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An Evaluation of the Percentile Approach for Establishing Sustainable Escapement Goals in lieu of Stock Productivity Information

by

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

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Weights and measures (metric)

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

Weights and measures (English)

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

Time and temperature

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

Physics and chemistry

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

General

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

Mathematics, statistics

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

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ABSTRACT

Stock-recruitment analysis is the typical method used to establish biological escapement goals (BEGs) that provide the greatest potential for maximum sustained yield (S_{MSY}) of Pacific salmon stocks in Alaska. For stocks where the necessary stock-specific information is lacking, there are no published methods for estimation of proxies for S_{MSY} to aid in the development of sustainable escapement goals (SEGs). One such proxy for S_{MSY} was developed by Bue and Hasbrouck (*unpublished*) in 2001 and is now commonly called the Percentile Approach. We analyzed the Percentile Approach and recommended changes to the approach based on outcomes of our analyses. All of the analyses indicate that the four tiers of the Percentile Approach are likely sub-optimal as proxies for determining a range of escapements around S_{MSY}. The upper bounds of SEGs developed with this approach may actually be unsustainable in that they may specify a spawning escapement that is close to or exceeds the carrying capacity of the stock. The lower bound percentile of SEG Tier 1 (25%) also appears somewhat higher than necessary. Escapements in the lower 60 to 65 percentiles are optimal across a wide range of productivities, serial correlation in escapements, and measurement error in escapements. We recommend that the current 4-tier Percentile Approach be replaced with the following 3 tiers for stocks with low to moderate (less than 0.40) average harvest rates:

- Tier 1 – high contrast (>8) and high measurement error (aerial and foot surveys) with low to moderate average harvest rates (<0.40), the 20th to 60th percentiles;
- Tier 2 – high contrast (>8) and low measurement error (weirs, towers) with low to moderate average harvest rates (<0.40), the 15th to 65th percentiles;
- Tier 3 – low contrast (≤8) with low to moderate average harvest rates (< 0.40), the 5th to 65th percentiles.

Use of the Percentile Approach is <u>not</u> recommended for the following situations:

- average harvest rates of 0.40 and greater;
- very low contrast (4 or less) and high measurement error (aerial or foot surveys).

Key words: Pacific salmon, productivity, stock-recruitment, Percentile Approach, sustainable escapement goal, S_{MSY} proxy, meta-analysis.

INTRODUCTION

BACKGROUND

Stock-recruitment analysis is the typical method used to estimate stock productivity and carrying capacity, and to establish biological escapement goals (BEGs) that provide the greatest potential for maximum sustained yield of Pacific salmon stocks in Alaska, consistent with the policy for statewide salmon escapement goals (Title 5 of the Alaska Administrative Code [AAC], Chapter 39, Section 223). Stock-specific information on harvest, escapement, and age composition over a series of years is necessary to conduct these analyses. Central to this recipe for escapement goal development is the calculation of a reliable estimate of escapement that produces maximum sustained yield, or S_{MSY}.

For Pacific salmon stocks where the necessary stock-specific information is lacking, there are no published methods for estimation of proxies for S_{MSY} to aid in the development of sustainable escapement goals (SEGs). Development of a proxy for S_{MSY} is a reasonable methodological approach because SEGs are defined as providing for sustainable yields rather than maximum sustainable yields, so that a reliable estimate of S_{MSY} is not required. One such proxy for S_{MSY} was developed by Bue and Hasbrouck[1] (*unpublished*) in 2001 and is now commonly called the

[1]Bue, B. G. and J. J. Hasbrouck. *Unpublished*. Escapement goal review of salmon stocks of Upper Cook Inlet. Report to the Board of Fisheries November 2001 (and February 2002). Alaska Department of Fish and Game, , Anchorage.

Percentile Approach. This approach is currently being used to develop SEGs statewide and was the principal method used for development of 140 of the 300 escapement goals established and in use throughout Alaska during 2012 (Munro and Volk 2013; Appendix A).

The Percentile Approach is based on the very simple principle that a range of observed escapements, or an index of escapements that have been sustained over a period of time, represent an SEG for a stock that has been fished and likely sustained some unknown level of yields over that same time period. Moreover, maintaining escapements of a stock within some range of percentiles observed over the time series of escapements represents a proxy for maintaining escapements within a range that encompasses S_{MSY}. Bue and Hasbrouck considered the contrast in observed escapements (maximum escapement divided by the minimum escapement) and supposed rate of harvest in prescribing 4 ranges of percentiles of observed escapements to apply in developing the SEG (Figure 1). For this report we have rearranged their 4 percentile ranges and named them as tiers as follows:

- Tier 1 – for high escapement contrast (greater than 8) and at least moderate harvest rate, the central 50-percentile range (25th to 75th percentiles)
- Tier 2 – for medium escapement contrast (4 to 8) and at most low harvest rate, the 15th percentile to the 75th percentile
- Tier 3 – for medium escapement contrast (4 to 8), the central 70-percentile range (15th to 85th percentiles)
- Tier 4 – for low escapement contrast (less than 4), the 15th percentile to maximum observed escapement (100th percentile).

Bue and Hasbrouck developed the 4 Percentile Approach tiers from the statistical principle that the central 70-percentile range of escapements (i.e., the 15th to 85th percentiles of tier 3) is the nonparametric analog of ± 1 standard deviation from the average escapement (or the central 67-percentile of the observations) and that a nonparametric approach would avoid the parametric problem of outliers in the form of very large escapements that would likely not produce sustainable yields. They also reasoned that as escapement contrast and harvest rate increases, the range of escapements thought to produce sustainable yields should narrow (Tiers 1 and 2). For situations of very low escapement contrast, they reasoned that a wider range of escapements should be allowed (Tier 4). Bue and Hasbrouck confirmed the utility of these tiers by observing favorable comparisons of SEG escapement ranges derived from the Percentile Approach with the estimated BEG ranges for 11 selected stocks. The specific stocks examined were 2 sockeye salmon (*Oncorhynchus nerka*) and 2 Chinook salmon (*O. tshawytscha*) stocks from Upper Cook Inlet, and 7 sockeye salmon stocks from Bristol Bay (Figure 2 and Figure 3).

REASON FOR EVALUATION

This evaluation was initiated due to the popularity and simplicity of the Percentile Approach as a proxy for S_{MSY} in the development of SEGs and concerns that arose as the approach was implemented throughout Alaska. As currently defined in the policy for the management of sustainable salmon fisheries (5 AAC 39.222(f)(36)), an SEG must be scientifically defensible, provide for sustainable yields, and consider uncertainty.

One tenet of scientifically defensibility is that the science must be peer reviewed and accepted by the scientific community. Another tenet is that the science must comport with broadly accepted and peer-reviewed scientific principles and the theory of sustained yield. Lastly, the science must be robust to uncertainty with respect to the measurement of escapements and the underlying dynamics of the stock. Although Bue and Hasbrouck reasoned that the tiers should provide for sustainable yields and defended their choice of percentiles by comparing results with BEG ranges from stocks that had information on productivity, their work is largely based on statistical (non-biological) considerations and remains unpublished, without the benefit of scientific peer review. Moreover, upper bounds of SEG ranges developed from this approach may be unsustainably high, especially when harvest rates are low (< 25%). The tiers and recommended percentiles also do not consider data quality in terms of error in the measurement of escapements or the minimum number of years of escapements in the time series; nor do they consider the potential for serial correlation of escapements in the time series. Lastly, there are now many more data sets in Alaska with information on productivity (and S_{MSY}) that could be used to compare BEGs with SEGs developed with the Percentile Approach.

This report attempts to resolve these concerns and provide a scientific evaluation of the Percentile Approach, with recommendations for applying this method in the future. Three methods of evaluation are utilized to investigate the theoretical, statistical, and empirical aspects of the Percentile Approach as a proxy for S_{MSY}.

