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Status of Sea Cucumber Stocks in Southeast Alaska and Evaluation of the Stock Assessment Program

by

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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

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by

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF TABLES (Continued)

LIST OF FIGURES

LIST OF FIGURES (Continued)

Figure **Page**

LIST OF APPENDICES

Appendix **Page**

ABSTRACT

Management of the sea cucumber commercial fishery in Southeast Alaska relies on information gathered in the annual stock assessment dive surveys. From 1990 through 2005, 83 areas have been surveyed at least once; 56 areas have been surveyed over multiple years. In turn, estimates of sea cucumber biomass, and trends in abundance and weight were derived from the survey data. This study developed models, to estimate average weight, density, and trends in both weight and abundance of sea cucumbers, compared these values for areas of different harvest histories, and to provide evidence for recommending changes in survey design.

The overall average weight was 213 gm, with an average coefficient of variation of 8.8%. Analysis of covariance results provided more precise estimates of average weight in the last year of weight measurements, and indicated that almost half of the areas showed a significant increase in weight, compared to earlier surveys. An increase in weight was more frequent in areas with multiple harvest openings. Collection of more than 10 to 15 animals from a transect location marginally improved precision.

In the last year of survey effort, average counts ranged from 0.1 to 48.7 sea cucumbers per 2-meter transect. The design-based approach produces an average abundance of 17.3 animals, compared to 19.2 animals for a negative binomial model. Precision of the model-based approach was substantially better than the design-based estimates. Significant decreases in number of sea cucumbers were estimated for the majority of areas. These decreases were similar in both control and harvest areas. Selecting a new set of transects each survey year while maintaining a small group of index transects in each survey year will improve the precision of density estimates. Information on which shoreline is fished and not fished by the commercial fleet did not significantly improve survey estimates.

Key words: sea cucumber, *Parastichopus californicus*, biomass, weight, abundance trends, Alaska

INTRODUCTION

The sea cucumber (*Parastichopus californicus)* fishery in Southeast Alaska is managed under a suite of conservation guidelines that were designed to minimize impacts on shallow marine ecosystems, while providing for sustainable yields to the commercial fishery (Woodby and Larson 1997; Woodby et al. 1993). The expected outcome of the management plan is an overall harvest rate of no more than 18.6% every three years in areas opened to commercial harvest. Several areas have been set aside as control areas which provide information on trends in abundance and size in populations not subjected to commercial harvest. Other areas with small abundances of sea cucumbers also are not opened to commercial fishing. This management structure results in a mosaic of areas which are opened on a 3-year rotation schedule, are not opened at all, or have been opened in the past but currently do not contain an abundance which can support commercial harvest (Figure 1).

Management of the sea cucumber resource in Southeast Alaska relies extensively on information gathered in the annual stock assessment dive surveys. This information serves two purposes. The most conventional use of survey data is to provide estimates of the biomass of sea cucumbers in areas scheduled to be opened to commercial harvest following the survey. Associated with biomass estimates is the precision of the estimate. Because fishery quotas are calculated as the lower bound of the one-sided 90% confidence interval of the biomass estimate, higher precision in biomass estimates translates into higher quotas for the commercial fishery. Another use of survey data is to monitor for changes in sea cucumber stock density and weight. An earlier analysis of changes in abundance over seven years of survey data found some populations have increased and in some areas populations have decreased, but significant changes in biomass could be attributed to either sea otter predation or management error (Woodby and Larson 1997). Control areas were designated to provide comparative information on stocks that are under no commercial harvest pressure. Comparison of trends in density and average weight between control and harvest areas provide insights into the impacts of commercial harvest on stock abundance and health and are useful in evaluation of the current management program.

Monitoring sea cucumber abundance and weight to assess the impact of commercial removal is of utmost importance in the initial stages of the recently developed fishery in Southeast Alaska. Understanding of the distribution and life history of the sea cucumber is limited (Imamura and Kruse 1990) and harvest of animals, even under a very conservative management regime, may impact the population, due to localized depletions (Orensanz et al. 1998). Worldwide, there has been an increasing demand for sea cucumber products, but, in general catches have been poorly documented and fisheries poorly managed (Conand and Byrn 1993). Declines in catch in a number of fisheries may be attributed to over-harvest of the resource. In response to concerns over the scarcity of information on the biology, abundance, and sustainable exploitation rate of sea cucumbers, Canada implemented an adaptive management program in 1997 with the goal of evaluating varying exploitation rates and alternative production models.

Reported here are estimates of the average weight of sea cucumbers by year and area and an examination of the trends in weights over survey years for each area. This report also summarizes the development of alternative statistical methods to estimate the average density and trends in abundances for areas in which two or more years of survey data have been collected. These methods are compared to existing design-based methods by estimating trends in abundance and recent average densities of populations in 56 areas. The statistical methods also provide a means to optimize survey design by identifying which sampling alternatives provide the best precision of both average density and trends in abundance.

OBJECTIVES

In summary, the objectives of this study are to:

1. Develop and evaluate statistical methods to:
    a. Estimate the average weight of sea cucumbers in a management area.
    b. Estimate the trend in weights in a management area and the significance of these trends.
    c. Estimate the mean density, expressed as number of sea cucumbers per linear 2-meters of shoreline, in a management area.
    d. Estimate the trend in abundance of sea cucumbers in a management area and the significance of these trends.
2. Apply these methods to the 1990 to 2005 survey data to evaluate the impact of commercial harvest on sea cucumber populations in Southeast Alaska
3. Determine which survey design considerations will significantly improve survey results including:
    a. Number of sites per survey area and number of sea cucumbers per site to sample for weights to measure both overall average weight in the survey area and to monitor year to year trends in average weight.
    b. Number of index sites (sampled each survey year) and replacement sites (sampled once then replaced by another randomly chosen site location surveyed the following survey year) to sample each survey year to estimate the overall average density and monitor trends in density of sea cucumbers in Southeast Alaska.

4. Evaluate the benefits of incorporating knowledge of the spatial distribution of fishing effort on survey site selection

5. Recommend improvements in statistical methods to estimate both average density and average weight of sea cucumbers in surveyed areas.

Future developments and improvements in sea cucumber stock assessment and management can proceed from these results by periodic evaluation and modification of stock assessment methods, constructing a cost function for various options, and incorporating other data into the estimation process.

Overview of Sea Cucumber Surveys

The analysis of count data has been studied extensively. Monitoring changes in abundance of a population requires proper statistical designs, to sample the habitat and to pinpoint appropriate statistical methods for describing the trend and the variability in trend estimates. Analysis of count data can be as diverse, complex, and controversial as the nature of the study itself. A number of investigators have divided studies designed to measure environmental trends into two types: design-based and model-based studies (Sauer et al. 2004; Bart et al. 2003; Edwards 1998; Urquhart et al. 1998; Dixon et al. 1998). Design-based models are based on a well-designed sampling program, where temporal and spatial scales are carefully considered. Accompanying factors which may directionally affect counts are considered in the sampling design or complete random selection of count data is carefully planned. Design-based models are generally simpler but may have larger standard errors or significant biases if unanticipated effects, such as observer differences, are present. Model-based methods attempt to incorporate factors that influence counts into the analysis. Model-based methods require statistical creativity, biological insight, and familiarity with conduct of the survey. A design-based approach can switch to a model-based approach if it becomes statistically necessary, but analyses cannot be switched from a model-based approach to a design-based approach (Edwards 1998).

Both types of models have been applied to bird counts. Assuming design-based data, Bart et al. (2003) applied simple linear regression to Breeding Bird Survey counts and recommended using this approach based on a simulation study. However Sauer et al. (2004) criticized this approach and suggested that the complexity inherent in model-based approaches is necessary, in some cases, to preclude large biases and erroneous conclusions. Much of the trend in bird counts is explained when observer bias is accounted for in a model-based approach (Link and Sauer 1997a; 1998). Other model-based approaches include generalized additive models (James et al. 1996; Fewster et al. 2000); hierarchical models (Link and Sauer 2002), and overdispersed Poisson models (Link and Sauer 1997b).

Modeling count data requires the selection of an appropriate statistical distribution that describes the inherent uncertainty in observing counts. The negative binomial distribution is a discrete probability distribution that has received wide recognition as a suitable descriptor of variability in animal abundance (i.e. Power and Moser 1999; White and Bennetts 1996; Anscombe 1949; and others). This distribution reflects the empirical evidence that the variance of counts invariably exceeds the mean value. Bowden et al. (1969) tested the fit of a number of distributions to counts of mule deer fecal groups, and suggested that the negative binomial offered the simplest explanation of the data. Link and Sauer (1997b) described bird counts using a negative binomial, characterized as an overdispersed Poisson variable, with the overdispersion arising from gamma mixtures.

There are a number of options in designing a dive survey. Timed searches (McShane 1994), patch-size estimates (McShane 1995), and linear transects or radial transects (Hart et al. 1997); Gorfine et al. 1998) have been suggested as preferred methods for assessing the abundance of some shallow water species and for diverse survey conditions. Hart et al. (1997) and Gorfine et al. (1998) evaluated timed searches and radial transects and found that factors such as diver experience and survey conditions may play a large role in biases of count and size data. Alternative types of counts, such as presence-absence surveys or time-to-encounter data can simplify surveys and may be preferred when there is little variability in abundance among survey sites and the target organism is rare or difficult to find (Pollock 2006). However, under most conditions, the survey method currently used by the Alaska Department of Fish and Game (ADF&G) to collect count data using standard transect techniques is preferred as long as the survey is carefully designed (Pollock 2006; Hart et al. 1997).

The current Southeast Alaska sea cucumber stock assessment survey program began in 1990, in response to the first sea cucumber fishery management plan (ADF&G 1990). This plan established a 3-year rotational harvest strategy and directed ADF&G to conduct stock assessment surveys in areas to be opened to commercial harvest, to estimate the overall biomass of sea cucumbers and a biologically and statistically acceptable harvest quota for these areas (Figure 1). In addition, a number of control areas were established, to monitor population trends under conditions of no commercial removal. Data from the 1990 to 2001 surveys and commercial catch information are presented and summarized in a series of reports (Larson et al. 2001a; 2001b; and, Hebert et al. 2001a; 2001b).

The stock assessment survey is conducted using two teams of SCUBA divers, to assess abundance and weight of sea cucumbers in an area. Transects are systematically allocated along the shorelines of each survey area and are oriented perpendicular to the shore. Latitude and longitude coordinates are provided for each transect; the same transects are used each time an area is surveyed. A pair of divers parallel each transect to depth. Each diver holds a 2-meter PVC tube perpendicular to the census path, and is separated from the other diver by approximately 10 meters (less in reduced visibility conditions). Occasionally (under very poor visibility conditions), diver pairs will use only one 2-meter survey rod between them, and count in adjacent 1-meter wide paths. The diver pair will make two sweeps, one on either side of the transect, to produce two counts; such counts are not considered to be independent. Divers descend to 18.3 m (60 feet of seawater) below mean lower low water. Each diver counts all sea cucumbers passing under their rod; resulting in paired counts for each transect. In a few cases, only one, or more than two counts are obtained. Divers obtain mean weights by randomly collecting approximately 15 cucumbers from every other transect (generally odd-numbered transects), and transporting them back to the support boat, where the sea cucumbers are eviscerated and weighed to the nearest gram. There have been minor modifications to survey methods since 1990, but, in general, count and weight data have been collected in a consistent manner since the beginning of the survey.

During the 1990 through the 2005 survey seasons, 83 areas were surveyed at least once, to estimate the number of sea cucumbers present in the specified shoreline (Tables 1 through 4). The surveyed areas include the following: 7 control areas; 4 areas that have multiple years of survey counts and harvest, but the survey has been discontinued in recent years; 10 areas that contained biomasses considered initially to low to allow harvest; 16 areas of only one year of survey and harvest data; and, 46 areas that have multiple years of harvest and survey information. The subdistrict 101-27 control area has 13 years of survey counts; many of the harvest areas have been surveyed 5 or 6 times, spanning 15 years. Most areas contain 18 to 20 established transects and average 125 km of surveyed shoreline. Up to 500 transects are surveyed each year for sea cucumber abundance, resulting in a total of 4,997 transect counts since 1990. Most of the areas also contain multiple years of weight measurements, with control areas within subdistricts 103-60 and 106-30 having 8 years of weight data. An average of 21 animals have been weighted from each sampled transect, and an average of 3 years and 7 transects have been sampled from each area for weights. Approximately 183 transects are sampled each year for sea cucumber weights, resulting in a total of 36,824 sea cucumbers being sampled for weight since 1990. Several other areas (e.g. Lituya Bay) have been surveyed, with few to no sea cucumbers seen; these areas are not considered in this report.

Prior to 1990, a total of 3.2 million pounds of sea cucumbers were harvested. Since adoption of the management plan in 1990, 19.6 million pounds (or 1.2 million pounds per year) have been harvested from 63 management areas (Tables 5 and 6, Figure 2). This is comparable to other west coast sea cucumber fisheries. Over the same time period, British Columbia catches have averaged 0.67 million pounds per year, but have increased to average 1.2 million lbs in the last 3 years. After a peak catch of 4.15 million pounds in 1991, Washington State catches have declined to an 1996-2004 average catch of 0.56 million lbs. The average harvest per year for individual areas in Southeast Alaska ranges from 4,399 lbs to 335,386 lbs with an overall average of 82,936 lbs per area and year. Each area is opened for harvest on a 3-year rotation, resulting in a maximum of 6 years of harvest effort for any area since 1990. Subdistrict 103-40 was initially divided into 2 subareas, with each area being on a different 3-year cycle and resulting in 9 years of reported catch. A total of 25 areas have been opened for commercial harvest for 5 or more years.

METHODS

AVERAGE WEIGHTS AND ESTIMATED TRENDS IN WEIGHTS BY AREA

Collection of sea cucumber weight data began in 1992. From 1992 through 2005, weight data were collected from 77 of the 83 areas surveyed (Tables 7 to 10). Fifty-six of these areas have multiple years of weight measurement, with an average of 3 years of survey data per area. An average of 8 transects per area and over 20 animals per transect were sampled for weights. For a given area, the average variance of individual weights (subscript ℓ denotes each individual sea cucumber sampled for weight) is the average of $s^2_{w_{ij}}$ over all years j and transects i, in an area, where $s^2_{w_{ij}} = \frac{\sum_{l=1}^{n_{ij}} \left(w_{ijl} - \overline{w}_{ij}\right)^2}{n_{ij} - 1}$, w_{ijl} is individual weights, $\overline{w}_{ij}$ is the mean weight for survey year j and transect i and n_{ij} is the number of sea cucumbers weighted for survey year j and transect i.

Because of differences in sample size, the average mean square error among transects is calculated as (Sokal and Rohlf 1981):

$$MS_{Among\,Groups(j)} = \frac{\left(\sum_{i=1}^{n_{T_j}} \frac{\left(\sum_{l=1}^{n_{ij}} w_{ijl} \right)^2}{n_{ij}} - \frac{\left(\sum_{i=1}^{n_{T_j}} \sum_{l=1}^{n_{ij}} w_{ijl} \right)^2}{\sum_{i=1}^{n_{T_j}} n_{ij}} \right)}{n_{T_j} - 1}, \qquad [1]$$

where n_{T_j} is the number of transects in survey year j and $MS_{Among\ Groups(j)}$ is an estimate of $\sigma^2 + n_0\sigma_A^2$, the variability in the overall average weight (Sokal and Rohlf 1981). The average mean square error within groups is estimated as

$$MS_{Within\,Groups(j)} = \frac{\left(\sum_{i=1}^{n_{T_j}} \sum_{l=1}^{n_{ij}} w_{ijl}^2 - \sum_{i=1}^{n_{T_j}} \frac{\left(\sum_{l=1}^{n_{ij}} w_{ijl} \right)^2}{n_{ij}} \right)}{\sum_{i=1}^{n_{T_j}} n_{ij} - n_{T_j}}. \qquad [2]$$

$MS_{Within\ Groups(j)}$ is an estimate of σ^2, the variance of individual weights. Since sample size differs among groups, an n_0 is used instead of an average n_{ij} across transects. This is calculated as

$$n_0 = \frac{1}{n_{T_j} - 1} \left(\sum_{i=1}^{n_{T_j}} n_{ij} - \frac{\sum_{i=1}^{n_{T_j}} n_{ij}^2}{\sum_{i=1}^{n_{T_j}} n_{ij}} \right). \qquad [3]$$

The expected variance (an estimate of σ^2_A) in transect mean values is then calculated as

$$Mean\,Square_{Means} = {(Mean\,Square_{Among\,Groups} - Mean\,Square_{Within\,Groups})} \big/ {n_0}. \qquad [4]$$

A total of 56 survey areas had multiple years of weight data and could be evaluated for changes in weight over the span of survey years. An analysis of covariance (Neter and Wasserman 1974) was conducted on the weight data, to estimate the change in weight for each of the 56 areas and determine if these changes were statistically significant. This analysis reduces the experimental error in the linear model by controlling for differences in average weight between transects. In general, if w_{ijl} is the weight (in grams) of specimen l from transect i and index year j (year index is relative to the last year of survey weights), then an estimate of w_{ijl} is,

$$\hat{w}_{ijl} = \alpha_i + \beta t_j, \qquad [5]$$

where α_i is the intercept for transect i and β is the change in weight, in grams, over the number of years prior to the last survey (t_j). The number of years is expressed as 0 (for the year of the last survey) or negative years (years prior to the survey). This results in a β value which is positive for increasing weights over time and negative for decreasing weights over time. The α_i is the estimated mean weight for transect i in the last year of survey measurements. Because the variance in average weight tends to increase with increasing average weight (Figure 3), a weighted analysis of covariance was used. The squared deviation minimized in the analysis of covariance is weighted by the inverse of the estimated variance of the average weight. This results in an individual weighting factor for each year and transect sampled. The variance is estimated as: Variance = 1024 + 0.47 x Mean Weight Squared (Figure 3). SAS programs using the GLM procedure (SAS 1985) were used to estimate average weights by transect in index year 0 (α_i's) and the annual change in weight (β) and its standard error.

The overall mean weight for an area in the last survey year is estimated using two methods: (1) only the sample weights collected during the last survey year (labeled sample mean and sample standard error) and (2) using estimated mean weights by transect from the analysis of covariance (labeled ANCOVA mean and ANCOVA standard error). The estimate of sample mean weight for an area ($\hat{w}_{..0}$) is calculated as the average of the individual transect average weights ($\hat{w}_{.i0}$) ($\hat{w}_{..0} = \sum_{i=1}^{n_{T_0}} \hat{w}_{.i0} \Big/ n_{T_0}$), and the standard error of the sample mean weight is the square root of the average squared deviation of average weights from the overall mean divided by the number of transects with weight sample means minus 1 (e.g. Hebert et al 2001a). The estimated ANCOVA mean and standard error are estimates identical to sample mean and standard error except the estimate average weights by transect in index year 0 (α_i's) are substituted for the $\hat{w}_{.i0}$ and n_{T_0} is replaced by the total number of transects with weight samples in any year (number of α_i's), not just the number of transects sampled in the last survey year.

SURVEY DESIGN FOR ESTIMATING AVERAGE WEIGHT AND TRENDS IN WEIGHT

Variability in estimated average weight is a function of the inherent variability in individual sea cucumber weights in each sampled transect, the variability in mean weights of each individual transect for each area and year, and the number of transects sampled and number of sea cucumbers sampled in each transect. Given an average variance of weights within transects (σ^2_t), an average variance of mean weights across transects (σ^2_A) , the total variance associated with average weight of sea cucumbers (σ^2_w) is $\sigma^2_w = (\sigma^2_A + \sigma^2_w/n_c)/n_t$ where n_c is the number of sea cucumbers sampled in each transect and n_t is the number of transects sampled (Cochran 1977).

Detection of trends in average weights in an area over two or more years of survey effort depends on a number of factors. The number of years of survey data has a substantial effect on measuring changes in weights, with more survey years, and by extension a longer time span of weight measurements, being more effective in detecting trends in weight. The magnitude of weight change itself will also affect the significance in results, with larger changes being easier to detect. Finally, the variability in weights within and across transects, the number of animals sampled per transect and the number of transects sampled each survey year, and the desired level of significance applied to the results will all affect the ability to detect a significant change in weight across years. The variance of the estimated change in weights (Var(β)) is

$$Var(\beta) = \frac{\dfrac{E(y^2)}{E(x^2)} - \dfrac{\left(E(xy)\right)^2}{\left(E(x^2)\right)^2}}{df} = \frac{\dfrac{E(y^2)}{E(x^2)} - \beta^2}{df} , \qquad [6]$$

following the notation of Sokal and Rohlf (1981), where $E(y^2)$ is the expected sum of the squared deviations over years and number of animals sampled per transect, $E(x^2)$ is the expected squared deviations in years for each animal sampled per transect and year, $E(xy)$ is the expected covariance between deviation in years and deviation in weights, and df is the degrees of freedom, equal to number of transects times number of animals sampled per transect minus number of transects and minus 1. The value for $E(y^2)$ is estimated as the average variance in individual weights times the number of animals measured for weight, number of years of surveys (either 2 or 6), and times the number of transects surveyed (1 to 20 transects). The value for $E(x^2)$ is calculated as the variance in survey years times the number of animals measured for weight, number of years of surveys, and times the number of transects surveyed. The E(xy) is calculated as the change in weight per year (β) times the variance in survey years , $E(x^2)$, times the number of animals measured for weight, number of years of surveys, and times the number of transects surveyed. The degrees of freedom are calculated as the number of sea cucumbers measured per transect times the number of transects minus the number of transects minus 1.

AVERAGE DENSITY AND ESTIMATED TRENDS IN ABUNDANCE BY AREA

We regard the transect counts as overdispersed Poisson random variables, with constant overdispersion within each transect arising from gamma mixtures. It is well known that gamma mixtures of Poisson random variables have negative binomial distributions (Johnson and Kotz 1969). The expected abundance on transect *i* and in year *j*, expressed in number of sea cucumbers per 2 meter wide transect, is expressed as $M_i \exp(\beta t_j)$. M_i is the expected abundance on transect *i* in year 0, the last year of survey effort, t_j is the difference in years between the survey year and the last year of survey effort (years before the last year have a negative t value), and β is a parameter that either increases or decreases M_i as a function of the difference between year j and the last year of the survey. This average rate of change over a specific time interval (β) is termed 'trend' (Link and Sauer 1997a) and describes the overall direction of change in abundance of the population as a whole, regardless of temporal scale, cyclical variations, within-year seasonal variation, spatial variations, and erratic fluctuations (Dixon et al. 1998). Let c_{ijh} represent the actual count of sea cucumbers in transect *i* and year *j* by diver count *h*. The probability of counting c_{ijh} animals is the negative binomial Probability Density Function, or PDF,

$$p(c_{ijh} / M_i; k; \beta) = \left(\frac{k}{M_i e^{\beta t_j}} \right)^k \frac{\Gamma(k + c_{ijh})}{\Gamma(k) c_{ijh}!} \left(\frac{k}{M_i e^{\beta t_j}} + 1 \right)^{-(k + c_{ijh})}, \qquad [7]$$

where *k* is a parameter of the distribution which describes the degree of clumping in the population (White and Bennetts 1996); *k* is inversely related to variance of the counts and $\Gamma(x)$ is the gamma function of *x*. Taking the log-likelihood of all c_{ijh} values results in,

$$\sum_i \sum_j \sum_h Ln[p(c_{ijh} / M_i; k; \beta)] = \sum_i \sum_j \sum_h kLn[k] - kLn(M_i) - k\beta t_j$$

$$- (k + c_{ijh}) Ln\left(\frac{k}{M_i e^{\beta t_j}} + 1 \right) + Ln(\Gamma(k + c_{ijh})) - Ln(\Gamma(k)) - Ln(c_{ijh}!) \qquad [8]$$

Maximizing this function with respect to β, k and M_i , results in the maximum likelihood estimate. The estimated average density (M_0) is the average of all M_i and the standard error of the average density, SE(M_0), is,

$$SE(M_0) = \sqrt{\frac{\sum_{i=1}^{n_T}(M_i - M_0)^2}{n_T - 1} \Big/ n_T}\ , \qquad [9]$$

where n_T is the number of transects.

The standard error of the parameters β and k are estimated by taking the inverse of the Hessian matrix and then the square root of the values corresponding to the second derivative of the β and k parameters, multiplied by -1. The first and second derivative functions are given in Appendix A. A SAS program using the MODEL procedure was used to minimize the log-likelihood function to obtain parameter estimates, and a BASIC program and Excel worksheets to summarize the results and obtain the standard errors of the parameter estimates.

SURVEY DESIGN FOR ESTIMATING AVERAGE DENSITY AND TREND IN ABUNDANCE

The decision on how many transects are required to achieve an acceptable level of precision, and whether to revisit existing transect locations (termed Index Sites), or choose new transect locations (termed Replacement Sites) for each survey year can be investigated by examining existing survey data and the variability in counts between and within transects and between years. A number of investigators have proposed a variety of survey designs, which trade off revisits to index sites with designs that incorporate some pattern of new sites. Urquhart et al (1998) summarizes a number of ‘panel’ survey designs; each panel consists of a set of survey sites and panels are chosen in some type of repeating pattern. This type of survey has also been called Sampling with Partial Replacement, or SPR (Skalski 1990). The choice of how to include new and index sites into the survey design depends on the relative importance of detecting a trend in abundance compared to estimates of a population’s status. Scott (1998) recommends permanent plots to estimate changes in forest resources, because the variance of trend estimates is reduced by the positive covariance between the occasions. Skalski (1990) recommends the use of new sample sites for each survey occasion, if the objective is solely to estimate population means. Since the objective of most studies is to both monitor trends in the population’s status, and to assess the current status of the population, a mixture of index sites with new sites selected each survey cycle is the best choice.

A slightly different statistical approach was developed to evaluate the best mixture of index and new transects for sea cucumber dive surveys in Southeast Alaska. A Probability Density Function (PDF) that is essentially a negative binomial PDF was developed with parameters M_0, β, and k that describes the probability of obtaining c_{ijh} counts on transect i, in year j, and diver count h. This PDF differs from the previous PDF, in that individual transect sea cucumber densities (M_i) are not calculated as part of the estimation process. This means that both new transects and index transects provide information towards estimating the values of M_0, β, and k. Let M_0 be the average density of sea cucumbers, and k be the variance parameter. Since the negative binomial PDF is a compound distribution of a gamma PDF and a Poisson PDF, we use a gamma distribution to describe the probability of selecting a transect location with m_i, such that,

$$P(m_i) = \left(\frac{k}{M_0}\right)^k \frac{1}{\Gamma(k)} m_i^{k-1} e^{-km_i / M_0} . \qquad [10]$$

where k is a parameter of the distribution which varies inversely with the variability in m_i. Let us assume an exponential rate of decrease of m_i for each t_j difference in years from last year of survey (t_j = 0, -3, etc., as surveys are conducted every third year and t_j is relative to the last year of survey data). Let $c_{ijh,}$ be the number of sea cucumbers counted in transect number i, year j, and diver count h. Given that $m_i e^{\beta t_j}$ cucumbers were present on the ith transect in year j, the joint probability of observing the actual c_{ijh} on transect i is described by the joint Poisson distribution,

$$P(c_{i,1,1},..c_{ijh}..c_{in_{yr}n_{h(yr)}} / m_i, \beta) =$$

$$\frac{\left(m_i e^{\beta t_1}\right)^{\sum_{h=1}^{n_{ih(1)}} c_{i,1,h}} e^{-n_{ih(1)} m_i e^{\beta t_1}} \left(m_i e^{\beta t_2}\right)^{\sum_{h=1}^{n_{ih(2)}} c_{i2h}} e^{-n_{ih(2)} m_i e^{\beta t_2}} .. \left(m_i e^{\beta t_j}\right)^{\sum_{h=1}^{n_{ih(j)}} c_{ijh}} e^{-n_{ih(j)} m_i e^{\beta t_j}} .. \left(m_i e^{\beta t_{n_{yr}}}\right)^{\sum_{h=1}^{n_{ih(n_{yr})}} c_{in_{yr}h}} e^{-n_{ih(n_{yr})} m_i e^{\beta t_{n_{yr}}}}}{c_{i,1,1}! c_{i,1,2}! c_{i,2,1}..c_{ijh}!..c_{in_{yr}n_{ih(n_{yr})}}!} \qquad [11]$$

where the ith transect (i = 1 to n_T) and for n_{yr} number of survey years and for $n_{ih(j)}$ number of diver counts on transect i and survey year j. The exponential and power terms are then combined, resulting in,

$$P(c_{i,1,1}, c_{i,1,2,}...c_{ijh}..c_{in_{i,yr}n_{i,h(n_{yr})}} / m_i) = \frac{e^{\beta \sum_{j=1}^{n_{i,yr}} t_{ij} \sum_{h=1}^{n_{i,h(j)}} c_{ijh}} m_i^{\sum_{j=1}^{n_{i,yr}} \sum_{h=1}^{n_{i,h(j)}} c_{ijh}} e^{-m_i \sum_{j=1}^{n_{i,yr}} n_{i,h(j)} e^{\beta t_{ij}}}}{\prod_{j=1}^{n_{i,yr}} \prod_{h=1}^{n_{ih(j)}} c_{ijh}!} \qquad [12]$$

The gamma PDF and the Poisson PDF are then multiplied together and integrated with respect to m_i , such that,

$$P(c_{i,1,1}, c_{i,1,2}, c_{i,2,1}..., c_{i,j,h} / k, M_0, \beta) = \left(\frac{k}{M_0}\right)^k \frac{e^{\beta \sum_{j=1}^{n_{i,yr}} t_{i,j} \sum_{h=1}^{n_{i,h(j)}} c_{ijh}}}{\Gamma(k) \prod_{j=1}^{n_{i,yr}} \prod_{h=1}^{n_{i,h(j)}} c_{ijh}!} \int_0^\infty m_i^{k-1+\sum_{j=1}^{n_{i,yr}} \sum_{h=1}^{n_{i,h(j)}} c_{ijh}} e^{-m_i \left(k/M_0 + \sum_{j=1}^{n_{i,yr}} n_{i,h(j)} e^{\beta t_{ij}} \right)} \partial m_i \cdot \qquad [13]$$

Since ,

$$\int_0^\infty c m_i^a e^{-b m_i} \partial m_i = c \frac{\Gamma(a+1)}{b^{a+1}} , \qquad [14]$$

evaluating the integral results in,

$$P(c_{i,1,1}, c_{i,1,2}, ..., c_{ijh} / k, M_0, \beta) = \left(\frac{k}{M_0}\right)^k \frac{e^{\beta \sum_{j=1}^{n_{i,yr}} t_{ij} \sum_{h=1}^{n_{i,h(j)}} c_{ijh}} \Gamma\left(k + \sum_{j=1}^{n_{i,yr}} \sum_{h=1}^{n_{i,h(j)}} c_{ijh}\right)}{\Gamma(k) \prod_{j=1}^{n_{i,yr}} \prod_{h=1}^{n_{i,h(j)}} c_{ijh}!} \left(\frac{k}{M_0} + \sum_{j=1}^{n_{i,yr}} n_{i,h(j)} e^{\beta t_{ij}}\right)^{-(k + \sum_{j=1}^{n_{i,yr}} \sum_{h=1}^{n_{i,h(j)}} c_{ijh})} \qquad [15]$$

This is the probability of observing c_{i11}, c_{i12},..c_{ijh} etc. counts on transect i. The probability of observing all counts on all transects (i = 1 to n_T) is the product of the previous equations over all i:

$$P(c_{1,1,1}, c_{1,1,2}, ..., c_{ijh} / k, M_0, \beta) =$$

$$\prod_{i=1}^{n_T} \left(\frac{k}{M_0}\right)^k \frac{e^{\beta \sum_{j=1}^{n_{i,yr}} t_{ij} \sum_{h=1}^{n_{i,h(j)}} c_{ijh}} \Gamma\left(k + \sum_{j=1}^{n_{i,yr}} \sum_{h=1}^{n_{i,h(j)}} c_{ijh}\right)}{\Gamma(k) \prod_{j=1}^{n_{i,yr}} \prod_{h=1}^{n_{i,h(j)}} c_{ijh}!} \left(\frac{k}{M_0} + \sum_{j=1}^{n_{i,yr}} n_{i,h(j)} e^{\beta t_{ij}}\right)^{-(k + \sum_{j=1}^{n_{i,yr}} \sum_{h=1}^{n_{i,h(j)}} c_{ijh})} \quad [16]$$

Note that the parameters β and k are equivalent to the parameters in the previous model developed to estimate the individual M_i. Taking the natural log of this joint PDF yields,

$$Ln[P(c_{i11}, ..., c_{ijh}, ..., c_{n_T, n_{n_T,yr}, n_{n_T,h(n_{n_T,yr})}} / k, M_0, \beta)] =$$

$$\sum_{i=1}^{n_T} \left[\begin{array}{l} kLn(k) - kLn(M_0) + \beta \sum_{j=1}^{n_{i,yr}} t_{ij} \sum_{h=1}^{n_{ih(j)}} c_{ijh} + Ln(\Gamma(k + \sum_{j=1}^{n_{i,yr}} \sum_{h=1}^{n_{i,h(j)}} c_{ijh})) - Ln(\Gamma(k)) - \sum_{j=1}^{n_{i,yr}} \sum_{h=1}^{n_{i,h(j)}} Ln(c_{ijh}!) \\ -(k + \sum_{j=1}^{n_{i,yr}} \sum_{h=1}^{n_{i,h(j)}} c_{ijh}) Ln\left(\frac{k}{M_0} + \sum_{j=1}^{n_{i,yr}} n_{i,h(j)} e^{\beta t_{ij}}\right) \end{array} \right] \quad [17]$$

Maximizing this function with respect to k, M_0, and β will result in the maximum likelihood estimates for these parameters. The standard error of the parameters β, k, and M_0 are estimated by taking the inverse of the Hessian matrix and then the square root of the negative values corresponding to the second derivative of the β and k parameters. The first and second derivative functions are given in Appendix A. A SAS program using the MODEL procedure was used to minimize the log-likelihood function to obtain parameter estimates, and a BASIC program and Excel worksheets to obtain the standard errors of the parameter estimates.

