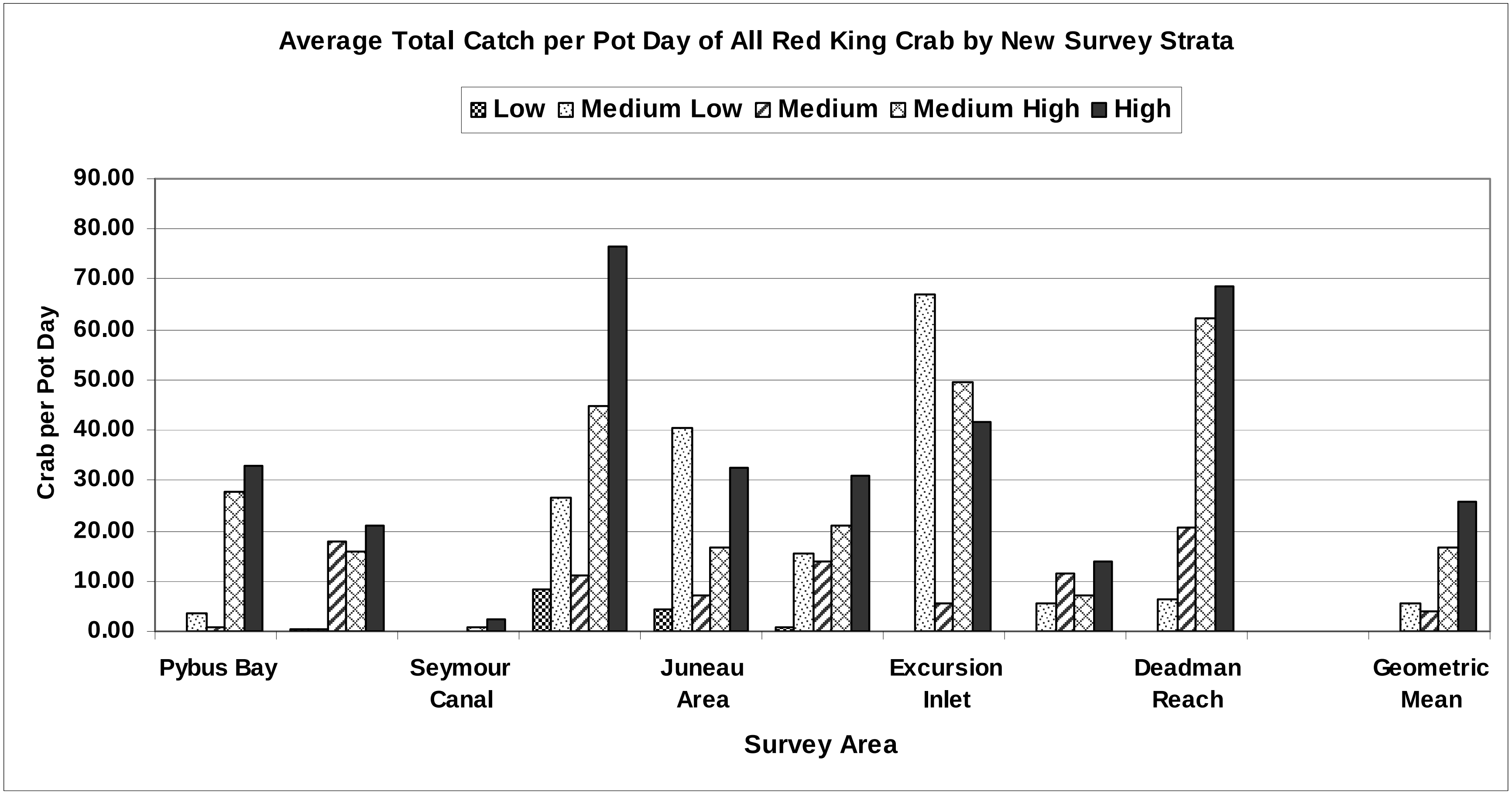


Figure 40.–Average catch per pot day of all red king crab stocks by survey area and new stratum designations.

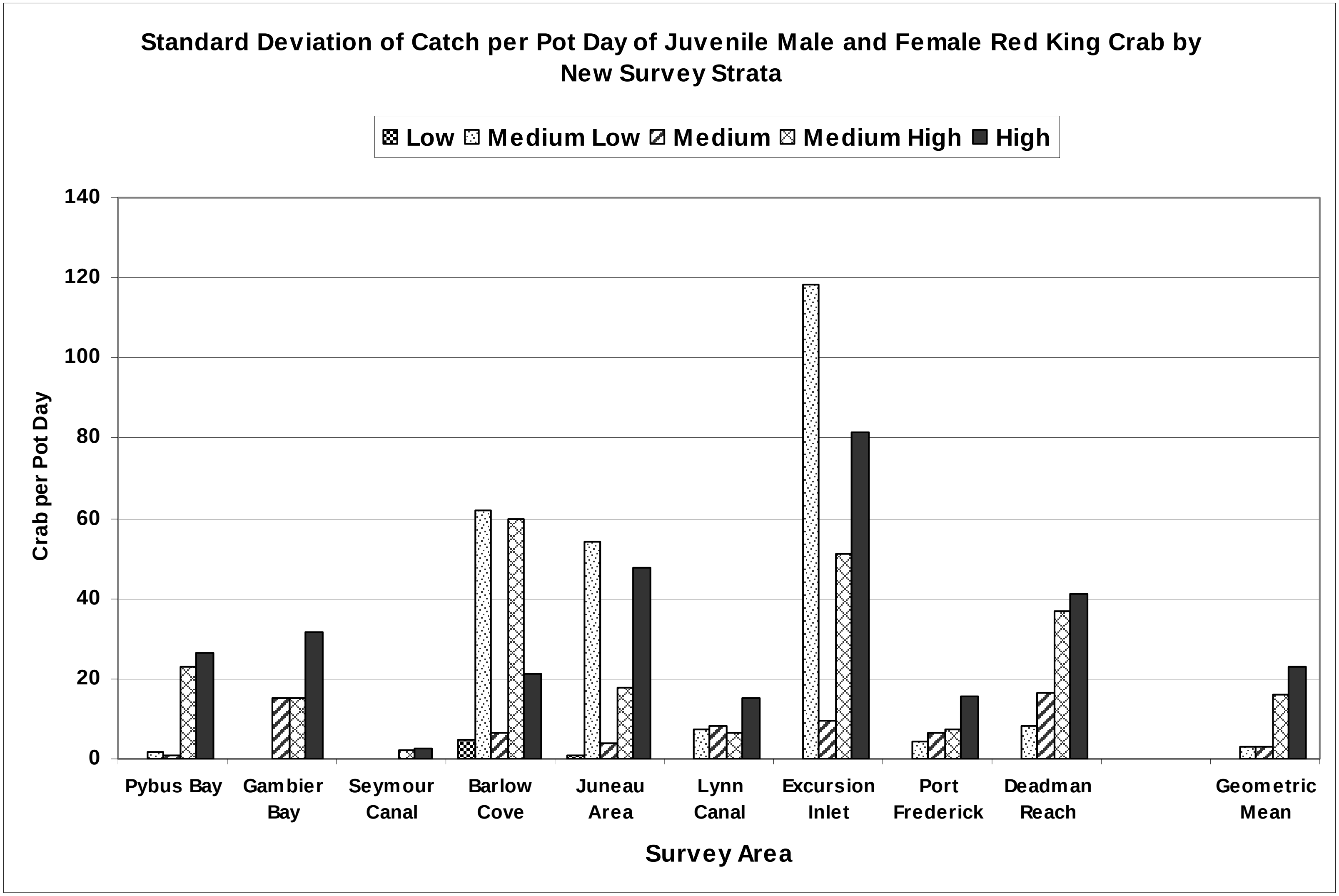


Figure 41.–Standard deviation of catch per pot day of female and juvenile male red king crab stocks by survey area and new stratum designations.

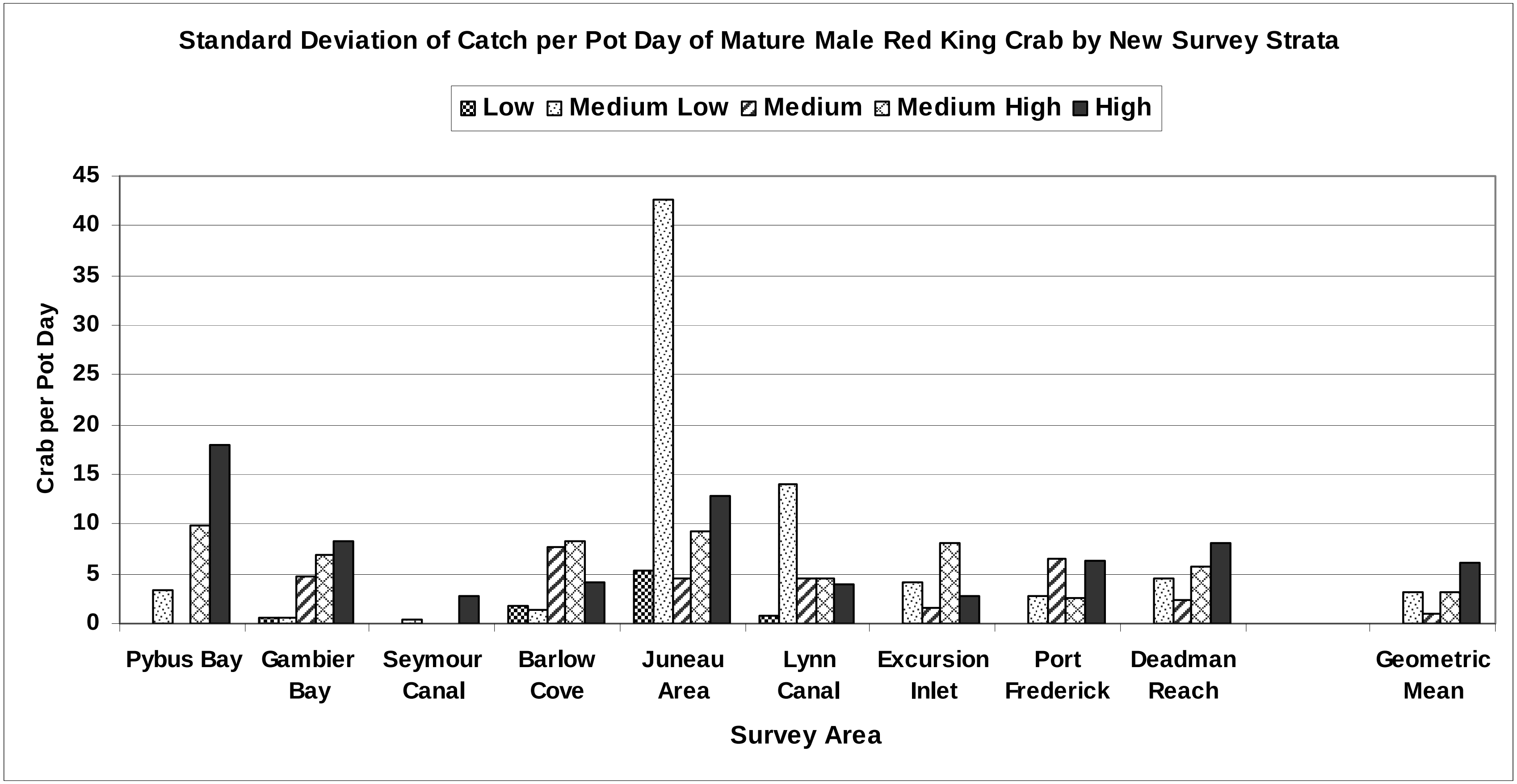


Figure 42.–Standard deviation of catch per pot day of mature male red king crab stocks by survey area and new stratum designations.