METHODS

THEORETICAL ANALYSIS

The Percentile Approach was evaluated with respect to the theoretical range of escapements expected under a range of productivities, harvest rates, and process and measurement errors. The production relationship used for this analysis was the familiar version of the Ricker model (Ricker 1975) that is typically used in escapement goal analyses in Alaska (Clark et al. 2009):

$$R = S\exp\left(\ln(\alpha) - \beta S\right), \tag{1}$$

where R is the production of adult salmon from the escapement S of adult salmon in the previous generation, α is a parameter governing productivity of the stock, and β is a scale parameter. For this analysis we are considering a multitude of possible stocks of the same carrying capacity but with differing productivity. To accomplish this, carrying capacity $\left(\ln(\alpha)/\beta\right)$ is rescaled to a value of 1 so that $\beta = \ln(\alpha)$ and the relationship is recast as:

$$R = S\exp\left(\ln(\alpha) - \ln(\alpha)S\right). \tag{2}$$

For any fixed rate of harvest u, the equilibrium (i.e., average) spawning level $\bar{S}$ can then be calculated (adapted from Ricker 1975):

$$\bar{S} = \frac{\left(\ln(\alpha) - \ln\left(\frac{1}{(1-u)}\right)\right)}{\ln(\alpha)} \tag{3}$$

Multiplicative process error $\left(\sigma_{\varepsilon}^{2}\ where,\ \varepsilon \sim N\left(0, \sigma_{\varepsilon}^{2}\right)\right)$ makes the relationship in Equation 2 stochastic, with expectation:

$$E[R \mid S] = S\exp(\ln(\alpha) - \ln(\alpha)S)\exp\left(\frac{\sigma_{\varepsilon}^{2}}{2}\right). \tag{4}$$

The theoretical frequency distribution around equilibrium spawning escapement is determined by the fixed rate of harvest, the process error of the stock-recruitment relationship, and, if escapements are estimated or indexed, by measurement error. Under a fixed rate of harvest, observed S over time can reasonably be expected to be log-normally distributed with mean $\bar{S}$ and variance σ_{ε}^{2}, with $\bar{S}$ dependent on the rate of harvest u (from Equation 3). If S is measured with error, then observed S would be log-normally distributed with mean $\bar{S}$ and variance $\left(\sigma_{\varepsilon}^{2} + \sigma_{S}^{2}\right)$, where σ_{S}^{2} governs sampling error associated with individual spawning escapement estimates.

Because log-productivity of salmon stocks in Alaska typically varies from 1 to 2, ln(α) was fixed at those 2 values in the analysis to represent the range of productivities that could occur. Harvest rate was fixed at 3 levels (u = 0.15, 0.25, and 0.40) in the analysis to represent a range of low to moderate average harvest rates that would typically be encountered in stock assessments where an SEG range would be applied (Table 2).

A hypothetical distribution of resultant escapements from both of these levels of log-productivity was expressed as the maximum value of 2 log-normal distributions of escapements, each with differing $\bar{S}$ due to the fixed harvest rate (Equation 3) and each with similar process and measurement error variances. For this analysis, process error was fixed at $\sigma_{\varepsilon} = 0.6$, which is typical for many salmon stocks. Measurement error was also fixed at 2 levels (σ_S = 0.05 or 0.50) to represent a range of possible assessments where spawning escapement is counted or precisely estimated (e.g., weirs or towers) or where spawning escapement is indexed or less precisely estimated (e.g., aerial or foot surveys; Table 2).

The cumulative distribution of the maximum values of the 2 log-normal distributions was used to calculate percentiles representing specific levels of spawning abundance corresponding to a desired range around S_{MSY}. The range around S_{MSY} was the smallest escapement that produces 90% of maximum sustained yield (MSY) at the lower bound (or L90) and the largest escapement that produces 70% of MSY at the upper bound (or U70). This range represents a conservative approach to development of an SEG, where low escapements that might cause overfishing are avoided at the lower bound and larger escapements that might be informative to better understanding future production are encouraged at the upper bound. A range based on the strict 90% of MSY boundaries (i.e., L90 to U90), as is typically estimated and used in BEG analyses, was considered but rejected as too narrow for development of an SEG when information on productivity of the stock is lacking. Table 2 shows the range of parameter values used in this analysis.

To ensure that the Percentile Approach is conservative with respect to our limited knowledge of stock-specific productivity, a maximum harvest rate of 0.40 was chosen because it represents the highest harvest rate that would result in observed escapements near or above S_{MSY}, even if productivity was low (i.e., ln(α) ≈ 1 and $u_{MSY} \approx 0.40$). While harvest rates greater than 0.40 can be optimal with respect to producing MSY for a particular stock, stock-specific knowledge of productivity would be needed to develop an escapement goal range that prevents overfishing.

SIMULATION ANALYSIS

While a theoretical analysis will provide insights into the likely range of percentiles that can be used as proxies for S_{MSY}, many aspects of salmon stock dynamics and fisheries are not fixed and may vary over the time period of spawning escapement data collection. A combined escapement-to-recruitment and recruitment-to-escapement Monte Carlo simulation model was constructed to examine the robustness of the Percentile Approach to these additional uncertainties.

Similar to the theoretical analysis, log-productivity was set at 3 levels (1, 1.5, and 2 after accounting for process error and serial correlation) to represent the range and typical value for this parameter. Rather than forcing each production model through the same carrying capacity, as was done for the theoretical analysis, the scale parameter was held constant in this analysis at $\beta = 1$ to reflect the dynamics of a single stock with varying productivity. For the escapement-to-recruitment component of the model, a more complex stochastic model of Ricker stock-recruitment was used. This model allows for lag-1 serial correlation among deviations from expected production over time (Noakes et al. 1987):

$$E\left[R_y \mid S_y\right] = S_y \exp\left(\ln(\alpha) - \beta S_y + \phi v_{y-1}\right) \exp\left(\frac{\sigma^2_{\varepsilon_y}}{2}\right), \tag{5}$$

where y is a subscript denoting the brood year, ϕ is the lag-1 correlation coefficient, and $v_{y\text{-}1}$ is the log-scale residual in the previous brood year:

$$v_{y-1} = \ln\left(R_{y-1}\right) - \ln\left(S_{y-1}\right) - \ln(\alpha) + \beta S_{y-1}. \tag{6}$$

The serial correlation coefficient was set at 2 levels (0.00 and 0.50) to reflect no and moderate lag-1 serial correlation, representing a range of serial correlation in production typically observed in Alaska salmon stocks.

The recruitment-to-escapement component of the model was accomplished by fishing at 5 different average harvest rates (u = 0.10, 0.18, 0.26, 0.33, and 0.39) corresponding to instantaneous rates of harvest of 0.10 to 0.50 (F) in increments of 0.10 (Table 3). Results from these 5 average rates of harvest were also grouped into low (0.10 and 0.18) and moderate (0.26, 0.33, and 0.39) levels of harvest. Annual variation in average harvest rate in the absence of a constraining escapement goal was modeled as a log-normal process with σ_F fixed at 0.3. Resultant escapements were estimated as:

$$S_y = R_y \exp(-F) \exp(\sigma_F), \tag{7}$$

which then produce the next generation (y + 1) of recruitment in the escapement-to-recruitment relationship (Equation 5).

As in the theoretical analysis, process error (σ_ε) was fixed at 0.6 and measurement error (σ_S) was set at 2 values (0.05 and 0.50) to reflect the range in precision of estimation of escapement seen in various types of assessments. We used a range of parameter values in this analysis(Table 3). Each realization of the model was a run of 100 brood years, with time series of 10 and 30 years of escapements extracted from the end of the 100 years and used to develop a SEG based on the

Percentile Approach. One thousand realizations were performed for each combination of parameter values.

Percentiles of the time series of simulated escapements were estimated, and all possible ranges of percentiles, from the minimum to maximum in increments of 5%, were calculated with the following restrictions: no percentile range (upper percentile-lower percentile) was narrower than 25%, the lower bound percentile was no greater than the 60th percentile, and the upper bound percentile was no lower than the 40th percentile. Included in these ranges of percentiles are the 4 current SEG tiers. Each potential SEG range was rated against the L90 to U70 range around S_{MSY} with the following formula:

$$Rating = \left|\frac{(P_L - L90)}{L90}\right| + \left|\frac{(P_U - U70)}{U70}\right|, \tag{8}$$

where P_L is the escapement value of the lower percentile of the range, P_U is the escapement value of the upper percentile of the range, and L90 and U70 are the lower and upper bounds around S_{MSY} as previously defined. Smaller values of *Rating* imply a better match to the L90–U70 interval around $S_{MSY,}$ and a *Rating* of zero is a perfect match of the L90–U70 interval around S_{MSY}.

*Rating*s of each percentile range were summarized by averaging the 1,000 realizations of the model for each combination of parameter value (Table 3), low and moderate harvest rates, level of contrast, and number of years of escapements. Summaries of the percentile range with the lowest (Best) *Rating* and of each of the current SEG tiers were also categorized by level of contrast (greater than 8 and 8 or less), measurement error (low or high), and number of years of escapements (10 and 30 years).

Uncertainty in determining the Best *Rating* was examined by plotting the Best upper bound percentile against the Best lower bound percentile for each of the 1,000 realizations of the model for each combination of log-productivity, serial correlation, measurement error, harvest rate, level of contrast, and number of years of escapements simulated.

Performance of the current Percentile Approach tiers was evaluated against those recommended in this report by comparing expected yields derived when the recommended escapement goals from each tier system were managed for exactly. Average expected yields were calculated as a percentage of MSY at the lower bound, midpoint, and upper bound of the applicable tier of the current Percentile Approach and compared to average expected yields relative to MSY at the bounds and midpoint of the applicable revised tier based on recommendations made within this report. Comparisons were also made by plotting the percentile range with the Best *Rating* and the expected yields as a percentage of MSY at the lower and upper bounds of the recommended SEG tier for each combination of log-productivity, serial correlation, measurement error, harvest rate, level of contrast, and number of years of escapements simulated.