RESULTS

AVERAGE WEIGHTS AND ESTIMATED TRENDS IN WEIGHTS BY AREA

The overall average weight of sea cucumbers by area ranges from 114 gm to 361 gm with an overall average of 213.1 gm. (Tables 7 to 10). The overall average variance of individual weight measurements is 3,382 gm^2, ranging from 1,388 gm^2 to 7,896 gm^2 for individual areas. The average of the estimated mean square error within transects is 3,288 gm^2, ranging from 1,368 gm^2 to 8,425 gm^2. Because the only difference between the average variance of individual weights and the estimated mean square error within transects is the computational treatment of the different numbers of animals weighted from sampled transects, the close agreement of these 2 estimates is expected. Estimates of mean square error between transects averages 2,269 gm^2 and ranges from 51 gm^2 to 9,420 gm^2. This is a measure of the variability in mean weights across transects and, when compared to the variability of mean weights within a transect (3,288 gm^2 divided by 23.4 measurements, the average number of measurements per transect or 140 gm^2), is comparatively large, contributing an estimated 94% of the overall variability in mean weight estimates. However, the overall variability in average weight for an area and year is relatively small, with the standard error of the mean estimate averaging 8.8% of the mean value. Although the variability in estimated mean weight for an area is relatively small, compared to the variability in mean density, it remains an important component of the overall variability in biomass estimates (Hebert et al. 2001a).

The average weight of sea cucumbers in the initial year of survey was back-calculated from ANCOVA estimated transect weights in the last survey year and the estimated change per year to examine overall differences in sea cucumber sizes by general location. These average weights would be more representative of natural population weights before removal by the commercial fishery. The average weights by survey area were then grouped by broad geographical regions into Southern Inside, Southern Outside, Northern Inside, and Northern Outside areas, to discern whether any differences in weights were evident by these large geographic regions. Southern Inside encompassed fishing districts 101, 102, 106 and 107; Southern Outside encompassed districts 103, 104, and 105. Northern Inside encompassed districts 108, 110, 111, 113, 115, and parts of districts 109 and 113; Northern Outside encompassed district 114, the coastline near Yakutat, and parts of districts 109 and 113 exposed to the Gulf of Alaska. (Figure 4). In general, sea cucumber sizes tended to be smaller and more variable in the Southern Inside areas, while Southern Outside areas are characterized by somewhat larger weights. The Northern Inside and Northern Outside areas were similar in average weights and variability in average weights. However, the overall variability in mean weights by area precludes any obvious pattern in size, from southern to northern, or inside to outside waters.

The sample mean weights of sea cucumbers in the last survey year were very similar to corresponding ANCOVA mean weights (Figures 5 to 7 and Tables 11 to 14). Of the 56 comparisons of mean weights in the last survey year in areas with 2 or more years of weight data, 26 of the ANCOVA means were larger than the corresponding sample mean weights, and 20 mean weights were smaller. The overall average weight using the sample calculations was 218.8 gm, compared to 218.0 gm using ANCOVA estimates. The largest differences were in statistical area 101-43, where the ANCOVA exceeded the sample mean weights by 68 gm, and in areas 105-41 and-42, where the sample mean exceeded the ANCOVA estimate by 66 gm. However, the ANCOVA standard errors were generally smaller. Of the 56 areas where ANCOVA was possible, 47 of the average weights had standard errors less than the sample averages (84%), and ANCOVA standard errors averaged 14.6 gm, compared to 17.7 gm for the sample results. The ANCOVA means use weight samples from other years and, in some cases, from transects not sampled in the last survey year, resulting in less variable mean weight estimates. Although this is a 19% reduction in standard error, when the ANCOVA results are used instead of sample mean and variance calculations, the resulting impact on overall biomass calculations is minimal.

The estimated change in weight (β) over the years of survey data was not consistent throughout the region. The estimated change in weights ranged from a loss of 10 gm per year to a gain of 10 gm per year and averaged a gain of 1.24 gm per year. However, a large number of areas did have a significant increase in weight, from the first survey year to the last survey year (Figure 8 and Tables 11 to 14). A total of 21 areas, out of 56 areas with multiple years of weight data (38%), did have significant increases in weight, while 27 areas showed no significant change in weight and 7 areas had a significant decrease in weight.

A comparison of harvest history on the change in weight suggested that commercial removal of sea cucumbers may produce an increase in weight in the remaining animals (Figure 9). Most of the areas with no harvest or just a single year of commercial harvest showed no significant change in weight. However, areas with 2 or more years of commercial removal of sea cucumbers tended to also have a higher likelihood of significant increases in weight of sea cucumbers from the first year of a survey to recent surveys, with 20 of 43 areas having significant increases in weight. The location of the area had little effect on the trend in weights (Figures 10 to 12).

SURVEY DESIGN FOR ESTIMATING AVERAGE WEIGHT AND TRENDS IN WEIGHT

Variability in estimated average weight is a function of the inherent variability in individual sea cucumber weights in each sampled transect, the variability in mean weights of each individual transect for each area and year, and the number of transects sampled and number of sea cucumbers sampled in each transect. The average variance of weights within transects (σ^2_t) is 3,382 gm^2, and the average variance of mean weights across transects (σ^2_A) is 2,265 gm^2 (Tables 7 to 10).

Figure 13 demonstrates the reduction in the variability of the estimate of average weight, as measured by the square root of the variance, or standard error, as both sample sizes of sea cucumbers within a transect and number of sampled transects increases. The amount of uncertainty in estimates of average weight of animals in an area with only one transect sampled for weights is unacceptably high, never decreasing below 50 gm (or a coefficient of variation of about 25% on an average sea cucumber weight of 200 gm) despite high numbers of animals sampled in the transect. Increasing the number of transects sampled will decrease the variance associated with average weight substantially more than increasing the number of sea cucumbers sampled within a transect. Sample sizes greater than 15 animals per transect do little to improve the precision of average weight estimates. Sample sizes less than 10 animals per transect may create biases due to nonrandom selection of a few animals, and are also not recommended. It is recommended that weight sampling protocol be 10 to 15 animals per transect and 10 to 15 transects per area, resulting in expected standard errors averaging from 13 to 17 gms, or coefficient of variations on weights averaging 200 gm of 6% to 9%.

Detection of trends in average weights in an area over 2 or more years of survey effort depends on a number of factors, including number of survey years, time span of weight measurements for sites, magnitude of weight change, number of transects surveyed, number of animals sampled, and variability within and across transects. In a series of steps to calculate an estimated variance for changes in weight (var(β); equation 6), E(y^2) is estimated as the average variance in individual weights (3382 gm^2) times the number of animals measured for weight (15 animals), number of years of surveys (either 2 or 6), and times the number of transects surveyed (1 to 20 transects). the value for E(x^2) is calculated as the variance in survey years (2.25 yr^2 for surveys conducted in index year 0 and -3 or 26.25 yr^2 for surveys conducted every 3 years from index year 0 to index year -15) times the number of animals measured for weight, number of years of surveys, and times the number of transects surveyed.

Figure 14 illustrates changes in power, or rather the probability of not detecting an actual change, (1 – power; with significance levels set at $\alpha = 0.05$), as number of transects, number of surveys, and weight changes. A 2 gm/year change is extremely difficult to detect after 2 years of surveys, even with a large number of transects. Even after sampling 20 transects and 15 animals per transect, there remains a 40% chance of not detecting a significant change in weight when weight is increasing or decreasing 2 gm/year. Increasing annual changes in weight and number of survey years quickly improves the ability to detect changes in weights. For example, there is a 95%

chance of detecting at least a 2 gm change in weight per year if 6 years of survey data are available, but only 10 transects are sampled each year. Detecting a change of 8 gm/year is highly probable after 2 years of survey data has been collected from 7 transects. Detecting large changes in weight (for example 8 gm/year) is effectively certain, even with only 2 transects sampled and 2 years of survey data available.

AVERAGE DENSITY AND ESTIMATED TRENDS IN ABUNDANCE BY AREA

Average densities were estimated using current (design-based) statistics (Larson et al. 2001a) and the negative binomial error model (NBE model-based) statistics (Tables 15 to 18). Estimates of the average density of sea cucumbers per 2-meter transect obtained in the 83 areas using the design-based approach ranged from 0.1 to 49 cucumbers/2 m in the last survey year. Estimates of the NBE model-based abundance in 53 areas with multiple years of data ranged from 3 to 50 cucumbers/2 m transect in the last survey year. When NBE model-based abundance estimates were compared to the design-based estimates, 27 of the 56 of the NBE model-based estimates were larger (57%), indicating that there was not a substantial difference in abundance estimates between the two methods. However, 49 of the 56 standard errors (88%) of the NBE model-based estimates were lower than the design-based estimates, indicating a substantial reduction in variance using the NBE model-based approach. The average standard error for the 56 areas for which estimates were obtained using both the NBE model-based and design-based approach was 3.7 animals for the NBE model-based estimates, compared to 4.6 animals for the design-based estimates, or a 20% reduction in standard error by using the NBE model-based estimate instead of the design-based estimate. The smaller variation in estimates of average abundance using the NBE model-based estimates is likely due to including data from past years in the estimation process, especially for areas where not all transects are surveyed in the most recent year. There was no obvious pattern in abundances by location of survey area (Figures 15 to 17).

There was a significant decreasing trend in density in 35 areas (66%) and nonsignificant relationships in 12 areas (23%; Tables 15 to 18 and Figures 18 to 21). The maximum estimated trend was -0.44 per year in statistical areas 113-71, -72, and -73, which equates to a loss of 36% of sea cucumber abundance per year. Only two surveys were conducted for this area in 1991 and 1994, after which surveys were discontinued because of poor abundance. Other areas in which large declines in abundance were also estimated for areas 109-62 (-0.253 or 22% per year), 112-16, -17, -63, and -65 (-0.176 or 16% per year) and 105-41 and 42 (-0.165 or 15% per year). Four areas had a significant increasing trend in abundance, with area 109-10, -11, and -13 having an increasing trend of 0.188 or 21% per year. The overall average trend in abundance is -0.051 or a decrease in abundance of 5% per year.

Survey areas were divided into two groups, based on their history of commercial harvest. The trends of control areas and areas with a single season of a commercial fishery (total of 13 areas), were compared to areas with two or more seasons of commercial harvest (total of 43 areas) (Figure 22). The proportion of areas with significant decreasing trends, non-significant trends, and significant increasing trends were very similar. Sixty-two percent of areas with little to no commercial harvest history had significant decreases in counts compared to 63% of areas with two or more years of commercial removal. There was a tendency of areas with increasing weights to also have increasing abundance, although the relationship is highly variable (Figure 23). For example, three of the four areas with significant increases in abundance also had significant increases in weights. However, 12 of 35 areas (37.5%) with significant decreases in abundance also had significant increases in weight.

SURVEY DESIGN FOR ESTIMATING AVERAGE DENSITY AND TREND IN ABUNDANCE

The average density of sea cucumbers in the last year of survey effort was estimated using the composite model-based method for all survey areas. The results of applying this model were compared to the design-based and NBE model-based approach (Tables 19 to 26, Figures 24 and 25). Both of the model-based methods produced comparable results. Comparison of average densities using the design-based and NBE model-based approaches to composite model-based estimates results in 27 of 56 estimates (48%) of the NBE model-based estimates being greater than the composite model-based estimates and 32 (57%) of the design-based estimates were greater than the composite model-based estimates. All estimated average densities were within the standard errors of the averages using other methods. The estimated standard errors of the NBE model-based approach are slightly smaller on the average with only 13 of 56 (23%) of the composite model-based standard errors being smaller than the NBE model-based standard errors. However, the composite model-based estimates were associated with smaller standard errors compared to the designed-based approach with 32 areas (57%) having smaller variability in the estimated density.

The estimated trend in abundances was also very similar between the NBE model-based and composite model-based approaches (Figure 26). Of the 53 areas studies, all but 4 comparisons showed the same trend in densities. In subdistricts 101-80 and 102-40, one method produced non-significant increase in densities and the other method produced non-significant decrease in densities. However, for subdistrict 103-40-004, the NBE model-based method calculated a significant decrease in abundance (1.7% decrease per year), compared to the composite model-based method estimate of a significant increase of 0.8% per year. For subdistrict 107-10, the NBE model-based method calculated a non-significant increase in density (0.4% increase per year) compared to the composite model-based method estimate of a significant decrease in density (1.3% increase per year). However, exactly one-half (28) of the areas had higher trends using the composite model-based approach compared to the NBE model-based approach. The standard errors of the composite model-based trend estimates were consistently less than corresponding standard errors of the NBE model-based method.

The k values for the composite model-based estimates were consistently smaller than the corresponding k values for the NBE model-based estimates. The k value is a measure of the variability in the model and is inversely related to the variance (smaller values signify higher variance). The difference in k values is likely due to differences in the structure of the 2 different approaches. The k values for the composite model-based approach are a function of variability in both counts, and of transect abundances. The k values for the NBE model-based approach only measures variability in counts, since transect abundance is estimated individually for each transect. Logically, the k value for the composite model-based approach incorporates more variability in its value than the k value for the NBE model-based approach.

There are a number of considerations when designing a sea cucumber dive survey study, both to estimate the average density of animals in the area in multiply years, and to assess the trend in abundance. The inherent variance in densities between and within transects, the magnitude of change, the number of survey years in the study, the number of transects to be counted and counts per transect, and the allocation of survey effort between index transects and random transects. Assuming an average k value (0.96), an instantaneous rate of decrease of β = -0.04 (3.9% per year), a series of 5 surveys conducted every 3 years over a 12 year period, 2 diver counts per transect, and an average density of 18.5 animals per 2-meter transect, and a total of 20 transects, the standard error of the average density estimate and the trend estimate is a function of how many of the 20 transects are set as index transects and how many are randomly selected as a new transect site each survey year. Figure 27 portrays the change in standard error of the density and trend estimates as we allocate different number of transect sites to either index, or random transects. The largest standard error for the trend estimate is when no sites are designated as index sites (coefficient of variation of 61%) and relatively large standard errors are also predicted for density estimates at either no index sites (coefficient of variation = 18%), or all index sites (coefficient of variation = 23%). The standard errors of both trend and density estimates decreases with increasing number of index sites, from 0 to 4 index sites. The standard error continues to decrease (although not as precipitously) for the trend estimate, reaching a minimum coefficient of variation of 9% at 20 index sites, and no random sites. The standard error of the density estimate increases from 5 to 20 index sites.

Although there are changes in the absolute magnitude of expected standard errors of density and trend estimates under different assumptions, the same relationship exists between these standard errors and the allocation of sampling sites between index and random sites. Increasing the variability of counts to the upper quartile variance (k = 0.46) of the 53 areas analyzed results in increases in the standard errors of density and trend estimates, but a minimum standard error for density estimates at 4 index sites and 16 random sites, and consistently decreasing standard error of trend estimates from 0 to 20 index sites (Figure 28). Removing a trend in abundance (β =0), results in the same tendency of the standard errors (Figure 29). Decreasing the number of years of survey effort from 5 to 2 years significantly increases the variability in trend estimates, but the same relationship exists between these standard errors and the allocation of sampling sites between index and random sites (Figure 30).

COMPARISON OF SUBDISTRICTS 106-10, 20, 22 FISHED AND NON-FISHED AREAS

Survey effort was expanded in subdistricts 106-10, -20, and -22, to determine if classification of survey shoreline into areas defined by commercial fishermen as areas likely to contain commercial effort and areas likely not to be fished, would improve assessment of sea cucumber population abundance and change in abundance. Shoreline was designated as either fished or non-fished, based on observations and harvest history of several sea cucumber fishermen (Figure 31). This shoreline is generally on the east side of Etolin Island in areas sheltered from high winds and seas. Nineteen transects were established in 1995, 1998, and 2001 surveys, with 10 sites in non-fished areas and 9 in fished areas. An additional 15 transects were selected, 8 in fished areas and 7 in non-fished areas. Surveys were conducted in 2004, to provide a quota for the commercial fishery and obtain a pre-fishery assessment of sea cucumber abundance in fished and non-fished areas. In 2005, ADF&G conducted a survey to obtain a post-fishery assessment of the difference in response of fished and non-fished areas to commercial harvest (Table 27).

Survey counts from fished areas average over twice the number of sea cucumbers as non-fished areas. However, the change in counts between survey years, and from the 2004 pre-fishery survey to the 2005 post-fishery survey, was highly variable and not consistently different between fished and non-fished areas. Statistics of the change in counts and percent change (defined as count in later year minus count in earlier divided by the sum of these counts by transect) are summarized in Table 28. An average decrease of 2.3 sea cucumbers/2-meter transect per 3-year survey cycle was estimated for non-fished areas, compared to an average decrease of 5.6 sea cucumbers/2-meter transect per 3-year survey cycle for fished areas. A larger decrease between 2004 pre-fishery survey counts and 2005 post-fishery survey counts was discovered, with decreases of 10.71 and 13.83 sea cucumbers/2-meter transect respectively being estimated. Similar differences were obtained in the percent change. However, no significant differences between fished and non-fished areas were obtained using both the parametric t-test and the non-parametric Mann-Whitney U test (Sokal and Rohlf 1981; Conover 1990). The percent of transects having decreases in counts was almost identical for both comparisons between survey years (54% vs. 52% for non-fished and fished areas respectively) and between pre- and post-fishery surveys (63% vs. 65% respectively.

DISCUSSION

The predominant trends in sea cucumber populations have been for weights to increase, while densities decrease over the same time period. These trends were observed for both control areas, areas with a short history of commercial harvest, and areas with a relatively long history of harvest. No consistent differences in weights or densities were observed by geographical location. Overall, sea cucumber populations appear to be affected as much by natural events as by the commercial fishery. A number of populations have been decimated in recent times by sea otter predation (Woodby and Larson 1997). The decrease in all control areas averaged 5.8% per year, compared to an average decrease of 5.0% per year for areas subjected to commercial harvests. However, the response of individual areas was highly variable and unpredictable. The estimated trends in control areas ranged from a 1% increase in abundance per year to a 13% decrease per year. The harvested areas ranged from a 21% increase to a 39% decrease per year. There are likely a number of causative factors, including commercial fishing removals, which affect abundance in each area differently. A more detailed evaluation of sea cucumber population changes by area may help explain the increases and decreases in densities and weights, and clarify the factors responsible for these changes.

Because of the highly variable nature of abundance measurements, separating the effects of commercial fishing from environmental effects is difficult. Hsieh (2006) compared the response of exploited species and unexploited species to environmental variables by examining the abundance of early life stage in the plankton. Hsieh concluded that the long-term variability in abundance of exploited species is higher than unexploited species and this increase in variability is likely caused by fishery-induced reduction of older individuals in the population. Hsieh et al. (2005) could not detect the impact of fishing on exploited populations, but did conclude that it is more likely to detect response of unexploited populations to environmental changes than exploited populations. Schroeter et al. (2001) was able to assess the effect of fishing on the population of sea cucumbers by comparing abundances in marine reserves to corresponding abundances in fished areas using a Before-After, Control-Impact (BACI) analysis. They found that the majority of fished sites showed declines in abundance, while populations located in marine reserves showed slight increases in abundance. In the seven populations the authors analyzed using the BACI methods, they estimated declines of 33% to 83% in abundance due to fishing.

Rochet and Trenkel (2003) suggested that monitoring changes in abundance and size of individuals in the population are two of the easiest to monitor and understand indicators of the impact of fishing on a population. The expectation is clear that both abundance and size will decrease with exploitation and data is usually available. Other population indicators for assessing the effects of fishing are total mortality, proportion of total mortality caused by fishing, age at maturity, and condition indices. However, life histories of individual species result in some species responding differently to exploitation. Fishing has a greater effect on slower growing, larger species with later maturity and lower rates of potential population increase (Jennings et al. 1999).

There are several ways to design surveys and the associated analytical methods, to both estimate the current status of the population (average density and weight) and to monitor changes in abundance and size of the animals. Our survey currently uses a design-based approach, where the selection of survey sites and counting methods are carefully considered. The underlying assumption that any linear meter of shoreline has an equal chance of being selected for diver counts, and sea cucumbers in any area of sea bottom have an equal probability of being collected for weight samples, is key to obtaining unbiased estimates of average density and weight, and the precision associated with these estimates. Although the statistics of abundance estimation associated with this design are simple and can be computed quickly and with basic spreadsheet calculations, the variability of the design-based estimates are greater than either of the model-based approaches. Both model-based approaches integrate counts from past years into the analysis, to help ‘smooth’ current year counts, and provide a less-variable measurement of abundance at each transect site. There is no advantage gained by collecting information on distribution of fishing effort.

The selection of a subset of new transect locations each survey year, combined with an index set of transect sites that are sampled each survey year, can increase the precision of density estimates at a small cost to the precision of trend estimates. Selection of new sites will also reduce the likelihood of a non-representative set of transects being in the initial selection. However, a model-based approach is necessary to take full advantage of information collected from previous replacement sites, new replacement sites, and index sites. Further investigations may also improve estimation precision and survey design, including how to select the index set of transects, adoption of more complex panel approaches for index site rotation into the sampling plan, stratification of the shoreline, further development of the statistical methods to account for year to year variability, and dealing with the high occurrence of transects with no sea cucumbers (Johnson and Kotz (1969) termed this type of modified distribution as a negative binomial PDF with zeros).

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TABLES AND FIGURES

Table 1.–Summary of sea cucumber stock assessment surveys in fishing districts 101 and 102 in Southeast Alaska, 1990–2005.

Area (District and Subdistricts)	Type of Survey Area [a]	Linear Shoreline (Km)	First Year of Survey	Total Years Surveyed	Maximum Number of Transects	Average Number of Transects	Total Number of Transects	Number of Years with Weights	Average Number of Transects with Weights	Total No. of Sea Cucumbers Weighed
101-11	Harvested	154.17	1991	5	28	19.6	98	4	8.0	822
101-11-002	Harvested	111.31	2004	1	20	20.0	20	1	9.0	130
101-23	Harvested	139.64	1992	5	20	19.2	96	4	8.0	694
101-25	Harvested	65.56	2000	2	26	26.0	52	2	13.5	486
101-27 con	Control	54.09	1993	13	24	17.1	222	7	5.6	1,278
101-29	Harvested	47.87	1990	6	20	17.3	104	5	8.4	618
101-30	Insufficient	170.80	2000	1	15	15.0	15	1	9.0	114
101-41	Harvested	26.02	1999	3	12	9.3	28	3	4.0	164
101-43	Harvested	53.44	1990	6	10	9.2	55	5	5.2	569
101-44,45,46,48	Harvested	211.87	1998	3	20	20.0	55	3	10.3	470
101-53	Harvested	61.57	1990	6	10	9.0	54	5	5.6	687
101-60	Harvested	61.12	1992	1	20	20.0	20	0	0	0
101-71	Harvested	55.56	1992	1	20	20.0	20	0	0	0
101-73	Harvested	30.00	1992	1	15	15.0	15	0	0	0
101-80	Harvested	220.39	1992	5	20	19.0	95	4	9.5	713
101-85	Harvested	89.27	1990	6	16	13.7	82	5	5.8	636
101-90	Harvested	146.96	1991	6	25	20.2	121	5	8.2	950
102-10	Harvested	175.94	1992	5	20	19.2	96	5	5.6	593
102-20	Harvested	103.45	1991	5	17	16.4	82	5	6.0	755
102-30	Harvested	159.00	1990	6	17	15.5	93	5	7.4	828
102-40	Harvested	166.74	2001	2	20	20.0	40	2	10.0	409
102-50	Harvested	104.45	1992	5	19	18.4	92	5	7.0	862
102-60	Harvested	249.02	2003	1	20	20.0	20	1	10.0	150
102-70[b]	Harvested	104.07	1990	6	22	16.8	101	5	9.4	814
102-80	Harvested	43.52	1991	5	14	13.8	69	4	6.0	714

[a] **Harvested** designates areas that are opened for harvest after the survey. **Insufficient** designates areas that have low abundances of sea cucumbers and are not opened and were surveyed only once. **No Quota** designates areas that were opened for harvest historically, but last survey indicated abundances too low for commercial harvest. Discontinued designates areas surveyed multiple times, but were not surveyed in recent years. **Control** are control areas.

[b] 102-70 Surveys did not include Thorn Bay until the 1999 Survey. Linear Shoreline includes Thorn Bay.

Table 2.–Summary of sea cucumber stock assessment surveys in fishing districts 103 to 107 in Southeast Alaska, 1990–2005.

Area (District and Subdistricts)	Type of Survey Area[a/]	Linear Shoreline (Km)	First Year of Survey	Total Years Surveyed	Maximum Number of Transects	Average Number of Transects	Total Number of Transects	Number of Years with Weights	Average Number of Transects with Weights	Total No. of Sea Cucumbers Weighed
102-80	Harvested	43.52	1991	5	14	13.8	69	4	6.0	714
103-11,15	Harvested	260.74	2001	2	26	21.5	43	2	10.0	300
103-21,30	Harvested	254.31	1999	3	24	16.0	48	3	6.3	322
103-23,25	Harvested	260.74	2003	1	20	20.0	20	1	11.0	183
103-40-001[b c]	Harvested	98.30	1991	5	14	13.6	68	4	6.3	590
103-40-002	Harvested	116.66	1991	4	16	14.0	56	3	5.0	213
103-40-003 con	Control	19.15	2000	6	24	22.7	136	6	5.2	883
103-40-004	Harvested	99.00	1991	6	29	18.2	109	5	6.8	735
103-50	Harvested	171.31	1992	5	20	18.6	93	6	5.2	587
103-60 con	Control	19.15	1998	8	20	19.9	159	8	5.1	1,259
103-70	Discontinued	92.60	1993	4	15	15.0	60	3	4.0	332
103-80	Harvested	117.79	1991	5	18	18.0	90	4	6.0	557
103-90[d]	Harvested	461.98	1991	6	30	24.7	148	5	9.4	1,088
104-10,20,30	Harvested	305.02	2005	1	25	25.0	25	1	16.0	263
105-10,20	Harvested	154.17	1990	1	26	26.0	26	0	0.0	0
105-31	Insufficient	156.96	2003	1	20	20.0	20	1	5.0	111
105-32, 109-43	Harvested	305.02	2003	1	15	15.0	15	1	7.0	132
105-41,42	No Quota	130.82	1995	3	19	17.7	53	3	7.0	403
106-10,20,22	Harvested	172.14	1995	5	34	24.0	120	5	11.4	923
106-30	Harvested	229.83	1994	4	18	16.3	65	4	6.0	656
106-30 con	Control	31.52	1998	8	20	20.0	160	8	5.8	1,369
106-41	Insufficient	101.61	2004	1	16	16.0	16	1	4.0	54
106-42,108-10,20,30,40	Harvested	207.43	2002	1	19	19.0	19	1	4.0	83
107-10	Harvested	106.68	1996	4	15	15.0	60	4	7.5	648
107-20	Harvested	213.91	1996	4	15	15.0	60	4	8.0	671
107-30,35	Harvested	113.15	1999	3	20	20.0	60	3	7.3	363

[a] **Harvested** designates areas that are opened for harvest after the survey. **Insufficient** designates areas that have low abundances of sea cucumbers and are not opened and were surveyed only once. **No Quota** designates areas that were opened for harvest historically, but last survey indicated abundances too low for commercial harvest. **Discontinued** designates areas surveyed multiple times, but were not surveyed in recent years. **Control** are control areas.

[b] 103-40 was divided into 4 subareas for earlier surveys and fisheries. The area has no been combined into 1 survey and harvest area (with 1 section (reserved as a control site).

[c] **103-40-001** was one of the areas remeasured after the initial surveys. **Shoreline** is the remeasured value.

[d] 103-90 (and other areas) was increased in size from the initial surveys.

Table 3.–Summary of sea cucumber stock assessment surveys in fishing districts 108 to 113 in Southeast Alaska, 1990–2005.

Area (District and Subdistricts)	Type of Survey Area[a]	Linear Shoreline (Km)	First Year of Survey	Total Years Surveyed	Maximum Number of Transects	Average Number of Transects	Total Number of Transects	Number Of Years with Weights	Average Number of Transects with Weights	Total No. of Sea Cucumbers Weighed
108-10,20	Harvested	82.27	2005	1	17	17.0	17	1	7.0	106
109-10,11,13	Harvested	99.77	2002	2	14	14.0	28	2	6.0	175
109-30	Insufficient	87.38	2000	1	15	15.0	15	1	6.0	87
109-44,45,50	Harvested	80.93	1994	1	14	14.0	14	1	3.0	111
109-62	No Quota	221.68	1992	5	20	20.0	100	3	5.7	379
110-21,22,24	Insufficient	141.40	1997	1	16	16.0	16	1	9.0	133
111-50	Harvested	154.25	2004	1	20	20.0	20	1	5.0	80
112-11,21	Harvested	124.27	1991	5	15	14.4	72	4	7.0	673
112-12,13,50	Harvested	131.43	2001	2	20	20.0	40	2	10.0	288
112-15	Insufficient	31.40	2005	1	20	20.0	20	1	8.0	118
112-15,61 114-25	Harvested	57.33	2004	1	20	20.0	20	1	7.0	105
112-16,17,63,65	Harvested	141.43	2002	2	25	25.0	50	2	11.0	420
112-18,19,80,90	Harvested	65.38	1992	5	20	19.6	98	4	8.0	599
112-22 con	Control	14.11	2000	1	20	20.0	20	1	4.0	154
112-41,42	Harvested	51.97	1997	3	15	12.3	37	3	9.3	656
112-	Harvested	121.80	1997	3	15	14.7	44	3	7.3	490
113-31	Harvested	141.12	1990	6	11	10.8	65	5	4.2	521
113-32	Harvested	47.95	1990	6	11	9.3	56	5	6.6	623
113-33	Harvested	81.49	1990	6	9	8.0	48	5	4.2	457
113-34	Harvested	56.95	1993	1	8	8.0	8	1	1.0	41
113-40 con	Control	0.00	2003	3	20	20.0	60	3	4.0	320
113-41-001,38	Harvested	101.30	1990	6	16	13.7	82	5	5.2	558
113-41-002 con	Control	23.18	2000	3	20	20.0	60	3	3.7	366
113-41-003,42,43 [b]	Discontinued	145.00	1992	4	19	16.8	67	4	8.5	548
113-51,52,53,54,59	Harvested	157.88	1990	6	17	15.7	94	5	8.0	874
113-55,56,57,58[/2]	Harvested	153.16	1992	5	20	19.6	98	4	7.5	498
113-62,63,64,65,66	Harvested	137.34	1991	5	30	20.8	104	4	6.3	623
113-71,72,73	Discontinued	133.34	1991	2	20	17.5	35	1	2.0	110

[a] **Harvested** designates areas that are opened for harvest after the survey. **Insufficient** designates areas that have low abundances of sea cucumbers and are not opened and were surveyed only once. **No Quota** designates areas that were opened for harvest historically, but last survey indicated abundances too low for commercial harvest. **Discontinued** designates areas surveyed multiple times, but were not surveyed in recent years. **Control** are control areas.

[b] 113-41-003, as well as subdistricts 113-42, -43, -55, -56, -57, -58 were remeasured after initial surveys. Shoreline is the remeasured value.

Table 4.–Summary of sea cucumber stock assessment surveys in fishing districts 114, 115, and in the Yakutat area, in Southeast Alaska, as well as totals and averages for all Southeast Alaska areas surveyed, 1990–2005.

Area (District and Subdistricts)	Type of Survey Area [a]	Linear Shoreline (Km)	First Year of Survey	Total Years Surveyed	Maximum Number of Transects	Average Number of Transects	Total Number of Transects	Number Of Years with Weights	Average Number of Transects with Weights	Total Number of Sea Cucumbers Weighed
114-25,80	Harvested	72.28	2005	1	20	20.0	20	1	10.0	149
114-27	Insufficient	62.39	2004	1	20	20.0	20	1	5.0	83
114-27,24,31,32,33,34	Insufficient	191.42	1990	1	15	15.0	15	0	0.0	0
115-10,20	Insufficient	88.74	2004	1	19	19.0	19	1	4.0	59
Yakutat	Insufficient	127.42	2005	1	61	61.0	61	1	16.0	239
Average		**124.50**	**—**	**4**	**19**	**18.0**		**3.0**	**6.6**	**444**
Total		**10,333.58**	**—**	**—**	**1,610**	**1,498**	**4,997**	**—**	**550**	**36,824**

[a] **Harvested** designates areas that are opened for harvest after the survey. **Insufficient** designates areas that have low abundances of sea cucumbers and are not opened and were surveyed only once.

Table 5.–Summary of commercial harvest of sea cucumbers in fishing districts 101 to 109, in Southeast Alaska, from prior to 1990/91, and 1990/91 to 2005/06.

Area (District and Subdistricts)	Total Harvest (in lbs) Prior to 1990/91 Season	Total Harvest (in lbs) from 1990/91 to 2005/06	Years Opened to Harvest From 1990/91 To 2005/06	First Year of Harvest during 1990/91 to 2005/06	Pounds Harvested per Year Opened
101-11	0	691,445	6	1991	115,241
101-23	167,218	944,378	5	1992	188,876
101-25	0	222,072	2	2000	111,036
101-29	301,264	168,329	3	1999	56,110
101-41	41,895	131,290	3	1999	43,763
101-43	26,738	114,515	6	1990	19,086
101-44,45,46,48	174,713	280,563	3	1998	93,521
101-53	0	80,737	5	1990	16,147
101-60	0	19,887	1	1992	19,887
101-71	0	7,394	1	1992	7,394
101-73	0	4,399	1	1992	4,399
101-80	48,514	248,964	4	1992	62,241
101-85	1,323	175,339	6	1990	29,223
101-90	117,397	431,613	5	1991	86,323
102-10	132,081	447,810	5	1992	89,562
102-20	0	409,592	6	1990	68,265
102-30	14,795	873,047	6	1990	145,508
102-40	0	407,996	2	2001	203,998
102-50	115,300	405,827	5	1992	81,165
102-60	0	347,738	2	1994	173,869
102-70	0	304,888	6	1990	50,815
102-80	0	121,823	5	1991	24,365
103-11,15	0	238,548	2	2001	119,274
103-21,30	0	441,561	2	2000	220,781
103-23,25	0	215,285	1	2003	215,285
103-40	0	1,286,250	9	1990	142,917
103-50	0	421,735	5	1992	84,347
103-70	1,850	93,118	3	1993	31,039
103-80	0	446,222	5	1991	89,244
103-90	404,236	1,182,339	4	1996	295,585
104-10,20,30	0	115,312	1	2005	115,312
105-10,20	600	20,896	2	1990	10,448
105-32, 109-43	6,075	28,812	1	2003	28,812
105-41,42	106,323	129,822	2	1995	64,911
106-10,20,22	52,187	911,539	4	1995	227,885
106-30	0	1,341,144	4	1994	335,286
106-42,108-10,20,30,40	3,906	44,874	2	2002	22,437
107-10	15,067	384,289	4	1996	96,072
107-20	0	347,406	4	1996	86,852
107-30,35	0	155,765	3	1999	51,922
109-10,11,13	0	34,214	2	2002	17,107
109-44,45,50	0	17,778	1	1994	17,778
109-62	49,634	437,216	4	1992	109,304

Table 6.–Summary of commercial harvest of sea cucumbers in fishing districts 110 to 114, in Southeast Alaska, from prior to 1990/91, and 1990/91 to 2005/006, as well as total harvests, and average years opened, and average pounds harvested per year opened.