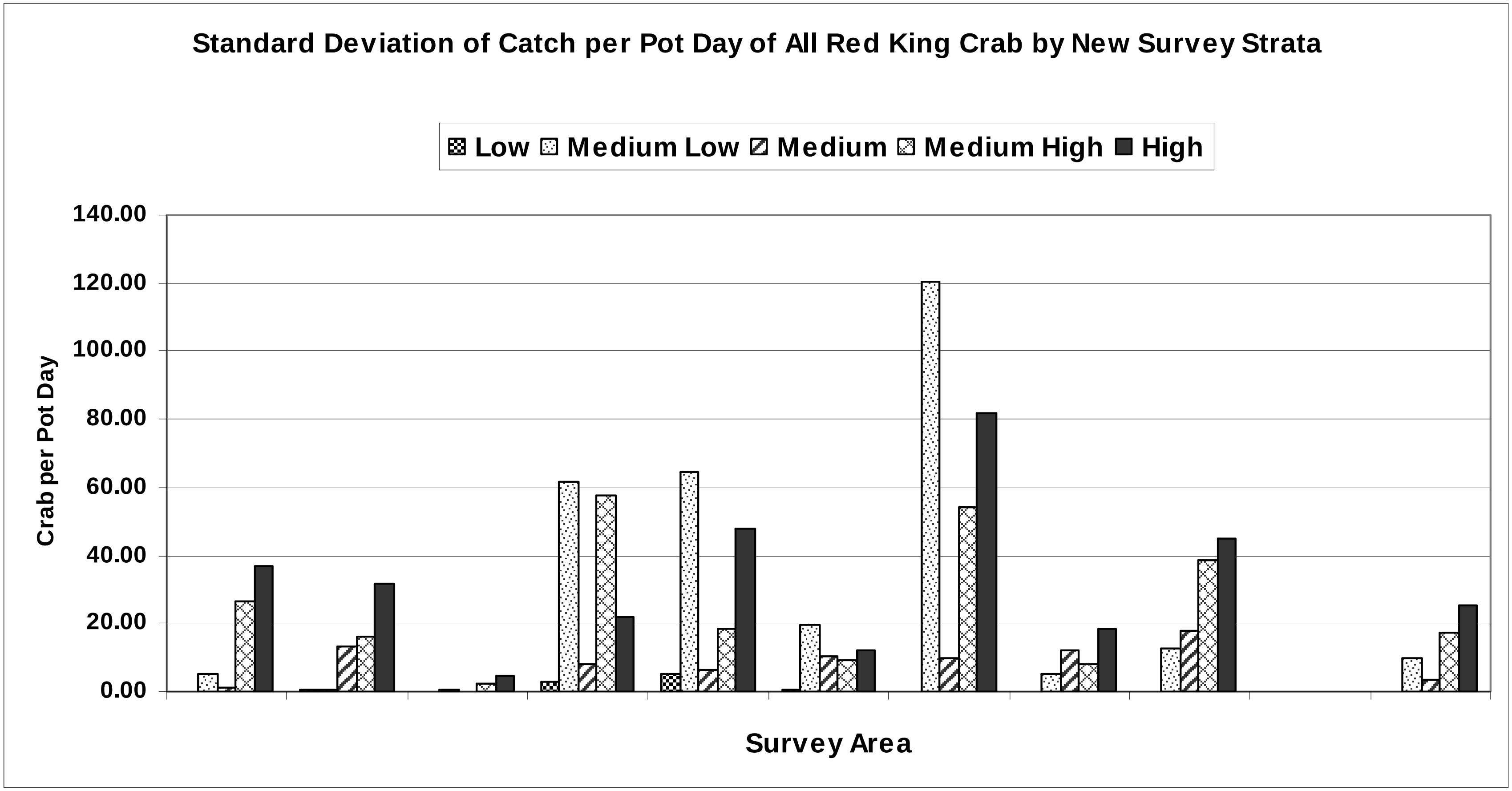


Figure 43.–Standard deviation of catch per pot day of catch of all red king crab stocks by survey area and new stratum designations.

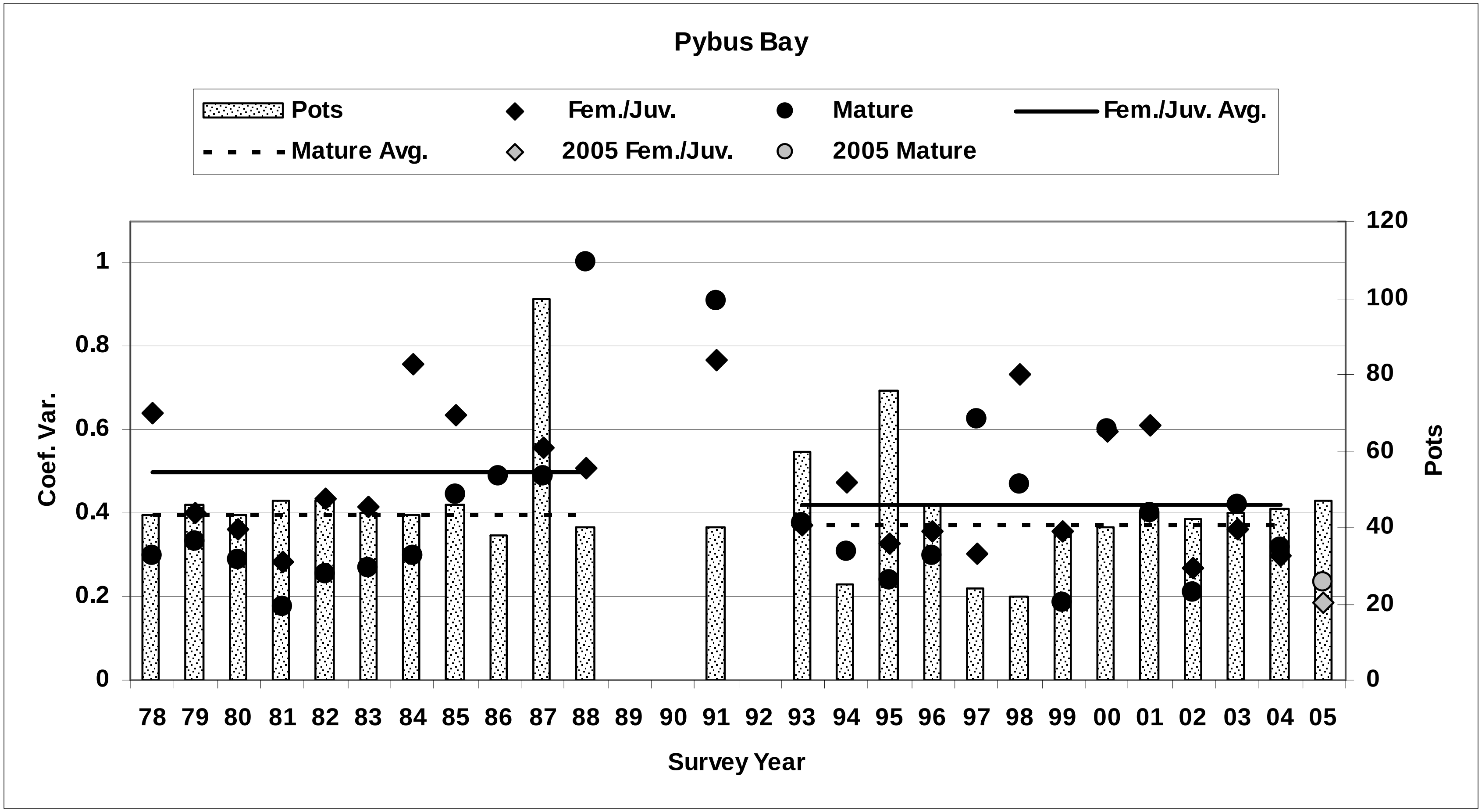


Figure 44.–Comparison of coefficients of variation for Pybus Bay survey catches, of annual estimated average juvenile male/female and mature male red king crab catch per pot day, and number of pots.

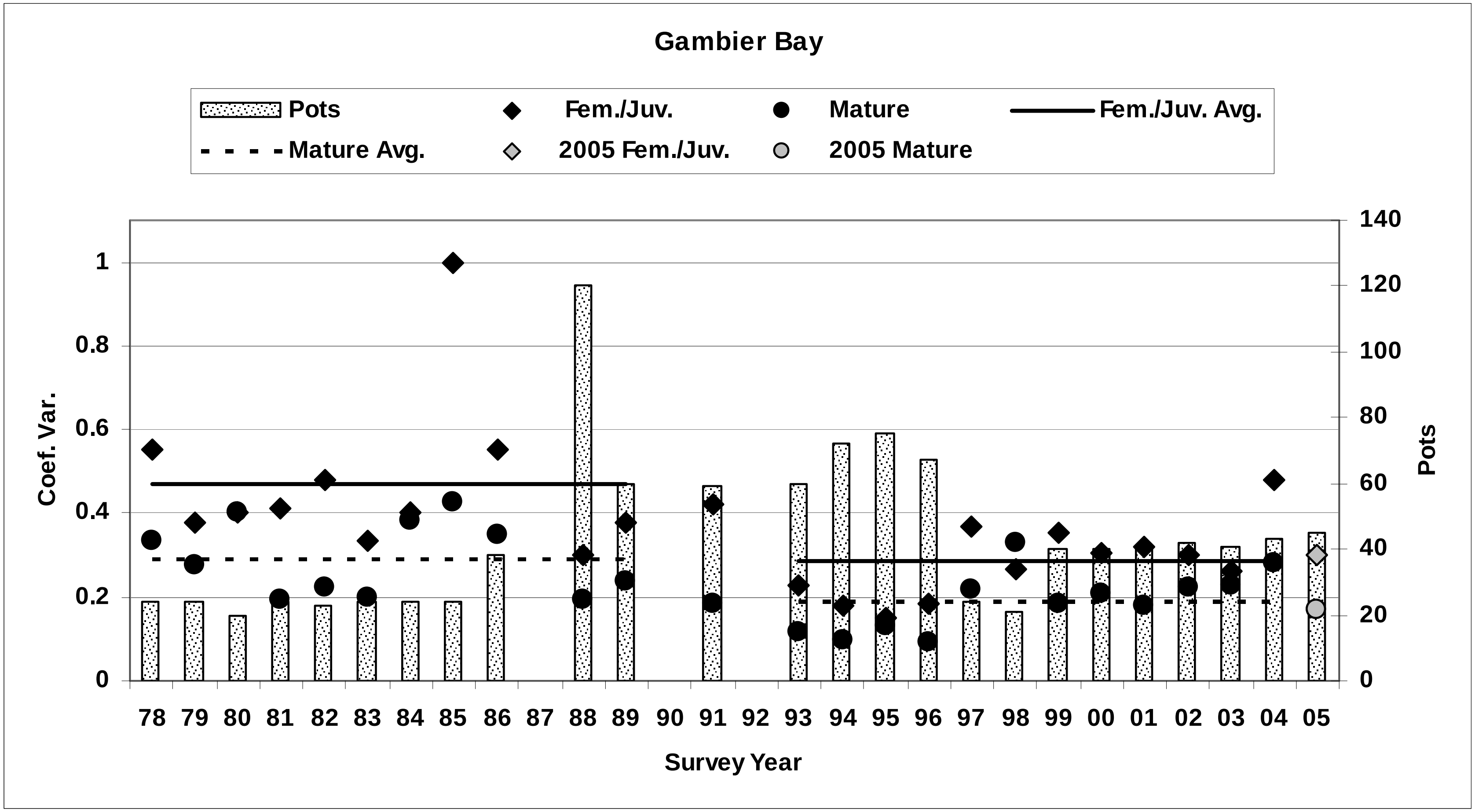


Figure 45.–Comparison of coefficients of variation for Gambier Bay survey catches, of annual estimated average juvenile male/female and mature male red king crab catch per pot day, and number of pots.