EMPIRICAL META-ANALYSIS

Lastly, the Percentile Approach was evaluated by comparing various percentile escapement intervals to S_{MSY} escapement intervals estimated from a standardized stock recruit analysis. Bue and Hasbrouck (*unpublished*) performed a similar comparison on 11 stocks in their initial formulation of the Percentile Approach.

A linearized form of the Ricker stock-recruitment model (Equation 5) was fit to 76 stock-recruitment data sets from throughout Alaska using a standard linear regression approach (Appendix B; Ricker 1975). These data included historical stock-recruitment observations for 7 pink salmon (*O. gorbuscha*), 7 coho salmon (*O. kisutch*), 43 sockeye salmon, 6 chum salmon (*O. keta*) stocks, and 13 Chinook salmon stocks. Ten data sets (all sockeye salmon stocks) were eliminated from the analysis due to inadequate statistical fits to the Ricker model (i.e., scale parameter β not significantly different from zero at an alpha level of 0.05) resulting in 66 stocks with reasonable estimates of S_{MSY}, L90, and U70 (Appendix C).

As in the simulation analysis, percentiles of the time series of observed escapements were estimated, and all possible ranges of percentiles, from the minimum to maximum in increments of 5% were calculated with the restrictions that no percentile range (upper percentile-lower percentile) was narrower than 25%, the lower bound percentile was no greater than the 60th percentile, and the upper bound percentile was no lower than the 40th percentile. Included in these ranges of percentiles are the 4 current SEG tiers. Each potential SEG range was rated against the L90 to U70 range around S_{MSY} by calculating the *Rating* (Equation 8). Summaries of the percentile range with the Best *Rating* and of each of the current SEG tiers were also categorized by species, level of contrast (greater than 8 and 8 or less), and low to moderate and high harvest rates (less than 0.4 and 0.4 and greater).

RESULTS

THEORETICAL ANALYSIS

Theoretical values for percentiles that encompass an L90–U70 range around S_{MSY} ranged from 1% to 24% for the lower bound, and from 28% to 74% for the upper bound, depending on the value of log-productivity, measurement error, and harvest rate (Table 4). When results for both values of log-productivity were combined to represent a lack of productivity information, reasonable percentile-based SEG ranges varied from 2–40% to 10–74% for low measurement error situations and from 5–42% to 17–69% for high measurement error situations (see also graphical results in Figure 4 and Appendix D). Results from this analysis approached that of Tier 1 and Tier 2 SEGs (25–75% and 15–75%) with a harvest rate of 0.40 and low log-productivity. Graphical representation of the theoretical analysis for a fixed harvest rate of 0.25 and low measurement error is shown in Figure 4.

SIMULATION ANALYSIS

None of the 4 SEG tiers had the Best percentile *Rating* for all possible scenarios of the low measurement error (σ_S = 0.05) series of simulations (Table 5). Best percentile *Rating* ranged from Min-50% to 20-70%, with low contrast (8 or less) scenarios favoring minimum and 5th percentiles for lower bounds, regardless of the number of years of escapements or presence of serially correlated escapements. Conversely, Best lower bound percentiles of 10 and 15% were common in the high contrast (greater than 8) scenarios. Best upper bound percentiles varied from 50 to 70%, positively related to the change in rate of harvest from low to moderate.

None of the 4 SEG tiers had the Best percentile *Rating* for all possible scenarios of the high measurement error (σ_S = 0.50) series of simulations (Table 6). Best percentile *Rating* ranged from Min-50% to 25-65%, with low contrast (8 or less) scenarios favoring minimum and 5th percentiles for lower bounds regardless of the presence of serially correlated escapements. No results were available for scenarios of low contrast and 30 years of data due to the effect of high measurement error on the apparent contrast in escapements over time. Best lower bound percentiles of 10 and 15% were common in the high contrast (greater than 8) scenarios with 10 years of escapements, but increased to 15 to 25% as the time series of escapements increased to 30 years. Best upper bound percentiles varied from 50 to 70%, positively related to the change in rate of harvest from low to moderate.

Measurement error and contrast emerged as the main determinants of Best percentiles from the simulations (Table 7). Percentile ranges of 15–65% for low measurement error and 20–60% for high measurement error when contrast was high emerged as robust to differences in harvest rate, presence of serial correlation, and the range in number of years of escapements. For situations of low contrast, a percentile range of 5–65% emerged as robust to differences in measurement error and presence of serial correlation.

Best lower and upper percentiles were highly variable between realizations of a simulation, reflecting the variability in contrast in the simulated escapements relative to S_{MSY} and the harvest rate relative to the harvest rate at MSY for a given log-productivity (Figure 5). Highest levels of variability were observed for low log-productivity and low contrast scenarios (for example, Figures 5(A) and 5(B); see also Appendix E). Conversely, lower levels of variability occurred for higher log-productivity and high contrast scenarios (for example, Figures 5(C) and 5(D); see also Appendix E).

EMPIRICAL META-ANALYSIS

Thirty of the 66 stocks in the meta-analysis had average harvest rates less than 0.40 (Table 8), with a range of average harvest rates from 0.06 to 0.39. Estimated log-productivity of the 30 stocks averaged 1.58 and ranged from 0.80 to 3.16. Estimated log-scale process error of these same stocks averaged 0.64 and ranged from 0.29 to 1.22, although some of this process error may be due to measurement error that was not accounted for in the stock-recruitment analyses. Estimated lag-1 serial correlation in log-productivity averaged 0.41 and ranged from -0.10 to 0.85 (Appendix C).

For these 30 stocks, percentile ranges that best matched the L90–U70 range around S_{MSY} (i.e., Best *Rating*) ranged from Min–45% to 40–85%. Of these 30 stocks, 24 of them had contrast greater than 8, and 6 had contrast of 8 or less. The 24 stocks with high contrast and low to moderate harvest rates had Best percentile ranges of 40–75% for 4 pink salmon stocks, 15-45% for 5 Chinook salmon stocks, 20–55% for 8 sockeye salmon stocks, 20–65% for 6 chum salmon stocks and 35–60% for 1 coho salmon stock (Table 8). Average *Rating* for these Best percentile ranges varied from 0.09 to 0.57, whereas average *Rating* for the 4 SEG tiers varied from 0.46 to 1.15 for Tier 1, 0.57 to 0.94 for Tier 2, 0.72 to 1.31 for Tier 3, and 2.19 to 2.31 for Tier 4.

The 6 stocks that had contrast of 8 or lower and low to moderate harvest rate had a Best percentile range of Min-45% for 2 Chinook salmon stocks and 4 sockeye salmon stocks (Table 8). Average *Rating* for these Best percentile ranges varied from 0.16 to 0.31, whereas average *Rating* for the 4 SEG tiers varied from 1.09 to 1.12 for Tier 1, 0.94 to 1.01 for Tier 2, 0.66 to 1.16 for Tier 3, and 1.77 to 2.12 for Tier 4.

Thirty-six of the 66 stocks in the meta-analysis had average harvest rates of 0.40 or more (Table 8), with a range of average harvest rate from 0.40 to 0.69. Estimated log-productivity of the 36 stocks averaged 1.90 and ranged from 1.00 to 2.97. Estimated log-scale process error of these same stocks averaged 0.55 and ranged from 0.26 to 1.03. Estimated lag-1 serial correlation in log-productivity averaged 0.44 and ranged from 0.00 to 0.84 (Appendix C).

For these 36 stocks, percentile ranges that best matched the L90-U70 range around S_{MSY} (i.e., Best *Rating*) ranged from Min-45% to 40-Max%. Of these 36 stocks, 21 of them had contrast greater than 8, and 15 had contrast of 8 or less. The 21 stocks with high contrast and high harvest rates had Best percentile ranges of 10-50% for 1 Chinook salmon stock, 15–65% for 2 coho salmon stocks, 35–75% for 15 sockeye salmon stocks, and 40–85% for 3 pink salmon stocks (Table 8). Average *Rating* for these Best percentile ranges varied from 0.00 to 0.44, whereas average *Rating* for the 4 SEG tiers varied from 0.44 to 0.58 for Tier 1, 0.51 to 0.61 for Tier 2, 0.61 to 0.67 for Tier 3, and 1.51 to 1.68 for Tier 4.

The 15 stocks that had contrast of 8 or lower and high harvest rate had a Best percentile range of 5–45% for 5 Chinook salmon stocks, 20–65% for 6 sockeye salmon stocks, and 40–75% for 4 coho salmon stocks (Table 8). Average *Rating* for these Best percentile ranges varied from 0.18 to 0.29, whereas average *Rating* for the 4 SEG tiers varied from 0.21 to 0.91 for Tier 1, 0.27 to 0.75 for Tier 2, 0.28 to 1.02 for Tier 3, and 0.85 to 1.66 for Tier 4.