Area (District and Subdistricts)	**Total Harvest (in lbs) Prior to 1990/91 Season**	**Total Harvest (in lbs) from 1990/91 to 2005/06**	**Years Opened to Harvest From 1990/91 To 2005/06**	**First Year of Harvest during 1990/91 to 2005/06**	**Pounds Harvested per Year Opened**
110-21,22,24	2,400	0	0	na	na
111-50	45	22,445	1	2004	22,445
112-11,21	27,377	360,309	5	1991	72,062
112-12,13,50	4,491	216,677	2	2001	108,339
112-15,61 114-25	0	13,848	1	2004	13,848
112-16,17,63,65	0	167,075	2	2002	83,538
112-18,19,80,90	2,868	135,814	5	1992	27,163
112-41,42	2,493	117,640	3	1997	39,213
112-43,44,45,46,47,48	25,011	199,459	3	1997	66,486
113-31	223,965	628,976	6	1990	104,829
113-32	13,548	58,715	5	1990	11,743
113-33	0	104,001	6	1990	17,334
113-34	5,829	13,512	1	1993	13,512
113-41-001,38	136,000	298,539	6	1990	49,757
113-41-003,42,43	515,566	578,245	5	1992	115,649
113-51,52,53,54,59	114,601	832,457	6	1990	138,743
113-55,56,57,58	67,109	388,228	5	1992	77,646
113-62,63,64,65,66	109,832	206,078	4	1991	51,520
113-71,72,73	28,483	73,421	2	1991	36,711
114-25,80	0	36,163	2	2004	18,082
Other	158,365	16,298	na	na	na
Total	**3,219,099**	**19,601,671**	—	—	—
Average	—	—	**3.6**	—	**82,936**

Table 7.–Summary of statistics concerning weight data collected in sea cucumber stock assessment surveys within district 101 in Southeast Alaska.

Area (District and Subdistrict)	Total Years with Weight Measures	Number of Transects w/ Weight Measures	Number of Transects/ Years w/ Weight Measures	Average Number of Sea Cucumbers Weighed per Transect Sampled	Overall Mean Weight	Average Variance of Individual Weights	Estimated Mean Square Error Within Transects	Estimated Mean Square Error Between Transects	Average Coefficient of Variation of Average Weight
101-11	4	16	32	28.3	207.9	3,947	3,432	4,903	13.8%
101-11-002	1	9	9	15.1	205.8	2,555	2,582	322	3.6%
101-23	4	10	32	23.4	214.1	3,025	2,957	1,734	7.0%
101-25	2	17	27	19.1	243.1	3,627	3,403	3,019	6.2%
101-27 con	7	9	39	35.9	241.4	3,235	3,307	1,866	7.6%
101-29	5	9	42	15.4	199.6	2,947	2,927	4,126	11.0%
101-30	1	9	9	13.3	163.8	2,582	1,532	2,439	15.5%
101-41	3	5	10	14.0	156.8	2,072	2,341	918	9.5%
101-43	5	7	26	23.5	178.1	2,894	2,812	1,354	9.9%
101-44,45,46,48	3	11	31	16.1	149.6	1,661	1,624	1,522	8.3%
101-53	5	7	28	28.9	114.0	1,388	1,369	1,467	13.0%
101-60	0	0	0	———	———	No Weight Data Taken		———	———
101-71	0	0	0	———	———	No Weight Data Taken		———	———
101-73	0	0	0	———	———	No Weight Data Taken		———	———
101-80	4	12	38	20.0	172.6	3,380	3,252	2,385	9.4%
101-85	5	7	29	24.0	184.4	2,609	2,742	2,758	12.8%
101-90	5	16	41	27.1	140.5	2,002	1,844	2,812	16.3%

Note: **Overall mean weight** is the average of transect and year mean weights in an area. **Average variance of individual weights** is the average of transect and year variance in weights, and provides a measure of variation in weights between individual sea cucumbers. **Average variance of transect mean weights** is the variance of means of transect weights averaged across years. The estimated variance of mean weights is the Average Variance of Transect Mean Weights minus the average of individual weight variance divided by sample size. **Average coefficient of variation of average weight** is a function of variability of average weights between transects and the number of transects sampled and is the quantity used in the estimate of overall precision of biomass.

Table 8.–Summary of statistics concerning weight data collected in sea cucumber stock assessment surveys within districts 102 to 104 in Southeast Alaska.

Area (District and Subdistrict)	Total Years with Weight Measures	Number of Transects w/ Weight Measures	Number of Transects/ Years w/ Weight Measures	Average Number of Sea Cucumbers Weighed per Transect Sampled	Overall Mean Weight	Average Variance of Individual Weights	Estimated Mean Square Error Within Transects	Estimated Mean Square Error Between Transects	Average Coefficient of Variation of Average Weight
102-10	5	9	28	22.9	234.6	3,599	3,316	2,033	8.6%
102-20	5	10	30	27.6	183.4	3,367	3,274	997	8.0%
102-30	5	10	37	24.4	179.9	2,580	2,474	2,052	9.3%
102-40	2	10	20	22.3	221.1	2,959	2,926	4,221	9.5%
102-50	5	12	35	27.5	174.0	3,054	3,182	3,044	13.8%
102-60	1	10	10	15.7	251.6	4,122	3,995	8,275	11.9%
102-70	5	13	47	18.6	214.9	3,280	3,337	3,486	9.9%
102-80	4	8	24	34.2	122.7	2,168	2,294	1,778	14.7%
103-11,15	2	10	20	15.5	228.0	4,221	4,125	1,919	6.5%
103-21,30	3	9	19	18.0	242.0	5,044	5,318	6,343	13.8%
103-23,25	1	11	11	17.3	257.7	5,590	5,601	9,420	11.2%
103-40-001	4	8	25	26.6	199.3	3,139	2,993	2,202	9.7%
103-40-002	3	6	15	15.0	231.0	3,069	2,965	3,785	11.7%
103-40-003 con	6	6	31	31.6	254.2	3,783	3,323	2,189	10.3%
103-40-004	5	9	34	23.7	237.1	3,499	2,880	3,005	11.3%
103-50	6	10	31	19.9	212.5	4,084	3,850	3,037	9.7%
103-60 con	8	6	41	34.7	227.8	2,233	2,225	827	5.5%
103-70	3	5	12	31.0	218.5	3,078	2,893	347	4.6%
103-80	4	8	24	25.0	263.8	5,450	5,108	3,299	9.2%
103-90	5	16	47	25.1	240.1	3,654	3,600	1,032	4.6%
104-10,20,30	1	16	16	17.0	247.4	6,293	6,302	3,188	6.3%

Note: **Overall mean weight** is the average of transect and year mean weights in an area. **Average variance of individual weights** is the average of transect and year variance in weights, and provides a measure of variation in weights between individual sea cucumbers. **Average variance of transect mean weights** is the variance of means of transect weights averaged across years. The estimated variance of mean weights is the Average Variance of Transect Mean Weights minus the average of individual weight variance divided by sample size. Average **coefficient of variation of average weigh**t is a function of variability of average weights between transects and the number of transects sampled and is the quantity used in the estimate of overall precision of biomass.

Table 9.–Summary of statistics concerning weight data collected in sea cucumber stock assessment surveys within districts 105 to 111 in Southeast Alaska.

Area (District and Subdistrict)	Total Years with Weight Measures	Number of Transects w/ Weight Measures	Number of Transects/ Years w/ Weight Measures	Average Number of Sea Cucumbers Weighed per Transect Sampled	Overall Mean Weight	Average Variance of Individual Weights	Estimated Mean Square Error Within Transects	Estimated Mean Square Error Between Transects	Average Coefficient of Variation of Average Weight
105-10,20	0	0	0			No Weight Data Taken			
105-31	1	5	5	23.0	266.7	4,813	4,410	2,409	9.5%
105-32, 109-43	1	7	7	19.9	360.9	6,815	6,189	918	3.8%
105-41,42	4	10	23	19.6	222.4	5,092	5,222	5,530	12.4%
106-10,20,22	5	16	57	17.1	234.4	3,683	3,254	4,191	8.8%
106-30	4	9	24	32.2	191.6	2,887	2,431	2,541	11.7%
106-30 con	8	6	46	31.9	291.1	5,523	5,572	5,477	10.7%
106-41	1	4	4	14.0	285.8	6,051	6,435	2,028	9.7%
106-42,108-10,20,30,40	2	7	11	17.6	163.1	1,821	1,880	2,340	11.3%
107-10	4	10	30	24.8	161.7	1,845	1,695	5,333	17.1%
107-20	4	10	32	22.9	150.3	2,469	2,444	1,487	10.0%
107-30,35	3	8	22	17.0	251.7	5,936	5,354	3,348	9.5%
108-10,20	0	0	0			No Weight Data Taken			
109-10,11,13	2	6	12	15.8	175.3	2,910	3,026	1,957	11.1%
109-30	1	6	6	15.3	228.8	4,258	4,105	934	6.0%
109-44,45,50	1	3	3	39.0	271.5	7,896	8,425	158	4.6%
109-62	3	8	17	24.8	166.3	1,911	1,919	1,156	11.0%
110-21,22,24	1	9	9	15.6	251.4	3,425	3,600	1,547	6.2%
111-50	1	5	5	17.2	215.7	2,962	2,865	775	6.5%

Note: **Overall mean weight** is the average of transect and year mean weights in an area. **Average variance of individual weights** is the average of transect and year variance in weights, and provides a measure of variation in weights between individual sea cucumbers. **Average variance of transect mean weights** is the variance of means of transect weights averaged across years. The estimated variance of mean weights is the Average Variance of Transect Mean Weights minus the average of individual weight variance divided by sample size. **Average coefficient of variation of average weight** is a function of variability of average weights between transects and the number of transects sampled and is the quantity used in the estimate of overall precision of biomass.

Table 10.–Summary of statistics concerning weight data collected in sea cucumber stock assessment surveys within districts 112 to 115 and Yakutat fishing area in Southeast Alaska, as well as averages for all fishing areas surveyed.

Area (District and Subdistrict)	Total Years with Weight Measures	Number of Transects w/ Weight Measures	Number of Transects/ Years w/ Weight Measures	Average Number of Sea Cucumbers Weighed Per Transect Sampled	Overall Mean Weight	Average Variance of Individual Weights	Estimated Mean Square Error Within Transects	Estimated Mean Square Error Between Transects	Average Coefficient of Variation of Average Weight
112-11,21	4	10	28	26.4	206.2	3,347	3,110	365	3.8%
112-12,13,50	2	3	3	15.2	187.4	1,422	1,368	1,461	6.6%
112-15	1	2	2	15.4	195.5	1,655	1,633	455	4.5%
112-16,17,63,65	2	3	3	20.8	184.5	1,944	2,003	1,037	5.4%
112-18,19,80,90	4	5	5	19.8	239.3	3,669	3,554	1,908	6.7%
112-22 con	1	2	2	41.3	212.1	2,385	2,391	1,182	8.3%
112-41,42	3	4	4	25.2	192.8	2,167	1,925	1,966	8.7%
112-43,44,45,46,47,48	3	4	4	24.1	222.9	2,067	1,924	1,054	6.2%
112-61 114-25	1	2	2	15.1	234.4	2,858	2,913	992	5.8%
113-31	5	6	5	27.5	217.5	3,493	3,149	3,620	13.4%
113-32	5	8	33	19.8	218.1	4,942	5,215	1,030	6.3%
113-33	5	5	21	23.0	220.1	4,545	4,597	915	7.4%
113-34	1	1	1	45.0	234.8	5,752	5,752	— Only 1 Sample Taken —	
113-40 con	3	4	12	29.8	211.7	2,571	2,567	520	5.6%
113-41-001,38	5	7	26	23.4	230.3	3,825	3,538	1,468	6.6%
113-41-002 con	3	4	11	37.7	228.7	2,155	2,204	406	4.8%
113-41-003,42,43	4	12	34	17.1	227.8	3,331	3,492	3,019	7.9%
113-51,52,53,54,59	5	12	40	24.6	197.4	2,996	2,683	1,119	6.7%
113-55,56,57,58	4	9	30	17.8	195.7	2,053	2,104	1,591	7.7%
113-62,63,64,65,66	4	9	25	28.1	215.4	3,078	2,668	2,991	12.8%
113-71,72,73	1	2	2	77.5	188.4	1,464	1,489	51	3.1%
114-25,80	1	10	10	15.7	221.7	2,937	2,914	236	3.0%
114-27	1	5	5	16.8	218.6	3,923	3,943	2,326	10.3%
114-27,24,31,32,33,34	0	0	0			No Weight Data Taken			
115-10,20	1	4	4	15.5	189.9	2,840	2,717	76	4.3%
Yakutat	1	16	16	15.7	215.5	2,475	2,359	2,456	5.8%
Average	**3.0**	**7.5**	**19.2**	**23.4**	**213.1**	**3,382**	**3,288**	**2,269**	**8.8%**

Note: **Overall mean weight** is the average of transect and year mean weights in an area. **Average variance of individual weights** is the average of transect and year variance in weights, and provides a measure of variation in weights between individual sea cucumbers. **Average variance of transect mean weights** is the variance of means of transect weights averaged across years. The estimated variance of mean weights is the Average Variance of Transect Mean Weights minus the average of individual weight variance divided by sample size. **Average coefficient of variation of average weight** is a function of variability of average weights between transects and the number of transects sampled and is the quantity used in the estimate of overall precision of biomass.

Table 11.– Summary of analysis of weight data in districts 101 and 102. Annual change is estimated from first to last year of survey (a positive change is a gain in weight). A probability of 0.05 or less designates significant change. Estimate weights in first year of survey are estimated as the average weight in last survey year plus the estimated change in weight to the first year of the survey using ANCOVA results.

Area (District And Subdistricts	Total Years w/ Weight Measures	No. of Transects w/ Weight Measures	Estimated Annual Change (gm/yr)	Significance of Slope		ANCOVA Estimates		Sample Estimates		Avg.Weight in 1st Survey Year Using ANCOVA Estimates
						Avg. Weight (Last Survey Year)	Std. Error of Avg. Weight	Avg. Weight (Last Survey Year)	Std. Error of Avg. Weight	
101-11	4	17	3.63	<.0001	Sig. Inc.	233.3	17.2	209.5	25.9	200.7
101-11-002	1	9	—— Only 1 year of weight data ——			205.8	—	205.8	7.5	205.8
101-23	4	12	2.19	0.0022	Sig. Inc.	229.9	12.3	213.6	11.0	210.2
101-25	2	17	-0.15	0.9449	NS	248.2	15.7	248.4	16.7	248.6
101-27 con	7	5	-0.14	0.8460	NS	240.2	14.9	250.1	12.2	241.0
101-29	5	9	1.49	0.1578	NS	202.8	19.5	215.0	21.5	185.0
101-30	1	9	—— Only 1 year of weight data ——			163.8	—	163.8	25.4	163.8
101-41	3	6	8.52	0.0006	Sig. Inc.	181.4	11.5	178.1	18.5	130.3
101-43	5	10	0.57	0.4664	NS	193.4	15.7	125.4	11.3	186.5
101-44,45,46,48	3	11	2.75	0.0002	Sig. Inc.	156.8	11.2	158.2	15.1	140.3
101-53	5	7	1.12	0.0012	Sig. Inc.	121.5	11.4	115.0	11.1	108.1
101-60	0	0	—— No Weight Data ——							
101-71	0	0	—— No Weight Data ——							
101-73	0	0	—— No Weight Data ——							
101-80	4	14	0.39	0.6314	NS	178.4	11.3	190.2	16.6	174.9
101-85	5	8	2.60	<.0001	Sig. Inc.	187.9	19.0	179.3	24.7	156.6
101-90	5	20	-0.01	0.9755	NS	137.5	8.4	143.3	12.5	137.7
102-10	5	12	4.99	<.0001	Sig. Inc.	257.7	17.3	244.2	21.3	197.8
102-20	5	11	-0.25	0.7279	NS	185.0	8.8	196.3	27.9	188.0
102-30	5	11	0.18	0.7136	NS	181.4	9.8	172.6	9.8	179.2
102-40	2	10	-1.50	0.3381	NS	219.4	21.5	221.3	24.7	223.9
102-50	5	14	0.49	0.4566	NS	172.8	15.0	195.3	23.7	167.0
102-60	1	10	—— Only 1 year of weight data ——			251.6	—	251.6	29.9	251.6
102-70	5	16	0.44	0.5820	NS	209.3	14.4	203.6	22.7	204.1
102-80	4	10	6.57	<.0001	Sig. Inc.	135.5	11.6	144.0	21.7	76.4

Note: Significance of trends is at the $P < .05$ probability with **Sig. Dec.**, **NS**, and **Sig. Inc**. meaning significant decrease, nonsignificant and significant increase, respectively.

Table 12.–Summary of analysis of weight data taken in districts 103 to 108 (and 109-43). Annual change is estimated from first to last year of survey (a positive change is a gain in weight). A probability of 0.05 or less designates significant change. Estimate weights in first year of survey are estimated as the average weight in last survey year plus the estimated change in weight to the first year of the survey using ANCOVA results.

						ANCOVA Estimates		Sample Estimates		
Area (District And Subdistricts	**Total Years w/ Weight Measures**	**No. of Transects w/ Weight Measures**	**Estimated Annual Change (gm/yr)**	**Significance of Slope**		**Avg. Weight (Last Survey Year)**	**Std. Error of Avg. Weight**	**Avg. Weight (Last Survey Year)**	**Std. Error of Avg. Weight**	**Avg.Weight in 1st Survey Year Using ANCOVA Estimates**
103-11,15	2	13	-2.40	0.4040	NS	219.7	12.7	219.9	16.3	226.9
103-21,30	3	10	-5.43	0.0065	Sig. Dec.	243.4	30.2	219.5	18.8	276.0
103-23,25	1	11	—— Only 1 year of weight data ——			257.7	—	257.7	28.9	257.7
103-40-001	4	18	-1.76	0.0699	NS	212.7	16.8	264.6	19.9	228.5
103-40-002	3	6	2.27	0.1199	NS	253.8	28.1	222.6	32.3	240.1
103-40-003 contr.	6	6	-4.12	0.0021	Sig. Dec.	230.5	6.9	266.0	16.3	251.1
103-40-004	5	17	-0.28	0.6606	NS	248.2	17.5	220.9	24.0	251.6
103-50	6	14	0.65	0.5492	NS	217.7	16.7	194.8	8.0	207.9
103-60 control	8	6	1.46	0.0202	Sig. Inc.	232.0	10.3	230.3	17.9	221.8
103-70	3	5	3.79	0.0045	Sig. Inc.	233.3	10.2	216.9	6.6	210.5
103-80	4	9	0.19	0.8532	NS	264.9	21.8	268.9	27.0	263.2
103-90	5	19	-0.28	0.6842	NS	238.0	9.2	256.4	9.4	241.4
104-10,20,30	1	16	—— Only 1 year of weight data ——			247.4		247.4	15.6	247.4
105-10,20	0	0	—— No Weight Data ——							
105-31	1	5	—— Only 1 year of weight data ——			266.7	—	266.7	25.2	266.7
105-32, 109-43	1	7	—— Only 1 year of weight data ——			360.9	—	360.9	13.7	360.9
105-41,42	4	12	-11.29	<.0001	Sig. Dec.	150.0	21.2	215.6	1.8	251.7
106-10,20,22	5	19	3.14	<.0001	Sig. Inc.	238.7	13.3	238.9	15.7	201.1
106-30	4	11	2.53	0.0004	Sig. Inc.	213.2	17.9	208.8	20.9	190.4
106-30 control	8	7	10.40	<.0001	Sig. Inc.	319.4	21.3	311.6	26.5	246.6
106-41	1	4	—— Only 1 year of weight data ——			285.9	—	285.9	27.8	285.9
106-42,108-10,20,30,40	2	8	-5.66	0.0479	Sig. Dec.	162.9	22.9	169.1	25.2	179.9
107-10	4	10	-1.30	0.0092	Sig. Dec.	161.6	23.1	180.0	25.6	173.4
107-20	4	11	4.51	<.0001	Sig. Inc.	167.6	11.9	153.3	12.6	127.1
107-30,35	3	11	1.47	0.4408	NS	248.2	19.0	244.6	19.4	239.3
108-10,20	0	0	—— No Weight Data ——							

Note: Significance of trends is at the P < .05 probability with **Sig. Dec**., **NS**, and **Sig. Inc**. meaning significant decrease, nonsignificant and significant increase, respectively.

Table 13.–Summary of analysis of weight data taken in districts 109 to 112 (and 114-25). Annual change is estimated from first to last year of survey (a positive change is a gain in weight). A probability of 0.05 or less designates significant change. Estimate weights in first year of survey are estimated as the average weight in last survey year plus the estimated change in weight to the first year of the survey using ANCOVA results.

Area (District And Subdistricts	Total Years w/ Weight Measures	No. of Transects w/ Weight Measures	Estimated Annual Change (gm/yr)	Significance of Slope		ANCOVA Estimates: Avg. Weight (Last Survey Year)	ANCOVA Estimates: Std. Error of Avg. Weight	Sample Estimates: Avg. Weight (Last Survey Year)	Sample Estimates: Std. Error of Avg. Weight	Avg.Weight in 1st Survey Year Using ANCOVA Estimates
109-10,11,13	2	8	9.19	0.0063	Sig. Inc.	183.6	16.7	197.7	21.8	156.1
109-30	1	6	—— Only 1 year of weight data ——			228.8	—	228.8	12.4	228.8
109-44,45,50	1	3	—— Only 1 year of weight data ——			271.5	—	271.5	24.7	271.5
109-62	3	8	0.19	0.8817	NS	174.8	12.7	152.9	24.7	173.7
110-21,22,24	1	9	—— Only 1 year of weight data ——			251.4	—	251.4	14.0	251.4
111-50	1	5	—— Only 1 year of weight data ——			215.7	—	215.7	14.0	215.7
112-11,21	4	14	1.32	0.0909	NS	217.0	6.3	223.5	9.4	205.1
112-12,13,50	2	10	3.09	0.0312	Sig. Inc.	191.9	12.2	194.0	14.3	182.6
112-15	1	2	—— Only 1 year of weight data ——			195.6	—	195.6	8.8	195.6
112-16,17,63,65	2	14	9.17	<.0001	Sig. Inc.	198.3	7.4	200.9	12.8	170.8
112-18,19,80,90	4	12	6.21	<.0001	Sig. Inc.	260.2	14.1	263.0	19.0	204.3
112-22 control	1	2	—— Only 1 year of weight data ——			212.1	—	212.1	17.5	212.1
112-41,42	3	13	8.37	<.0001	Sig. Inc.	224.0	15.5	229.5	20.6	173.8
112-43,44,45,46,47,48	3	10	7.20	<.0001	Sig. Inc.	252.7	12.1	244.9	9.6	209.5
112-61 114-25	1	2	—— Only 1 year of weight data ——			234.4	—	234.4	13.5	234.4

Note: Significance of trends is at the P < .05 probability with **Sig. Dec**., **NS**, and **Sig. Inc**. meaning significant decrease, nonsignificant and significant increase, respectively.

Table 14.–Summary of analysis of weight data taken in districts 113, 114, 115, and the Yakutat area, as well as averages for all districts sampled in Southeast Alaska. Annual change is estimated from first to last year of survey (a positive change is a gain in weight). A probability of 0.05 or less designates significant change. Estimate weights in first year of survey are estimated as the average weight in last survey year plus the estimated change in weight to the first year of the survey using ANCOVA results.

Area (District And Subdistricts	Total Years w/ Weight Measures	No. of Transects w/ Weight Measures	Estimated Annual Change (gm/yr)	Significance of Slope		ANCOVA Estimates		Sample Estimates		Avg.Weight in 1st Survey Year Using ANCOVA Estimates
						Avg. Weight (Last Survey Year)	Std. Error of Avg. Weight	Avg. Weight (Last Survey Year)	Std. Error of Avg. Weight	
113-31	5	8	-2.73	<.0001	Sig. Dec.	210.6	18.1	240.3	40.1	243.4
113-32	5	12	-1.87	0.0297	Sig. Dec.	218.9	13.4	243.9	17.0	241.4
113-33	5	7	2.79	0.0022	Sig. Inc.	237.5	11.6	271.8	16.1	204.1
113-34	1	1	—— Only 1 year of weight data ——			234.8	—	234.8	—	234.8
113-40 con	3	4	0.91	0.7819	NS	212.8	10.5	211.9	13.4	207.3
113-41-001,38	5	10	2.30	0.0086	Sig. Inc.	234.3	9.4	224.2	11.5	206.8
113-41-002 con	3	4	-3.57	0.2098	NS	225.7	6.5	222.5	12.2	232.8
113-41-003,42,43	4	14	2.85	0.0073	Sig. Inc.	237.8	14.7	229.5	18.8	212.1
113-51,52,53,54,59	5	12	3.24	<.0001	Sig. Inc.	212.6	9.6	210.1	13.9	173.7
113-55,56,57,58	4	12	3.43	<.0001	Sig. Inc.	210.7	11.0	213.2	15.1	179.8
113-62,63,64,65,66	4	11	3.25	<.0001	Sig. Inc.	234.2	18.9	245.8	25.4	204.9
113-71,72,73	1	2	—— Only 1 year of weight data ——			188.4	—	188.4	5.9	188.4
114-25,80	1	10	—— Only 1 year of weight data ——			221.7	—	221.7	6.6	221.7
114-27	1	5	—— Only 1 year of weight data ——			218.6	—	218.6	22.4	218.6
114-27,24,31,32,33,34	0	0	—— No Weight Data ——							
115-10,20	1	4	—— Only 1 year of weight data ——			189.9	—	189.9	8.2	189.9
Yakutat	1	16	—— Only 1 year of weight data ——			215.5	—	215.5	12.5	215.5
Average	—	—	**1.56**			**218.0**	**14.6**	**218.8**	**17.7**	**208.9**

Note: Significance of trends is at the P < .05 probability with **Sig. Dec.**, **NS**, and **Sig. Inc**. meaning significant decrease, nonsignificant and significant increase, respectively.

Table 15.–Estimated average density of sea cucumbers per 2-meter transect in districts 101 and 102 of Southeast Alaska survey areas using the design-based estimates currently employed in data analysis and using the negative binomial model estimates. Estimates of trends in abundance, associated standard error and statistical significance of these trends, and estimates of the k parameter are also obtained from the negative binomial model.

				Density-Based Est., Last Survey Year		**Negative Binomial Model-Based Results, Last Survey Year**						
Area (District and Subdistricts)	**Type of Survey**	**Years Surveyed First**	**Last**	**Avg. No. Animals per 2-m Transect**	**Std. Err. of Avg. No. of Animals**	**Statistic. Model Avg. Density**	**Std. Err. of Avg. Density**	**Trend in Abundance**	**Std. Err. of Change**	**Significance of Change In Est.** [1/]	**Est. K Value**	**Std. Err. of K Value**
101-11	Harvested	1991	2003	19.36	4.88	22.68	3.82	-0.0250	0.0097	Sig. Dec	3.90	0.54
101-11-002	Harvested	2004	2004	21.70	8.87				No Weight Data			
101-23	Harvested	1992	2004	32.45	7.93	34.49	7.44	-0.0455	0.0103	Sig. Dec	3.47	0.44
101-25	Harvested	2000	2003	48.67	13.90	49.52	13.80	-0.0188	0.0349	NS	5.29	1.10
101-27 con	Control	1993	2005	28.54	7.29	25.96	4.60	-0.0341	0.0076	Sig. Dec	4.23	0.36
101-29	Harvested	1990	2005	23.23	5.09	23.15	4.28	-0.0802	0.0216	Sig. Dec	1.53	0.16
101-30	Insufficient	2000	2000	10.30	2.46				No Weight Data			
101-41	Harvested	1999	2005	24.73	7.16	21.53	4.67	-0.0477	0.0312	NS	5.15	1.30
101-43	Harvested	1990	2005	8.30	2.35	8.31	2.17	-0.0448	0.0185	Sig. Dec	1.87	0.36
101-44,45,46,48	Harvested	1998	2004	18.77	3.06	22.53	3.17	0.0622	0.0220	Sig. Inc.	4.56	0.82
101-53	Harvested	1990	2005	23.39	3.63	23.07	3.59	0.0208	0.0165	NS	1.64	0.25
101-60	Harvested	1992	1992	10.98	1.93				No Weight Data			
101-71	Harvested	1992	1992	7.53	1.28				No Weight Data			
101-73	Harvested	1992	1992	6.57	1.68				No Weight Data			
101-80	Harvested	1992	2004	10.16	2.20	9.36	1.59	-0.0014	0.0138	NS	2.22	0.35
101-85	Harvested	1990	2005	10.59	3.01	11.41	2.49	-0.0169	0.0141	NS	1.86	0.29
101-90	Harvested	1991	2003	28.86	5.01	26.19	2.88	-0.0165	0.0072	Sig. Dec	6.01	0.73
102-10	Harvested	1992	2004	10.90	3.40	10.41	2.86	-0.0655	0.0108	Sig. Dec	3.25	0.53
102-20	Harvested	1991	2003	25.65	5.50	20.13	3.86	-0.0470	0.0124	Sig. Dec	2.89	0.42
102-30	Harvested	1990	2005	21.94	3.29	27.41	2.52	-0.0061	0.0093	NS	3.06	0.36
102-40	Harvested	2001	2004	34.10	6.47	32.67	4.92	-0.0284	0.0341	NS	6.47	1.39
102-50	Harvested	1992	2004	31.47	7.23	32.71	6.67	0.0383	0.0136	Sig. Inc.	2.13	0.26
102-60	Harvested	2003	2003	38.10	6.83				No Weight Data			
102-70	Harvested	1990	2004	18.12	3.66	18.47	2.66	-0.0118	0.0110	NS	2.27	0.27
102-80	Harvested	1991	2003	27.89	6.43	29.87	5.81	-0.0329	0.0146	Sig. Dec	2.17	0.29

Note: Significance of trends is at the P < .05 probability with **Sig. Dec.**, **NS**, and **Sig. Inc.** meaning significant decrease, nonsignificant and significant increase, respectively.

Table 16.–Estimated average density of sea cucumbers per 2-meter transect in districts 103 to 107 in Southeast Alaska survey areas using the design-based estimates currently employed in data analysis and using the negative binomial model estimates. Estimates of trends in abundance, associated standard error and statistical significance of these trends, and estimates of the k parameter are also obtained from the negative binomial model.

				Density-Based Est., Last Survey Year		Negative Binomial Model-Based Results, Last Survey Year						
Area (District and Subdistricts)	**Type of Survey**	**Years Surveyed First**	**Last**	**Avg. No. Animals per 2m Transect**	**Std. Err. of Avg. No. of Animals**	**Statistic. Model Avg. Density**	**Std. Err. of Avg. Density**	**Trend in Abundance**	**Std. Err. of Change**	**Significance of Change In Est.** [1/]	**Est. K Value**	**Std. Err. of K Value**
103-11,15	Harvested	2001	2004	22.79	7.13	14.27	4.61	-0.0653	0.0197	Sig. Dec	12.76	4.55
103-21,30	Harvested	1999	2003	25.44	5.90	26.36	5.91	0.0368	0.0304	NS	6.13	1.44
103-23,25	Harvested	2003	2003	33.85	7.18			No Weight Data				
103-40-001	Harvested	1991	2005	29.82	4.35	30.53	3.33	-0.0027	0.0088	NS	4.69	0.67
103-40-002	Harvested	1991	2005	11.03	2.49	12.46	2.22	-0.0628	0.0164	Sig. Dec	2.52	0.47
103-40-003 con	Control	2000	2005	18.55	3.26	16.66	2.25	-0.0488	0.0242	Sig. Dec	2.79	0.32
103-40-004	Harvested	1991	2005	26.13	7.42	18.08	2.66	-0.0171	0.0087	Sig. Dec	2.69	0.33
103-50	Harvested	1992	2004	12.60	3.70	10.82	2.67	-0.0544	0.0123	Sig. Dec	3.49	0.54
103-60 con	Control	1998	2005	26.63	2.84	29.19	3.02	0.0077	0.0118	NS	5.24	0.52
103-70	Discontinued	1993	2002	5.73	3.29	5.46	1.99	-0.1582	0.0197	Sig. Dec	1.56	0.35
103-80	Harvested	1991	2003	8.81	2.35	9.81	1.96	-0.1169	0.0140	Sig. Dec	1.81	0.27
103-90	Harvested	1991	2005	15.15	5.70	11.15	2.32	-0.1061	0.0159	Sig. Dec	1.16	0.10
104-10,20,30	Harvested	2005	2005	17.73	3.70			No Weight Data				
105-10,20	Harvested	1990	1990	6.71	2.53			No Weight Data				
105-31	Insufficient	2003	2003	2.58	1.04			No Weight Data				
105-32, 109-43	Harvested	2003	2003	7.45	3.36			No Weight Data				
105-41,42	No Quota	1995	2001	6.68	1.94	6.96	1.66	-0.1652	0.0322	Sig. Dec	1.99	0.40
106-10,20,22	Harvested	1995	2005	26.82	4.57	33.88	4.61	-0.0261	0.0148	NS	2.64	0.28
106-30	Harvested	1994	2003	39.38	10.23	38.09	9.22	-0.0779	0.0176	Sig. Dec	2.97	0.44
106-30 con	Control	1998	2005	48.35	7.16	41.46	5.67	-0.0388	0.0124	Sig. Dec	4.24	0.39
106-41	Insufficient	2004	2004	2.56	1.51			No Weight Data				
106-42,108-10,20,30,40	Harvested	2002	2002	5.26	1.52			No Weight Data				
107-10	Harvested	1996	2005	35.50	9.33	42.10	10.08	0.0040	0.0185	NS	2.85	0.48
107-20	Harvested	1996	2005	21.70	3.70	20.60	3.45	0.0357	0.0124	Sig. Inc.	6.25	1.18
107-30,35	Harvested	1999	2005	14.38	3.55	13.68	2.98	0.0390	0.0274	NS	2.16	0.43

Note: Significance of trends is at the $P < .05$ probability with **Sig. Dec., NS**, and **Sig. Inc**. meaning significant decrease, nonsignificant and significant increase, respectively.