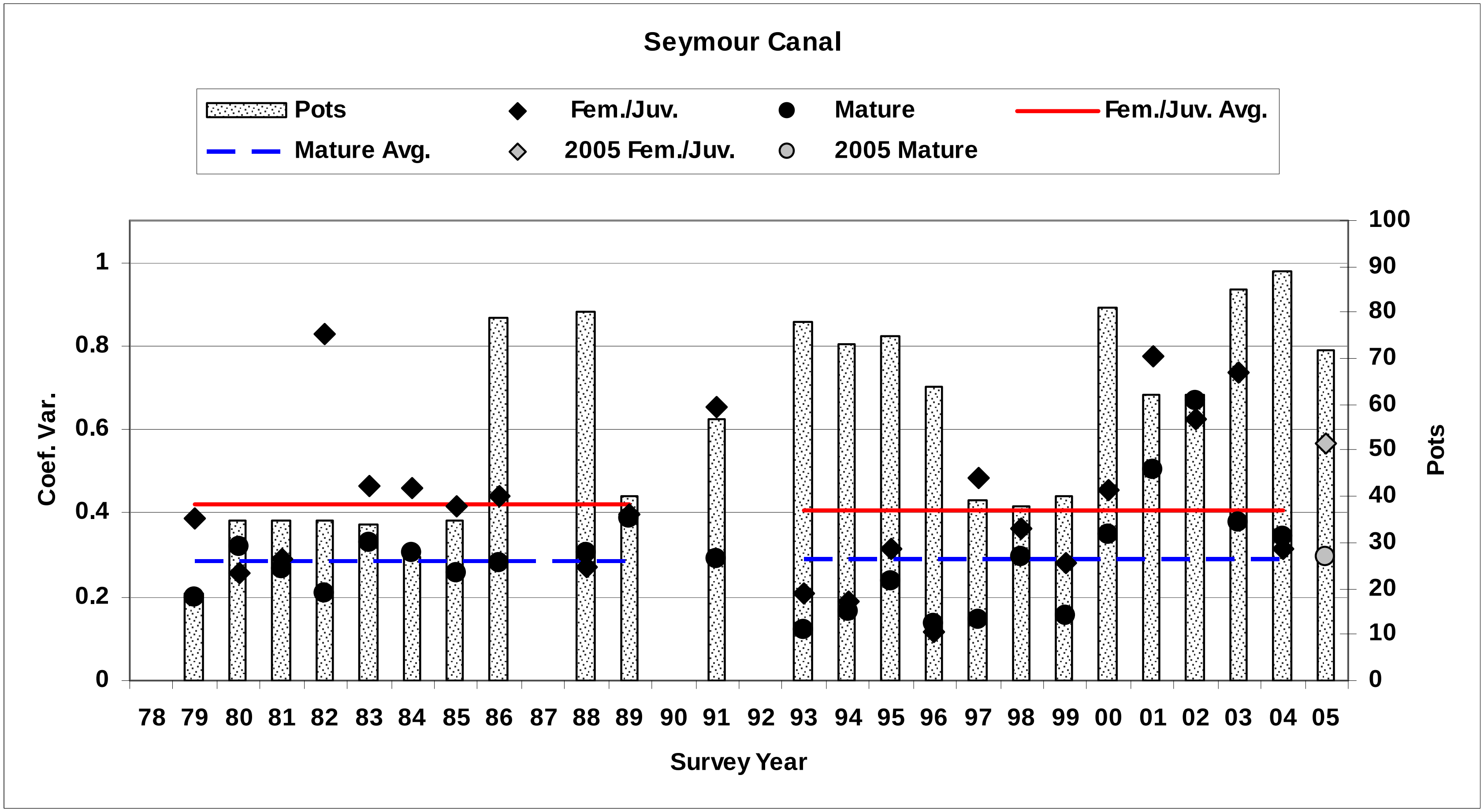


Figure 46.–Comparison of coefficients of variation for Seymour Canal survey catches, of annual estimated average juvenile male/female and mature male red king crab catch per pot day, and number of pots.

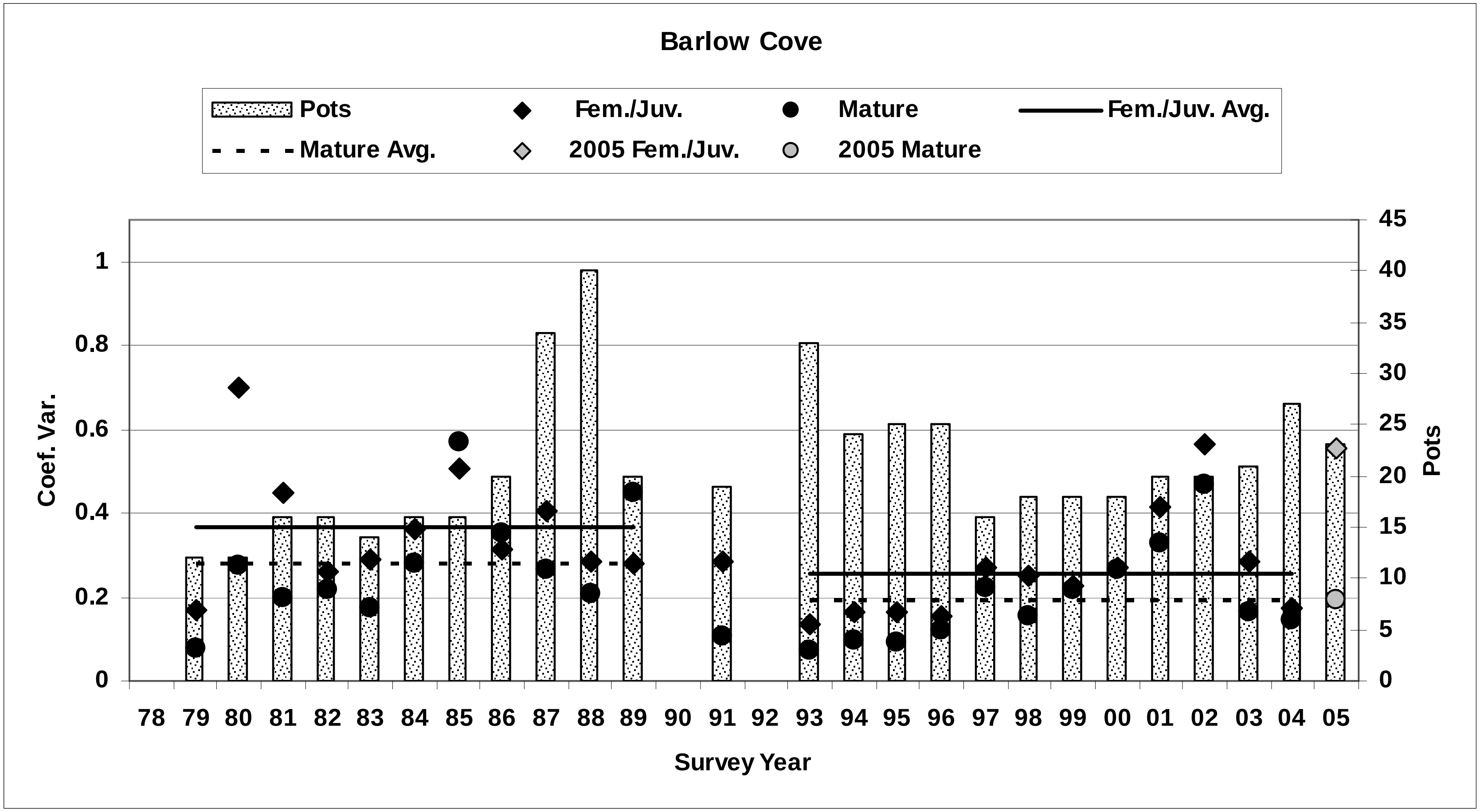


Figure 47.–Comparison of coefficients of variation for Barlow Cove survey catches, of annual estimated average juvenile male/female and mature male red king crab catch per pot day, and number of pots.

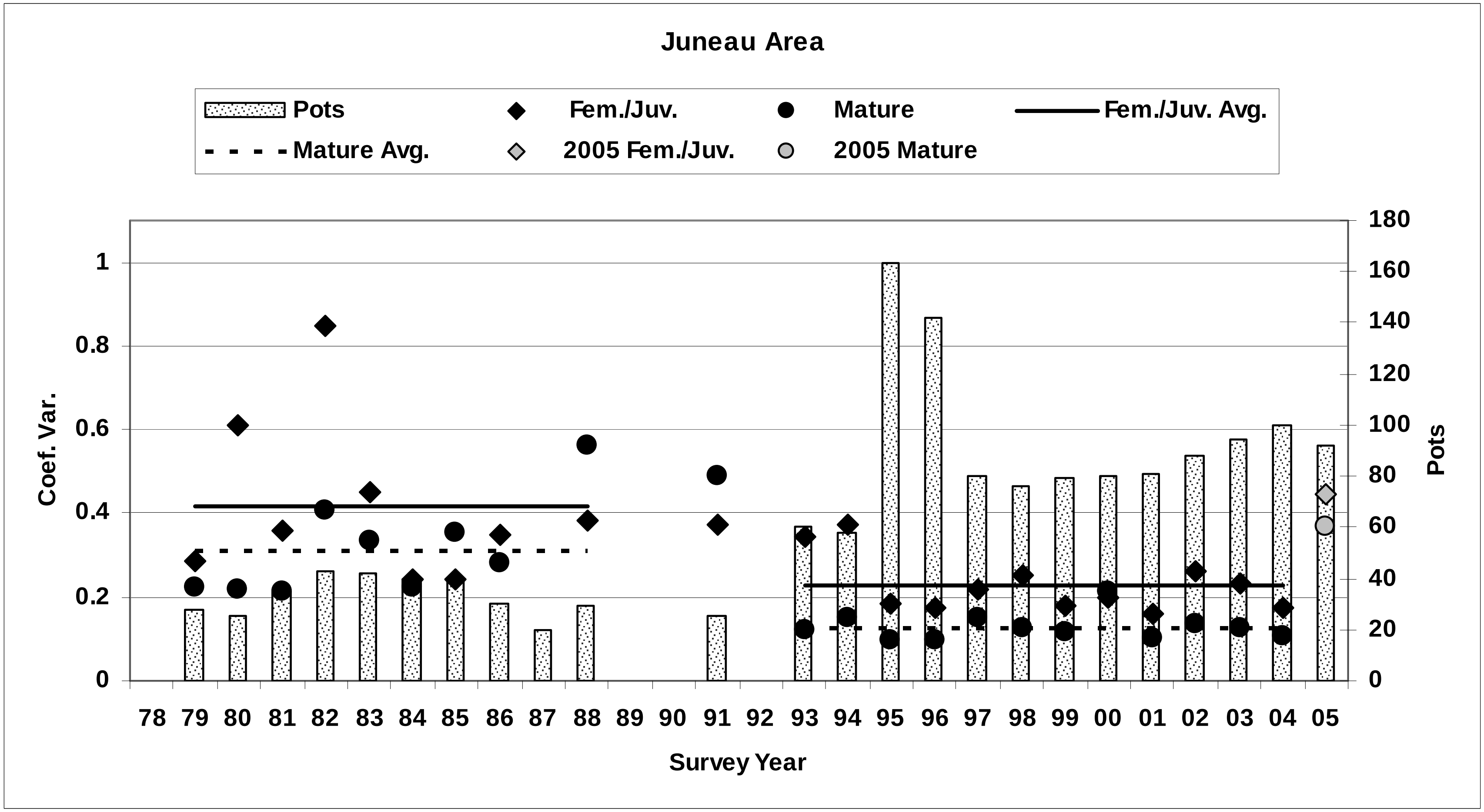


Figure 48.–Comparison of coefficients of variation for Juneau Area survey catches, of annual estimated average juvenile male/female and mature male red king crab catch per pot day, and number of pots.