There appeared to be little to no relationship between average harvest rate and Best lower bound percentile and a weak positive relationship between average harvest rate and the Best upper bound percentile for all 66 stocks (Figure 6). Percentiles from minimum to 40th were selected as Best lower bounds across a wide range of average harvest rates. With only 2 exceptions (both pink salmon stocks), Best upper bound percentiles of 75% and greater were selected only at average harvest rates greater than 0.30.

DISCUSSION

All 3 of the analyses indicate that the 4 tiers of the Percentile Approach currently used (Figure 2) are likely sub-optimal as proxies for determining a range of escapements around S_{MSY} in lieu of information about productivity of salmon stocks. While there were differences among the 3 analyses, in general escapements in the lower 60 to 65 percentiles are optimal across a wide range of productivities, serial correlation in escapements, and measurement error in escapements, particularly in situations of low to moderate harvest rates.

SEGs based on the current Percentile Approach, especially the upper bounds, may actually be unsustainable in that they may specify a spawning escapement that is close to or exceeds the carrying capacity of the stock where there is the expectation of no sustainable yields. For example, from the theoretical analysis, at a harvest rate of 0.25, escapements greater than the 70 percentile have a high probability of exceeding carrying capacity (Figure 4, Panel C). At a harvest rate of 0.40, this percentile increases to 80% so that the upper bound of SEG Tiers 3 (85%) and 4 (100%) are most likely unsustainable even in cases of moderate harvest rates. Simulation results corroborate the same general indication that optimal Best upper bound percentiles occur most often at 55 to 65%, not 75% and higher (Table 7). While 28 of the 66 stocks in the meta-analysis have a Best upper bound percentile that exceeds 65% (Table 8), the average harvest rate of these 28 stocks is 0.52, much higher than would be recommended for use of the Percentile Approach. Of the 30 salmon stocks with average harvest rates less than 0.40, only 5 have upper bound percentiles greater than 65% (Yukon fall chum, Kotzebue chum, Kodiak Mainland pink, Northern SE Outside pink, and South Peninsula Odd pink) and these 5 stocks have a much lower average log-productivity ($\ln(\alpha)$ = 1.19) than the other 25 stocks ($\ln(\alpha)$ = 1.66).

The lower bound percentile of SEG Tier 1 (25%) appears somewhat higher than necessary given the results of these analyses. The theoretical analysis indicates that lower bound percentiles of 17% or less are Best across a range of productivities (Table 4). Similarly, simulation analyses indicate that lower bound percentiles of 5 to 20% are Best across a wide range of harvest rates, depending primarily on the level of measurement error and contrast (Table 7). The meta-analysis indicates that overall Best lower bound percentiles typically range from the minimum to 20% for stocks with harvest rates of 0.40 or less (Table 8). Twenty-nine of the 66 stocks had a Best lower bound percentile of 20% or less, and of the 30 stocks with average harvest rates of less than 0.40, 16 had a Best lower bound percent of 20% or less.

Although 37 of the 66 stocks in the meta-analysis had a Best lower bound percentile of 25% or more, 23 of these stocks had harvest rates of 0.40 or greater (Table 8). Average harvest rate of stocks with a lower bound percentile less than 25% was 0.36, and for stocks with a 25% or higher lower bound percentile it was 0.43. Of the 14 stocks with a lower bound percentile of 25% or more and average harvest rates less than 0.40, average process error (residual error plus error due to lag-1 serial correlation) was the highest (0.44) of all the stocks in the meta-analysis (0.26) and higher than the highest value used in the simulation analysis (0.24). This means that for some stocks with low to moderate harvest rates, there may be extreme density-independent variation in escapements that would cause the optimal lower bound percentile to be higher than 25%, especially for stocks with low log-productivity ($\ln(\alpha) \approx 1$).

While the analyses presented provide consistent and reasonable outcomes with respect to the current Percentile Approach, several aspects of salmon population dynamics were ignored or greatly simplified to facilitate the analyses. For example, only one form of stock-recruitment function (Ricker) was presented in the analyses where others could be considered (e.g., Beverton-Holt [Beverton and Holt 1957] or hockey-stick [Barrowman and Myers 2000] forms). Other forms of stock-recruitment function were not used because they have been shown to not fit salmon production data in Alaska very well and would likely have resulted in lower values for best percentiles given the asymptotic shape of these other forms of stock-recruitment function.

Other or additional criteria beyond the Best *Rating* compared to an L90 and U70 range around S_{MSY} could have been employed for determining the recommended percentiles for an SEG range. For example, another potential measure of the adequacy of an escapement goal range is that the lower bound has a low probability of enabling long-term problems with population viability (e.g., lower bound of escapement goal set at a very small percentage of carrying capacity). Use of the L90 criterion for evaluating the lower bound of the Percentile Approach and restricting the maximum harvest rate of this approach to 0.40 ensured that these potential problems were minimized.

A simple age composition was used in the theoretical and simulation analyses, with one age at maturity. Different species of salmon have differing age composition and differing rates of maturation at age, so it was difficult to choose one over the other in analyses that could potentially apply to any species of salmon. Several differing age compositions were contemplated in constructing the simulation analysis, but these were rejected in favor of a single age at maturation. The inclusion of more complex age composition and maturation rates into the simulation analyses, which tend to moderate the amount of contrast in escapements, would have universally resulted in slightly lower values for Best percentiles than those reported herein, so that the results of this study are somewhat conservative with respect to recommended percentiles for species of salmon with multiple ages and differing rates of maturation.

Values of the parameters of interest in the simulation study were limited to log-productivities of 1 to 2, lag-1 serial correlation of 0.00 or 0.50, and log-scale process error of 0.6, although a survey of these parameters from the meta-analysis confirms that these are the most commonly estimated values for these parameters. We also did not focus attention on scenarios of very low contrast (< 4) as they are fairly rare in salmon escapement data sets from Alaska, especially in situations of high measurement error (Appendix A). We ignored measurement error in estimation of stock-recruitment parameters for data sets in the meta-analysis as these data were not consistently available for all 66 stocks.

RECOMMENDATIONS

Based on the analyses and our discussion above, we recommend that the current 4-tier Percentile Approach be replaced with the following 3 tiers for stocks with low to moderate (less than 0.40) average harvest rates:

- Tier 1 – high contrast (>8) and high measurement error (aerial and foot surveys) with low to moderate average harvest rates (<0.40), the 20th to 60th percentiles
- Tier 2 – high contrast (>8) and low measurement error (weirs, towers) with low to moderate average harvest rates (<0.40), the 15th to 65th percentiles
- Tier 3 – low contrast (≤8) with low to moderate average harvest rates (<0.40), the 5th to 65th percentiles

The lower bound percentiles of these 3 tiers can also be used in developing lower-bound SEGs for stocks with low to moderate average harvest rates.

These recommended tiers appear to represent reasonable proxies for S_{MSY}. When the recommended tiers were applied to the simulation analyses as SEG ranges for management, expected yields with respect to MSY improved over those derived from the current Percentile Approach. In particular, performance in terms of expected yields relative to MSY decreased slightly at the lower bound but increased markedly at the midpoint and upper bounds of escapement goals derived from the recommended tiers (Table 9). Reasonable and sustainable levels of expected yield were projected for a wide range of log-productivity, serial correlation, and harvest rates, given the recommended tiers based on the amount of measurement error and contrast in observed escapements (Figure 7 and Appendix F). It should be noted that these results are expectations across a large number of simulated stocks. As such, implementation of the percentile method on an individual stock would be subject to greater variability in performance.

With some exceptions, when applied to 30 stocks in the meta-analysis with average harvest rates less than 0.40, the recommended tiers provided reasonable and sustainable proxies for a range around S_{MSY} (Figure 8). Notable exceptions are Kodiak Mainland and Northern SE Outside pink salmon stocks, where the escapement range calculated from the recommended tier does not overlap with the L90-U70 range around S_{MSY} and could potentially result in overfishing. These 2 stocks have fairly low log-productivities (0.80 and 1.22) and very high levels of contrast (>200), likely caused by high levels of measurement error in estimation of escapements, situations that can cause estimates of S_{MSY} (and therefore the L90-U70 range) to be biased high (Su and Peterman 2012). We do not believe that species-specific recommendations of optimal percentiles (e.g., for pink salmon stocks) are warranted, as the primary factors in determining whether observed escapements encompass, exceed, or are beneath S_{MSY} are the rate of harvest and the productivity of the stock.

Use of the Percentile Approach is *not* recommended for the following situations:

- average harvest rates of 0.40 and greater
- very low contrast (4 or less) and high measurement error (aerial or foot surveys)

Stocks with average harvest rates of 0.40 and greater should undergo improvements in stock assessment so that run reconstruction and production modeling can be achieved to determine an appropriate SEG or BEG. In situations of high harvest rates, Clark et al. (2009) showed that comparison of the observed average harvest rate against the estimated harvest rate at MSY is a diagnostic for the adequacy of the current escapement goal (e.g., observed $u >> u_{MSY}$ indicates that the current escapement goal is too low). Although not recommended, if the Percentile Approach is used in this situation, we suggest that the lower bound be set no lower than the 25th percentile to avoid potential overfishing and the upper bound be set at the 75th percentile or greater, regardless of the level of measurement error.