Table 17.–Estimated average density of sea cucumbers per 2-meter transect in districts 108 to 112, in Southeast Alaska survey areas using the design-based estimates currently employed in data analysis and using the negative binomial model estimates. Estimates of trends in abundance, associated standard error and statistical significance of these trends, and estimates of the k parameter are also obtained from the negative binomial model.

				Density-Based Est., Last Survey Year		Negative Binomial Model-Based Results, Last Survey Year						
Area (District and Subdistricts)	Type of Survey	Years Surveyed First	Last	Avg. No. Animals per 2m Transect	Std. Err. of Avg. No. of Animals	Statistic. Model Avg. Density	Std. Err. of Avg. Density	Trend in Abundance	Std. Err. of Change	Significance of Change In Est. 1/	Est. K Value	Std. Err. of K Value
108-10,20	Harvested	2005	2005	12.76	2.94							
109-10,11,13	Harvested	2002	2005	10.46	2.27	11.19	2.37	0.1878	0.0608	Sig. Inc.	4.10	1.46
109-30	Insufficient	2000	2000	7.23	1.73				No Weight Data			
109-44,45,50	Harvested	1994	1994	6.50	2.28				No Weight Data			
109-62	No Quota	1992	2004	0.10	0.10	2.87	0.92	-0.2525	0.0198	Sig. Dec	0.76	0.03
110-21,22,24	Insufficient	1997	1997	5.22	1.84				No Weight Data			
111-50	Harvested	2004	2004	4.95	1.65				No Weight Data			
112-11,21	Harvested	1991	2003	13.30	2.14	14.26	1.72	-0.0322	0.0127	Sig. Dec	3.27	0.47
112-12,13,50	Harvested	2001	2004	24.40	4.75	24.52	4.38	-0.1085	0.0244	Sig. Dec	13.68	3.86
112-15	Insufficient	2005	2005	5.85	1.38				No Weight Data			
112-15,61 114-25	Harvested	2004	2004	12.05	4.48				No Weight Data			
112-16,17,63,65	Harvested	2002	2005	17.04	3.99	15.87	2.81	-0.1755	0.0394	Sig. Dec	3.86	0.80
112-18,19,80,90	Harvested	1992	2004	10.29	2.77	11.81	2.65	-0.0197	0.0156	NS	1.50	0.20
112-22 con	Control	2000	2000	9.04	1.44				No Weight Data			
112-41,42	Harvested	1997	2003	20.27	3.89	21.15	3.89	-0.0899	0.0256	Sig. Dec	7.56	1.74
112-43,44,45,46,47,48	Harvested	1997	2003	21.43	6.55	18.80	5.61	-0.0345	0.0162	Sig. Dec	10.45	2.72

Note: Significance of trends is at the P < .05 probability with **Sig. Dec., NS**, and **Sig. Inc**. meaning significant decrease, nonsignificant and significant increase, respectively.

Table 18.–Estimated average density of sea cucumbers per 2-meter transect in districts 113 to 115, and the Yakutat area, in Southeast Alaska survey areas using the design-based estimates currently employed in data analysis and using the negative binomial model estimates. Estimates of trends in abundance, associated standard error and statistical significance of these trends, and estimates of the k parameter are also obtained from the negative binomial model, as well as averages for all districts surveyed.

				Density-Based Est., Last Survey Year		**Negative Binomial Model-Based Results, Last Survey Year**						
Area (District and Subdistricts)	**Type of Survey Area**	**Years Surveyed**		**Avg. No. Animals per 2m Transect**	**Std. Err. of Avg. No. of Animals**	**Statistic. Model Avg. Density**	**Std. Err. of Avg. Density**	**Trend in Abundance**	**Std. Err. of Change**	**Significance of Change In Est. [1/]**	**Est. K Value**	**Std. Err. of K Value**
		First	**Last**									
113-31	Harvested	1990	2005	7.91	2.53	7.57	2.02	-0.0779	0.0178	Sig. Dec	1.55	0.26
113-32	Harvested	1990	2005	4.09	0.58	5.26	1.08	-0.0407	0.0170	Sig. Dec	2.37	0.44
113-33	Harvested	1990	2005	8.67	2.59	11.34	3.63	-0.0111	0.0171	N	2.33	0.50
113-34	Harvested	1993	1993	7.00	1.34	No Weight Data						
113-40 con	Control	2003	2005	10.18	1.88	9.83	1.65	-0.1043	0.0643	NS	5.63	1.32
113-41-001,38	Harvested	1990	2005	10.40	2.41	8.43	1.72	-0.0481	0.0130	Sig. Dec	1.70	0.24
113-41-002 con	Control	2000	2002	11.43	1.74	11.03	1.45	-0.1399	0.0590	Sig. Dec	5.62	1.24
113-41-003,42,43	Discontinued	1992	2004	27.50	9.51	19.99	3.40	-0.0303	0.0130	Sig. Dec	3.06	0.41
113-51,52,53,54,59	Harvested	1990	2005	22.21	5.84	22.21	5.45	-0.0350	0.0090	Sig. Dec	3.08	0.39
113-55,56,57,58	Harvested	1992	2004	9.13	2.61	9.16	1.72	-0.0968	0.0121	Sig. Dec	2.11	0.28
113-62,63,64,65,66	Harvested	1991	2003	18.84	9.67	11.02	3.98	-0.0711	0.0143	Sig. Dec	2.03	0.33
113-71,72,73	Discontinued	1991	1994	7.22	2.82	5.96	2.10	-0.4443	0.0255	Sig. Dec	17.76	10.90
114-25,80	Harvested	2005	2005	23.05	4.91	No Weight Data						
114-27	Insufficient	2004	2004	7.70	4.42	No Weight Data						
114-27,24,31,32,33,34	Insufficient	1990	1990	6.13	2.95	No Weight Data						
115-10,20	Insufficient	2004	2004	6.86	3.17	No Weight Data						
Yakutat	Insufficient	2005	2005	7.32	1.70	No Weight Data						
Average	——	——	——	**17.37**	**4.18**	**19.17**	**3.70**	**-0.0508**	**0.0198**	——	**4.01**	**0.91**

Note: Significance of trends is at the P < .05 probability with **Sig. Dec., NS**, and **Sig. Inc**. meaning significant decrease, nonsignificant and significant increase, respectively.

Table 19.–Comparison of average density estimates of sea cucumbers using the design-based estimates, negative binomial model estimates and composite model estimates for districts 101 and 102 in Southeast Alaska survey areas.

	Design-Based Estimates for Last Survey Year		**Model-Based Estimates for Last Survey Year**		**Composite Model-Based Estimates for Last Survey Year**	
Area (District and	**Avg. No. Of Animals per 2-m Transect**	**Std. Err. of Avg. No. of Animals**	**Avg. No. of Animals per 2-m Transect**	**Std. Err. of Avg. No. of Animals**	**Avg. No. of Animals per 2-m Transect**	**Std. Err. of Avg. No. of Animals**
101-11	19.36	4.88	22.68	3.82	20.92	4.99
101-11-002	21.70	8.87	––	––	––	––
101-23	32.45	7.93	34.49	7.44	33.79	7.27
101-25	48.67	13.90	49.52	13.80	48.72	13.25
101-27 con	28.54	7.29	25.96	4.60	27.51	4.25
101-29	23.23	5.09	23.15	4.28	22.73	4.42
101-30	10.30	2.46	––	––	––	––
101-41	24.73	7.16	21.53	4.67	20.71	5.89
101-43	8.30	2.35	8.31	2.17	8.14	2.36
101-44,45,46,48	18.77	3.06	22.53	3.17	21.09	3.22
101-53	23.39	3.63	23.07	3.59	22.75	6.85
101-60	10.98	1.93	––	––	––	––
101-71	7.53	1.28	––	––	––	––
101-73	6.57	1.68	––	––	––	––
101-80	10.16	2.20	9.36	1.59	9.59	1.58
101-85	10.59	3.01	11.41	2.49	11.42	3.50
101-90	28.86	5.01	26.19	2.88	27.39	2.80
102-10	10.90	3.40	10.41	2.86	10.78	3.97
102-20	25.65	5.50	20.13	3.86	21.58	5.26
102-30	21.94	3.29	27.41	2.52	27.45	2.78
102-40	34.10	6.47	32.67	4.92	34.09	5.13
102-50	31.47	7.23	32.71	6.67	29.40	7.48
102-60	38.10	6.83	––	––	––	––
102-70	18.12	3.66	18.47	2.66	17.76	2.52
102-80	27.89	6.43	29.87	5.81	29.75	5.74

Table 20.–Comparison of average density estimates of sea cucumbers using the design-based estimates, negative binomial model estimates and composite model estimates for districts 103 to 108 in Southeast Alaska survey areas.

	Design-Based Estimates for Last Survey Year		**Model-Based Estimates for Last Survey Year**		**Composite Model-Based Estimates for Last Survey Year**	
Area (District and	**Avg. No. Of Animals per 2-m Transect**	**Std. Err. of Avg. No. of Animals**	**Avg. No. of Animals per 2-m Transect**	**Std. Err. of Avg. No. of Animals**	**Avg. No. of Animals per 2-m Transect**	**Std. Err. of Avg. No. of Animals**
103-11,15	22.79	7.13	14.27	4.61	15.04	5.35
103-21,30	25.44	5.90	26.36	5.91	25.61	6.33
103-23,25	33.85	7.18	––	––	––	––
103-40-001	29.82	4.35	30.53	3.33	30.84	3.45
103-40-002	11.03	2.49	12.46	2.22	12.96	2.94
103-40-003 control	18.55	3.26	16.66	2.25	18.09	2.98
103-40-004	26.13	7.42	18.08	2.66	22.86	4.80
103-50	12.60	3.70	10.82	2.67	12.21	3.31
103-60 con	26.63	2.84	29.19	3.02	28.53	2.83
103-70	5.73	3.29	5.46	1.99	8.02	4.53
103-80	8.81	2.35	9.81	1.96	11.30	3.43
103-90	15.15	5.70	11.15	2.32	16.43	3.27
104-10,20,30	17.73	3.70	––	––	––	––
105-10,20	6.71	2.53	––	––	––	––
105-31	2.58	1.04	––	––	––	––
105-32, 109-43	7.45	3.36	––	––	––	––
105-41,42	6.68	1.94	6.96	1.66	7.36	2.46
106-10,20,22	26.82	4.57	33.88	4.61	32.87	4.44
106-30	39.38	10.23	38.09	9.22	38.04	9.49
106-30 control	48.35	7.16	41.46	5.67	40.49	6.14
106-41	2.56	1.51	––	––	––	––
106-42,108-10,20,30,40	5.26	1.52	––	––	––	––
107-10	35.50	9.33	42.10	10.08	39.02	9.26
107-20	21.70	3.70	20.60	3.45	20.46	4.80
107-30,35	14.38	3.55	13.68	2.98	12.41	3.65
108-10,20	12.76	2.94	––	––	––	––

Table 21.–Comparison of average density estimates of sea cucumbers using the design-based estimates, negative binomial model estimates and composite model estimates for districts 109 to 112 in Southeast Alaska survey areas.

	Design-Based Estimates for Last Survey Year		Model-Based Estimates for Last Survey Year		Composite Model-Based Estimates for Last Survey Year	
Area (District and	**Avg. No. Of Animals per 2-m Transect**	**Std. Err. of Avg. No. of Animals**	**Avg. No. of Animals per 2-m Transect**	**Std. Err. of Avg. No. of Animals**	**Avg. No. of Animals per 2-m Transect**	**Std. Err. of Avg. No. of Animals**
109-10,11,13	10.46	2.27	11.19	2.37	10.46	3.03
109-30	7.23	1.73	––	––	––	––
109-44,45,50	6.50	2.28	––	––	––	––
109-62	0.10	0.10	2.87	0.92	6.76	3.12
110-21,22,24	5.22	1.84	––	––	––	––
111-50	4.95	1.65	––	––	––	––
112-11,21	13.30	2.14	14.26	1.72	14.33	1.98
112-12,13,50	24.40	4.75	24.52	4.38	24.39	6.01
112-15	5.85	1.38	––	––	––	––
112-15,61 114-25	12.05	4.48	––	––	––	––
112-16,17,63,65	17.04	3.99	15.87	2.81	17.25	4.34
112-18,19,80,90	10.29	2.77	11.81	2.65	9.53	2.45
112-22 con	9.04	1.44	––	––	––	––
112-41,42	20.27	3.89	21.15	3.89	21.64	5.05
112-43,44,45,46,47,48	21.43	6.55	18.80	5.61	18.87	5.73

Table 22.–Comparison of average density estimates of sea cucumbers using the design-based estimates, negative binomial model estimates and composite model estimates for districts 113, 114, 115 and Yakutat area, in Southeast Alaska survey areas, as well as averages for all surveys.

	Design-Based Estimates for Last Survey Year		Model-Based Estimates for Last Survey Year		Composite Model-Based Estimates for Last Survey Year	
Area (District and	**Avg. No. Of Animals per 2-m Transect**	**Std. Err. of Avg. No. of Animals**	**Avg. No. of Animals per 2-m Transect**	**Std. Err. of Avg. No. of Animals**	**Avg. No. of Animals per 2-m Transect**	**Std. Err. of Avg. No. of Animals**
113-31	7.91	2.53	7.57	2.02	6.83	2.05
113-32	4.09	0.58	5.26	1.08	4.43	0.83
113-33	8.67	2.59	11.34	3.63	10.75	3.60
113-34	7.00	1.34	––	––	––	––
113-40 control	10.18	1.88	9.83	1.65	10.13	2.08
113-41-001,38	10.40	2.41	8.43	1.72	9.75	2.74
113-41-002 control	11.43	1.74	11.03	1.45	10.84	1.60
113-41-003,42,43	27.50	9.51	19.99	3.40	23.31	4.13
113-51,52,53,54,59	22.21	5.84	22.21	5.45	20.23	5.46
113-55,56,57,58	9.13	2.61	9.16	1.72	11.21	2.69
113-62,63,64,65,66	18.84	9.67	11.02	3.98	17.20	4.48
113-71,72,73	7.22	2.82	5.96	2.10	6.29	2.17
114-25,80	23.05	4.91	––	––	––	––
114-27	7.70	4.42	––	––	––	––
114-27,24,31,32,33,34	6.13	2.95	––	––	––	––
115-10,20	6.86	3.17	––	––	––	––
Yakutat	7.32	1.70	––	––	––	––
Average	16.75	4.09	19.17	3.70	19.50	4.29

Table 23.–Comparison of estimated trends in density and k values of sea cucumbers in districts 101 and 102 in Southeast Alaska survey areas using the negative binomial model estimates and composite model estimates.

	Model-Based Estimates for Last Survey Year			Composite Model-Based Estimates for Last Survey Year			Model-Based Estimates for Last Survey Year		Composite Model-Based Estimates for Last Survey Year	
Area (District and Subdistrict)	**Trend in Density**	**Std. Error of Trend Ests.**	**Signif. of Est. Change**	**Trend in Density**	**Std. Error of Trend Ests.**	**Signif. of Est. Change**	**Est. K Value**	**Std. Error of Est. K Value**	**Est. K Value**	**Std. Error of Est. K Value**
101-11	-0.0250	0.0097	Sig. Dec	-0.0372	0.0033	Sig. Dec	3.90	0.54	0.64	0.07
101-11-002	—	—	—	—	—	—	—	—	—	—
101-23	-0.0455	0.0103	Sig. Dec	-0.0492	0.0025	Sig. Dec	3.47	0.44	1.09	0.08
101-25	-0.0188	0.0349	NS Dec.	-0.0300	0.0092	Sig. Dec	5.29	1.10	0.52	0.07
101-27 control	-0.0341	0.0076	Sig. Dec	-0.0220	0.0025	Sig. Dec	4.23	0.36	1.77	0.43
101-29	-0.0802	0.0216	Sig. Dec	-0.0880	0.0041	Sig. Dec	1.53	0.16	1.34	0.09
101-30	—	—	—	—	—	—	—	—	—	—
101-41	-0.0477	0.0312	NS Dec.	-0.0632	0.0122	Sig. Dec	5.15	1.30	0.97	0.11
101-43	-0.0448	0.0185	Sig. Dec	-0.0479	0.0055	Sig. Dec	1.87	0.36	1.12	0.11
101-44,45,46,48	0.0622	0.0220	Sig. Inc.	0.0402	0.0086	Sig. Inc.	4.56	0.82	2.23	0.55
101-53	0.0208	0.0165	NS Inc.	0.0186	0.0045	Sig. Inc.	1.64	0.25	1.12	0.13
101-60	—	—	—	—	—	—	—	—	—	—
101-71	—	—	—	—	—	—	—	—	—	—
101-73	—	—	—	—	—	—	—	—	—	—
101-80	-0.0014	0.0138	NS Dec.	0.0027	0.0057	NS	2.22	0.35	1.97	0.47
101-85	-0.0169	0.0141	NS Dec.	-0.0167	0.0050	Sig. Dec	1.86	0.29	0.64	0.09
101-90	-0.0165	0.0072	Sig. Dec	-0.0078	0.0030	Sig. Dec	6.01	0.73	4.00	0.72
102-10	-0.0655	0.0108	Sig. Dec	-0.0595	0.0044	Sig. Dec	3.25	0.53	0.37	0.07
102-20	-0.0470	0.0124	Sig. Dec	-0.0338	0.0036	Sig. Dec	2.89	0.42	0.94	0.09
102-30	-0.0061	0.0093	NS Dec.	-0.0062	0.0026	Sig. Dec	3.06	0.36	6.12	1.02
102-40	-0.0284	0.0341	NS Dec.	0.0005	0.0127	NS	6.47	1.39	2.28	0.59
102-50	0.0383	0.0136	Sig. Inc.	0.0209	0.0034	Sig. Inc.	2.13	0.26	0.82	0.09
102-60	—	—	—	—	—	—	—	—	—	—
102-70	-0.0118	0.0110	NS Dec.	-0.0197	0.0035	Sig. Dec	2.27	0.27	2.34	0.53
102-80	-0.0329	0.0146	Sig. Dec	-0.0336	0.0034	Sig. Dec	2.17	0.29	1.96	0.61

Note: Significance of trends is at the $P < .05$ probability with **Sig. Dec**., **NS**, and **Sig. Inc**. meaning significant decrease, nonsignificant,and significant increase respectively.

Table 24.–Comparison of estimated trends in density and k values of sea cucumbers in districts 103 to 107 in Southeast Alaska survey areas using the negative binomial model estimates and composite model estimates.

	Model-Based Estimates for Last Survey Year			Composite Model-Based Estimates for Last Survey Year			Model-Based Estimates for Last Survey Year		Composite Model-Based Estimates for Last Survey Year	
Area (District and Subdistrict)	**Trend in Density**	**Std. Error of Trend Ests.**	**Signif. of Est. Change**	**Trend in Density**	**Std. Error of Trend Ests.**	**Signif. of Est. Change**	**Est. K Value**	**Std. Error of Est. K Value**	**Est. K Value**	**Std. Error of Est. K Value**
103-11,15	-0.0653	0.0197	Sig. Dec	-0.0318	0.0165	NS	12.76	4.55	0.31	0.06
103-21,30	0.0368	0.0304	NS Inc.	0.0209	0.0113	NS	6.13	1.44	0.69	0.07
103-23,25	—	—	—	—	—	—	—	—	—	—
103-40-001	-0.0027	0.0088	NS Dec.	-0.0013	0.0031	NS	4.69	0.67	6.06	1.13
103-40-002	-0.0628	0.0164	Sig. Dec	-0.0549	0.0052	Sig. Dec	2.52	0.47	1.25	0.10
103-40-003 control	-0.0488	0.0242	Sig. Dec	-0.0174	0.0084	Sig. Dec	2.79	0.32	1.58	0.38
103-40-004	-0.0171	0.0087	Sig. Dec	0.0079	0.0030	Sig. Inc.	2.69	0.33	0.78	0.07
103-50	-0.0544	0.0123	Sig. Dec	-0.0340	0.0043	Sig. Dec	3.49	0.54	0.69	0.08
103-60 con	0.0077	0.0118	NS Inc.	0.0013	0.0046	NS	5.24	0.52	5.28	0.92
103-70	-0.1582	0.0197	Sig. Dec	-0.0685	0.0083	Sig. Dec	1.56	0.35	0.21	0.07
103-80	-0.1169	0.0140	Sig. Dec	-0.0947	0.0040	Sig. Dec	1.81	0.27	0.61	0.09
103-90	-0.1061	0.0159	Sig. Dec	-0.0312	0.0031	Sig. Dec	1.16	0.10	0.86	0.07
104-10,20,30	—	—	—	—	—	—	—	—	—	—
105-10,20	—	—	—	—	—	—	—	—	—	—
105-31	—	—	—	—	—	—	—	—	—	—
105-32, 109-43	—	—	—	—	—	—	—	—	—	—
105-41,42	-0.1653	0.0402	Sig. Dec	-0.1434	0.0121	Sig. Dec	1.99	0.40	0.48	0.08
106-10,20,22	-0.0261	0.0148	NS Dec.	-0.0391	0.0035	Sig. Dec	2.64	0.28	1.63	0.35
106-30	-0.0779	0.0176	Sig. Dec	-0.0790	0.0037	Sig. Dec	2.97	0.44	0.90	0.09
106-30 con	-0.0388	0.0124	Sig. Dec	-0.0454	0.0036	Sig. Dec	4.24	0.39	2.20	0.58
106-41	—	—	—	—	—	—	—	—	—	—
106-42,108-10,20,30,40	—	—	—	—	—	—	—	—	—	—
107-10	0.0040	0.0185	NS Inc.	-0.0126	0.0042	Sig. Dec	2.85	0.48	1.20	0.10
107-20	0.0357	0.0133	Sig. Inc.	0.0345	0.0065	Sig. Inc.	6.25	1.18	1.23	0.10
107-30,35	0.0390	0.0311	NS Inc.	0.0076	0.0107	NS	2.16	0.43	0.59	0.08

Note: Significance of trends is at the P < .05 probability with **Sig. Dec., NS.**, and **Sig. Inc.** meaning significant decrease, nonsignificant, and significant increase respectively.

Table 25.–Comparison of estimated trends in density and k values of sea cucumbers in districts 108 to 112 in Southeast Alaska survey areas using the negative binomial model estimates and composite model estimates.

	Model-Based Estimates for Last Survey Year			Composite Model-Based Estimates for Last Survey Year			Model-Based Estimates for Last Survey Year		Composite Model-Based Estimates for Last Survey Year	
Area (District and Subdistrict)	**Trend in Density**	**Std. Error of Trend Ests.**	**Signif. of Est. Change**	**Trend in Density**	**Std. Error of Trend Ests.**	**Signif. of Est. Change**	**Est. K Value**	**Std. Error of Est. K Value**	**Est. K Value**	**Std. Error of Est. K Value**
108-10,20	—	—	—	—	—	—	—	—	—	—
109-10,11,13	0.1879	0.0630	Sig. Inc.	0.1444	0.0310	Sig. Inc.	4.10	1.46	0.89	0.10
109-30	—	—	—	—	—	—	—	—	—	—
109-44,45,50	—	—	—	—	—	—	—	—	—	—
109-62	-0.2527	0.0372	Sig. Dec	-0.1110	0.0047	Sig. Dec	0.76	0.03	0.24	0.06
110-21,22,24	—	—	—	—	—	—	—	—	—	—
111-50	—	—	—	—	—	—	—	—	—	—
112-11,21	-0.0322	0.0127	Sig. Dec	-0.0313	0.0047	Sig. Dec	3.27	0.47	3.52	0.77
112-12,13,50	-0.1085	0.0272	Sig. Dec	-0.1118	0.0140	Sig. Dec	13.68	3.86	0.84	0.09
112-15	—	—	—	—	—	—	—	—	—	—
112-15,61 114-25	—	—	—	—	—	—	—	—	—	—
112-16,17,63,65	-0.1757	0.0452	Sig. Dec	-0.1177	0.0149	Sig. Dec	3.86	0.80	0.64	0.07
112-18,19,80,90	-0.0197	0.0172	NS Dec.	-0.0543	0.0047	Sig. Dec	1.50	0.20	0.77	0.08
112-22 control	—	—	—	—	—	—	—	—	—	—
112-41,42	-0.0899	0.0256	Sig. Dec	-0.0806	0.0101	Sig. Dec	7.56	1.74	1.25	0.10
112-43,44,45,46,47,48	-0.0345	0.0184	NS Dec.	-0.0334	0.0094	Sig. Dec	10.45	2.72	0.73	0.10

Note: Significance of trends is at the P < .05 probability with **Sig. Dec**., **NS**, and **Sig. Inc**. meaning significant decrease, nonsignificant, and significant increase respectively.

Table 26.–Comparison of estimated trends in density and k values of sea cucumbers in Southeast Alaska survey areas using the negative binomial model estimates and composite model estimates.

	Model-Based Estimates for Last Survey Year			Composite Model-Based Estimates for Last Survey Year			Model-Based Estimates for Last Survey Year		Composite Model-Based Estimates for Last Survey Year	
Area (District and Subdistrict)	**Trend in Density**	**Std. Error of Trend Ests.**	**Signif. of Est. Change**	**Trend in Density**	**Std. Error of Trend Ests.**	**Signif. of Est. Change**	**Est. K Value**	**Std. Error of Est. K Value**	**Est. K Value**	**Std. Error of Est. K Value**
113-31	-0.0769	0.0183	Sig. Dec	-0.0900	0.0046	Sig. Dec	1.55	0.26	0.76	0.09
113-32	-0.0407	0.0170	Sig. Dec	-0.0679	0.0085	Sig. Dec	2.37	0.44	2.99	0.85
113-33	-0.0111	0.0171	NS Dec.	-0.0191	0.0061	Sig. Dec	2.33	0.50	1.01	0.12
113-34	—	—	—	—	—	—	—	—	—	—
113-40 control	-0.1043	0.0643	NS Dec.	-0.0732	0.0339	Sig. Dec	5.63	1.32	1.24	0.08
113-41-001,38	-0.0481	0.0143	Sig. Dec	-0.0256	0.0044	Sig. Dec	1.70	0.24	0.81	0.08
113-41-002 control	-0.1399	0.0590	Sig. Dec	-0.1577	0.0312	Sig. Dec	5.62	1.24	2.51	0.10
113-41-003,42,43	-0.0321	0.0138	Sig. Dec	-0.0013	0.0042	NS Dec.	3.06	0.41	1.42	0.55
113-51,52,53,54,59	-0.0350	0.0101	Sig. Dec	-0.0484	0.0029	Sig. Dec	3.08	0.39	0.81	0.09
113-55,56,57,58	-0.0968	0.0146	Sig. Dec	-0.0613	0.0042	Sig. Dec	2.11	0.28	0.88	0.09
113-62,63,64,65,66	-0.0740	0.0158	Sig. Dec	-0.0107	0.0040	Sig. Dec	2.03	0.33	0.50	0.06
113-71,72,73	-0.4916	0.0695	Sig. Dec	-0.3550	0.0336	Sig. Dec	17.76	10.90	0.38	0.07
114-25,80	—	—	—	—	—	—	—	—	—	—
114-27	—	—	—	—	—	—	—	—	—	—
114-27,24,31,32,33,34	—	—	—	—	—	—	—	—	—	—
115-10,20	—	—	—	—	—	—	—	—	—	—
Yakutat	—	—	—	—	—	—	—	—	—	—
Average	-0.052	0.021		-0.041	0.008		4.006	0.910	1.446	0.248

Note: Significance of trends is at the P < .05 probability with **Sig. Dec**., **NS, a**nd **Sig. Inc**. meaning significant decrease, non-significant, and significant increase respectively.

Table 27.–Average counts by transect and year for area 106-10, -22, and -22. Transects are assigned to fished or not fished areas of shoreline, based on information from commercial fishermen.

	Average Count					
Transect	**1995**	**1998**	**2001**	**2004**	**2005**	**Type**
4	7.5	18.5	13.0	12.5	20.5	Not Fished
6	56.0	28.0	27.0	29.0	16.0	Not Fished
7	30.0	17.0	23.0	29.5	23.5	Not Fished
9	7.5	17.0	14.0	9.5	16.5	Not Fished
10	32.5	23.0	33.5	25.5	19.0	Not Fished
13	2.5	12.0	29.5	43.0	26.0	Not Fished
14	84.0	35.0	27.5	20.0	32.5	Not Fished
15	4.5	11.0	17.0	4.0	2.0	Not Fished
16	—	6.5	0.0	3.0	5.5	Not Fished
18	—	25.5	29.5	17.0	12.5	Not Fished
40	—	—	—	36.5	46.0	Not Fished
41	—	—	—	57.0	26.5	Not Fished
42	—	—	—	81.3	19.0	Not Fished
44	—	—	—	58.0	21.0	Not Fished
47	—	—	—	8.5	10.0	Not Fished
52	—	—	—	56.5	23.0	Not Fished
53	—	—	—	0.0	0.0	Not Fished
1	40.5	—	90.0	8.0	69.5	Fished
2	55.5	41.0	53.0	43.7	14.5	Fished
3	2.0	11.0	24.5	10.5	18.0	Fished
5	31.0	35.5	122.0	39.5	3.0	Fished
8	134.0	115.0	60.0	46.5	20.5	Fished
11	33.5	31.0	16.0	37.0	33.5	Fished
12	2.0	53.0	61.0	105.0	5.0	Fished
17	—	46.5	66.0	1.5	6.5	Fished
19	—	241.5	72.0	215.5	151.5	Fished
43	—	—	—	17.5	25.5	Fished
45	—	—	—	63.5	32.5	Fished
46	—	—	—	16.5	44.5	Fished
48	—	—	—	26.5	25.5	Fished
49	—	—	—	39.0	46.0	Fished
50	—	—	—	33.0	16.0	Fished
51	—	—	—	51.0	37.0	Fished
54	—	—	—	73.5	43.5	Fished
Avgerage Not Fished	**28.1**	**19.4**	**21.4**	**28.9**	**18.8**	——
Average Fished	**42.6**	**71.8**	**62.7**	**48.7**	**34.9**	——

Table 28.–Summary of statistics, compared to fished and non-fished areas in 106-10, -20, and -22. Percent change is difference in counts, divided by sum of counts from the transect and years.

Comparison	Statistic	Not Fished Shoreline	Fished Shoreline
Difference in counts every three years from 1995-2004	Average	-2.27	-5.6
	Number of Comparisons	28	23
	Std. Error Mean	2,57	12.88
	Range	-49.0 - 17.5	-169.5 - 143.5
Percent Change from Average Count every three years, 1995-2004	Average	1.00%	-0.95%
	Std. Error Mean	7.49%	9.84%
	Range	-100% - 100%	-96% - 93%
Difference in counts from 2004 to 2005	Average	-10.71	-13.83
	Number of Comparisons	16	17
	Std. Error Mean	1.29	8.75
	Range	-62.3 - 12.5	-100.0 - 61.5
Percent Change from Average Count from 2004 to 2005	Average	-11.98%	-9.28%
	Std. Error Mean	7.34%	11.36%
	Range	-62% - 29%	-91% - 79%

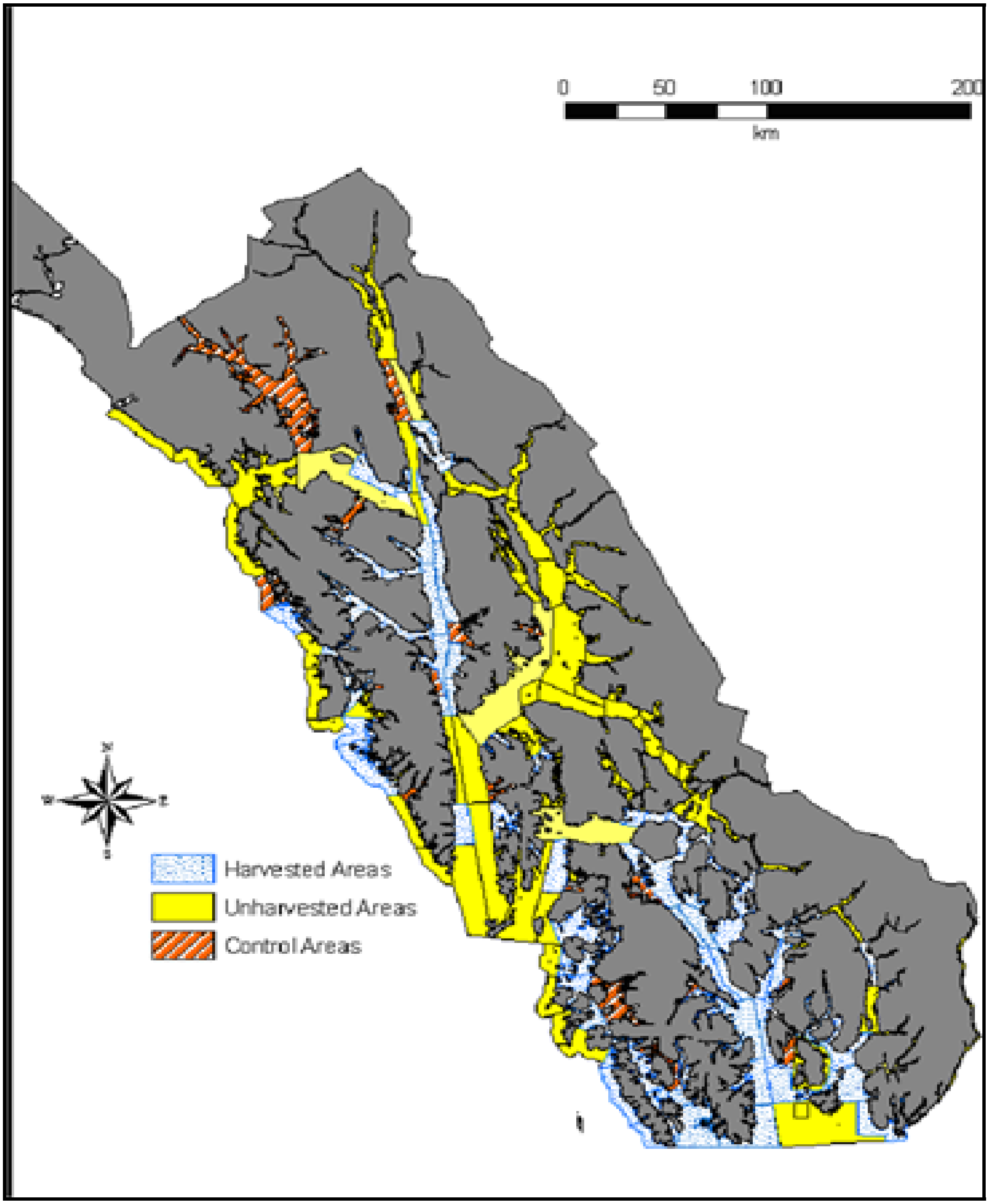

Figure 1.–Southeast Alaska sea cucumber management areas. Harvested areas are areas that are currently surveyed and commercially fished or have been fished in earlier years but current estimated biomass is too low for commercial harvest. Unharvested areas are areas that have not been surveyed or have been surveyed and virgin biomass is too low for commercial harvest. Control areas have not been commercially harvested since 1990.