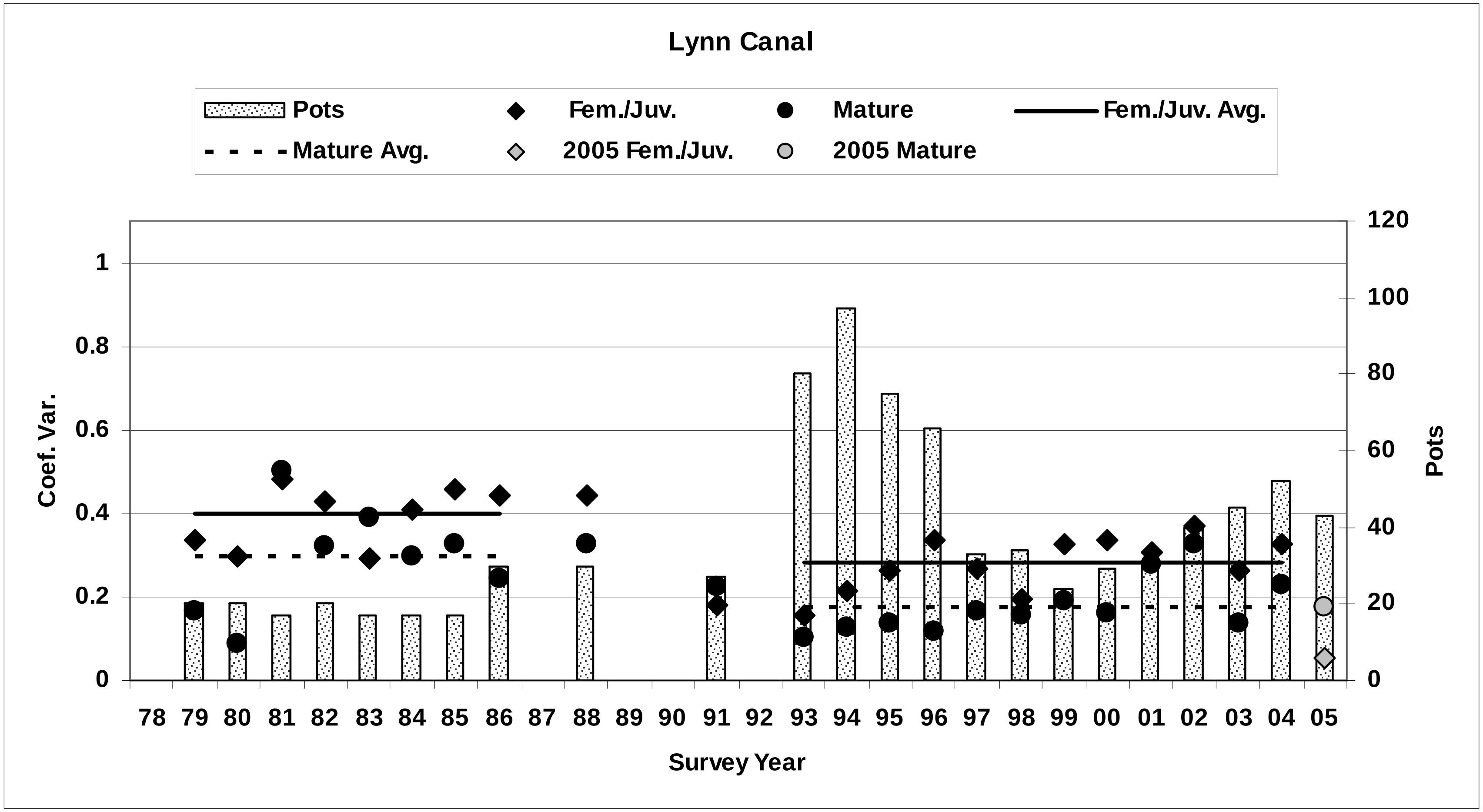


Figure 49.–Comparison of coefficients of variation of annual estimated average juvenile male/female and mature male red king crab catch per pot day, and number of pots for Lynn Canal survey catches.

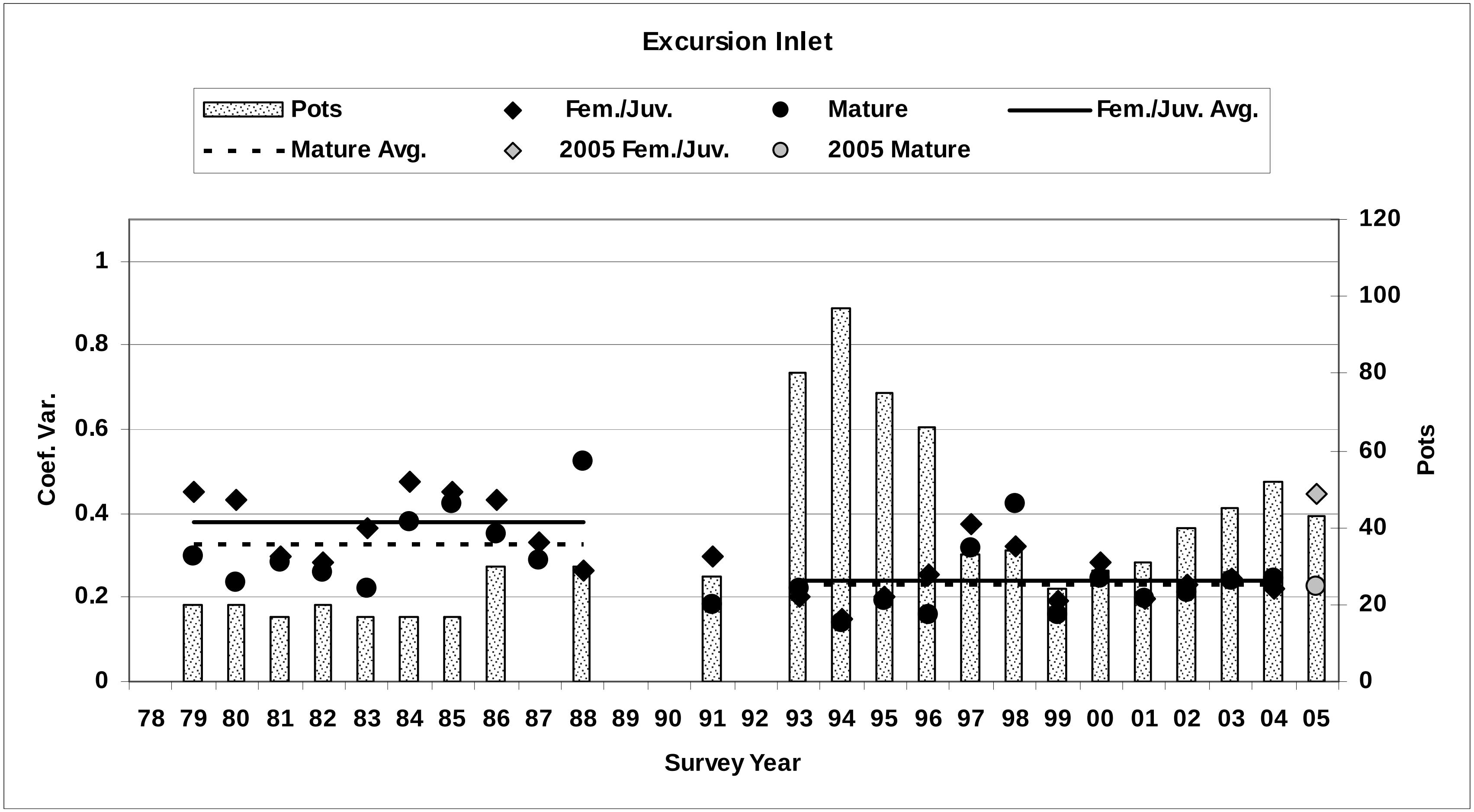


Figure 50.–Comparison of coefficients of variation for Excursion Inlet survey catches, of annual estimated average juvenile male/female and mature male red king crab catch per pot day, and number of pots.

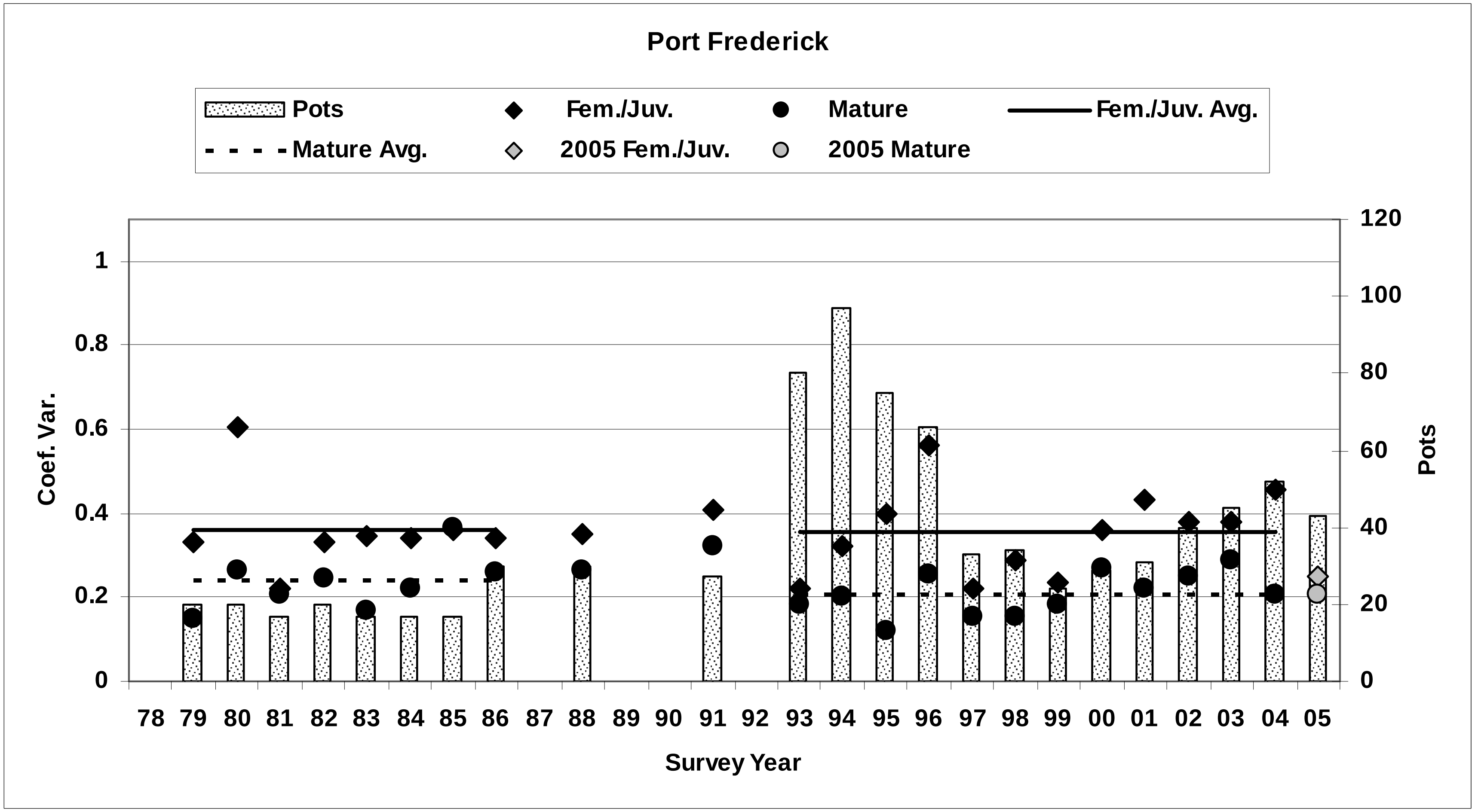


Figure 51.–Comparison of coefficients of variation for Port Frederick survey catches, of annual estimated average juvenile male/female and mature male red king crab catch per pot day, and number of pots.