Conditions of very low contrast (4 or less) over long time spans (> 10 years) when escapements are measured imprecisely (i.e., indexed) indicate a high potential for bias due to depensatory counting or other density-related effects that limit the utility of these data for informing an escapement goal developed by any method. In general, indexed escapements should be verified against independent estimates of total abundance to ensure that the index of escapement scales consistently with abundance.

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TABLES AND FIGURES

Table 1.–Definitions of variables used in this report.

Variable	Definition
ln(α)	The log-productivity parameter of the Ricker stock-recruitment model
σ_{ε}	The standard error of the multiplicative process error
σ_S	The standard error of simulated escapements
L90	The largest escapement that is less than S_{MSY} and produces at least 90% of MSY
U70	The smallest escapement that is greater than S_{MSY} and produces at least 70% of MSY
S_{MSY}	Spawners that produce MSY
u	Harvest rate
$\overline{S}$	Average escapement
ϕ	The lag-1 correlation coefficient of the Ricker model with lagged serial correlation in expected production over time
σ_F	The standard error of simulated instantaneous harvest rates
Contrast	The maximum escapement divided by the minimum escapement
Years	Years of simulated escapements
n	Number of years of information in the brood table
Best	Lowest *Rating*
Rating	Absolute relative difference between the L90 and P_L plus the absolute relative difference between U70 and P_U
25-75	*Rating* of the tier 1 percentiles of Bue and Hasbrouck (Unpublished)
15-75	*Rating* of the tier 2 percentiles of Bue and Hasbrouck (Unpublished)
15-85	*Rating* of the tier 3 percentiles of Bue and Hasbrouck (Unpublished)
15-Max	*Rating* of the tier 4 percentiles of Bue and Hasbrouck (Unpublished)
LB	The lower bound of either the current or recommended percentile range
Mid	The midpoint of either the current or recommended percentile range
UB	The upper bound of either the current or recommended percentile range
SEQ	The estimated carrying capacity of the stock
P_L	The escapement at the lower bound percentile
P_U	The escapement at the upper bound percentile

Note: These definitions of variables are used in column headings for Tables 2–9 and in the Appendices.

Table 2.–Parameter values used in the theoretical analysis of the Percentile Approach.

ln(α)	σ_ε	σ_S	L90	S_{MSY}	U70	u	$\bar{S}$
1	0.60	0.05	0.28	0.43	0.72	0.15	0.84
						0.25	0.71
						0.40	0.49
1	0.60	0.50	0.28	0.43	0.72	0.15	0.84
						0.25	0.71
						0.40	0.49
2	0.60	0.05	0.23	0.36	0.65	0.15	0.92
						0.25	0.86
						0.40	0.74
2	0.60	0.50	0.23	0.36	0.65	0.15	0.92
						0.25	0.86
						0.40	0.74

Note: Column headings are defined in Table 1.

Table 3.–Parameter values used in the simulation analysis of the Percentile Approach.

ln(α)	φ	σ_ε	σ_S	σ_F	L90	S_{MSY}	U70	Range of *u*
1	0.00	0.60	0.05	0.30	0.28	0.43	0.72	0.10-0.39
	0.50							
	0.00		0.50	0.30				
	0.50							
1.5	0.00	0.60	0.05	0.30	0.38	0.59	1.03	0.10-0.39
	0.50							
	0.00		0.50	0.30				
	0.50							
2	0.00	0.60	0.05	0.30	0.46	0.72	1.31	0.10-0.39
	0.50							
	0.00		0.50	0.30				
	0.50							

Note: Column headings are defined in Table 1.

Table 4.–Parameter values and lower and upper percentiles calculated from the theoretical analysis.

ln(α)	σ_ε	σ_S	L90	S_{MSY}	U70	u	$\overline{S}$	Lower Percentile	Upper Percentile
1	0.60	0.05	0.28	0.43	0.72	0.15	0.84	4%	40%
						0.25	0.71	6%	51%
						0.40	0.49	18%	74%
1	0.60	0.50	0.28	0.43	0.72	0.15	0.84	8%	42%
						0.25	0.71	12%	51%
						0.40	0.49	24%	69%
2	0.60	0.05	0.23	0.36	0.65	0.15	0.92	1%	28%
						0.25	0.86	1%	33%
						0.40	0.74	3%	41%
2	0.60	0.50	0.23	0.36	0.65	0.15	0.92	4%	33%
						0.25	0.86	5%	36%
						0.40	0.74	7%	43%
Both	0.60	0.05	0.23		0.72	0.15		2%	40%
						0.25		3%	51%
						0.40		10%	74%
Both	0.60	0.50	0.23		0.72	0.15		5%	42%
						0.25		7%	51%
						0.40		17%	69%

Note: Column headings are defined in Table 1.

Table 5.–Summary of simulation analysis results for low measurement error (σ_S =0.05) for log-productivities of 1.0, 1.5, and 2.0 combined.

φ	Contrast	Years	*u*	Best	Rating	25-75	15-75	15-85	15-Max
0.0	>8	10	0.10-0.18	10-60	0.60	1.02	0.84	1.19	2.66
			0.23-0.39	15-70	0.71	0.81	0.75	0.94	1.96
			0.10-0.39	15-60	0.68	0.89	0.78	1.04	2.24
0.5	>8	10	0.10-0.18	15-60	0.84	1.13	1.01	1.32	2.68
			0.23-0.39	15-70	0.98	1.05	1.01	1.16	2.10
			0.10-0.39	15-65	0.93	1.08	1.01	1.23	2.33
0.0	≤8	10	0.10-0.18	Min-60	0.58	1.34	1.08	1.28	1.78
			0.23-0.39	5-70	0.64	0.92	0.77	0.87	1.20
			0.10-0.39	5-70	0.69	1.09	0.90	1.03	1.43
0.5	≤8	10	0.10-0.18	Min-50	0.67	1.34	1.12	1.30	1.81
			0.23-0.39	5-70	0.81	1.09	0.94	1.04	1.38
			0.10-0.39	Min-65	0.75	1.19	1.01	1.14	1.55
0.0	>8	30	0.10-0.18	10-55	0.44	0.96	0.72	1.07	3.10
			0.23-0.39	20-70	0.61	0.70	0.62	0.79	2.22
			0.10-0.39	15-65	0.56	0.80	0.66	0.90	2.57
0.5	>8	30	0.10-0.18	15-60	0.64	0.97	0.82	1.16	3.23
			0.23-0.39	20-70	0.80	0.84	0.82	0.98	2.52
			0.10-0.39	20-65	0.77	0.89	0.82	1.05	2.80
0.0	≤8	30	0.10-0.18	5-60	0.35	0.96	0.71	0.94	1.73
			0.23-0.39	5-70	0.33	0.63	0.46	0.61	1.26
			0.10-0.39	5-65	0.35	0.78	0.57	0.75	1.47
0.5	≤8	30	0.10-0.18	Min-50	0.31	1.28	1.00	1.27	2.10
			0.23-0.39	Min-55	0.30	1.08	0.80	1.05	1.81
			0.10-0.39	Min-50	0.31	1.17	0.88	1.14	1.94

Note: Column headings are defined in Table 1.

Table 6.–Summary of simulation analysis results for high measurement error (σ_S =0.50) for log-productivities of 1.0, 1.5, and 2.0 combined.

φ	Contrast	Years	*u*	Best	Rating	25-75	15-75	15-85	15-Max
0.0	>8	10	0.10-0.18	10-50	0.66	1.23	1.05	1.55	3.59
			0.23-0.39	15-60	0.74	0.91	0.85	1.15	2.56
			0.10-0.39	15-60	0.73	1.04	0.93	1.31	2.97
0.5	>8	10	0.10-0.18	10-50	0.83	1.31	1.15	1.58	3.41
			0.23-0.39	15-60	0.96	1.11	1.06	1.31	2.65
			0.10-0.39	15-60	0.93	1.19	1.10	1.42	2.95
0.0	≤8	10	0.10-0.18	Min-50	0.59	1.38	1.11	1.35	1.96
			0.23-0.39	5-70	0.68	0.95	0.81	0.93	1.32
			0.10-0.39	5-60	0.68	1.12	0.93	1.10	1.58
0.5	≤8	10	0.10-0.18	Min-50	0.68	1.35	1.12	1.35	1.90
			0.23-0.39	5-60	0.83	1.13	1.00	1.12	1.49
			0.10-0.39	Min-60	0.78	1.22	1.05	1.21	1.65
0.0	>8	30	0.10-0.18	15-55	0.45	1.01	0.84	1.35	4.62
			0.23-0.39	20-65	0.60	0.73	0.71	1.01	3.45
			0.10-0.39	20-60	0.60	0.84	0.76	1.15	3.92
0.5	>8	30	0.10-0.18	15-55	0.63	1.03	0.93	1.41	4.81
			0.23-0.39	25-65	0.82	0.89	0.91	1.18	3.76
			0.10-0.39	20-60	0.76	0.95	0.92	1.27	4.18
0.0	≤8	30	0.10-0.18	ND	ND	ND	ND	ND	ND
			0.23-0.39	ND	ND	ND	ND	ND	ND
			0.10-0.39	ND	ND	ND	ND	ND	ND
0.5	≤8	30	0.10-0.18	ND	ND	ND	ND	ND	ND
			0.23-0.39	ND	ND	ND	ND	ND	ND
			0.10-0.39	ND	ND	ND	ND	ND	ND

Note: Column headings are defined in Table 1.