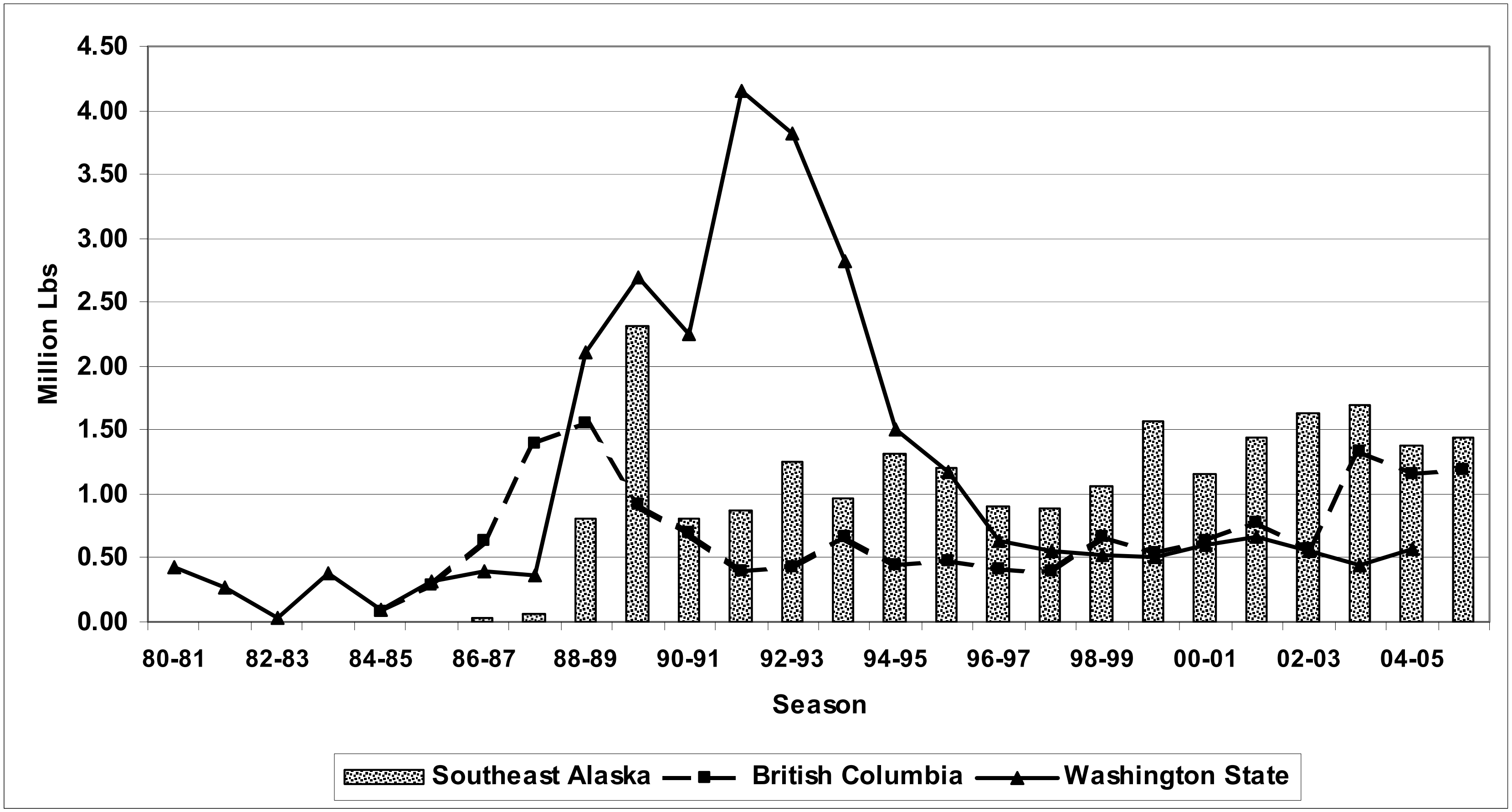

Figure 2.–Total catch (million Lbs split weight) of sea cucumbers in Southeast Alaska, compared with Washington State and British Columbia catches. Canadian catch statistics were obtained from internet site http://www-sci.pac.dfo-mpo.gc.ca/sa/Commercial/AnnSumm_e.htm and http://www-sci.pac.dfo-mpo.gc.ca/sa/Commercial/HistoricStats_e.htm. Washington State catch statistics were obtained from internet site http://www.st.nmfs.gov/st1/commercial/landings/gc_runc.html. British Columbia catches were converted to split weight by multiplying by the factor 0.368 (factor used in Stock Status Report C6-10 (2002); Fisheries and Oceans, Canada, Pacific Region).

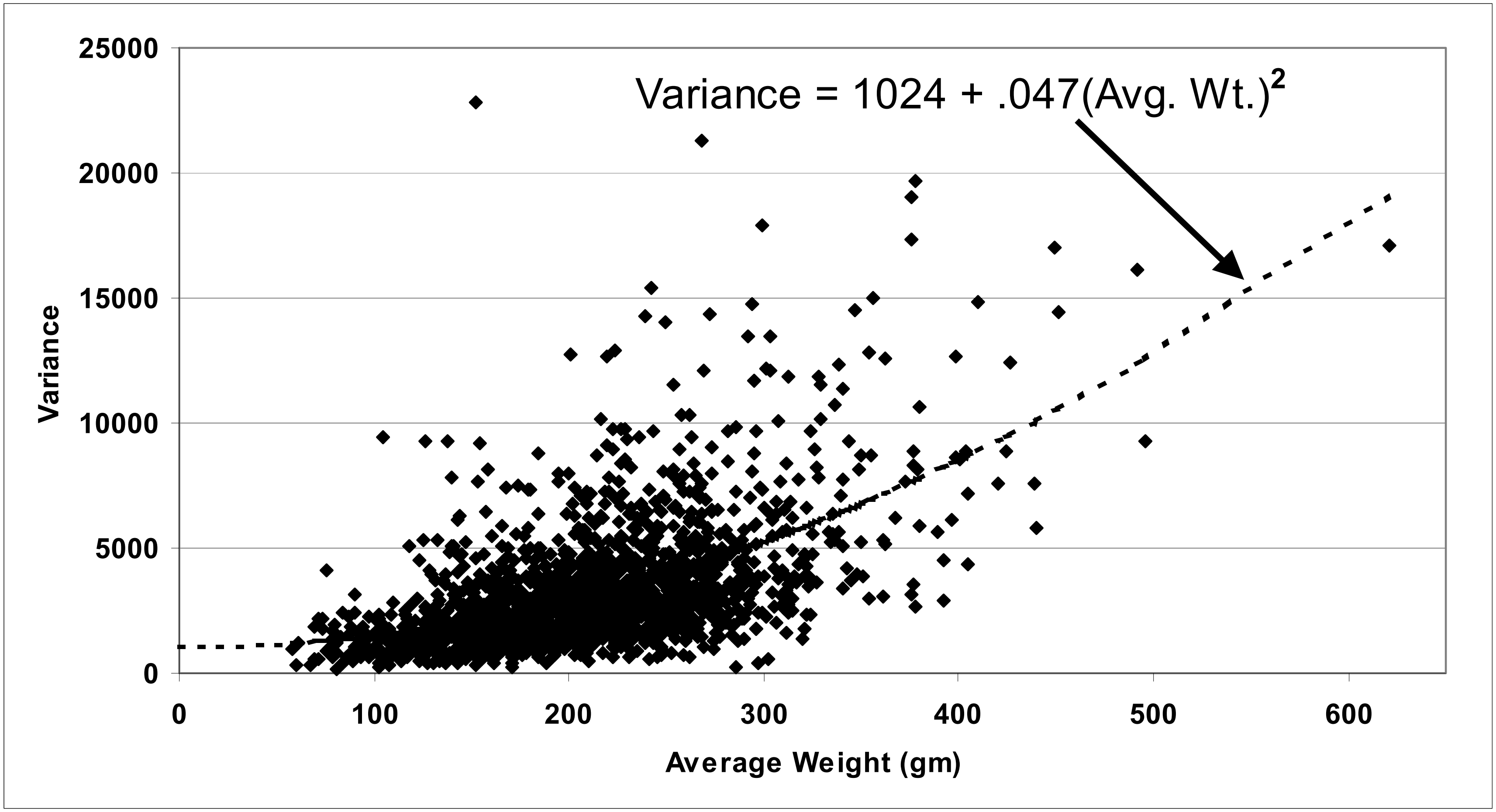

Figure 3.–Relationship between average weight of sea cucumbers from 1,724 area, survey year, and transect samples and the variance of individual weights from these samples. Equation of line was estimated by linear regression. Slope and intercept were highly significant ($P < 0.0001$).

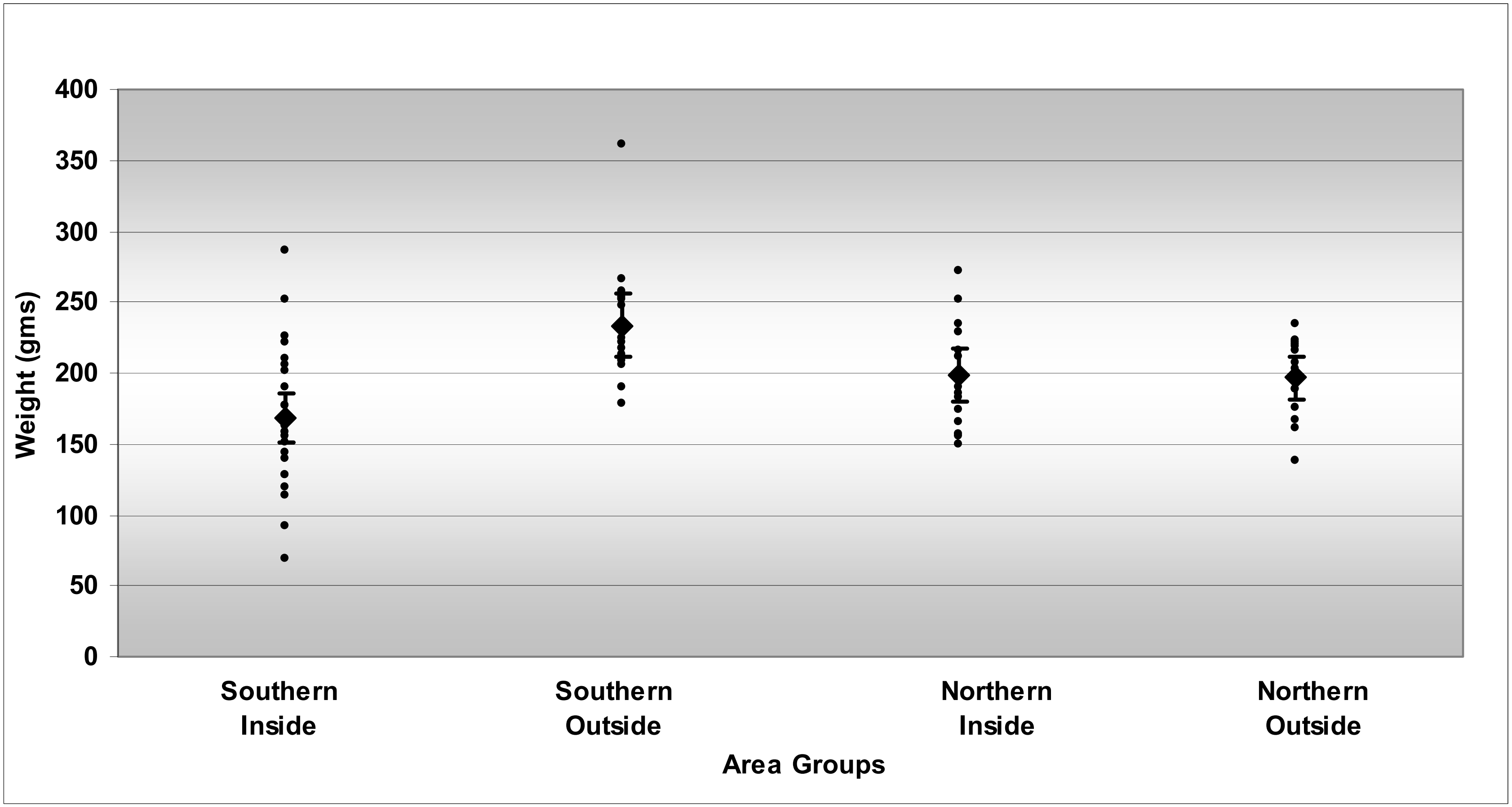

Figure 4.–Estimated initial survey year average weight in the major quadrants of Southeast Alaska.. Southern Inside includes districts 101, 102, 106, and 107. Southern Outside includes areas 103, 104, and 105. Northern Inside includes areas 108, 110, 111, 112, 115, and inside parts of 109 and 113. Northern Outside areas include 114, Yakutat, and outside parts of 109 and 113.

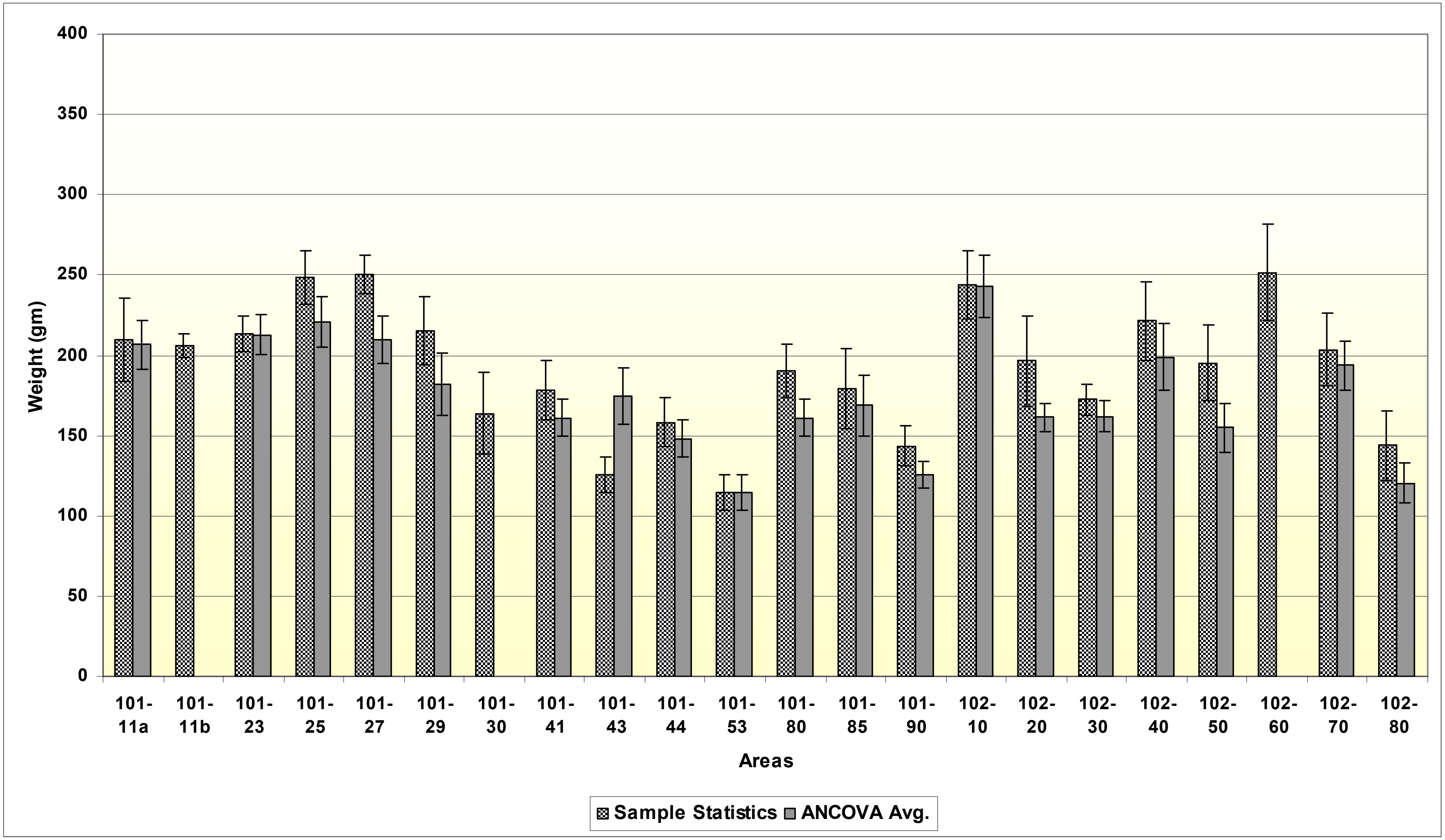

Figure 5.–Comparison of estimates of average weight using standard sampling statistics and analysis of covariance statistics for survey areas in Districts 101 and 102.

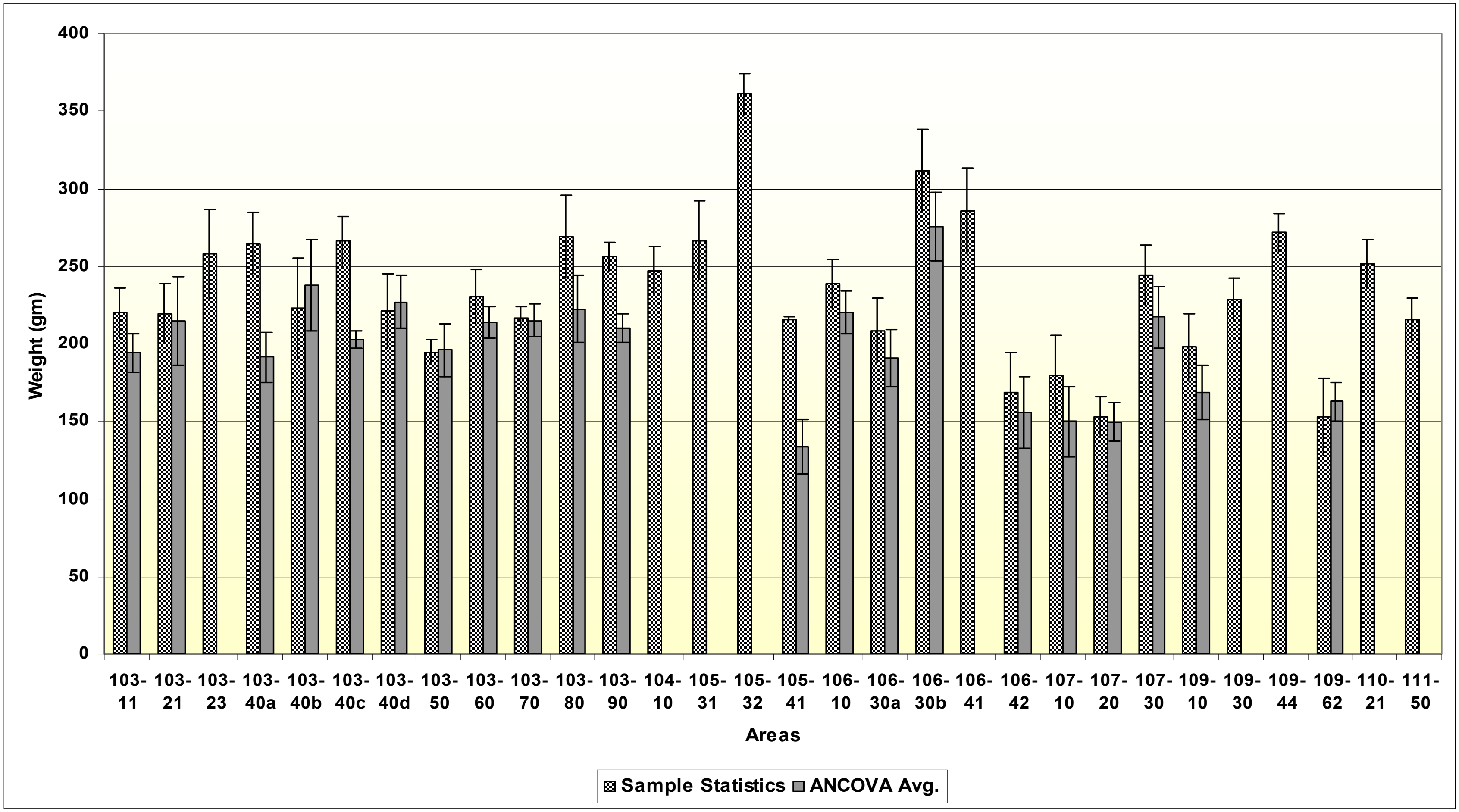

Figure 6.–Comparison of estimates of average weight using standard sampling statistics and analysis of covariance statistics for survey areas in Districts 103 through 111.

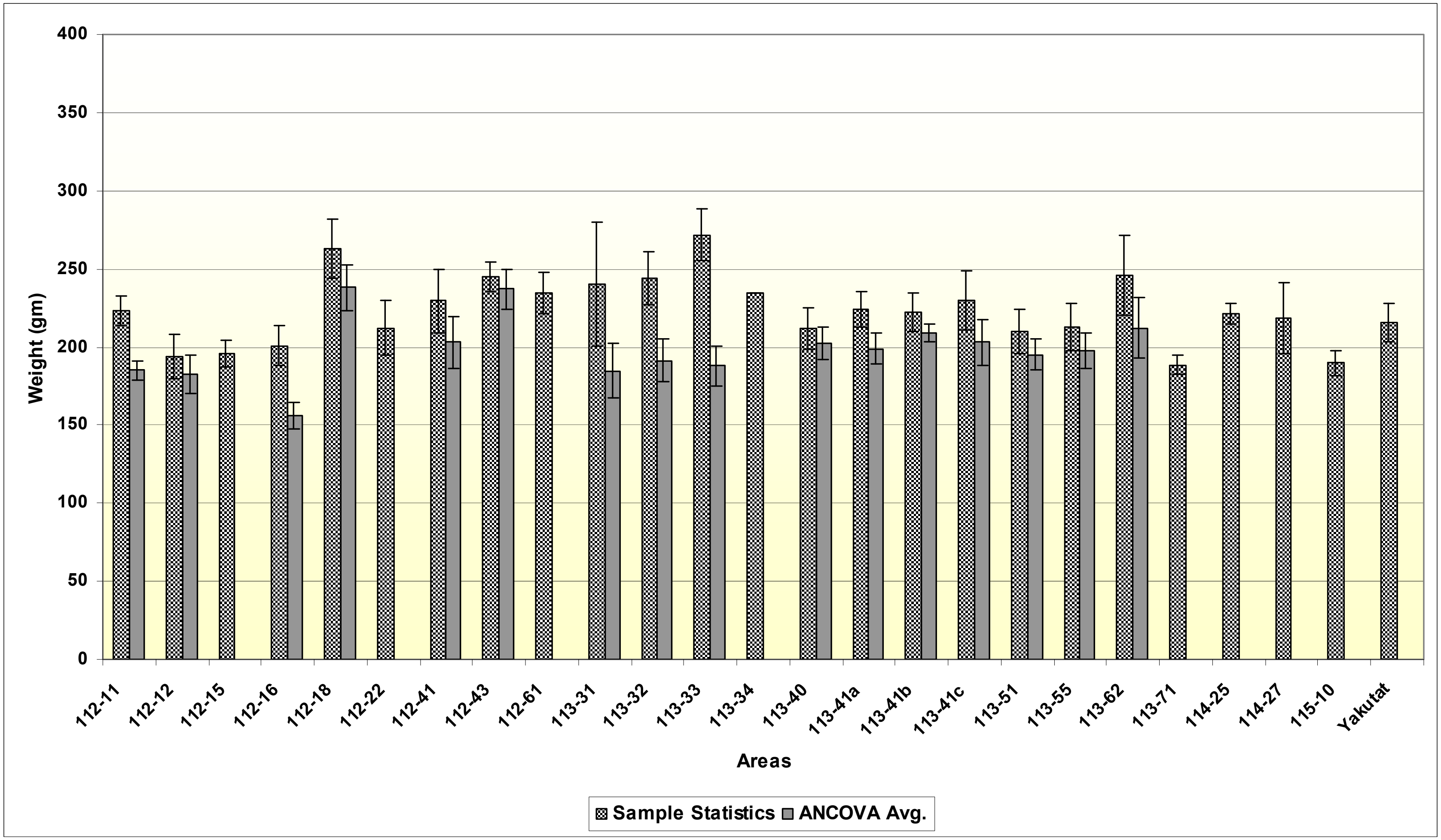

Figure 7.–Comparison of estimates of average weight using standard sampling statistics and analysis of covariance statistics for survey areas in Districts 112 through 114 and Yakutat.

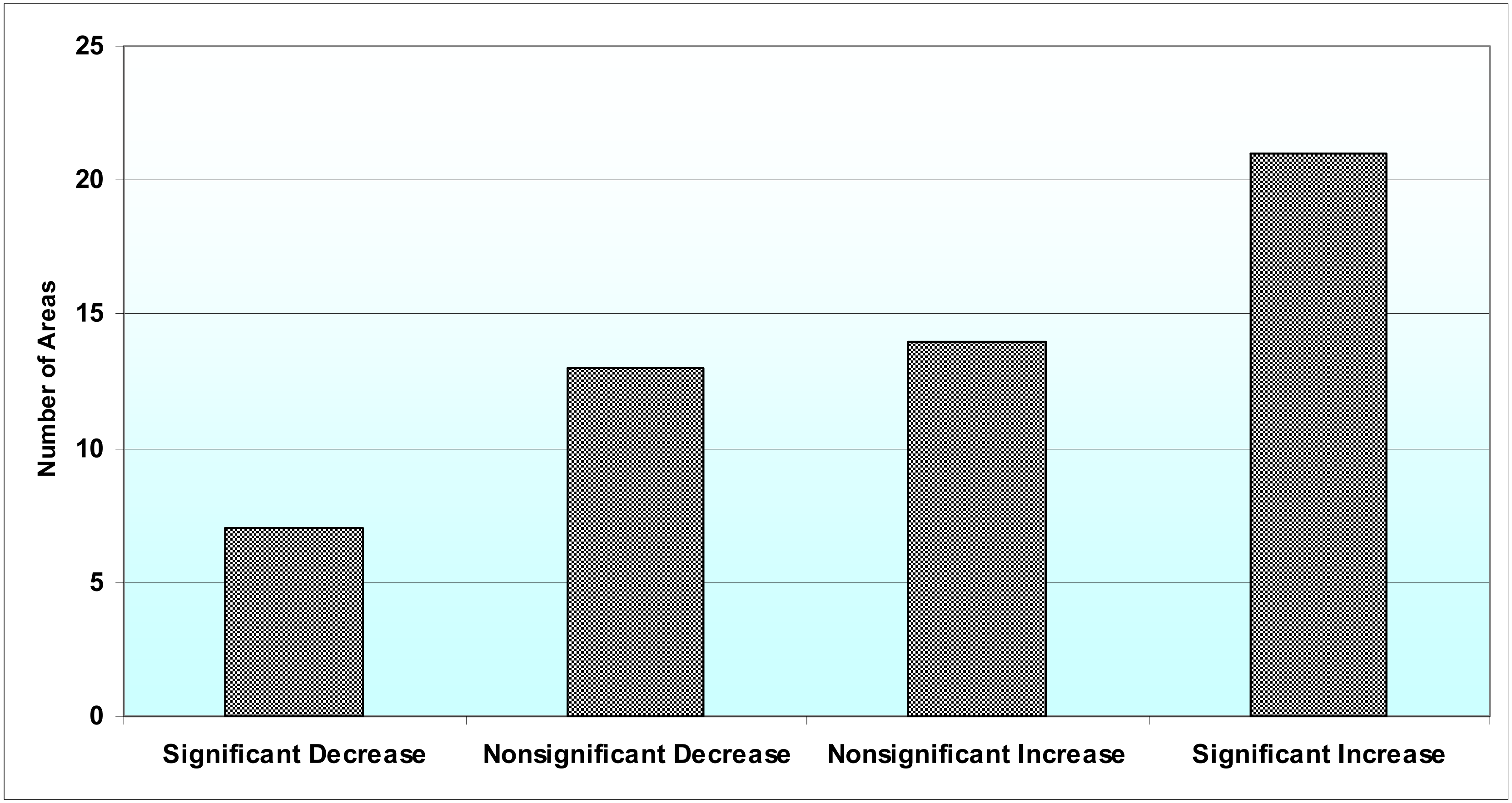

Figure 8.– Direction and statistical significance of estimated change in average weight in areas with multiple years of weight measurements.

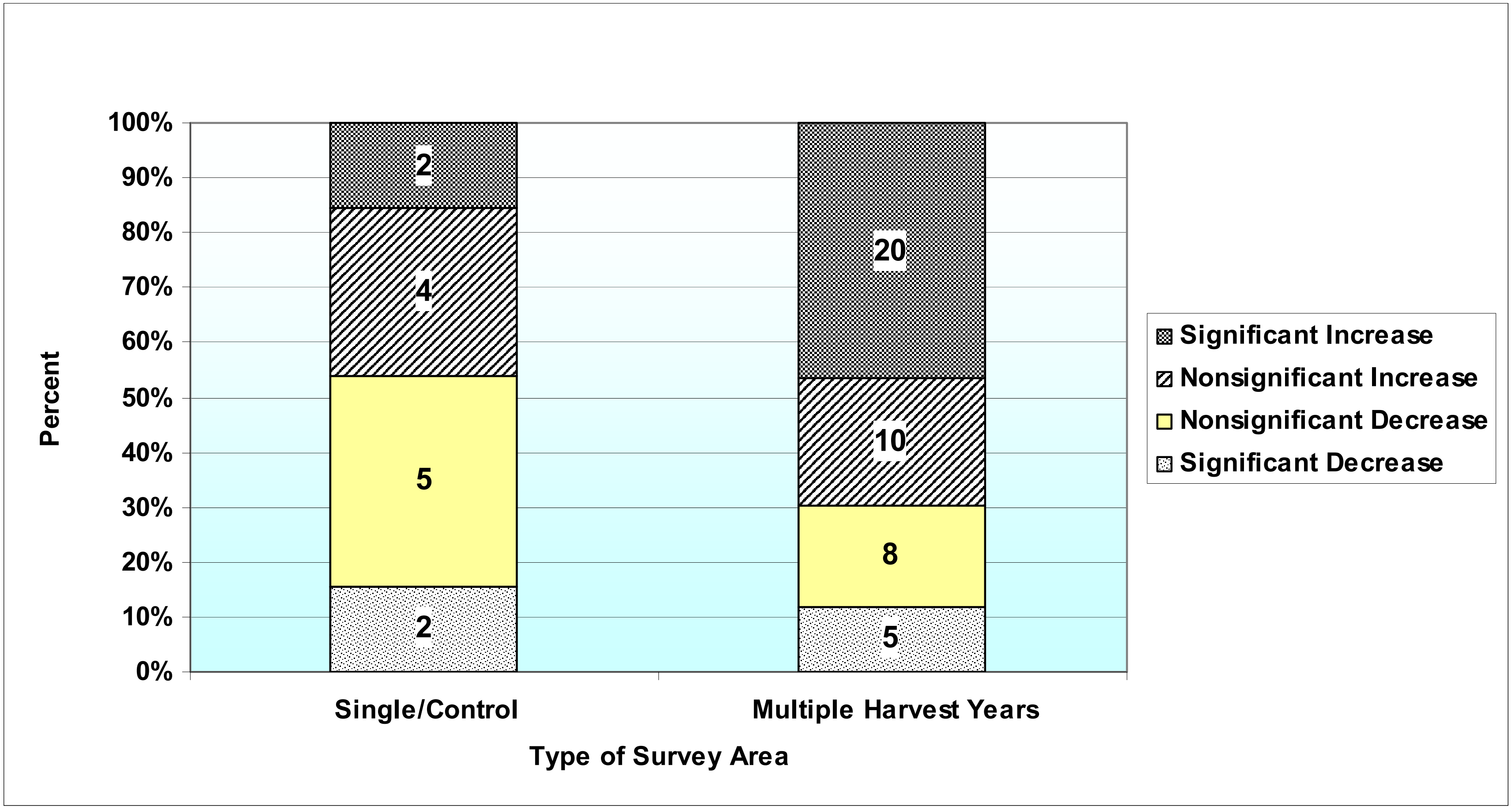

Figure 9.–Comparison of harvest history with trend direction and statistical significance of average weights. Single/Control areas are areas with no history of commercial harvest or a single year of commercial harvest. Multiple Harvest Years areas are areas with 2 to 5 years of commercial harvest.