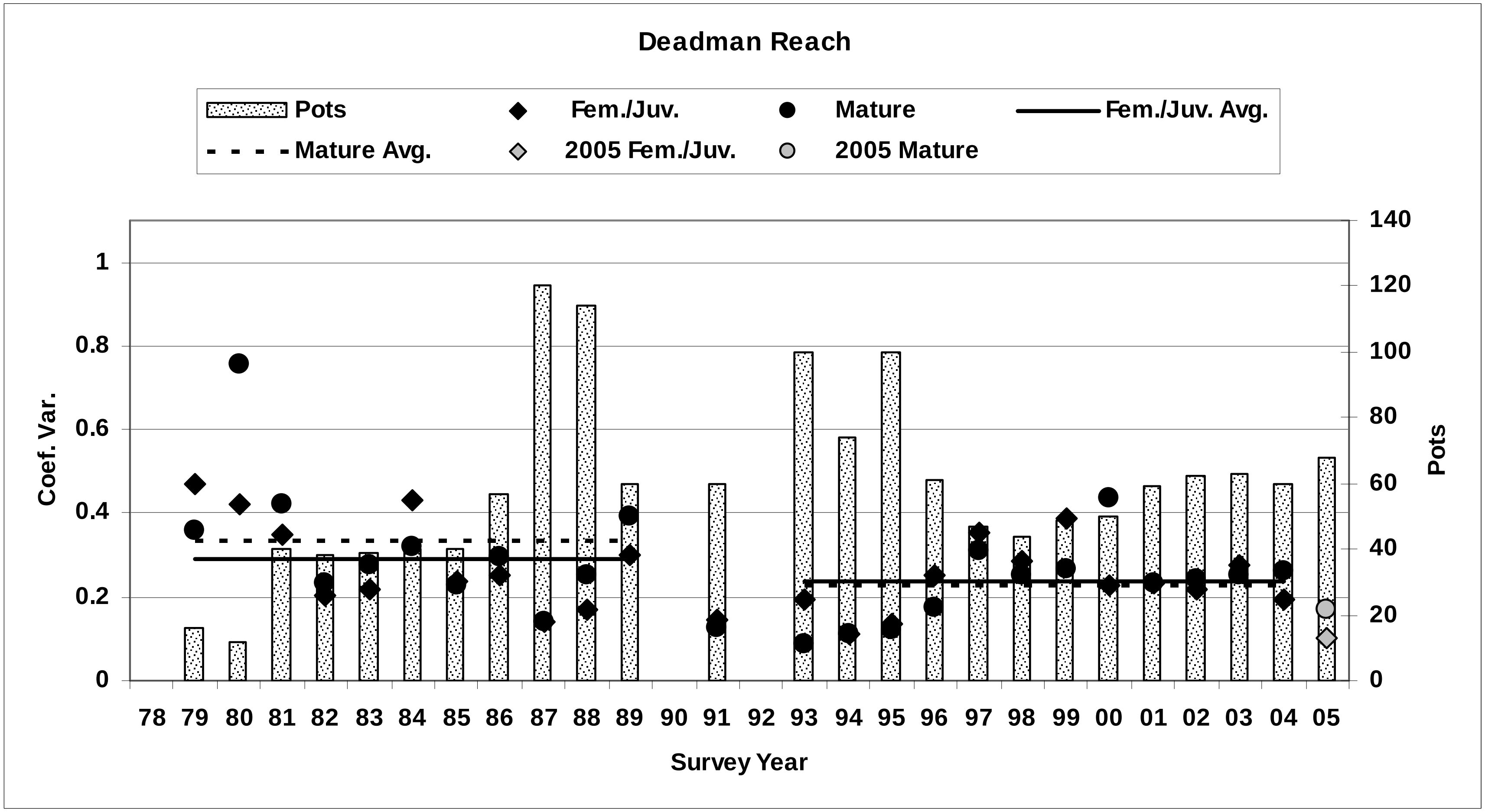


Figure 52.–Comparison of coefficients of variation for Deadman Reach survey catches, of annual estimated average juvenile male/female and mature male red king crab catch per pot day, and number of pots.

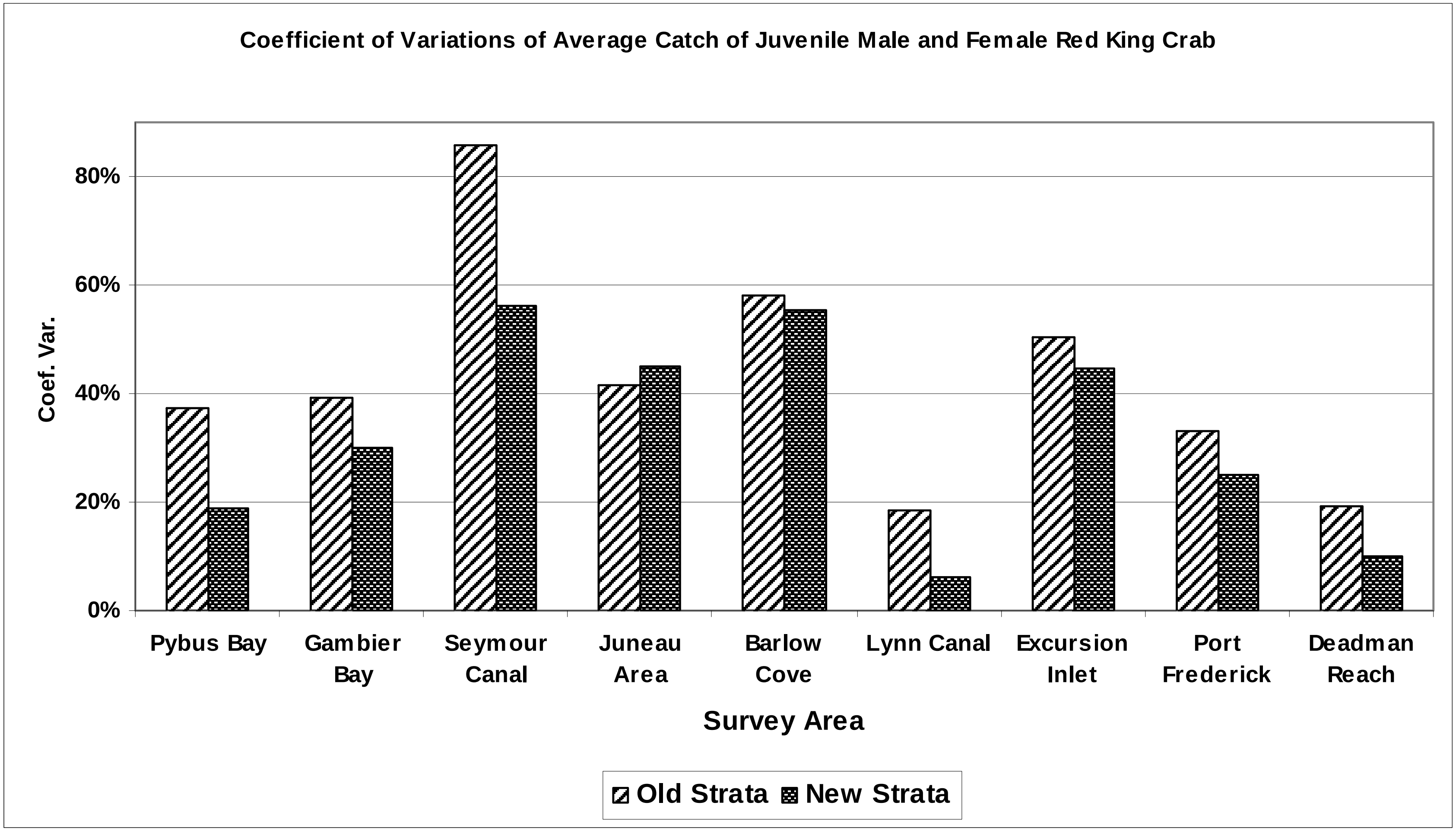


Figure 53.–Comparison of the coefficient of variation of the estimated average catch of juvenile male and female red king crab in 2005 using restratified survey areas and using the previous stratification design. The adjusted pots are the estimated number of pots required under the previous stratification design to achieve the estimated level of precision under the new stratification design.

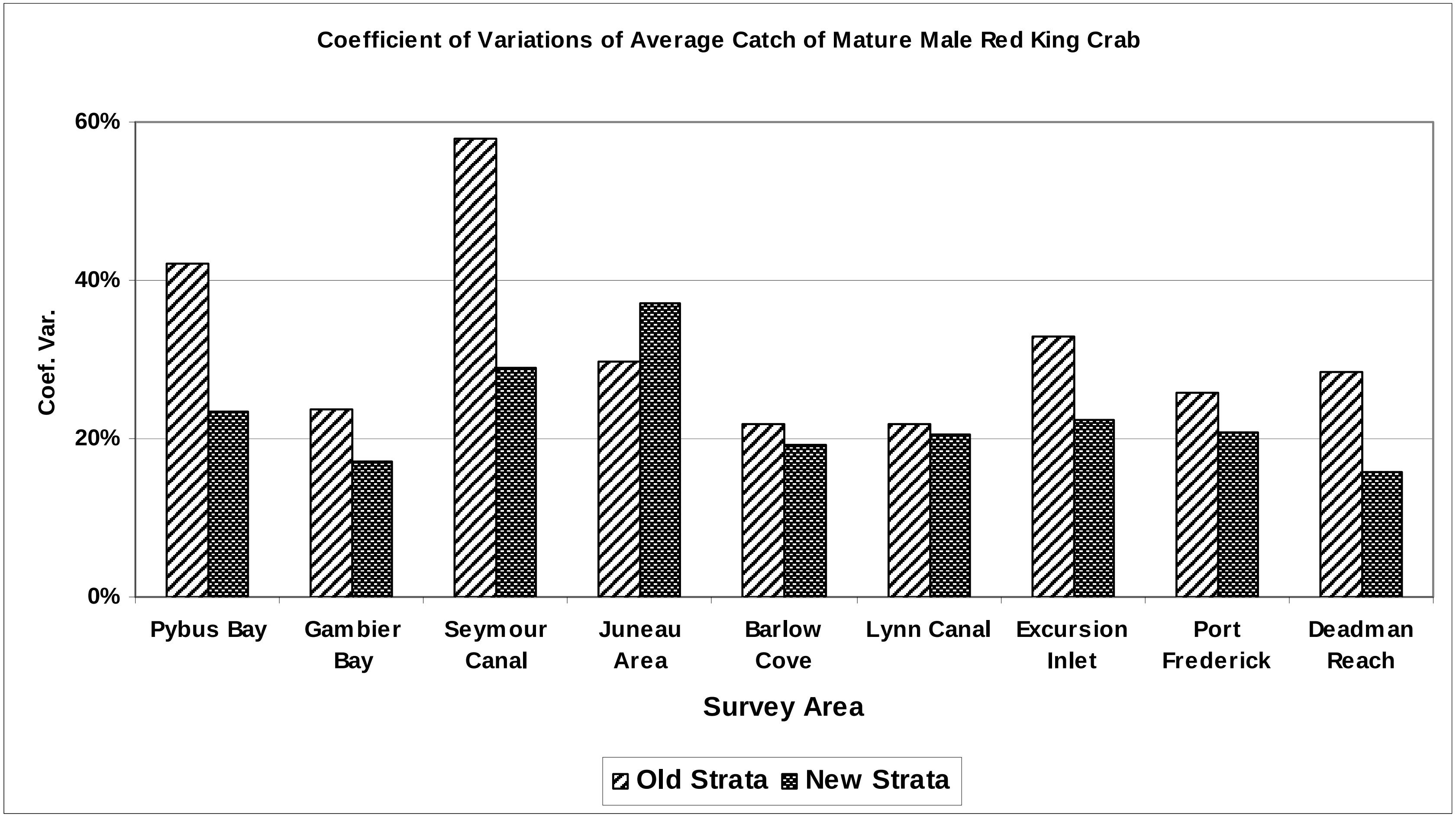


Figure 54.–Comparison of the coefficient of variation of the estimated average catch of mature male red king crab in 2005 using restratified survey areas and using the previous stratification design. The adjusted pots are the estimated number of pots required under the previous stratification design to achieve the estimated level of precision under the new stratification design.