Table 7.–Generalized summary of simulation analysis results. Results in bold are the recommendations for updated SEG tiers.

Measurement Error	Serial Correlation?	*u*	Contrast	Years	Best	Rating	25-75	15-75	15-85	15-Max
Low	Both	0.10-0.39	>8	10	15-60	0.81	0.99	0.90	1.14	2.29
High					15-60	0.83	1.12	1.02	1.37	2.96
Low	**Both**	**0.10-0.39**	**>8**	**30**	**15-65**	**0.67**	**0.85**	**0.74**	**0.98**	**2.69**
High					**20-60**	**0.68**	**0.90**	**0.84**	**1.21**	**4.05**
Low	Both	0.10-0.39	≤8	10	5-70	0.72	1.14	0.96	1.09	1.49
High					5-60	0.73	1.17	0.99	1.16	1.62
Low	Both	0.10-0.39	≤8	30	Min-55	0.33	0.98	0.73	0.95	1.71
High					ND	ND	ND	ND	ND	ND
Both	No	0.10-0.39	>8	10	15-60	0.71	0.97	0.86	1.18	2.61
	Yes				15-65	0.93	1.14	1.06	1.33	2.64
Both	No	0.10-0.39	>8	30	15-65	0.58	0.82	0.71	1.03	3.25
	Yes				20-60	0.77	0.92	0.87	1.16	3.49
Both	No	0.10-0.39	≤8	10	5-65	0.69	1.11	0.92	1.07	1.51
	Yes				Min-65	0.77	1.21	1.03	1.18	1.60
Both	No	0.10-0.39	≤8	30	ND	ND	ND	ND	ND	ND
	Yes				ND	ND	ND	ND	ND	ND
Both	Both	0.10-0.18	>8	10	10-55	0.73	1.17	1.01	1.41	3.09
		0.26-0.39			15-65	0.85	0.97	0.92	1.14	2.32
Both	Both	0.10-0.18	>8	30	15-55	0.54	0.99	0.83	1.25	3.94
		0.26-0.39			20-70	0.71	0.79	0.77	0.99	2.99
Both	Both	0.10-0.18	≤8	10	Min-55	0.63	1.35	1.11	1.32	1.86
		0.26-0.39			5-70	0.74	1.02	0.88	0.99	1.35
Both	Both	0.10-0.18	≤8	30	ND	ND	ND	ND	ND	ND
		0.26-0.39			ND	ND	ND	ND	ND	ND
Both	Both	0.10-0.39	>8	10	15-60	0.82	1.05	0.96	1.25	2.62
				30	20-65	0.67	0.87	0.79	1.09	3.37
Both	**Both**	**0.10-0.39**	**≤8**	**10**	**5-65**	**0.73**	**1.16**	**0.97**	**1.12**	**1.55**
				30	ND	ND	ND	ND	ND	ND

Note: Column headings are defined in Table 1.

Table 8.–Summary of empirical information and percentile ranges obtained by applying the Percentile Approach to 66 Pacific salmon stocks in Alaska.

Stock or # of Stocks	Species	Years	Contrast	*u*	Best	Rating	25-75	15-75	15-85	15-Max
Afognak	sockeye	28	8.5	0.13	35-60	0.25	0.78	0.89	0.98	1.60
Akwe	sockeye	19	40.0	0.40	40-75	0.09	0.48	0.84	1.64	2.26
Alsek	sockeye	30	3.4	0.31	Min-45	0.48	1.35	1.19	1.27	2.26
Alsek	Chinook	32	10.7	0.12	5-45	0.16	1.43	1.18	1.44	2.85
Andreafsky	chum	38	30.9	0.17	25-60	0.12	0.32	0.55	1.06	2.50
Anvik	chum	38	8.1	0.36	20-65	0.10	0.74	0.47	0.70	1.37
Auke	coho	30	4.1	0.62	30-85	0.11	0.25	0.34	0.28	0.48
Ayakulik	Chinook	33	26.1	0.14	15-50	0.02	1.10	0.67	0.90	1.93
Bear late run	sockeye	31	3.3	0.69	20-75	0.01	0.06	0.07	0.13	0.41
Berners	coho	28	16.1	0.66	40-85	0.26	0.56	0.72	0.60	1.48
Buskin	sockeye	20	4.2	0.38	Min-45	0.32	1.70	1.68	1.87	2.46
Chena	Chinook	23	4.6	0.45	5-45	0.09	1.23	0.92	0.99	1.47
Chignik	Chinook	32	11.4	0.44	10-50	0.00	0.58	0.51	0.61	1.68
Chignik late run	sockeye	58	4.6	0.63	15-85	0.05	0.25	0.16	0.05	0.47
Chilkat	sockeye	31	8.7	0.55	30-65	0.12	0.18	0.31	0.58	1.20
Chilkat	Chinook	18	4.0	0.07	Min-45	0.25	1.31	1.20	1.40	2.14
Chilkat	coho	15	8.1	0.41	15-60	0.07	0.50	0.30	0.73	1.69
Chilkat	chum	17	23.2	0.26	20-45	0.28	1.18	1.07	1.21	3.37
Chilkoot	sockeye	34	14.3	0.48	20-50	0.03	0.36	0.33	0.46	0.56
Coghill	sockeye	48	25.8	0.63	40-85	0.53	0.74	0.90	0.78	1.69
Copper	sockeye	50	6.1	0.67	20-75	0.10	0.15	0.16	0.15	0.65
Crescent	sockeye	41	4.6	0.38	10-60	0.03	0.68	0.42	0.59	0.96
Deshka	Chinook	36	11.2	0.13	15-45	0.12	0.91	0.58	0.77	2.23
East Alsek	sockeye	38	8.6	0.42	30-85	0.04	0.27	0.46	0.31	0.82
Eshamy	sockeye	38	90.2	0.62	40-75	0.16	0.39	0.57	0.79	1.31
Ford Arm	coho	27	4.9	0.61	40-85	0.04	0.23	0.32	0.25	0.73
Ford Arm	sockeye	27	14.4	0.07	20-50	0.05	0.49	0.44	1.32	2.96

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Table 8.– Page 2 of 4.

Stock or # of Stocks	Species	Years	Contrast	*u*	Best	Rating	25-75	15-75	15-85	15-Max
Frazer	sockeye	44	34.6	0.43	35-75	0.07	0.31	0.54	0.63	1.86
Goodnews	sockeye	29	8.0	0.44	5-45	0.06	0.65	0.56	0.70	2.67
Goodnews	Chinook	29	4.3	0.34	Min-50	0.07	0.88	0.68	0.92	1.40
Hugh Smith	coho	28	7.6	0.67	40-85	0.08	0.28	0.33	0.31	0.99
Igushik	sockeye	54	124.3	0.57	40-85	0.56	0.77	0.92	0.81	2.81
Italio	sockeye	31	55.7	0.06	35-60	0.29	1.42	1.57	1.91	3.37
Karluk	Chinook	34	18.3	0.15	10-45	0.50	1.64	1.33	1.54	1.99
Karluk early run	sockeye	29	8.7	0.36	10-45	0.29	1.58	1.39	1.48	1.94
Karluk late run	sockeye	29	20.0	0.39	25-60	0.03	0.13	0.31	0.45	0.91
Kasilof	sockeye	42	13.0	0.69	25-75	0.03	0.03	0.34	0.52	1.24
Kenai	sockeye	42	27.8	0.65	40-Max	0.47	0.92	1.02	0.87	0.73
Klukshu	sockeye	30	9.7	0.33	10-45	0.13	0.69	0.51	0.74	1.56
Kodiak Archipelago	pink	43	19.1	0.50	40-85	0.03	0.53	0.74	0.54	1.70
Kodiak Mainland	pink	41	265.3	0.20	40-85	0.61	1.01	1.21	1.00	3.72
Kotzebue	chum	37	10.4	0.39	30-75	0.12	0.14	0.34	0.36	2.54
Kwiniuk	chum	44	10.4	0.16	35-65	0.06	0.37	0.43	0.63	1.79
Lost	sockeye	37	46.9	0.45	30-65	0.03	0.32	0.65	0.85	2.08
McDonald	sockeye	30	8.0	0.50	30-50	0.11	0.36	0.49	0.61	0.88
Nelson	sockeye	36	4.8	0.56	10-60	0.12	0.48	0.36	0.54	1.18
Nelson	Chinook	29	7.0	0.47	10-45	0.09	0.35	0.30	0.65	2.02
Northern SE Inside	pink	50	17.3	0.40	40-85	0.67	0.95	1.03	0.85	1.15
Northern SE Outside	pink	50	290.8	0.25	40-85	0.87	1.16	1.22	1.03	2.19
Nushagak	Chinook	44	6.5	0.52	10-55	0.08	0.65	0.41	0.68	1.29
Nushagak	coho	22	13.8	0.22	35-60	0.09	0.61	0.72	0.82	2.19
Nushagak	sockeye	31	11.8	0.67	40-85	0.58	0.72	0.84	0.74	2.14
Redoubt	sockeye	28	228.0	0.07	25-50	0.33	1.39	1.82	2.35	3.80
Salcha	Chinook	23	6.8	0.46	Min-45	0.38	2.22	1.97	2.35	2.83

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Table 8.–Page 3 of 4.