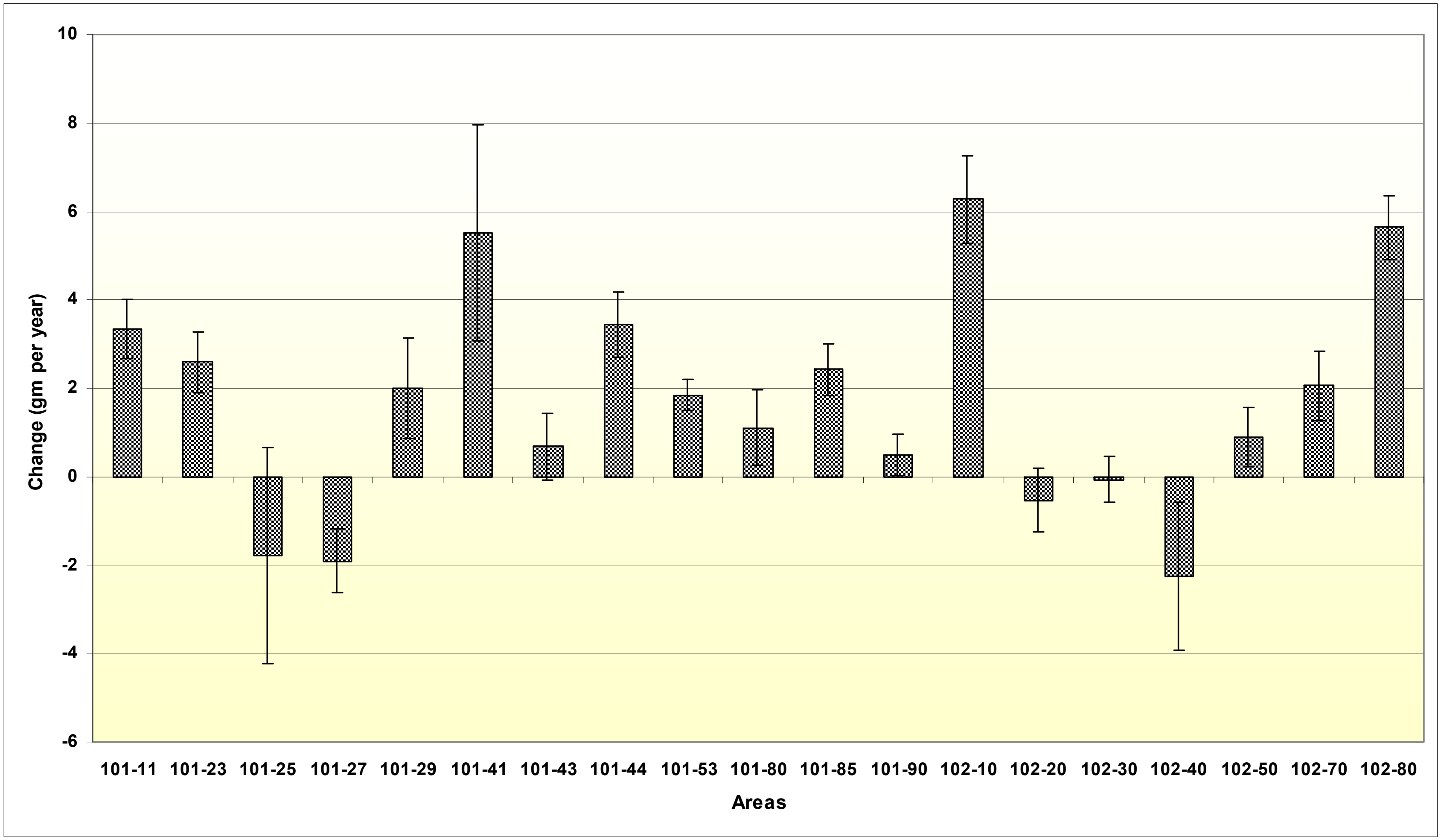

Figure 10.–Estimated trends in change in mean weights in Districts 101 and 102 areas. Error bars are +/- 1 standard error about the estimated mean change.

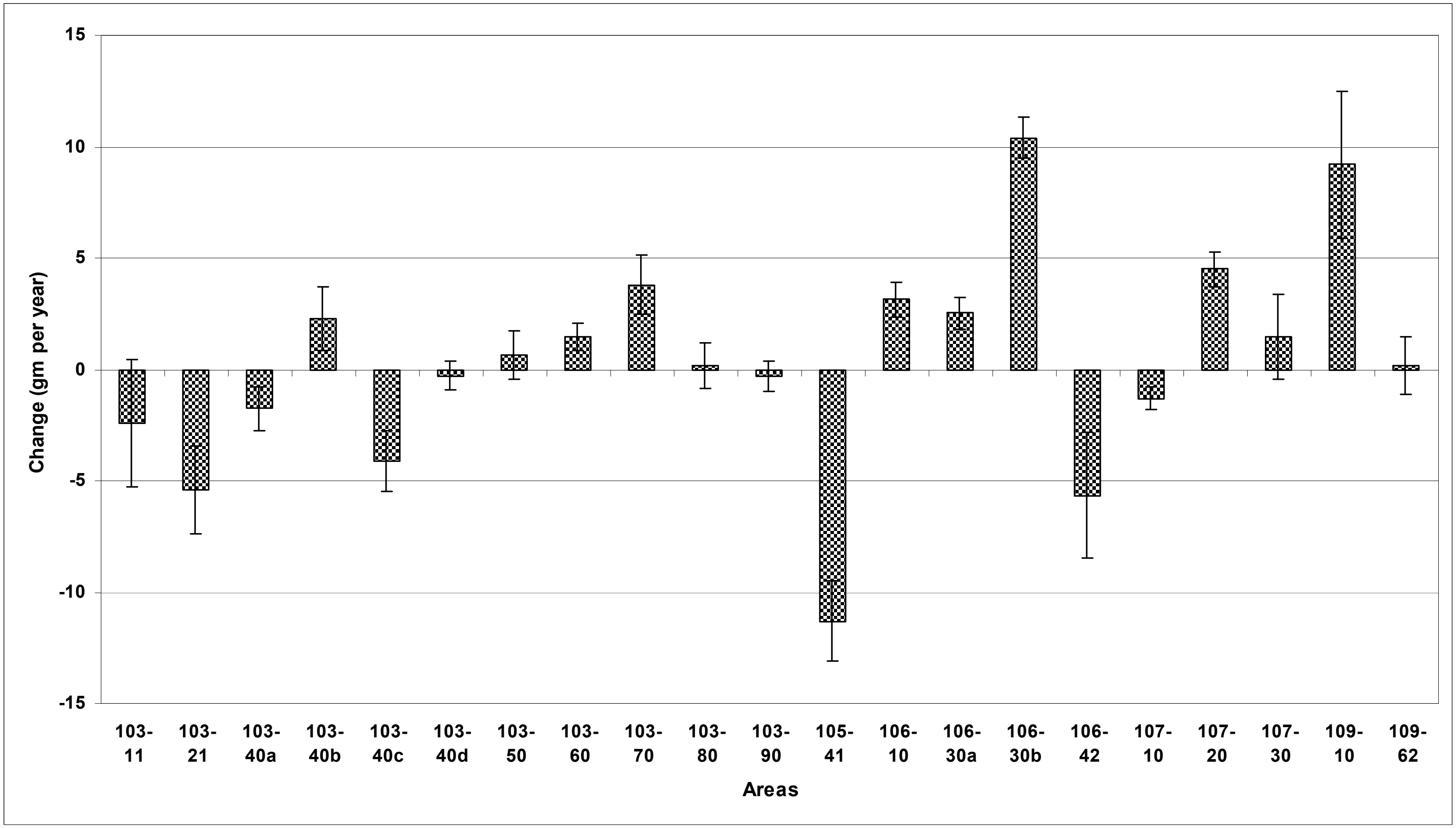

Figure 11.–Estimated trends in change in mean weights in Districts 103 through 111. Error bars are +/- 1standard error about the estimated mean change.

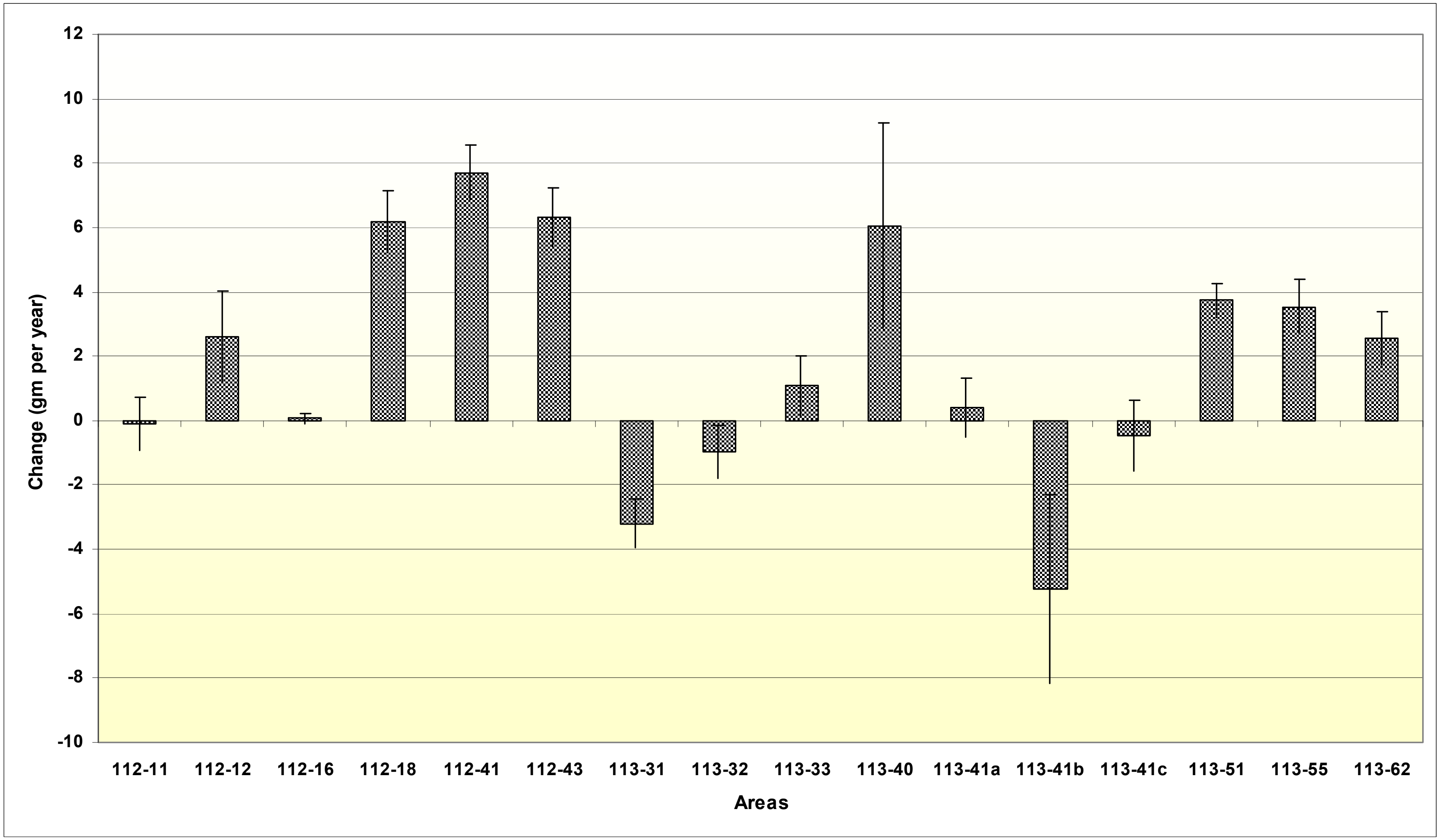

Figure 12.–Estimated trends in change in mean weights in Districts 112 and 113. Error bars are +/- 1 standard error about the estimated mean change.

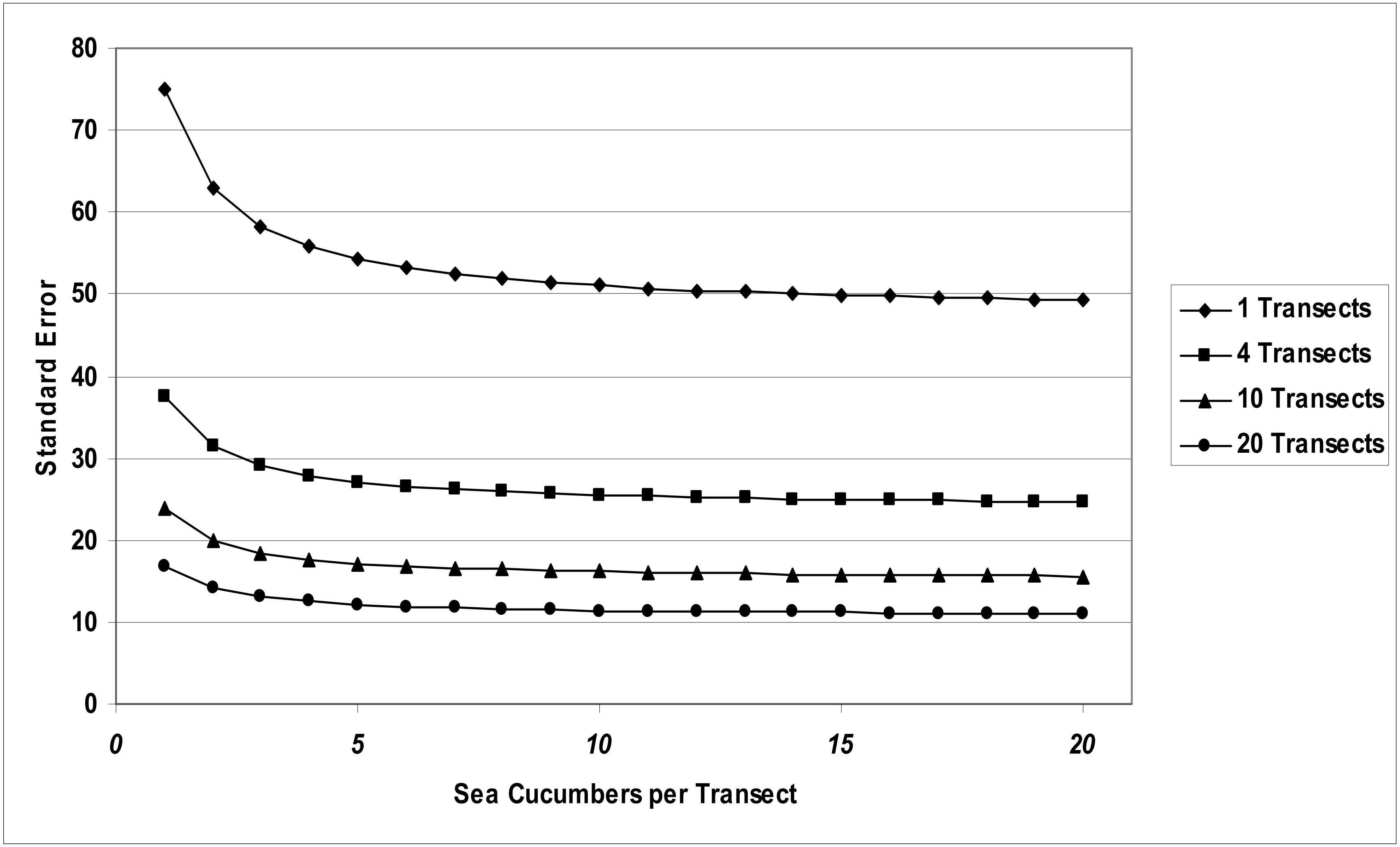

Figure 13.–Estimated standard error of average weight as a function of number of transects sampled and number of sea cucumbers per transect sampled for weight.

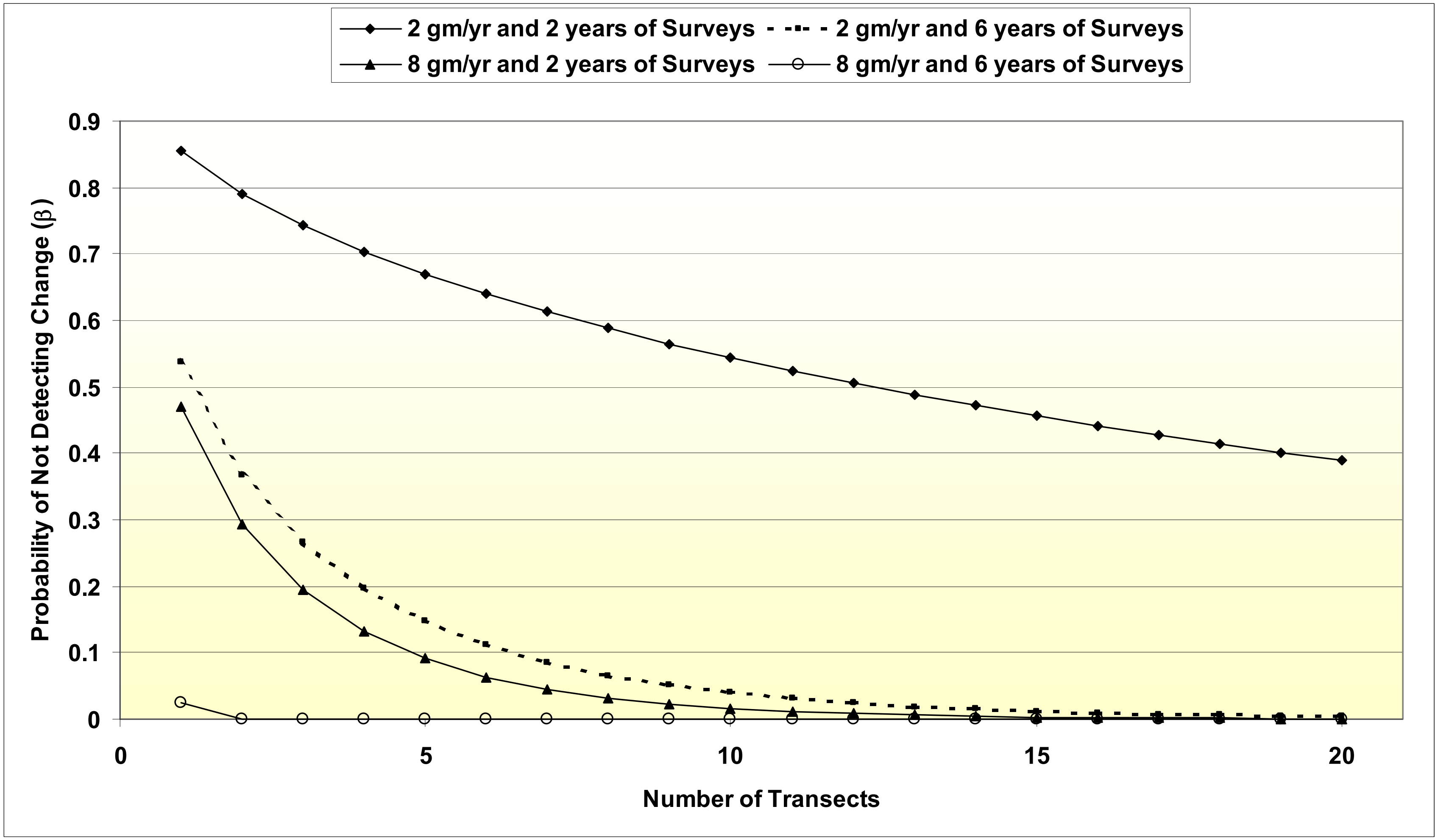

Figure 14.–Estimated probability of not detecting a trend in mean weights (1-Power) as a function of the true change in weight, number of years of surveys with weight data, and number of transects. It is assumed that each sample contains 15 individual sea cucumber weights and a three year rotation.

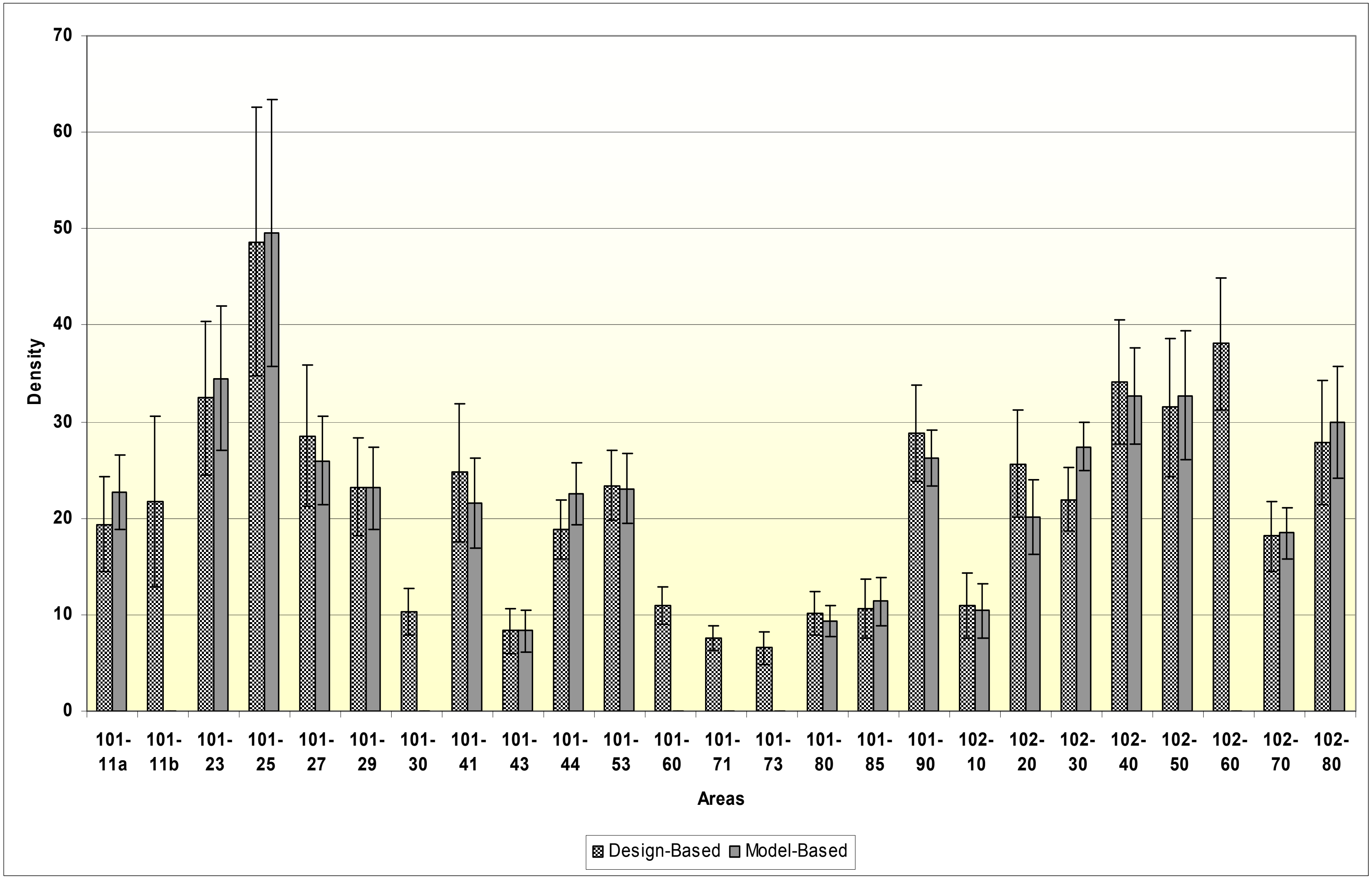

Figure 15.–Estimated abundance in last survey year and associated standard errors of areas in Districts 101 and 102 using design-based and model based estimation methods.

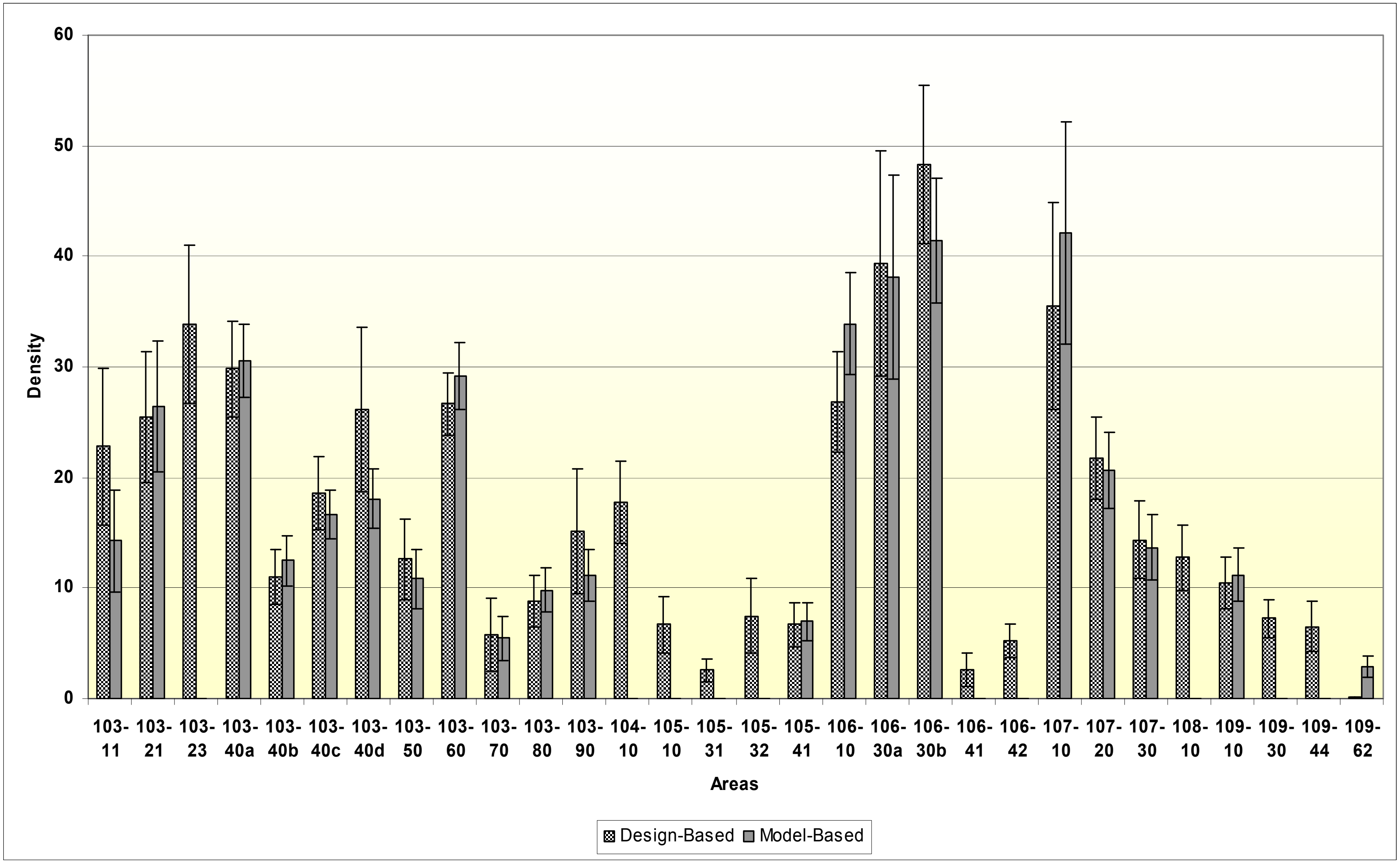

Figure 16.–Estimated abundance in last survey year and associated standard errors of areas in Districts 103 through 109 using design-based and model based estimation methods.

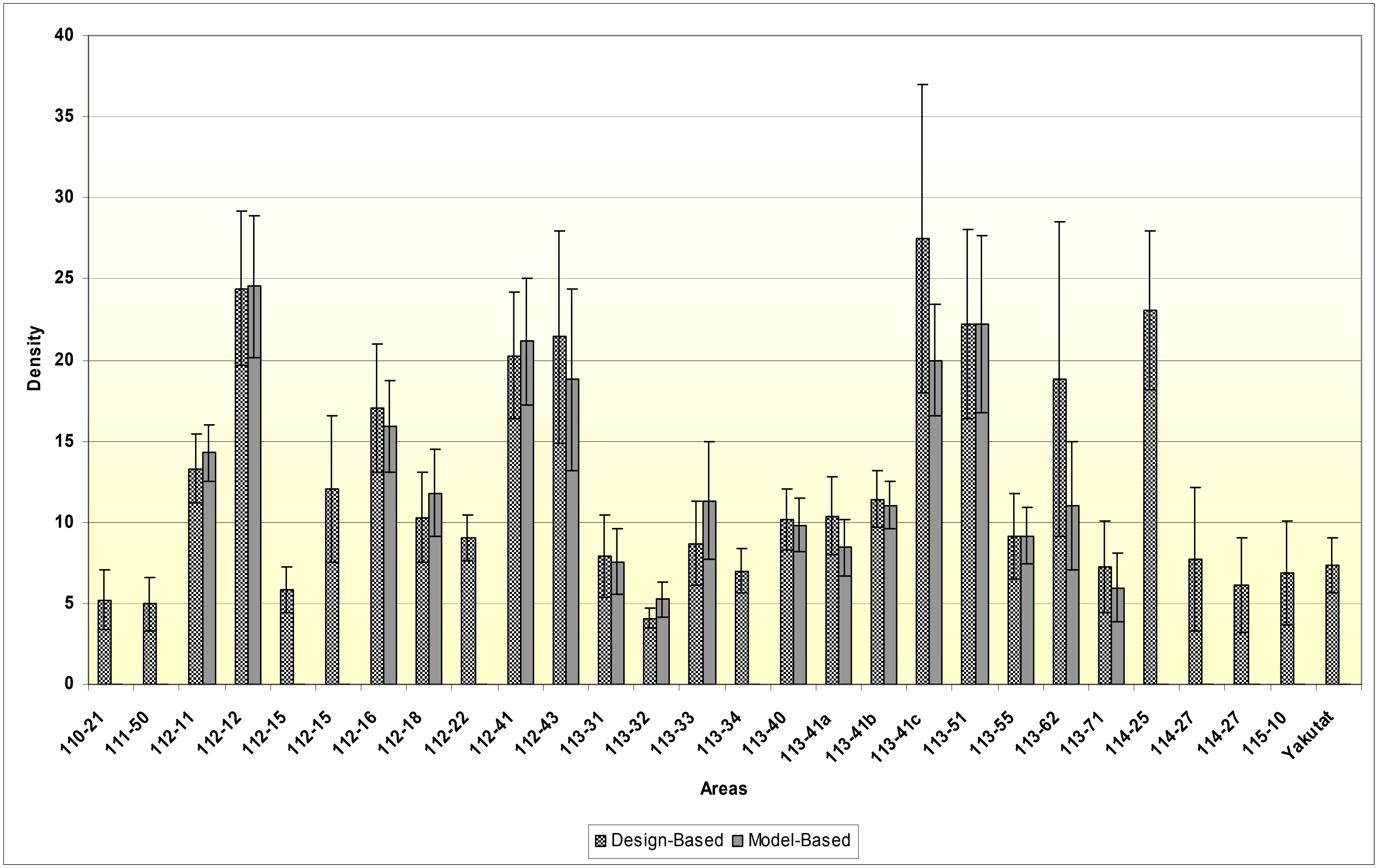

Figure 17.–Estimated abundance in last survey year and associated standard errors of areas in Districts 111 through 115 and Yakutat using design-based and model based estimation methods.

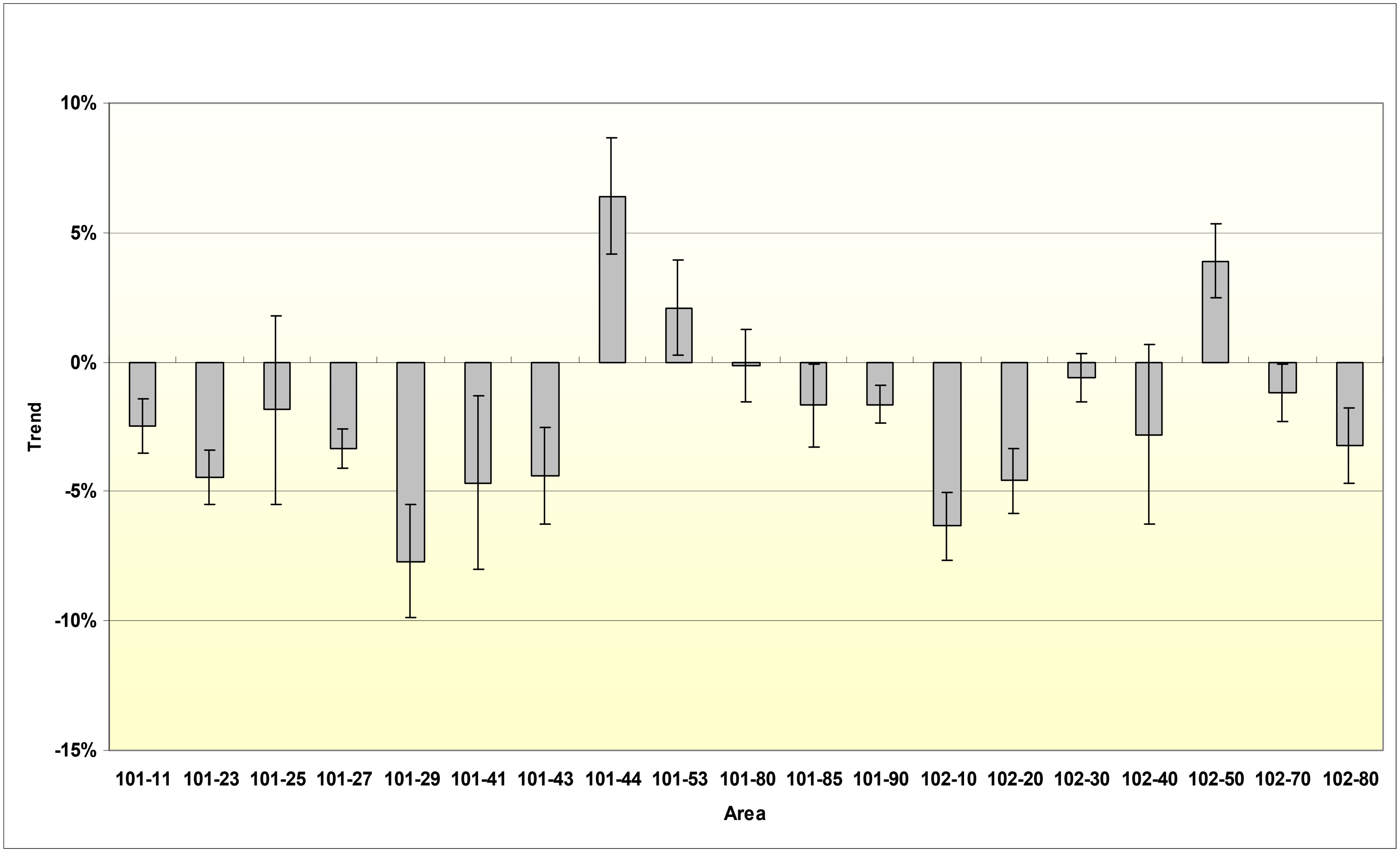

Figure 18.–Estimated trends in annual change in average density of sea cucumbers in Districts 101 and 102. Error bars are +/1 standard error about the estimated mean change. Percent change for each area is calculated as (exp(β)-1), where (β) represents the estimated change in weight.