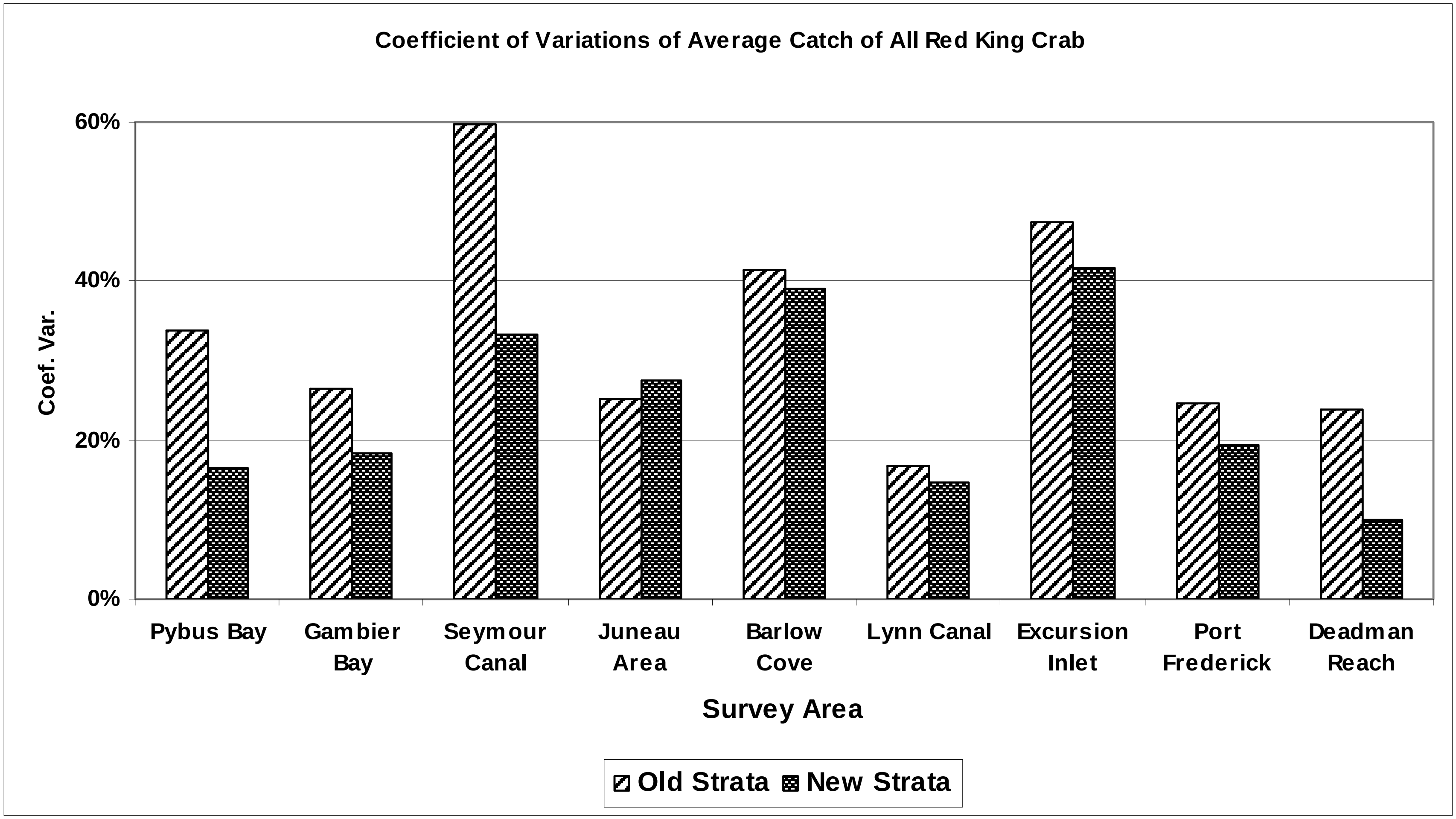


Figure 55.–Comparison of the coefficient of variation of the estimated average catch of all red king crab in 2005 using restratified survey areas and using the previous stratification design. The adjusted pots are the estimated number of pots required under the previous stratification design to achieve the estimated level of precision under the new stratification design.

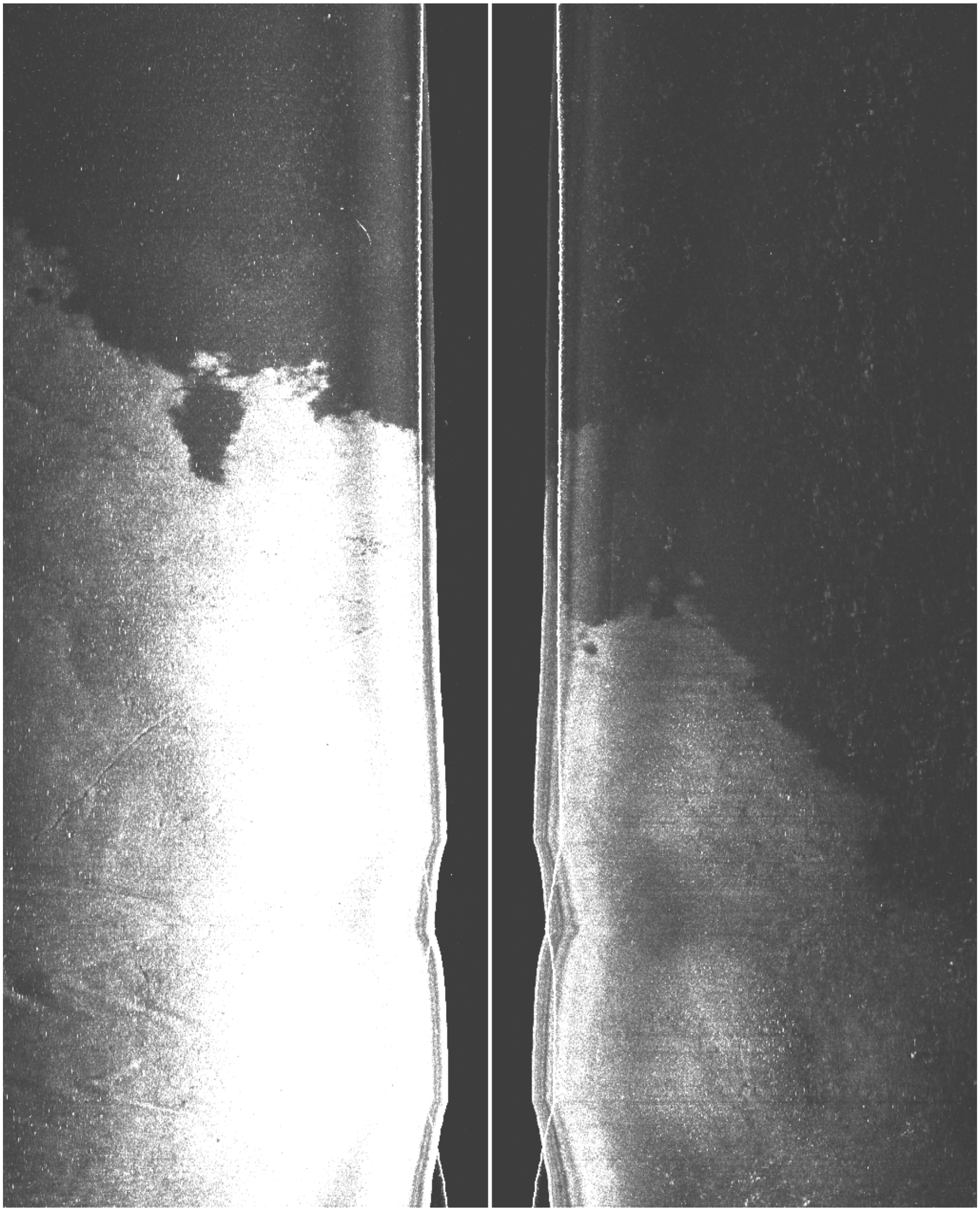
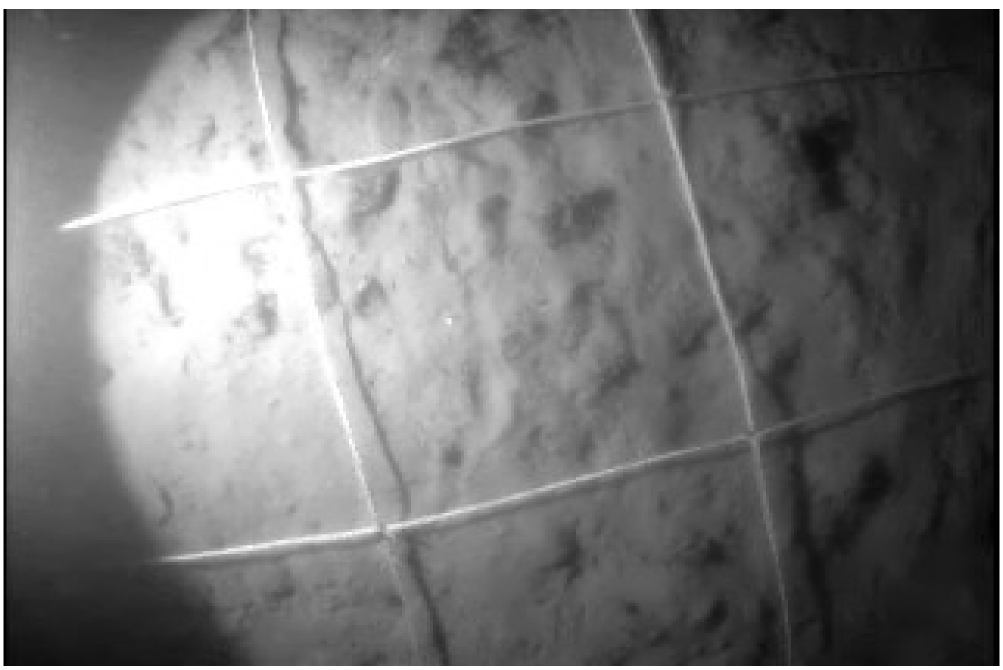


Figure 56.–Example of sonar returns from Stephens Passage pilot sidescan sonar project. The darker returns are indicative of a mud/soft mud bottom, while the light returns indicate a harder cobble mud bottom.

a. Camera picture of mud and soft mud bottom.



b. Camera picture of cobble and mud hard (rock) bottom.

Figure 57.–Examples of the two types of benthic substrate identified by camera.