Stock or # of Stocks	Species	Years	Contrast	*u*	Best	Rating	25-75	15-75	15-85	15-Max
Saltery	sockeye	34	7.0	0.25	Min-50	0.08	0.86	0.75	0.97	2.78
Situk	sockeye	34	9.7	0.43	15-75	0.05	0.31	0.05	0.19	1.67
Speel	sockeye	27	100.1	0.31	30-65	0.06	0.39	0.55	1.23	2.32
South Pen. even	pink	24	74.6	0.32	35-60	0.02	0.22	0.47	0.67	2.29
South Pen. odd	pink	23	57.8	0.33	40-75	0.18	0.51	0.73	1.16	1.73
Southern SE	pink	50	18.2	0.48	40-85	0.26	0.61	0.69	0.58	0.89
Taku	Chinook	35	9.7	0.18	20-45	0.11	0.69	0.56	0.72	2.40
Taku	coho	21	6.8	0.48	25-65	0.06	0.08	0.10	0.28	1.18
Togiak	sockeye	54	21.1	0.58	35-85	0.05	0.45	0.54	0.37	1.22
Unuk	Chinook	18	3.6	0.42	30-75	0.05	0.09	0.16	0.42	0.67
Wood	sockeye	54	13.9	0.53	35-85	0.06	0.29	0.47	0.38	1.62
Yukon	chum	36	9.5	0.32	35-85	0.02	0.45	0.56	0.33	1.67
5	Chinook		>8	<0.40	15-45	0.37	1.15	0.86	1.07	2.28
1				≥0.40	10-50	0.00	0.58	0.51	0.61	1.68
2			≤8	<0.40	Min-45	0.16	1.09	0.94	1.16	1.77
5				≥0.40	5-45	0.29	0.91	0.75	1.02	1.66
6	chum		>8	<0.40	20-65	0.38	0.46	0.57	0.72	2.20
1	coho		>8	<0.40	35-60	0.09	0.61	0.72	0.82	2.19
2				≥0.40	15-65	0.44	0.53	0.51	0.67	1.59
4			≤8	≥0.40	40-75	0.18	0.21	0.27	0.28	0.85
4	pink		>8	<0.40	40-75	0.57	0.79	0.82	1.03	2.29
3				≥0.40	40-85	0.32	0.49	0.61	0.66	1.51
8	sockeye		>8	<0.40	20-55	0.44	0.86	0.94	1.31	2.31
15				≥0.40	35-75	0.38	0.44	0.59	0.66	1.55
4			≤8	<0.40	Min-45	0.31	1.15	1.01	1.18	2.12
6				≥0.40	20-65	0.26	0.33	0.30	0.36	1.04

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Table 8.–Page 4 of 4.

Stock or # of Stocks	Species	Years	Contrast	u	Best	Rating	25-75	15-75	15-85	15-Max
24	All		>8	<0.40	20-55	0.54	0.79	0.82	1.03	2.29
21				≥0.40	40-75	0.47	0.49	0.61	0.66	1.51
6			≤8	<0.40	Min-45	0.26	1.13	0.89	1.17	2.00
15				≥0.40	15-55	0.39	0.49	0.44	0.56	1.20

Note: Column headings are defined in Table 1.

Table 9.–Expected yield as a percentage of MSY at the lower bound (LB), midpoint (Mid), and upper bound (UB) of the appropriate current or recommended SEG tier from the simulation analysis.

					Current Tier			Recommended Tier		
σ_S	φ	Contrast	Years	μ	LB	Mid	UB	LB	Mid	UB
0.05	0.0	>8	10	0.10-0.18	90	68	8	84	85	46
				0.23-0.39	81	81	50	73	87	70
				0.10-0.39	84	76	33	78	86	60
	0.5	>8	10	0.10-0.18	81	59	1	75	77	37
				0.23-0.39	73	67	31	66	76	54
				0.10-0.39	76	64	19	70	77	47
	0.0	≤8	10	0.10-0.18	93	59	-8	92	82	40
				0.23-0.39	87	72	22	83	88	68
				0.10-0.39	90	67	10	87	85	57
	0.5	≤8	10	0.10-0.18	89	52	-13	90	75	33
				0.23-0.39	83	58	3	81	79	53
				0.10-0.39	86	56	-3	85	78	45
0.05	0.0	>8	30	0.10-0.18	95	70	10	89	88	46
				0.23-0.39	86	84	54	77	90	74
				0.10-0.39	90	78	36	82	89	63
	0.5	>8	30	0.10-0.18	86	72	15	78	86	50
				0.23-0.39	71	79	51	61	82	69
				0.10-0.39	77	76	37	68	84	62
	0.0	≤8	30	0.10-0.18	96	78	20	91	91	53
				0.23-0.39	93	81	23	86	96	74
				0.10-0.39	95	79	21	88	94	65
	0.5	≤8	30	0.10-0.18	98	68	7	95	85	39
				0.23-0.39	98	64	-6	94	90	55
				0.10-0.39	98	66	0	94	88	48
0.50	0.0	>8	10	0.10-0.18	90	65	8	89	84	55
				0.23-0.39	84	80	51	82	87	75
				0.10-0.39	86	74	33	85	86	67
	0.5	>8	10	0.10-0.18	80	61	8	79	76	51
				0.23-0.39	70	70	41	68	75	64
				0.10-0.39	74	66	28	73	75	59
	0.0	≤8	10	0.10-0.18	93	61	1	93	81	40
				0.23-0.39	87	73	26	83	87	69
				0.10-0.39	90	68	16	87	85	57
	0.5	≤8	10	0.10-0.18	88	60	6	88	78	42
				0.23-0.39	80	63	16	77	79	60
				0.10-0.39	84	62	12	82	79	53
0.50	0.0	>8	30	0.10-0.18	95	69	9	94	88	59
				0.23-0.39	86	84	54	83	90	79
				0.10-0.39	90	78	36	87	89	71
	0.5	>8	30	0.10-0.18	86	71	14	84	86	61
				0.23-0.39	71	79	50	67	81	74
				0.10-0.39	77	75	36	74	83	69
	0.0	≤8	30	0.10-0.18	ND	ND	ND	ND	ND	ND
				0.23-0.39	ND	ND	ND	ND	ND	ND
				0.10-0.39	ND	ND	ND	ND	ND	ND
	0.5	≤8	30	0.10-0.18	ND	ND	ND	ND	ND	ND
				0.23-0.39	ND	ND	ND	ND	ND	ND
				0.10-0.39	ND	ND	ND	ND	ND	ND

Note: Column headings for variables of the simulation analysis are defined in Table 1.

Contrast[a]	Range
Low (< 4)	15th percentile - Maximum
Medium (4 - 8)	15th and 85th percentile
High (> 8) and at most low exploitation	15th and 75th percentile
High (> 8) and at least moderate exploition	25th and 75th percentile

[a] Relative range of the entire time series of escapement data calculated by dividing the maximum observed escapement by the minimum observed escapement.

Figure 1.–Excerpted table from Bue and Hasbrouck (*unpublished*) that describes the 4 ranges of percentiles used in the Percentile Approach to development of SEGs.