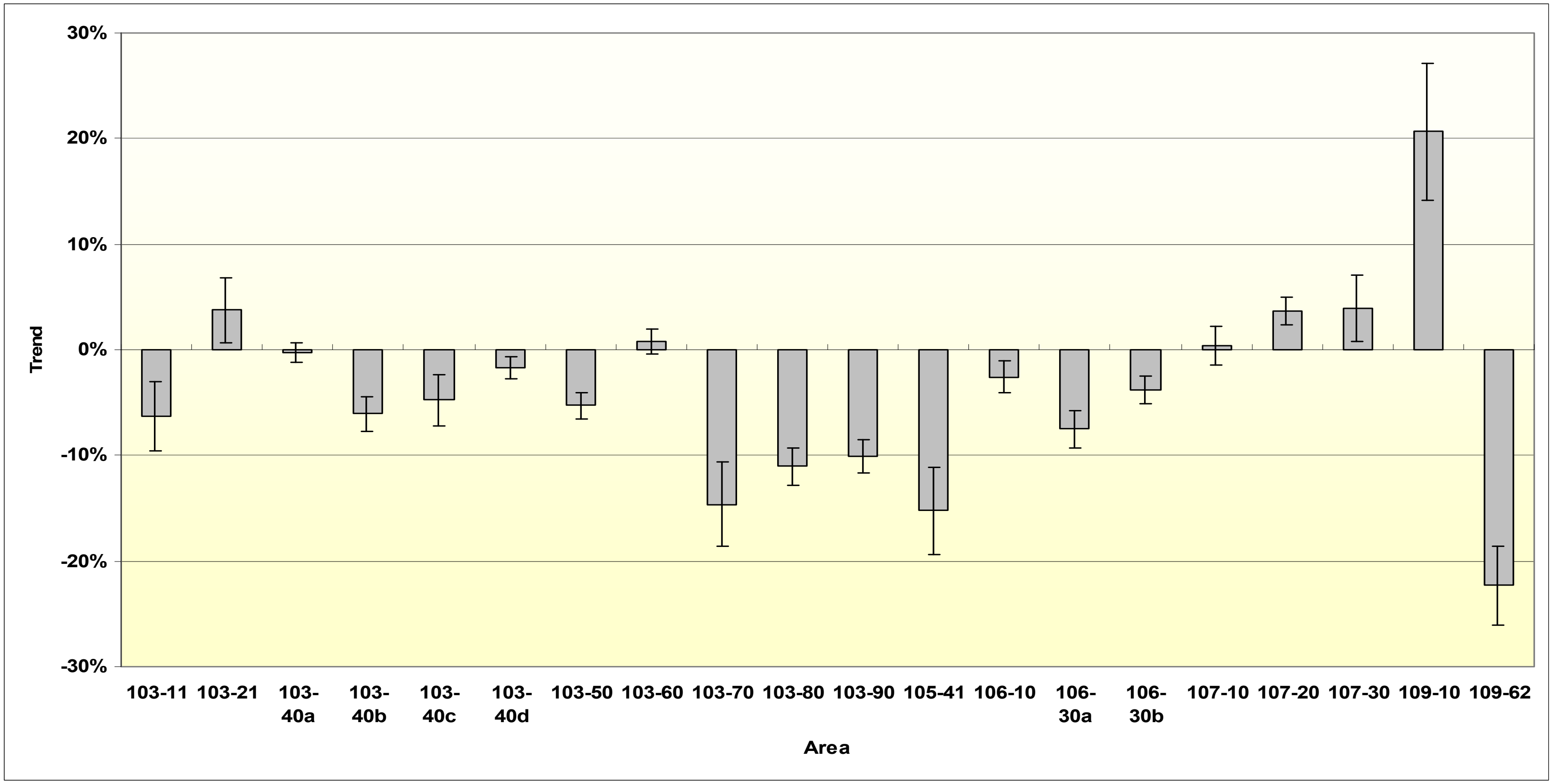

Figure 19.–Estimated trends in annual change in average density of sea cucumbers in Districts 103 through 109. Error bars are +/- 1 standard error about the estimated mean change. Percent change for each area is calculated as (exp(β)-1), where (β) represents the estimated change in weight.

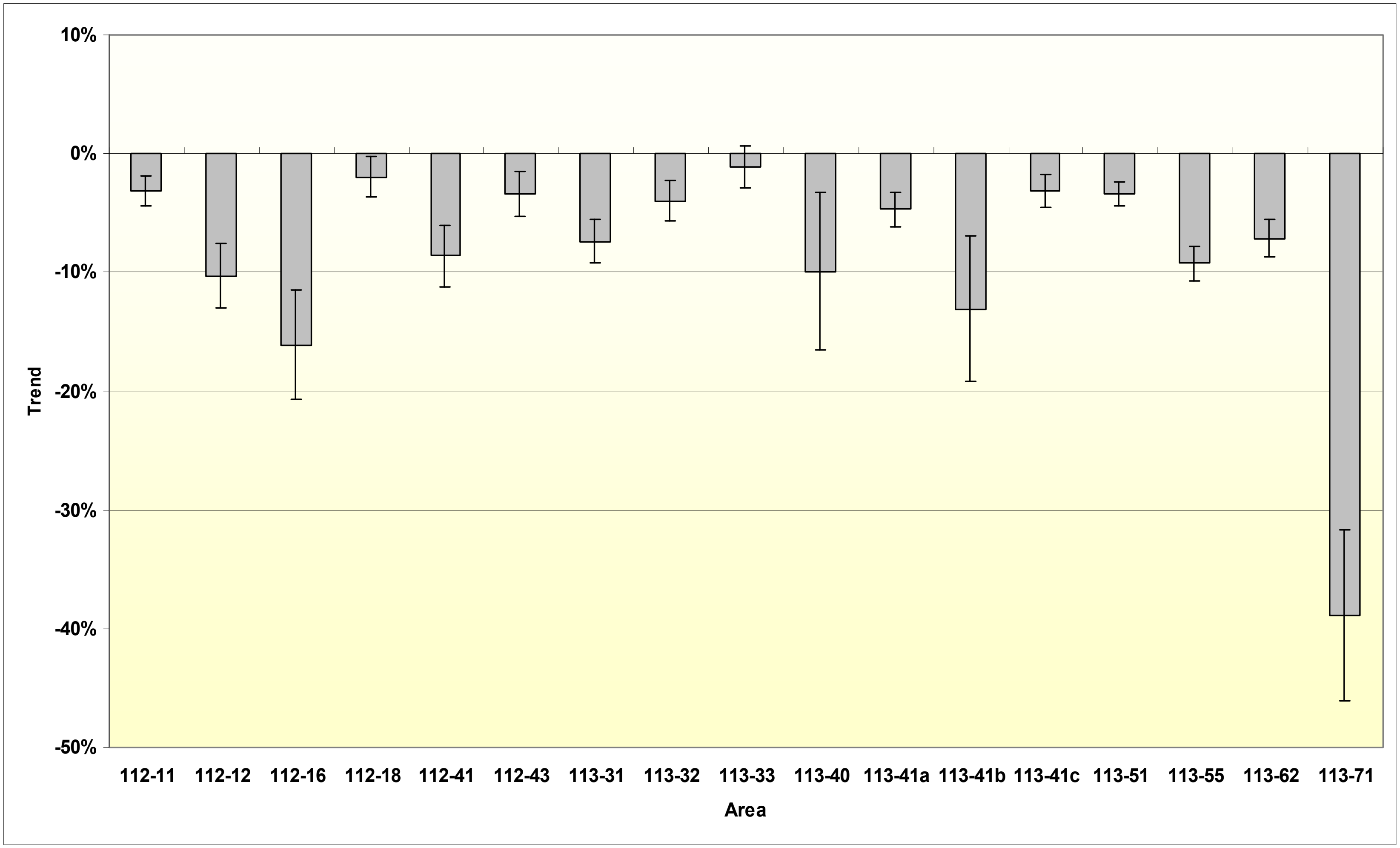

Figure 20.–Estimated trends in annual change in average density of sea cucumbers in Districts 112 and 113. Error bars are +/- 1 standard error about the estimated mean change. Percent change for each area is calculated as (exp(β)-1), where (β) represents the estimated change in weight.

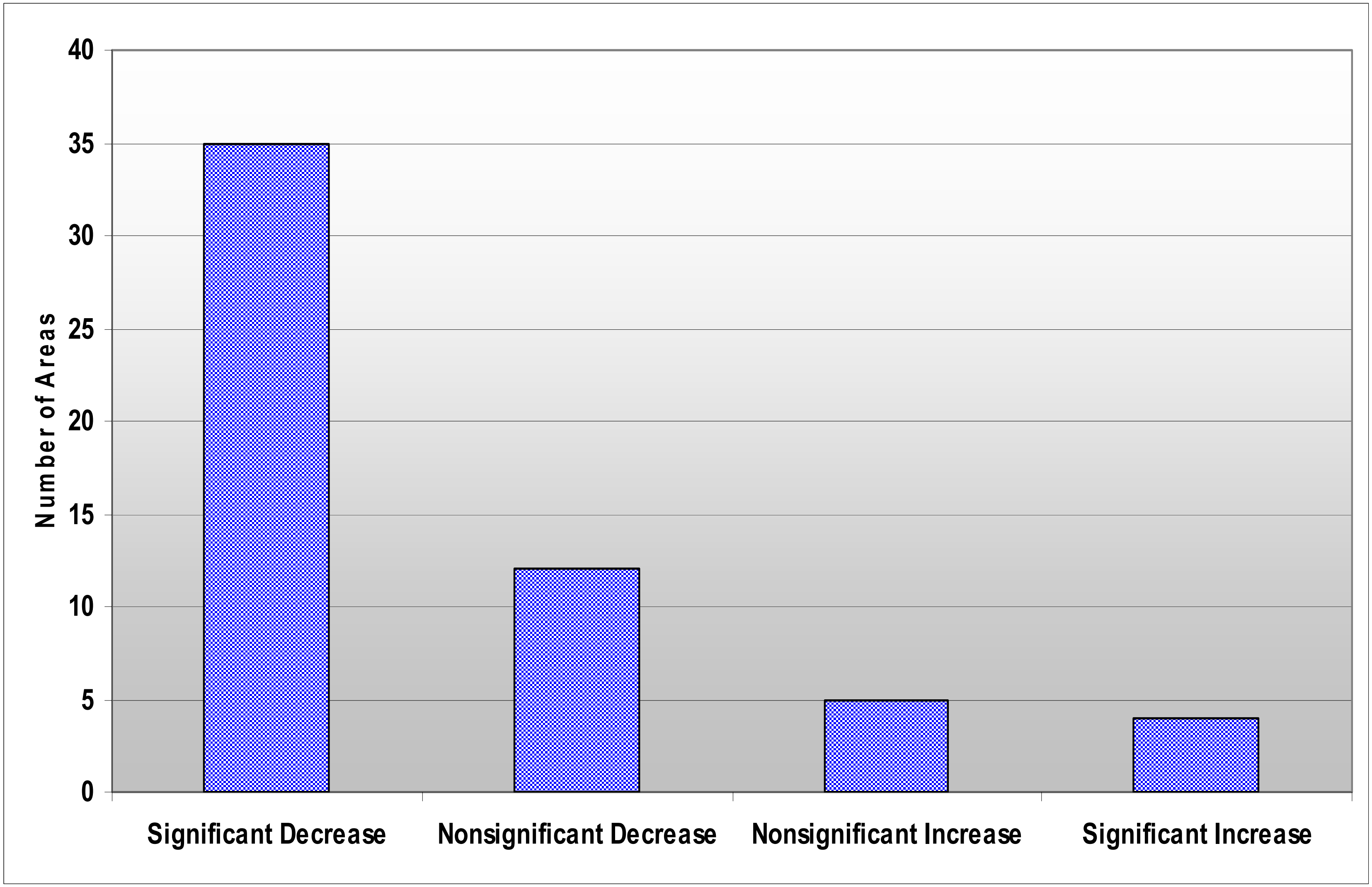

Figure 21.– Direction and statistical significance of estimated change in average density of sea cucumbers in areas with multiple years of count data.

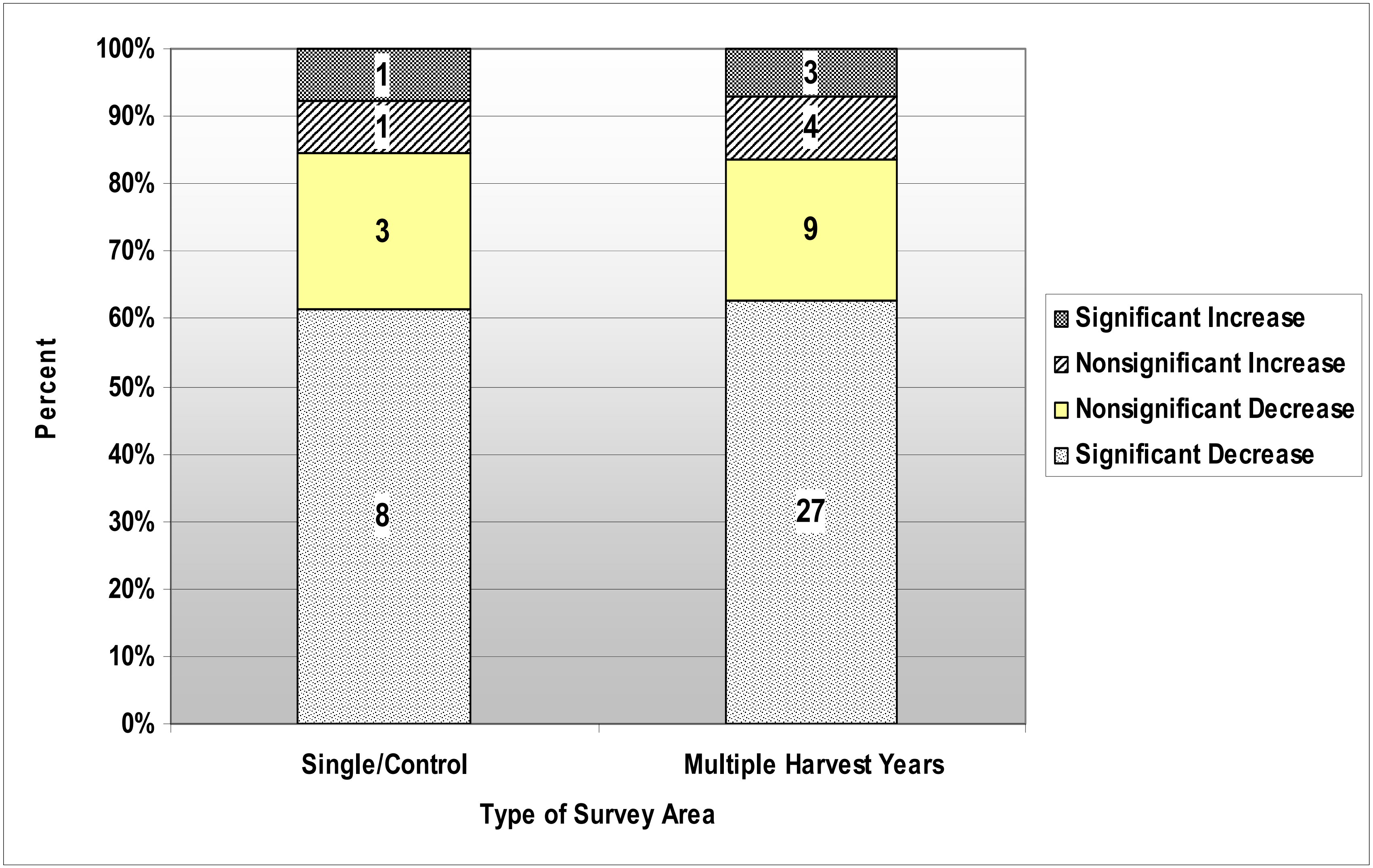

Figure 22.– Comparison of harvest history with trend direction and statistical significance of average counts of sea cucumbers. Single/Control areas are areas with no history of commercial harvest or a single year of commercial harvest. Multiple Harvest Years areas are areas with 2 to 5 years of commercial harvest.

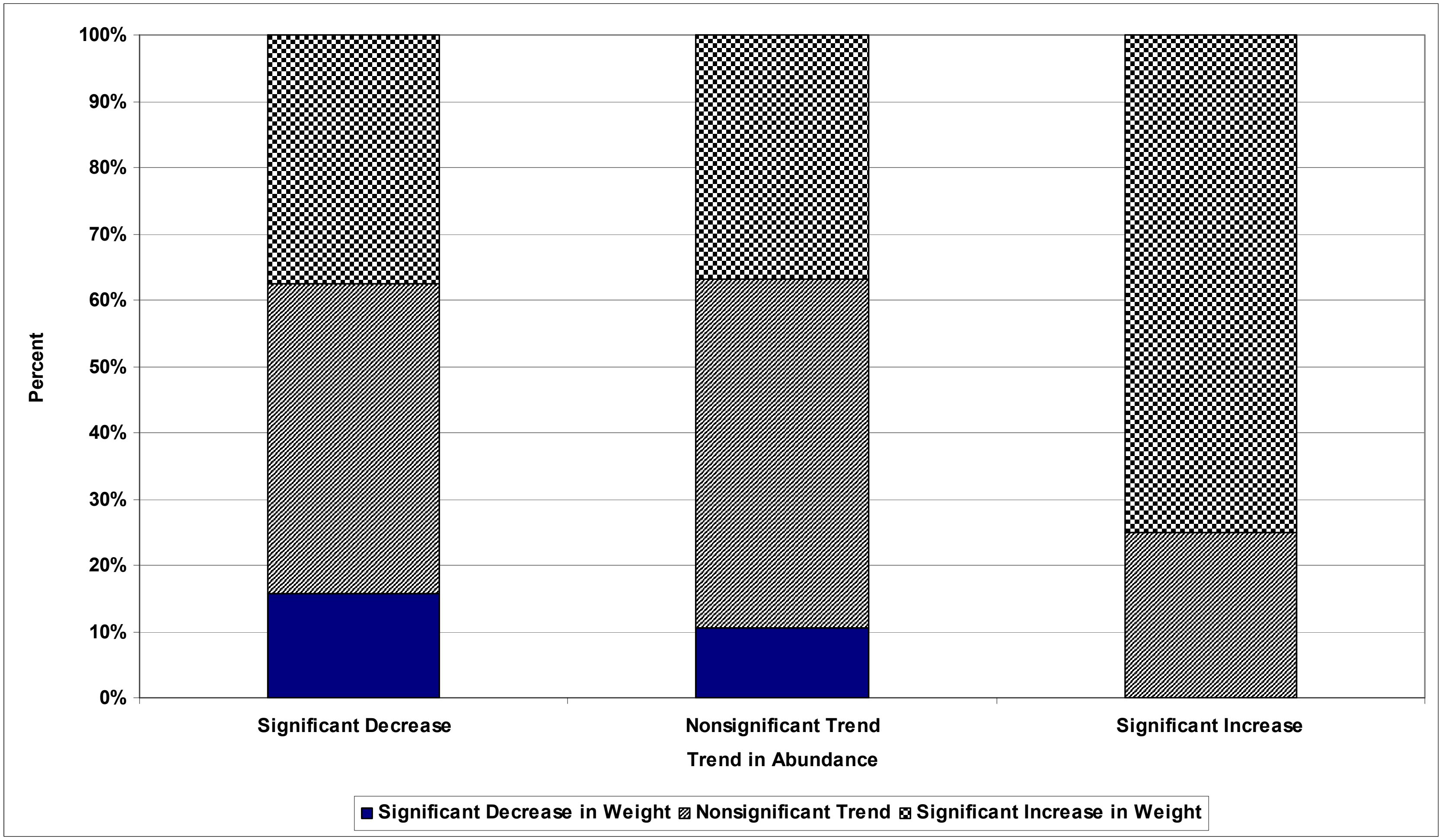

Figure 23.–Comparison of trend in abundance with trend in weight for the 55 areas with multiple years of count and weight data.

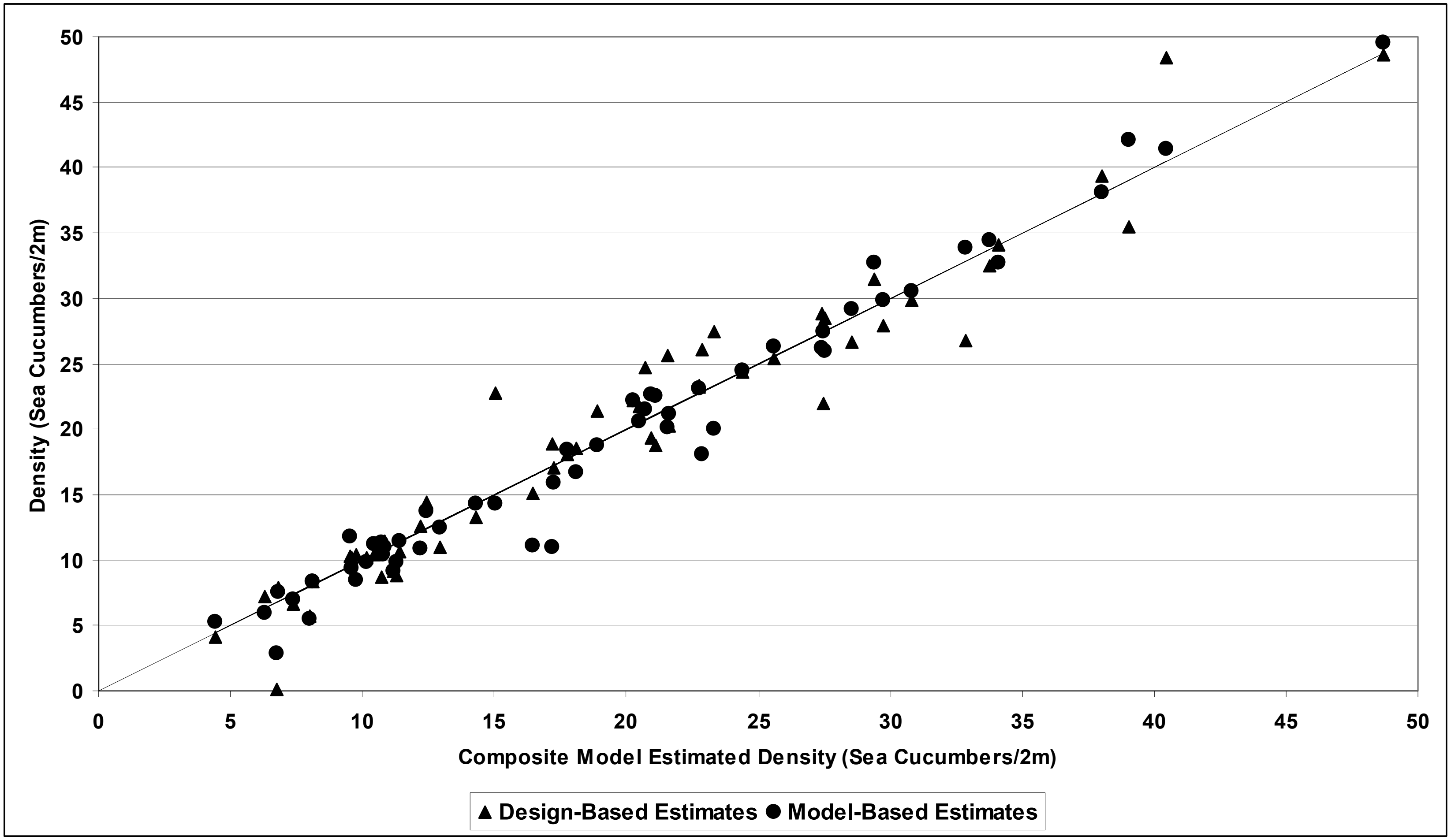

Figure 24.–Comparison of sea cucumber density estimates using the composite model with density estimates using the design-based and model-based methods. Solid line is the 1:1 composite model line for comparative purposes.

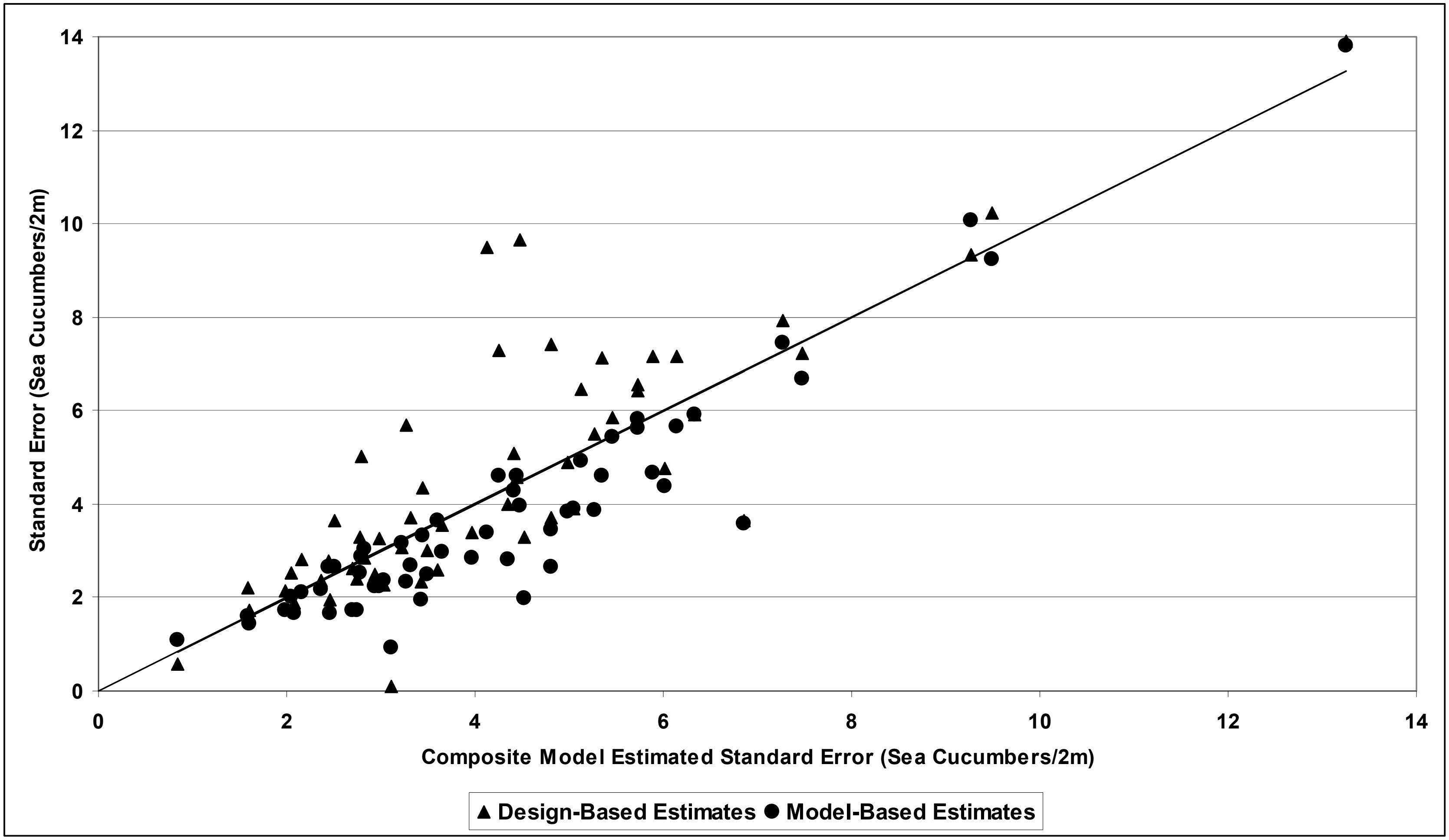

Figure 25.–Comparison of sea cucumber standard errors of density estimates using the composite model with standard errors using the design-based and model-based methods. Solid line is the 1:1 composite model line for comparative purposes.

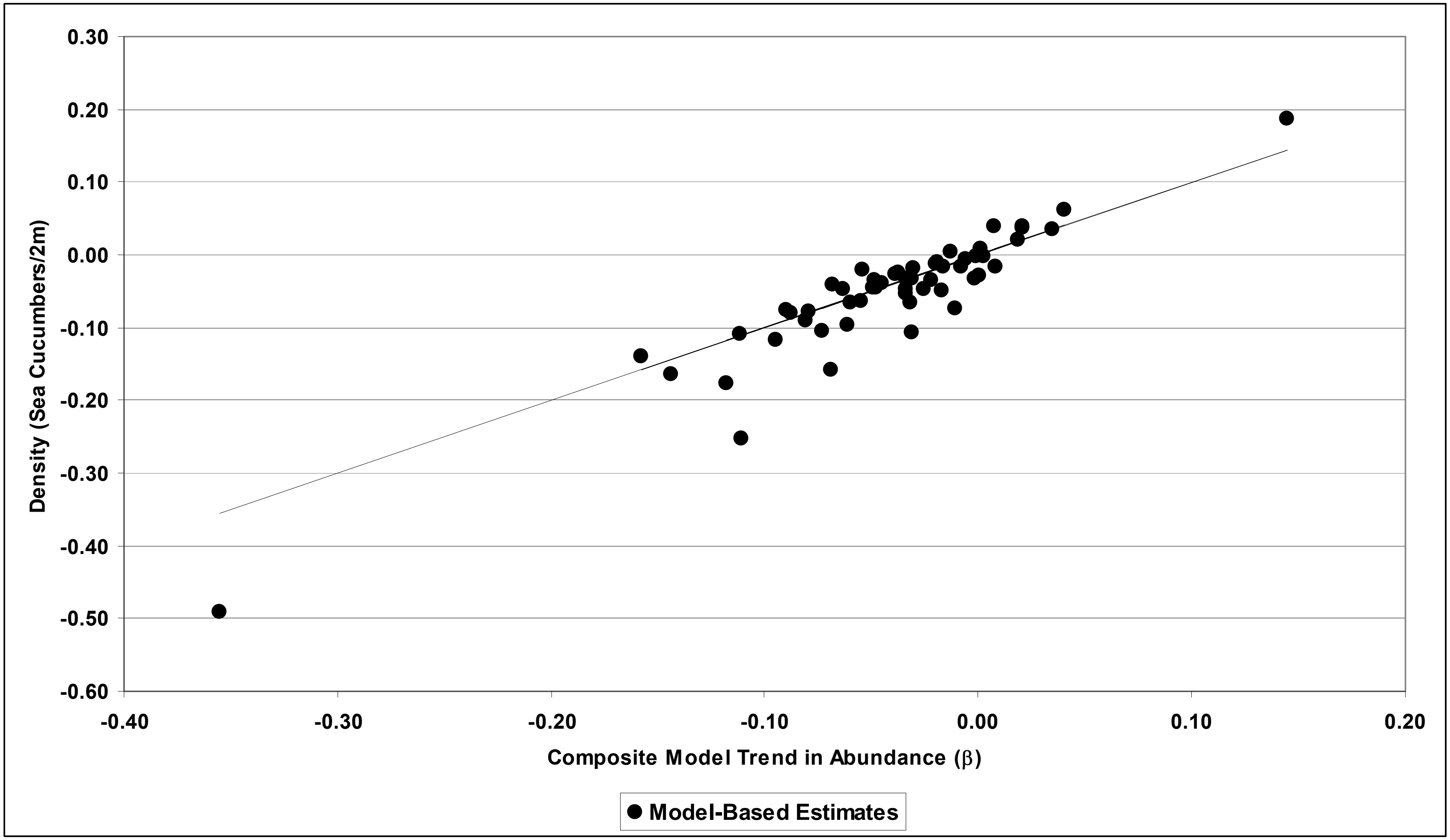

Figure 26.–Comparison of estimated trends in sea cucumber abundance using the composite model with trend estimates using the model-based methods. Solid line is the 1:1 composite model line for comparative purposes.