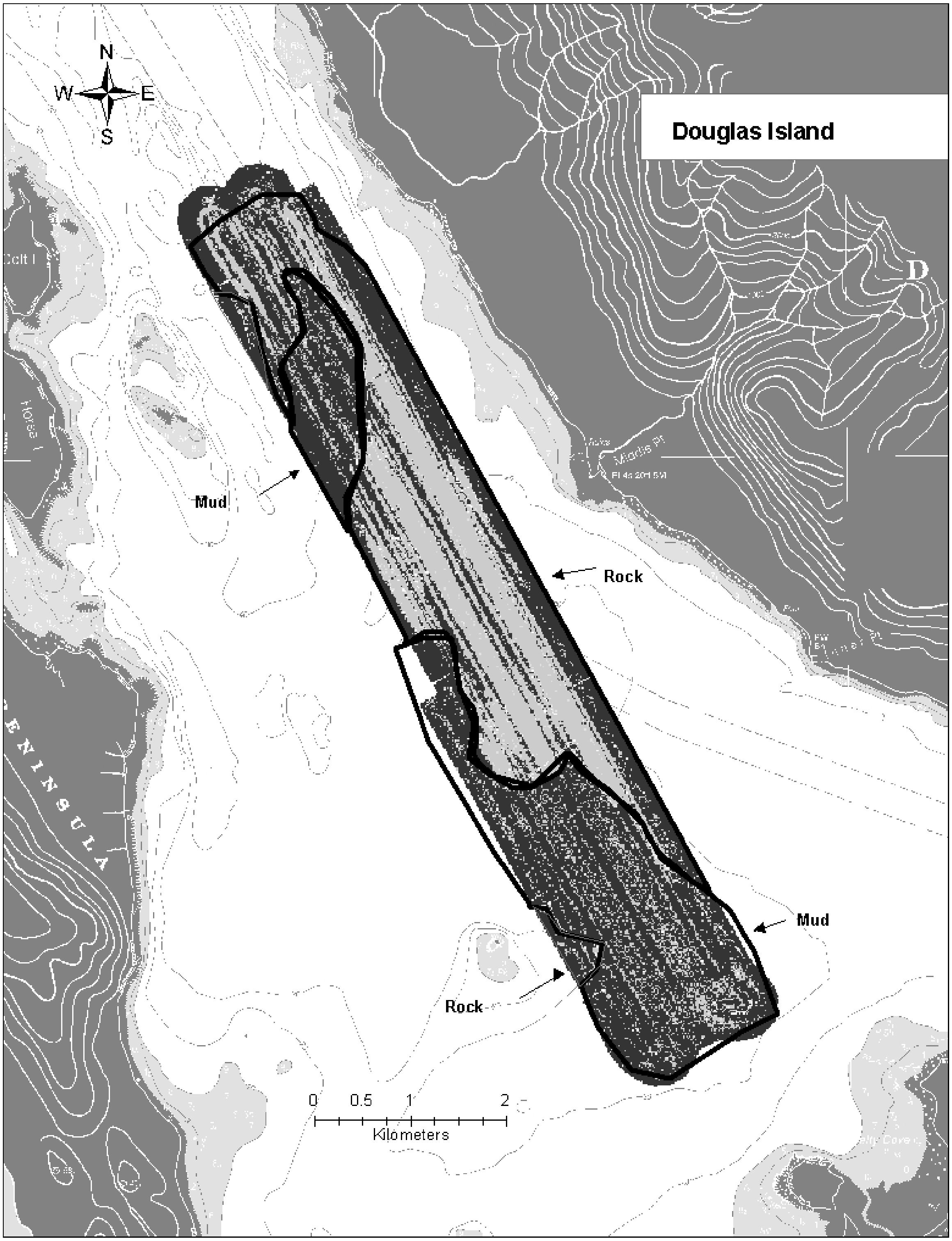


Figure 58.–Integrated sonar returns and areas of the benthic habitat designated as rock and mud.

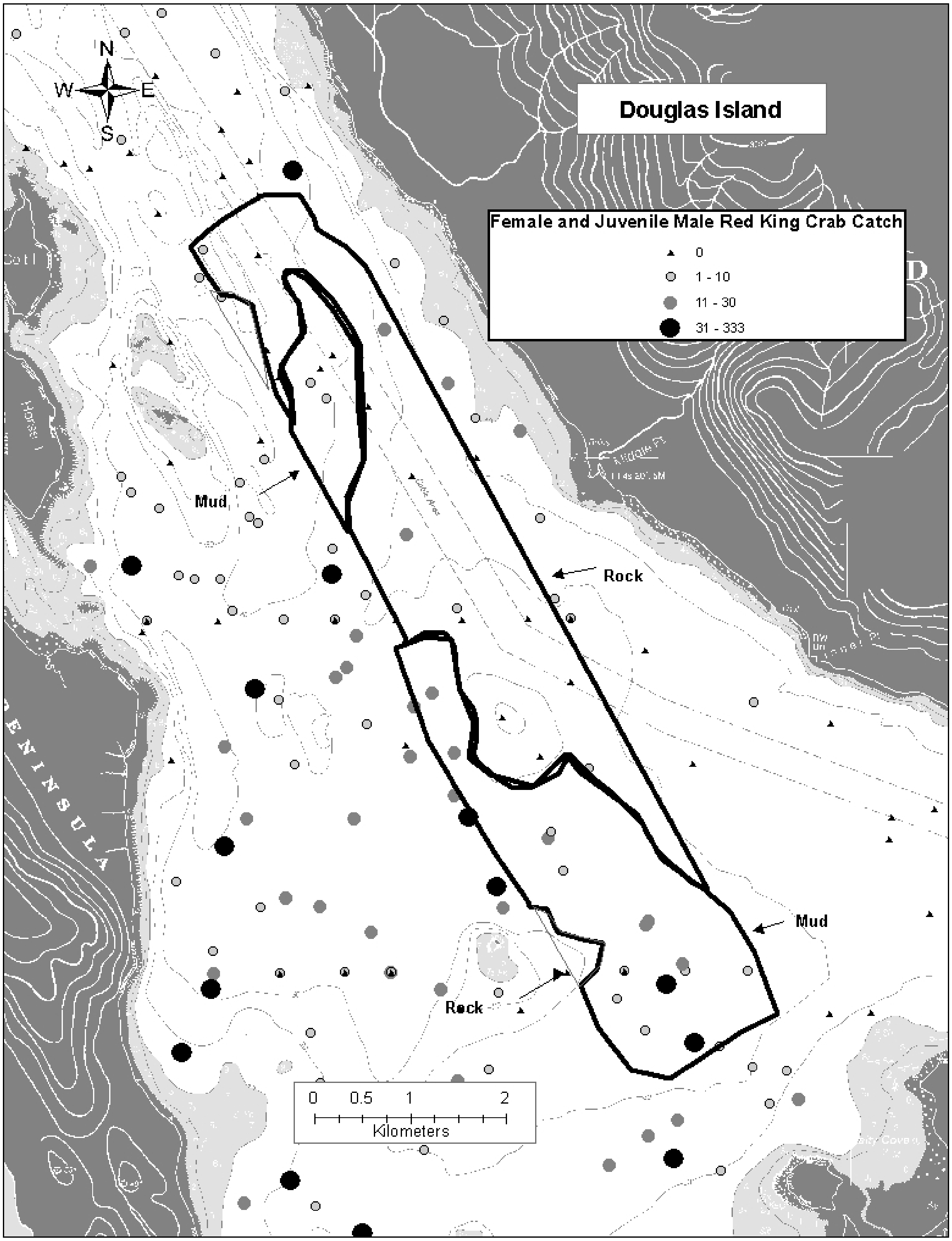


Figure 59.–Catch of red king crab juvenile males and females in the vicinity of the sonar surveys.

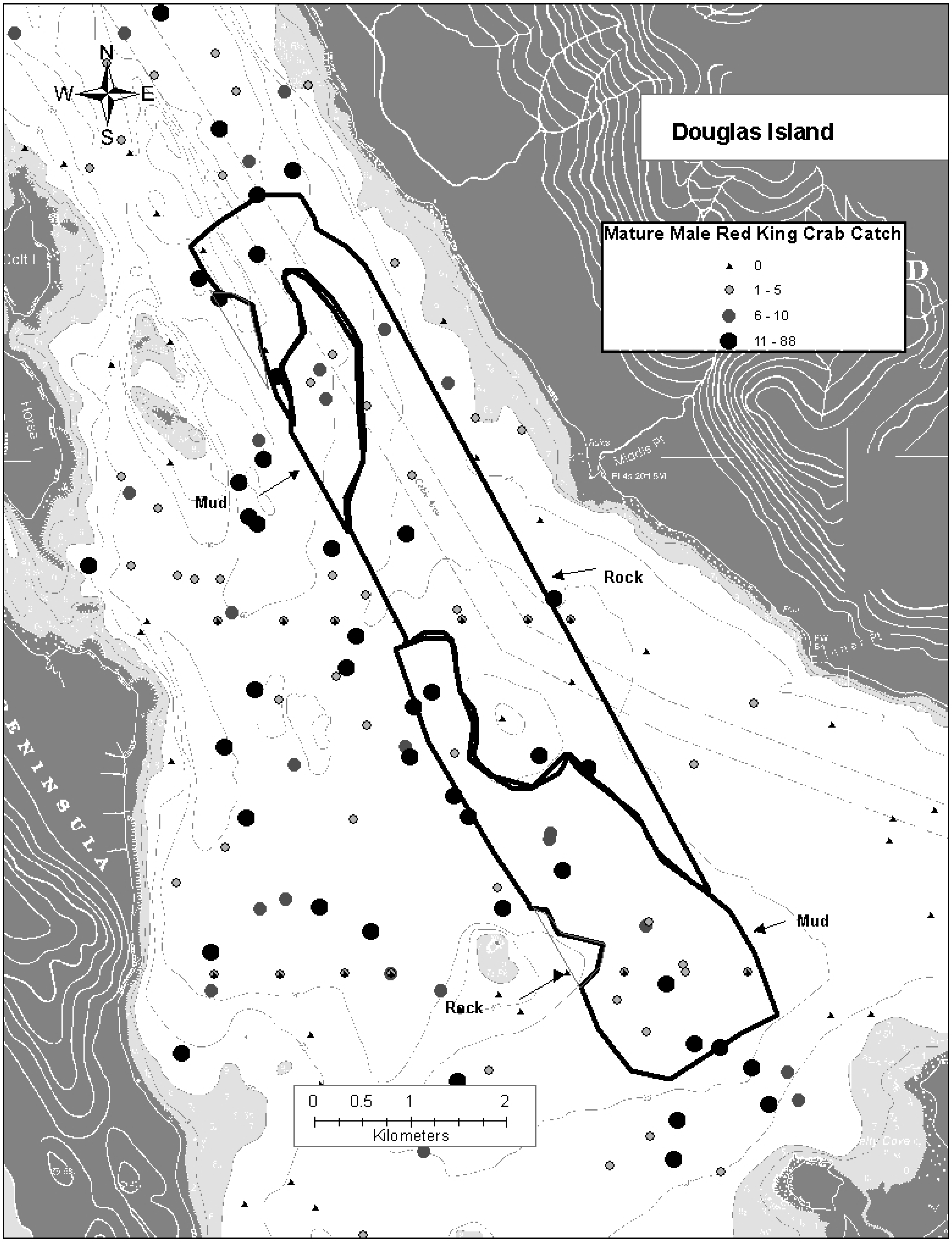


Figure 60.–Catch of mature male red king crab in the vicinity of the sonar surveys.