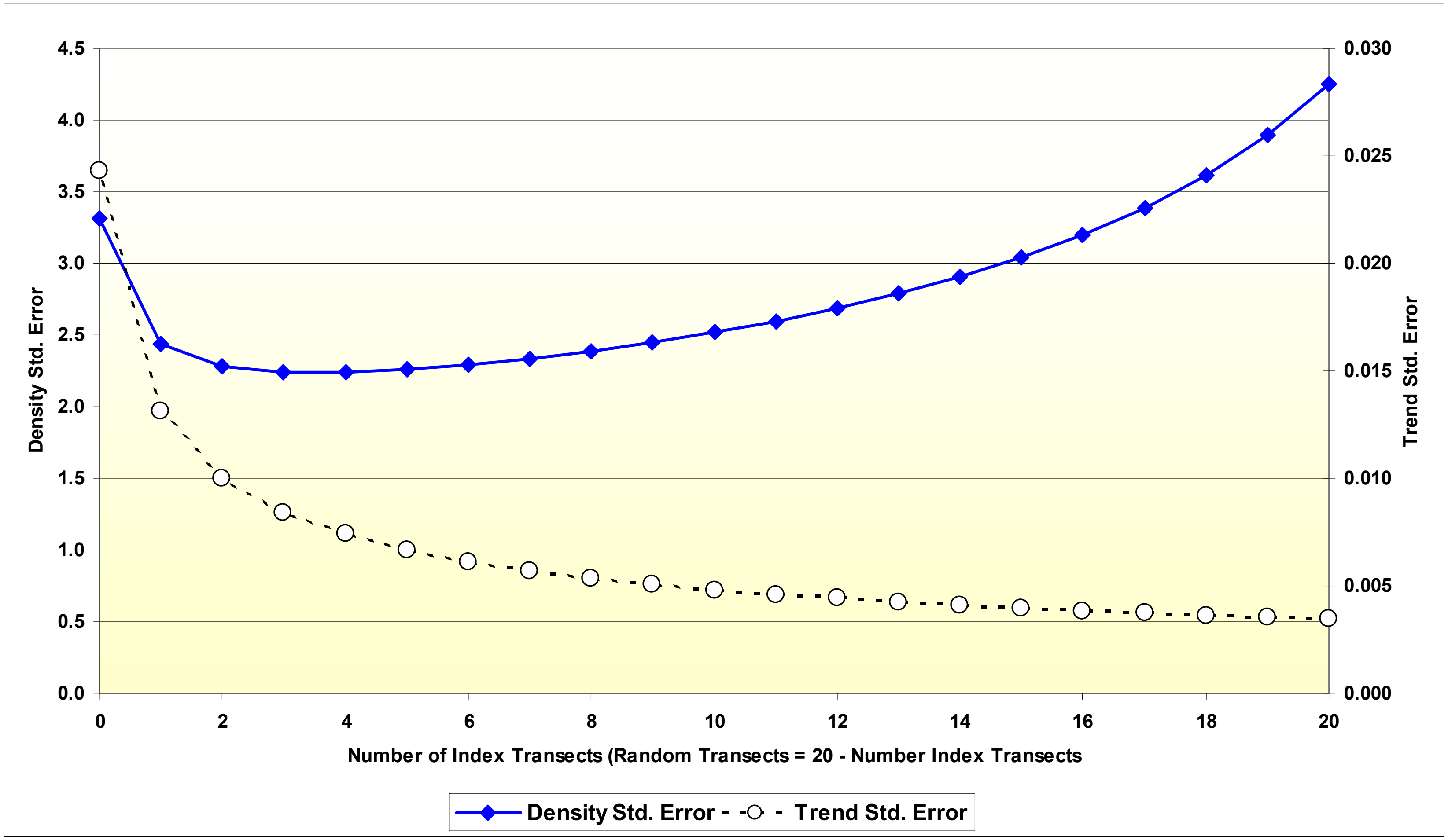

Figure 27.–Estimated standard error of average density (sea cucumbers per 2 meter transect) and standard error of trend in abundance as a function of different number of index and random transects. A total of 20 transects are divided into either index or random transects. Model values include 5 surveys conducted over a 12 year period (every 3 years), median estimated variability in counts (k – 0.96), average density of 18.5 animals per 2 meter transect, 2 diver counts per transect, and a decreasing abundance of 3.9% per year.

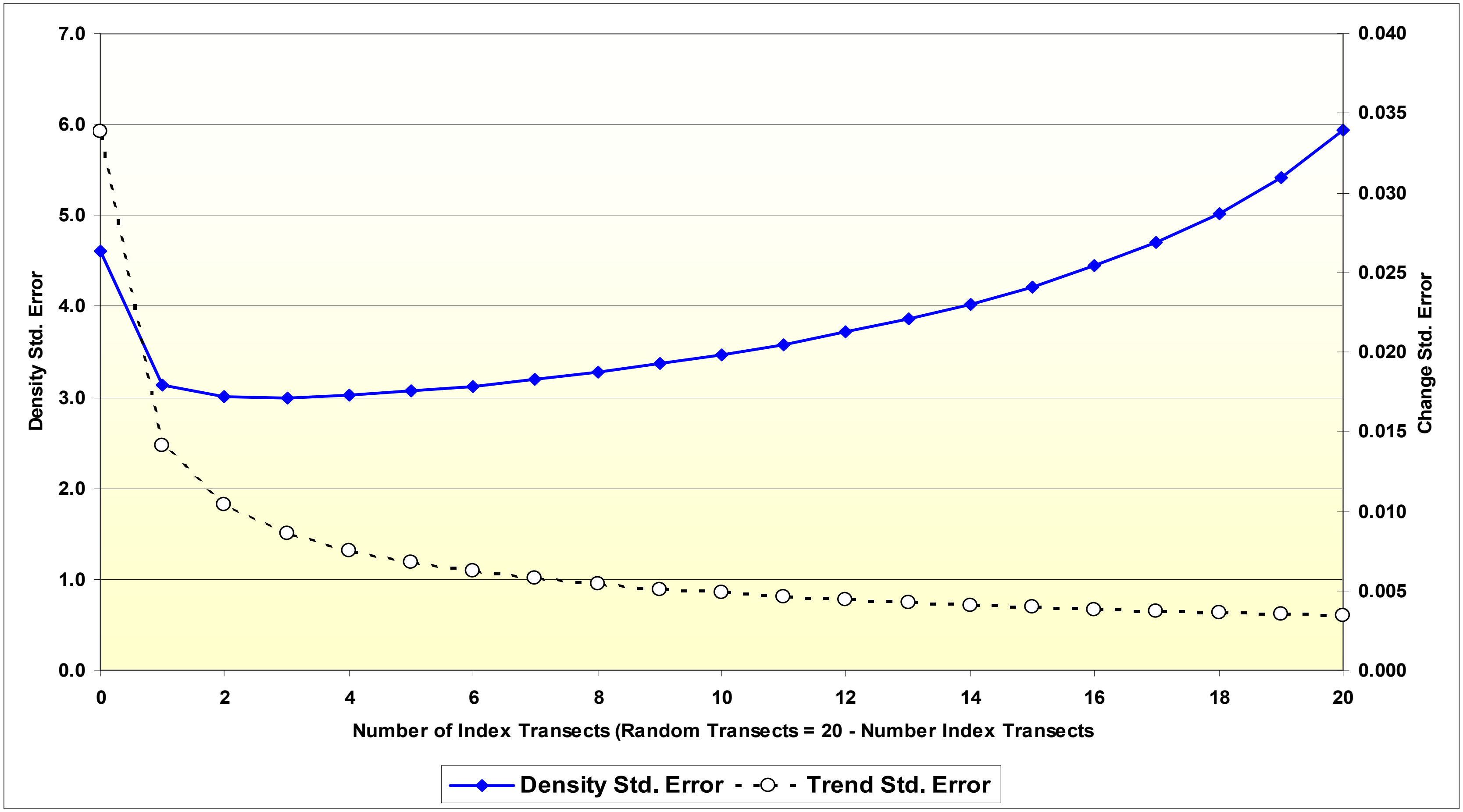

Figure 28.–Estimated standard error of average density (sea cucumbers per 2 meter transect) and standard error of trend in abundance as a function of different number of index and random transects. A total of 20 transects are divided into either index or random transects. Model values include 5 surveys conducted over a 12 year period (every 3 years), relatively high variability in counts (k = 0.46), average density of 18.5 animals per 2 meter transect, 2 diver counts per transect, and a decreasing abundance of 3.9% per year.

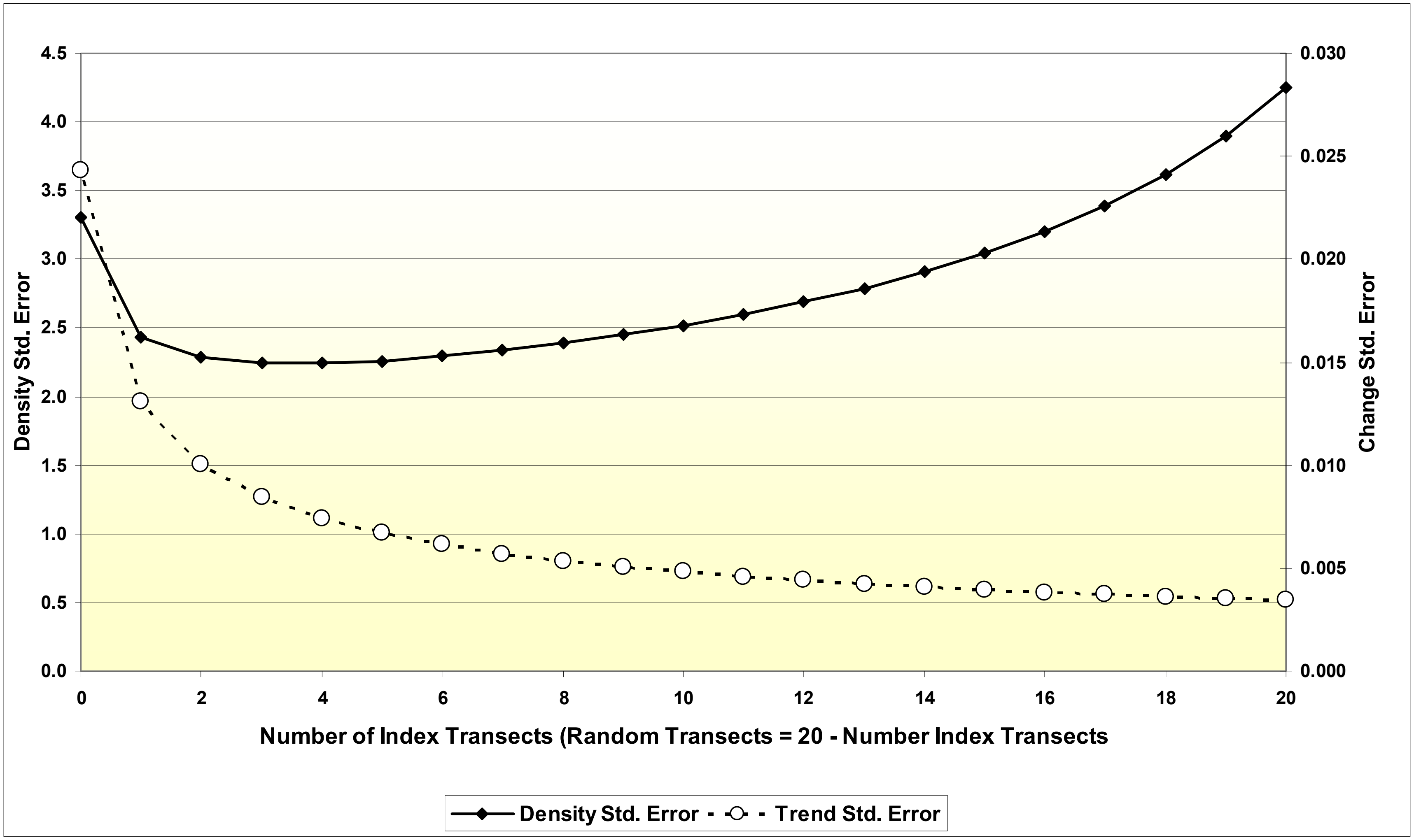

Figure 29.–Estimated standard error of average density (sea cucumbers per 2 meter transect) and standard error of trend in abundance as a function of different number of index and random transects. A total of 20 transects are divided into either index or random transects. Model values include 5 surveys conducted over a 12 year period (every 3 years), relatively high variability in counts (k = 0.46), average density of 18.5 animals per 2 meter transect, 2 diver counts per transect, and no trend in abundance.

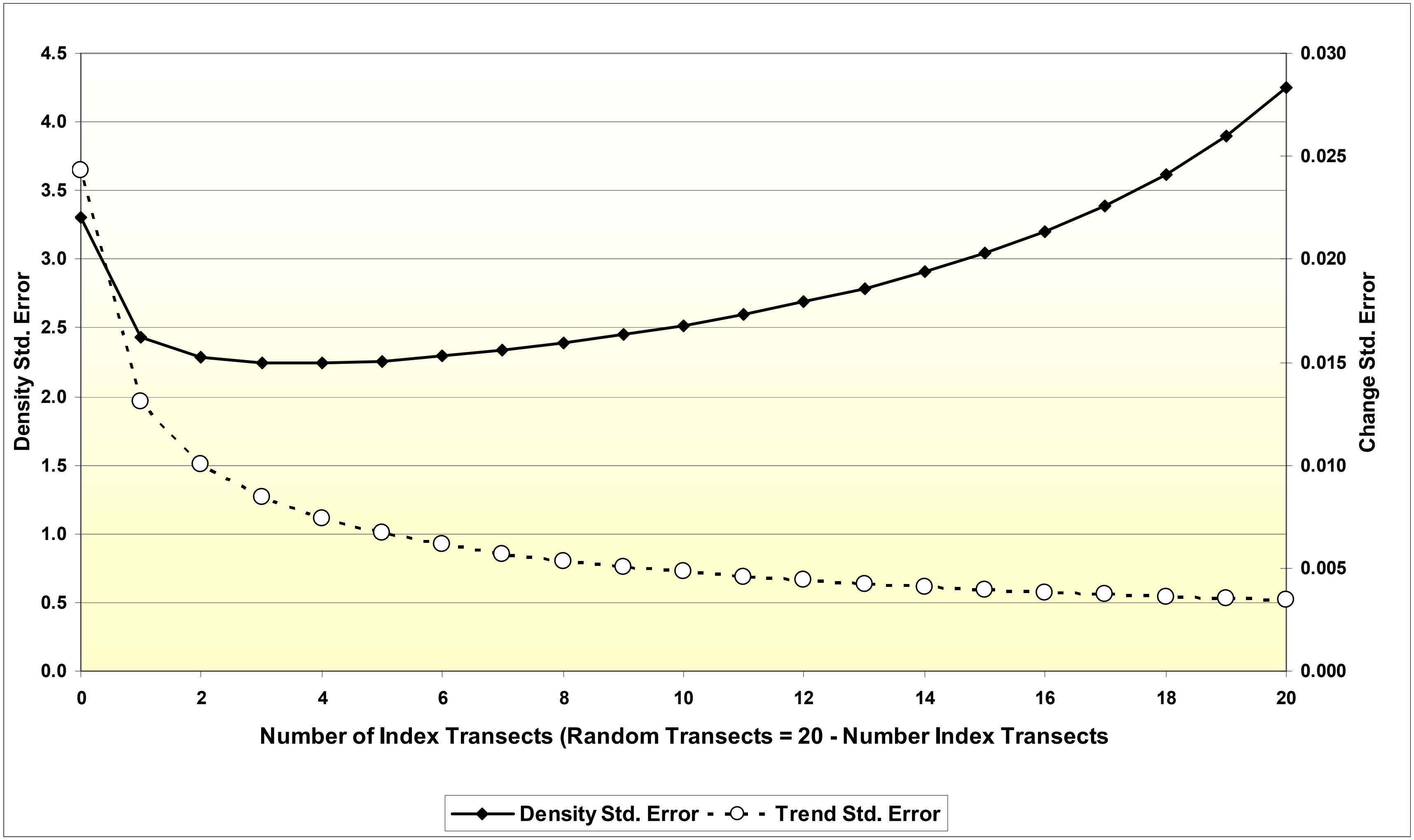

Figure 30.–Estimated standard error of average density (sea cucumbers per 2 meter transect) and standard error of trend in abundance as a function of different number of index and random transects. A total of 20 transects are divided into either index or random transects. Model values include 2 surveys conducted over a 3 year period, median estimated variability in counts (k – 0.96), average density of 18.5 animals per 2 meter transect, 2 diver counts per transect, and a decreasing abundance of 3.9% per year.

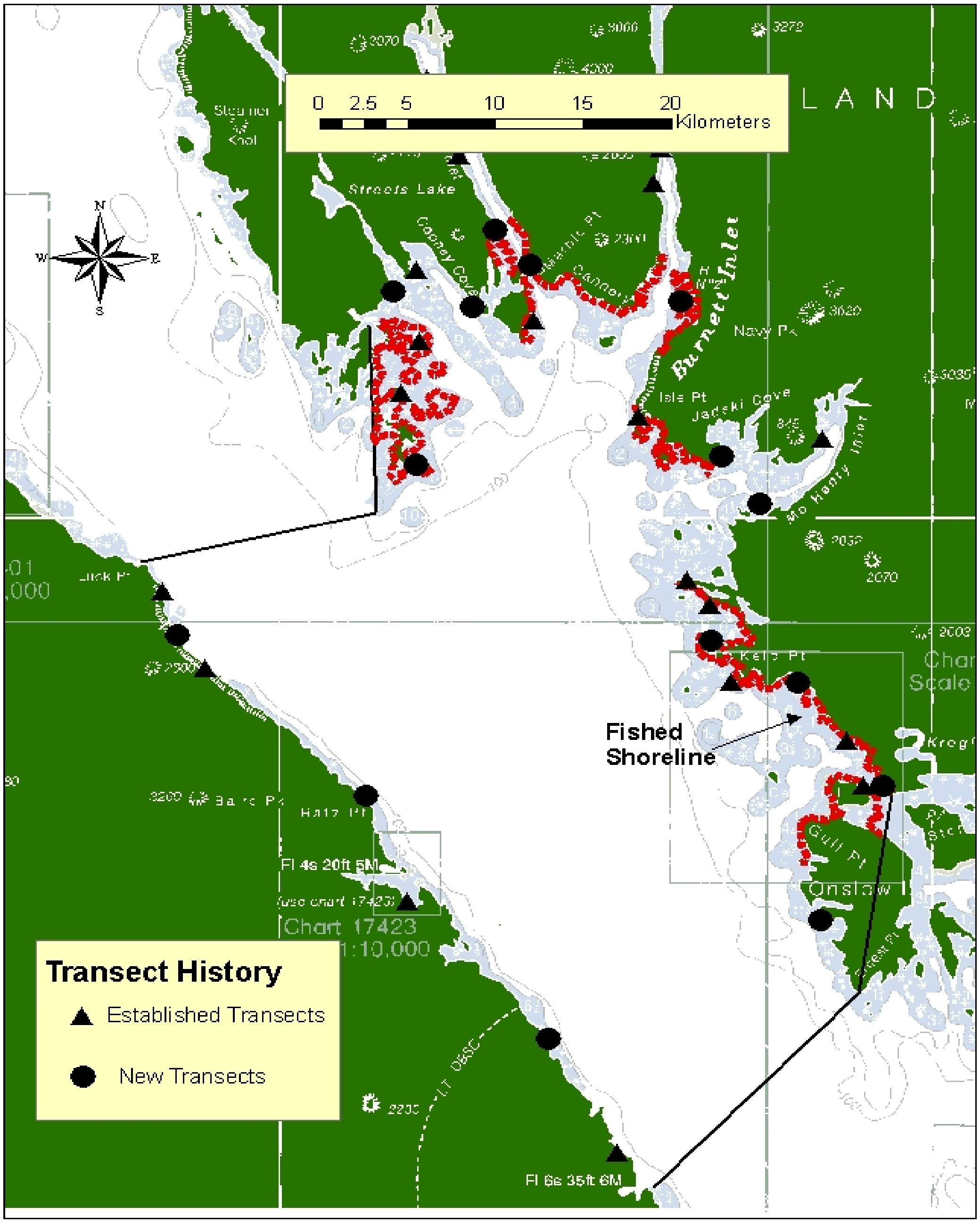

Figure 31.–Area 106-10, 20, 22 with transect locations and estimated shoreline that is fished and unfished shoreline.

APPENDIX A

Appendix. A.–The derivatives of the log-likelihood function:

Derivatives of the log-likelihood function,

$$\sum_i \sum_j \sum_h Ln[p(c_{ijh} / M_i; k; \beta)] = \sum_i \sum_j \sum_h kLn[k] - kLn(M_i) - k\beta t_j$$

$$- (k + c_{ijh}) Ln\left(\frac{k}{M_i e^{\beta t_j}} + 1 \right) + Ln(\Gamma(k + c_{ijh})) - Ln(\Gamma(k)) - Ln(c_{ijh}!) \tag{1}$$

are as follows:

For each M_i (this assumes of course that the M_is are independent as the joint probability density function maintained),

$$\partial \sum_j Ln(p(c_{ijh} / M_i; M_2; .M_{n_T}; \beta; k)) \Big/ \partial M_i = \sum_j \sum_h \frac{k(c_{ijh} - M_i e^{\beta t_j})}{M_i (k + M_i e^{\beta t_j})} \tag{2}$$

and for β and k

$$\partial \sum_j \sum_i Ln(p(c_{ij} / M_i; M_2; .M_{n_t}; \beta; k)) \Big/ \partial \beta = \sum_i \sum_j \sum_h \left(\frac{(c_{ijh} - M_i e^{\beta t_j})}{(k + M_i e^{\beta t_j})} \right) t_j k \tag{3}$$

And,

$$\partial \sum_j \sum_i Ln(p(c_{ijh} / M_i; M_2; .M_{n_t}; \beta; k)) \Big/ \partial k = \sum_i \sum_j \sum_h 1 + Ln(K) - Ln(M_i) - \beta t_j + \partial Ln(\Gamma(k + c_{ijh})) / \partial k$$

$$- \partial Ln(\Gamma(k)) / \partial k - \frac{(k + c_{ijh})}{k + M_i e^{\beta t_j}} - Ln\left(\frac{k}{M_i e^{\beta t_j}} + 1 \right) \tag{4}$$

The derivative of the log of the gamma function is termed the digamma function and can be approximated by,

$$\partial Ln(\Gamma(k)) / \partial k = \sum_{i=1}^{\infty} \frac{k}{i(i + k)} - \gamma - \frac{1}{k}, \tag{5}$$

and

$$\partial Ln(\Gamma(k + c_{ijh})) / \partial k = \sum_{i=1}^{\infty} \frac{k + c_{ijh}}{i(i + k + c_{ijh})} - \gamma - \frac{1}{(k + c_{ijh})}, \tag{6}$$

where γ is Euler's constant equal to 0.577215665.

-continued-

The second derivatives are:

$$\partial^2 \sum_j \sum_h Ln(p(c_{ijh}/M_i;M_2;.M_{n_t};\beta;k)) \Big/ \partial M_i^2 = \sum_j \sum_h \frac{-k(kc_{ijh}+2M_i e^{\beta t_j} c_{ijh} - M_i^2 e^{2\beta t_j})}{M_i^2 (k+M_i e^{\beta t_j})^2}, \quad (7)$$

$$\partial^2 \sum_j \sum_i \sum_h Ln(p(c_{ijh}/M_i;M_2;.M_{n_t};\beta;k)) \Big/ \partial\beta^2 = \sum_i \sum_j \sum_h -\left(\frac{(k+c_{ijh})}{(k+M_i e^{\beta t_j})^2}\right) t_j^2 k M_i e^{\beta t_j}, \quad (8)$$

$$\partial^2 \sum_j \sum_i \sum_h Ln(p(c_{ijh}/M_i;M_2;.M_{n_t};\beta;k)) \Big/ \partial k^2 = \sum_i \sum_j \sum_h \frac{1}{k} - \frac{2}{k+M_i e^{\beta t_j}} + \frac{k+c_{ijh}}{(k+M_i e^{\beta t_j})^2} + \quad (9)$$

$$\partial^2 Ln(\Gamma(k+c_{ijh}))/\partial k^2 - \partial^2 Ln(\Gamma(k))/\partial k^2$$

where the second derivative of the log of the gamma function is termed the trigamma function and can be approximated by,

$$\partial^2 Ln(\Gamma(k))/\partial k^2 = \sum_{i=1}^{\infty} \frac{i}{i(i+k)^2} + \frac{1}{k^2}, \text{ and} \quad (10)$$

$$\partial^2 Ln(\Gamma(k+c_{ijh}))/\partial k^2 = \sum_{i=1}^{\infty} \frac{i}{i(i+k+c_{ijh})^2} + \frac{1}{(k+c_{ijh})^2}. \quad (11)$$

The partial derivatives are as follows:

$$\partial^2 \sum_j \sum_h Ln(p(c_{ijh}/M_i;M_2;.M_{n_t};\beta;k)) \Big/ \partial M_i \partial k = \sum_j \sum_h \frac{c_{ijh}-M_i e^{\beta t_j}}{M_i(k+M_i e^{\beta t_j})} - \frac{k(c_{ijh}-M_i e^{\beta t_j})}{M_i(k+M_i e^{\beta t_j})^2}, \quad (12)$$

$$\partial^2 \sum_j \sum_i \sum_h Ln(p(c_{ijh}/M_i;M_2;.M_{n_t};\beta;k)) \Big/ \partial\beta\partial k = \sum_i \sum_j \sum_h t_j \left(\frac{(c_{ijh}-M_i e^{\beta t_j})}{(k+M_i e^{\beta t_j})}\right) - t_j k \left(\frac{(c_{ijh}-M_i e^{\beta t_j})}{(k+M_i e^{\beta t_j})^2}\right) \quad (13)$$

And,

$$\partial^2 \sum_j \sum_h Ln(p(c_{ijh}/M_i;M_2;.M_{n_t};\beta;k)) \Big/ \partial M_i \partial\beta = \sum_j -t_j k e^{\beta t_j} \left(\frac{1}{(k+M_i e^{\beta t_j})} + \frac{c_{ijh}-M_i e^{\beta t_j}}{(k+M_i e^{\beta t_j})^2}\right) \quad (14)$$

–continued–

For the second model, its equation is as follows:

$$Ln[P(c_{i1},c_{i,2},...,c_{i,n_s}/k,M_0,\beta)] =$$

$$\sum_{i=1}^{n_T}\left[\begin{array}{l} kLn(k) - kLn(M_0) + \beta\sum_{j=1}^{n_{i,yr}} t_j \sum_{h=1}^{n_{ih(j)}} c_{ijh} + Ln(\Gamma(k + \sum_{j=1}^{n_{i,yr}}\sum_{h=1}^{n_{ih(j)}} c_{ijh})) - Ln(\Gamma(k)) - \sum_{j=1}^{n_{i,yr}}\sum_{h=1}^{n_{ih(j)}} Ln(c_{ijh}!) \\ -(k + \sum_{j=1}^{n_{i,yr}}\sum_{h=1}^{n_{ih(j)}} c_{ijh})Ln\left(\frac{k}{M_0} + \sum_{j=1}^{n_s} n_{ih(j)}e^{\beta t_j}\right) \end{array}\right] \qquad (15)$$

The first and second derivatives with respect to M_0 are

$$\partial\ Ln[P(c_{i1},c_{i,2},...,c_{i,n_s})] \Big/ \partial M_0 = -\tfrac{n_T k}{M_0} + \sum_{i=1}^{n_T} \frac{k(k + \sum_{j=1}^{n_{i,yr}}\sum_{h=1}^{n_{ih(j)}} c_{ijh})}{M_0\left(k + M_0\sum_{j=1}^{n_{i,yr}} n_{ih(j)}e^{\beta t_j}\right)}, \text{ and} \qquad (16)$$

$$\partial^2 Ln[P(c_{i1},c_{i,2},...,c_{i,n_s})] \Big/ \partial M_0^2 = \tfrac{n_T k}{M_0^2} - \sum_{i=1}^{n_T} \frac{k(k + \sum_{j=1}^{n_{i,yr}}\sum_{h=1}^{n_{ih(j)}} c_{ijh})\left(k + 2M_0\sum_{j=1}^{n_{i,yr}} n_{ih(j)}e^{\beta t_j}\right)}{M_0^2\left(k + M_0\sum_{j=1}^{n_{i,yr}} n_{ih(j)}e^{\beta t_j}\right)^2} \qquad (17)$$

The first and second derivatives of the probability function with respect to β are

$$\partial\ Ln[P(c_{i1},c_{i,2},...,c_{i,n_s})] \Big/ \partial\beta = \sum_{i=1}^{n_T}\ \sum_{j=1}^{n_{i,yr}} t_j \sum_{h=1}^{n_{ih(j)}} c_{ijh} - \frac{(k + \sum_{j=1}^{n_{i,yr}}\sum_{h=1}^{n_{ih(j)}} c_{ijh})M_0\sum_{j=1}^{n_{i,yr}} n_{ih(j)}t_j e^{\beta t_j}}{\left(k + M_0\sum_{j=1}^{n_{i,yr}} n_{ih(j)}e^{\beta t_j}\right)} \qquad (18)$$

and,

$$\partial^2 Ln[P(c_{i1},c_{i,2},...,c_{i,n_s})] \Big/ \partial\beta^2 = \sum_{i=1}^{n_T}\ \frac{\left(k + \sum_{j=1}^{n_{i,yr}}\sum_{h=1}^{n_{ih(j)}} c_{ijh}\right)\left(M_0\sum_{j=1}^{n_{i,yr}} n_{ih(j)}t_j e^{\beta t_j}\right)^2}{\left(k + M_0\sum_{j=1}^{n_{i,yr}} n_{ih(j)}e^{\beta t_j}\right)^2} - \qquad (19)$$

$$\frac{\left(k + \sum_{j=1}^{n_{i,yr}}\sum_{h=1}^{n_{ih(j)}} c_{ijh}\right)\left(M_0\sum_{j=1}^{n_{i,yr}} n_{ih(j)}t_j^2 e^{\beta t_j}\right)}{\left(k + M_0\sum_{j=1}^{n_{i,yr}} n_{ih(j)}e^{\beta t_j}\right)}$$

-continued-

The first and second derivatives of the probability function with respect to *k* are,

$$\partial\ Ln[P(c_{i1},c_{i,2},...,c_{i,n_s})] \Big/ \partial k = \sum_{i=1}^{n_T} \ Ln(k)+1-Ln(M_0)+ \left. \partial Ln\left(\Gamma\left(k+\sum_{j=1}^{n_{i,yr}}\sum_{h=1}^{n_{ih(j)}} c_{ijh}\right)\right) \right/ \partial k - \partial Ln(\Gamma(k)) \Big/ \partial k \tag{20}$$

$$-\frac{(k+\sum_{j=1}^{n_{i,yr}}\sum_{h=1}^{n_{ih(j)}} c_{ijh})}{k+M_0\sum_{j=1}^{n_{i,yr}} n_{ih(j)s}e^{\beta t_j}} - Ln\left(\frac{k}{M_0}+\sum_{j=1}^{n_{i,yr}} n_{ih(j)}e^{\beta t_j}\right)$$

and,

$$\partial^2 Ln[P(c_{i1},c_{i,2},...,c_{i,n_s})] \Big/ \partial k^2 = \sum_{i=1}^{n_T} \ \frac{1}{k}+ \left. \partial^2 Ln\left(\Gamma\left(k+\sum_{j=1}^{n_{i,yr}}\sum_{h=1}^{n_{ih(j)}} c_{ijh}\right)\right) \right/ \partial k^2 - \partial^2 Ln(\Gamma(k)) \Big/ \partial k^2 \tag{21}$$

$$+\frac{(k+\sum_{j=1}^{n_{i,yr}}\sum_{h=1}^{n_{ih(j)}} c_{ijh})}{\left(k+M_0\sum_{j=1}^{n_{i,yr}} n_{ih(j)}e^{\beta t_j}\right)^2} - \frac{2}{\left(k+M_0\sum_{j=1}^{n_s} n_{ijs}e^{\beta y_j}\right)}$$

The derivatives of $Ln(\Gamma(k))$ and $Ln(\Gamma(k+c_{ijh}))$ are the digamma and trigamma functions and are the same as those previously presented.

The partial derivatives of the probability function with respect to M_0 and β, M_0 and k, and k and β, are

$$\partial\ Ln[P(c_{i1},c_{i,2},...,c_{i,n_s})] \Big/ \partial\beta\partial M_0 = \sum_{i=1}^{n_T} \ \frac{(k+\sum_{j=1}^{n_{yr}}\sum_{h=1}^{n_{ijs}} c_{ijh})M_0\sum_{j=1}^{n_{yr}} n_{ijs}e^{\beta y_j}\sum_{j=1}^{n_{yr}} n_{ijs}y_je^{\beta y_j}}{\left(k+M_0\sum_{j=1}^{n_s} n_{ijs}e^{\beta y_j}\right)^2} - \tag{22}$$

$$\frac{(k+\sum_{j=1}^{n_s}\sum_{h=1}^{n_{ijs}} c_{ijh})\sum_{j=1}^{n_{yr}} n_{ijs}y_je^{\beta y_j}}{\left(k+M_0\sum_{j=1}^{n_s} n_{ijs}e^{\beta y_j}\right)}$$

-continued-

$$\partial^2 Ln[P(c_{i1}, c_{i,2}, ..., c_{i,n_s})] \Big/ \partial M_0 \partial k = -\tfrac{n_T}{M_0} + \sum_{i=1}^{n_T} \frac{2k + \sum_{j=1}^{n_s} \sum_{h=1}^{n_{ijs}} c_{ijh}}{M_0 \left(k + M_0 \sum_{j=1}^{n_s} n_{ijs} e^{\beta y_j} \right)} - \frac{k(k + \sum_{j=1}^{n_s} \sum_{h=1}^{n_{ijs}} c_{ijh})}{M_0 \left(k + M_0 \sum_{j=1}^{n_s} n_{ijs} e^{\beta y_j} \right)^2}, \quad (23)$$

and,

$$\partial^2 Ln[P(c_{i1}, c_{i,2}, ..., c_{i,n_s})] \Big/ \partial \lambda \partial k = \sum_{i=1}^{n_T} \frac{(k + \sum_{j=1}^{n_s} \sum_{h=1}^{n_{ijs}} c_{ijh}) M_0 \sum_{j=1}^{n_{yr}} n_{ijs} y_j e^{\beta y_j}}{\left(k + M_0 \sum_{j=1}^{n_s} n_{ijs} e^{\beta y_j} \right)^2} - \frac{M_0 \sum_{j=1}^{n_{yr}} n_{ijs} y_j e^{\beta y_j}}{\left(k + M_0 \sum_{j=1}^{n_s} n_{ijs} e^{\beta y_j} \right)} \quad (24)$$