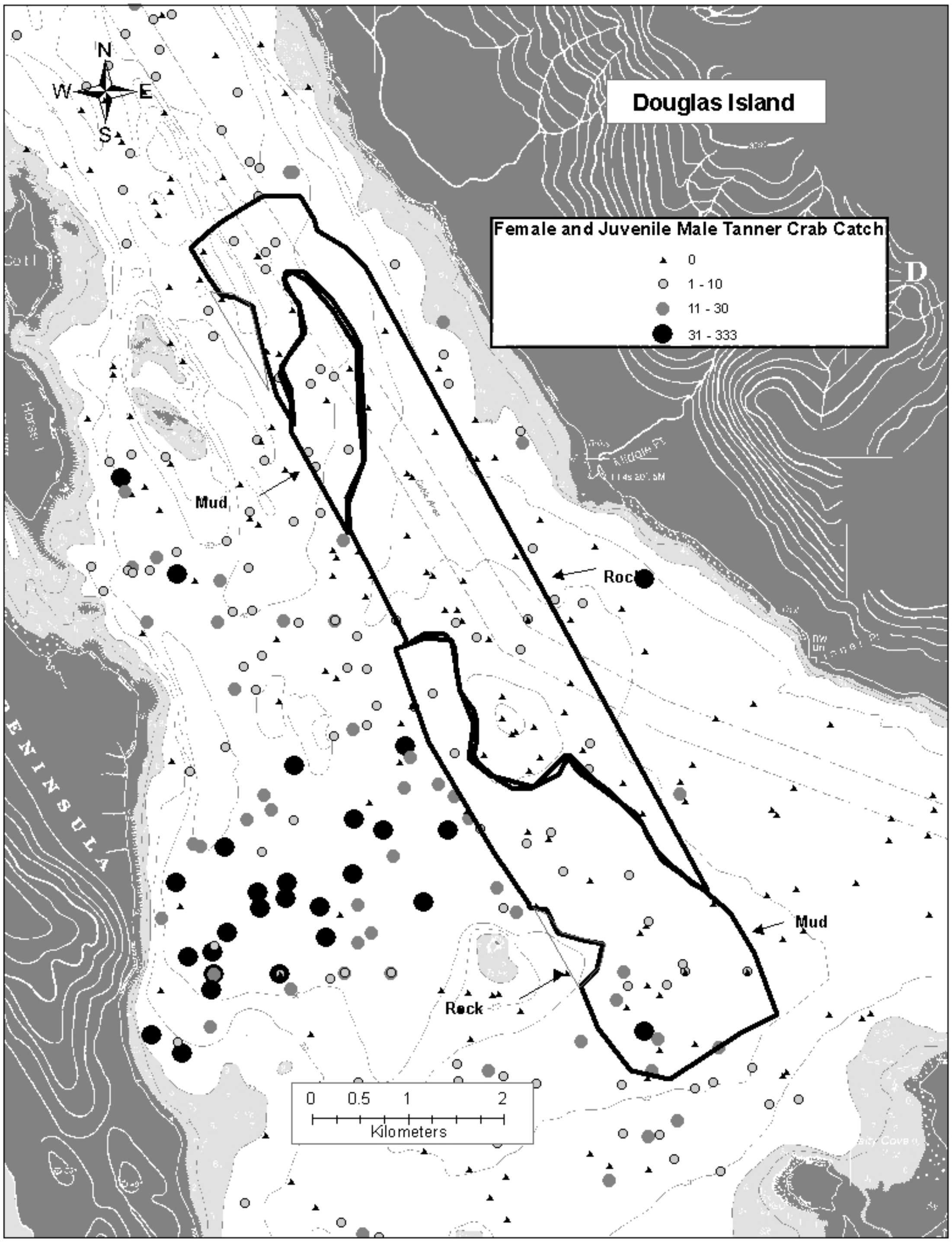


Figure 61.–Catch of Tanner crab juvenile males and females in the vicinity of the sonar surveys.

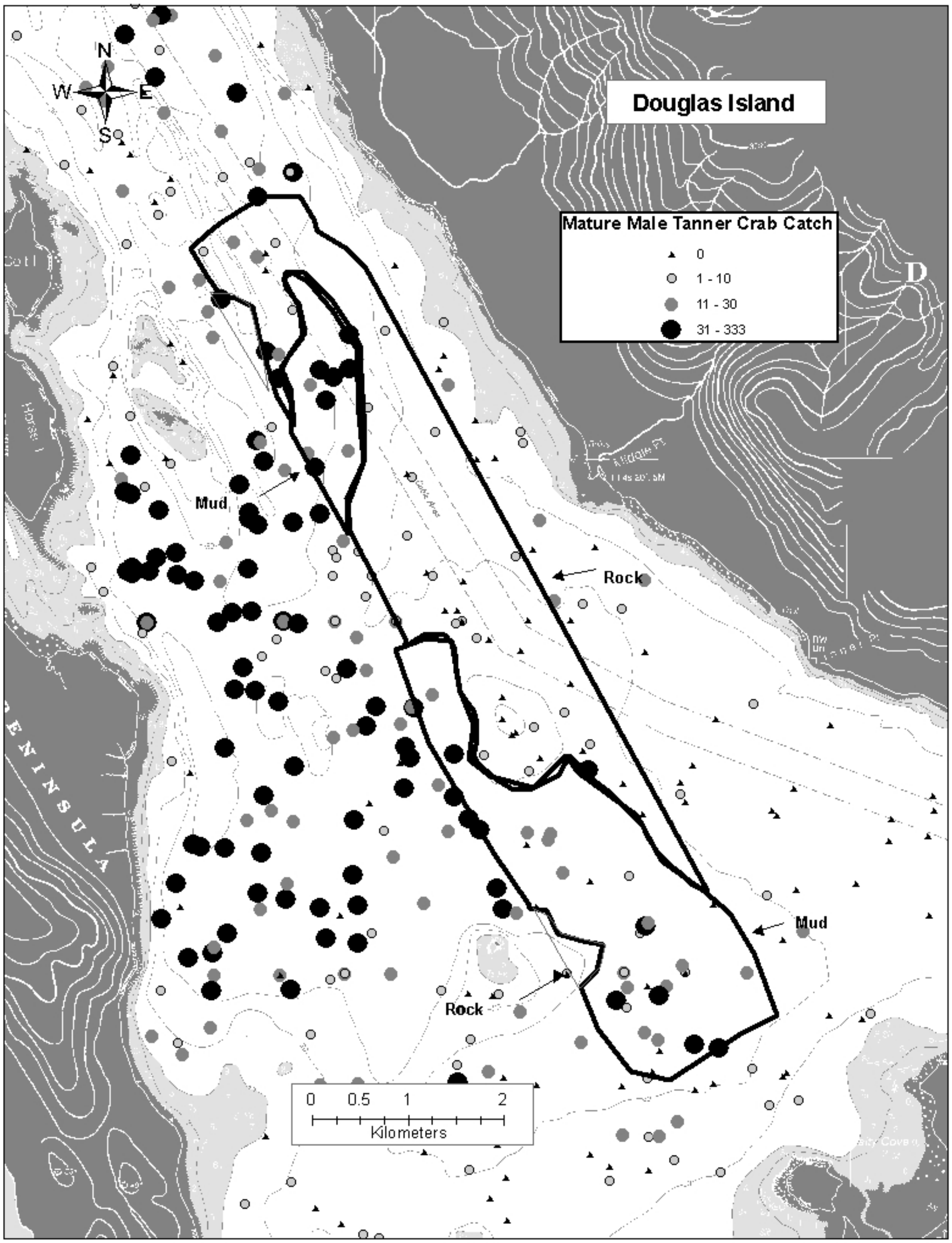


Figure 62.–Catch of Tanner crab mature males in the vicinity of the sonar surveys.

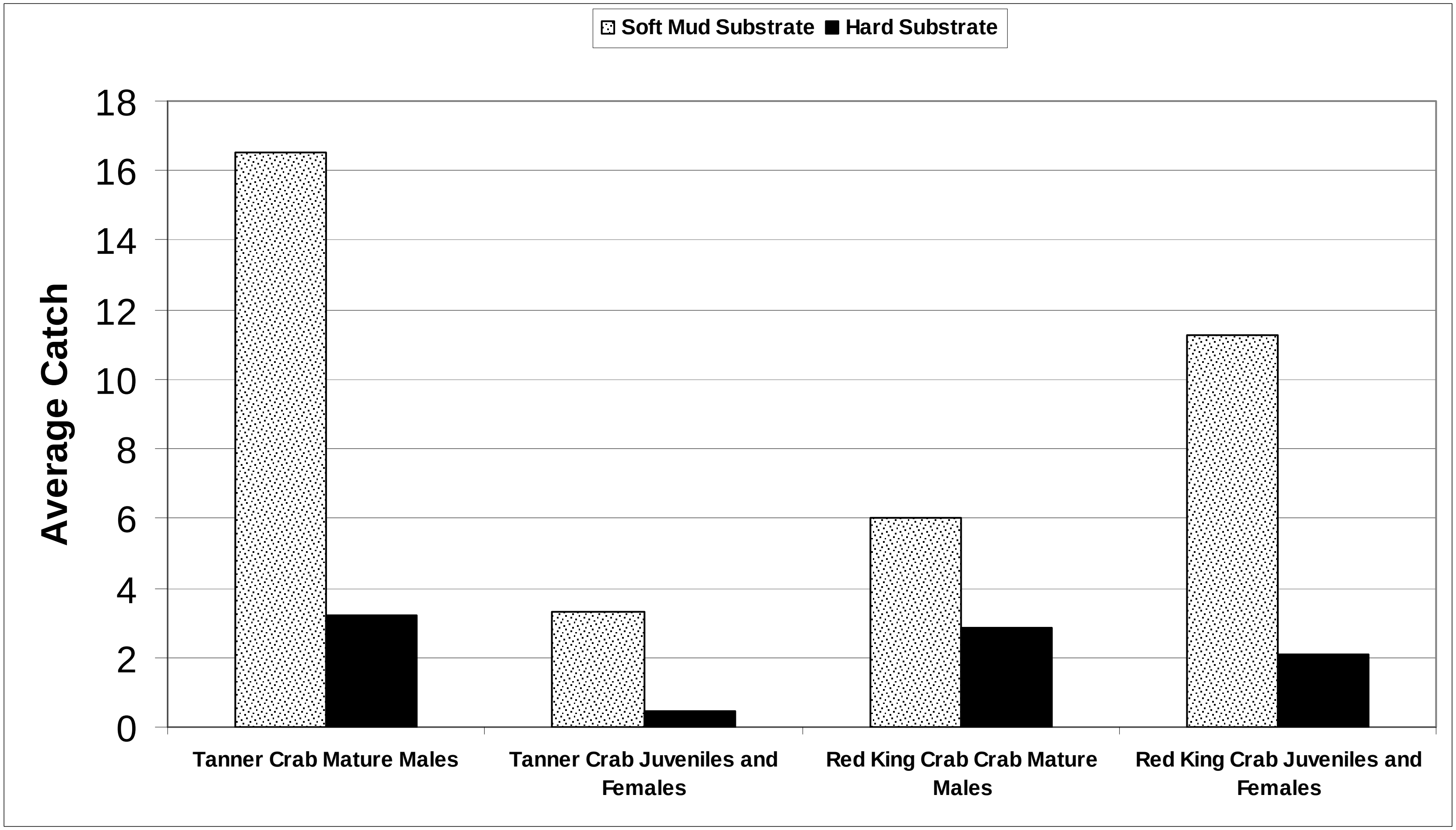


Figure 63.–Comparison of historical catches of red king crab and Tanner crab in the stock assessment surveys in the vicinity of the sidscan sonar survey.