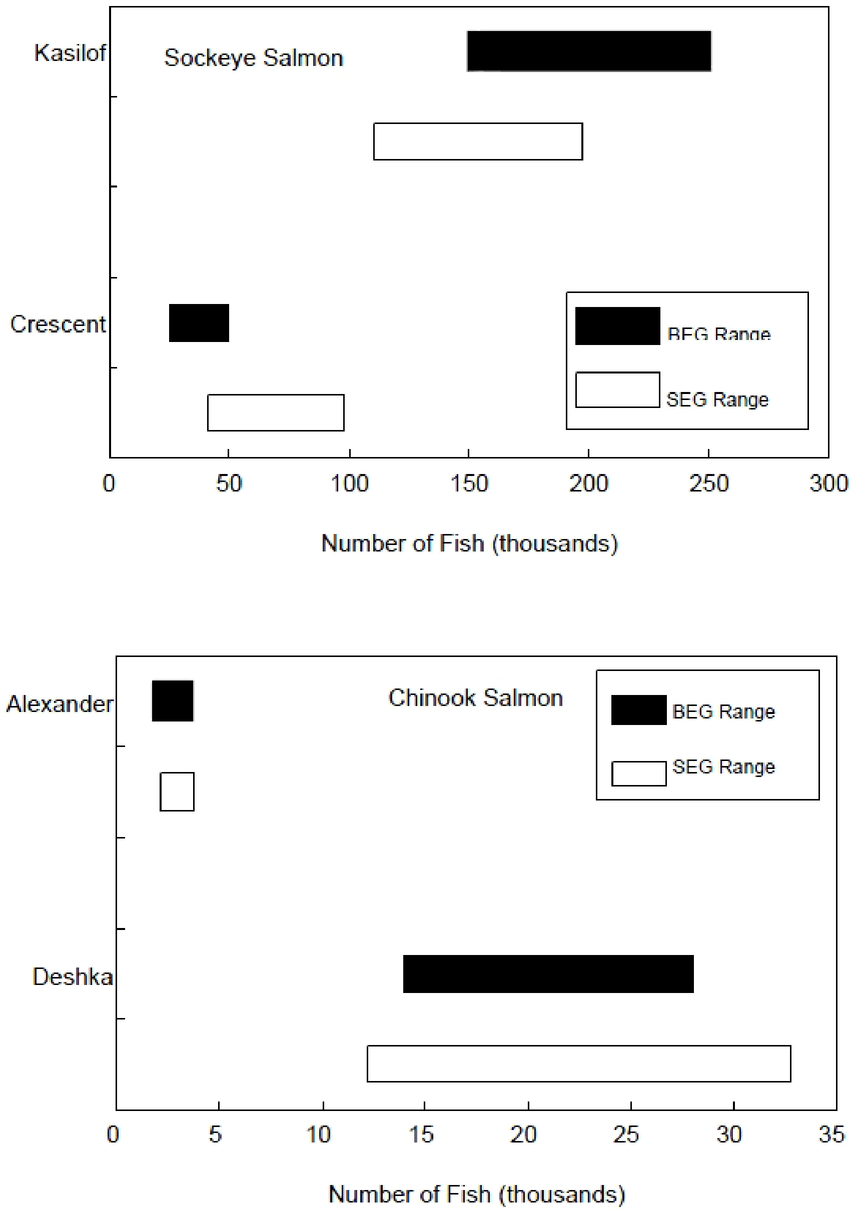

Figure 2.–Excerpted figure from Bue and Hasbrouck (*unpublished*) that compares SEG ranges derived from the Percentile Approach to those from the development of a BEG for 2 sockeye salmon and 2 Chinook salmon stocks in Upper Cook Inlet.

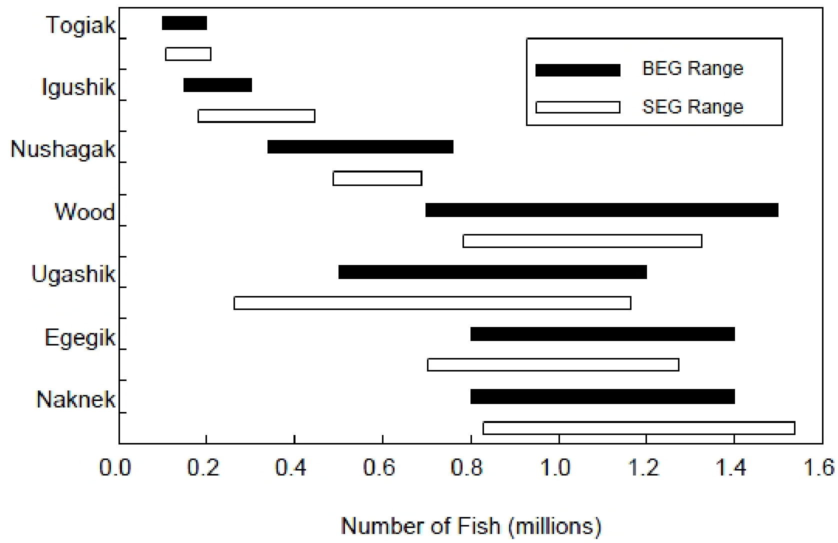

Figure 3.–Excerpted figure from Bue and Hasbrouck (*unpublished*) that compares SEG ranges derived from the Percentile Approach to those from the development of a BEG for 7 sockeye salmon stocks in Bristol Bay.

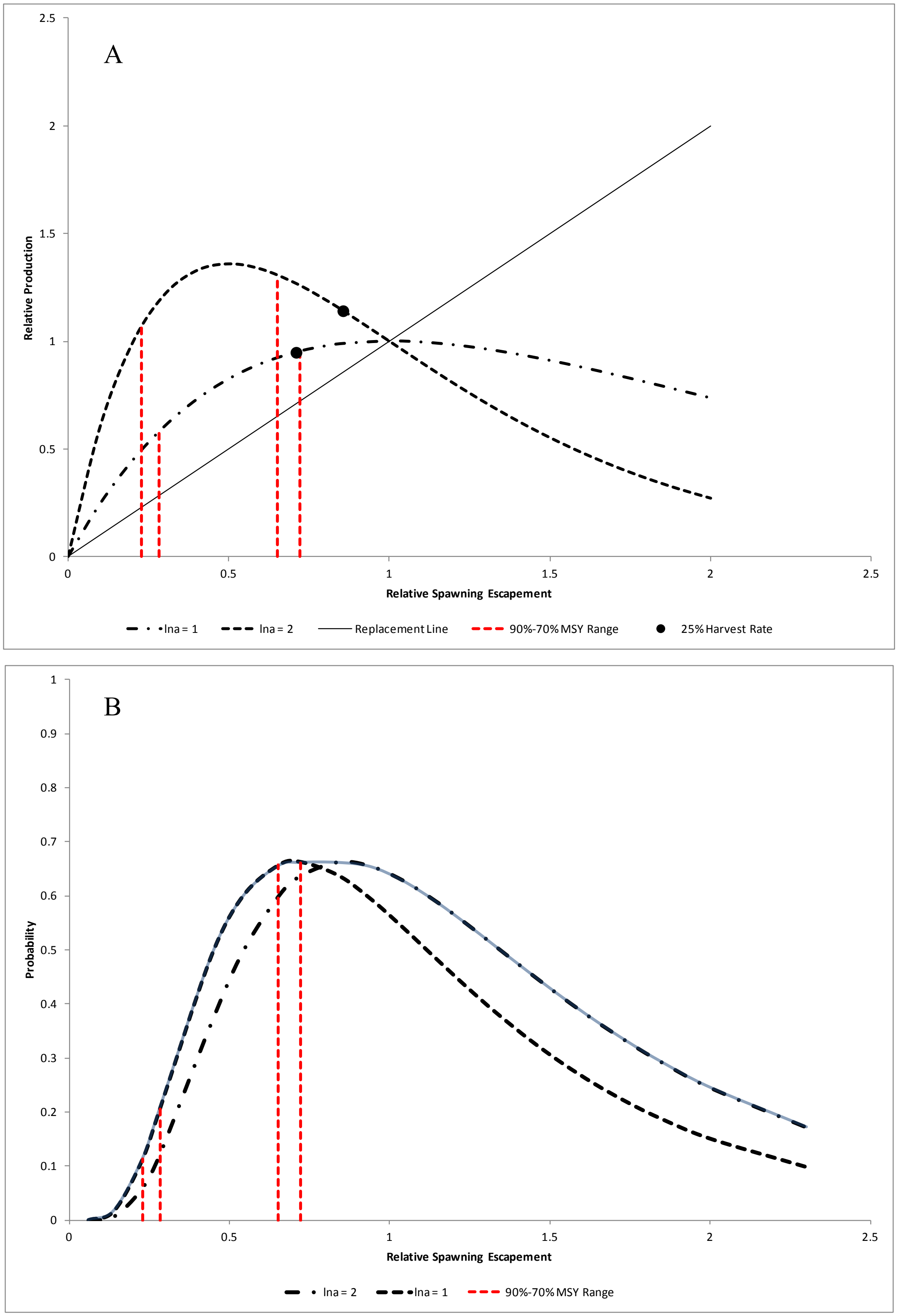

Figure 4.–Panel A: 2 hypothetical stock-recruitment relationships (dashed curves), the L90 and U70 lines (vertical dashed lines) for each relationship, and equilibrium points (black circles) based on a fixed harvest rate of 0.25. Panel B: 2 hypothetical log-normal distributions (dashed curves) around the 2 equilibrium spawning escapements from Panel A and the same L90 and U70 lines from Panel A.

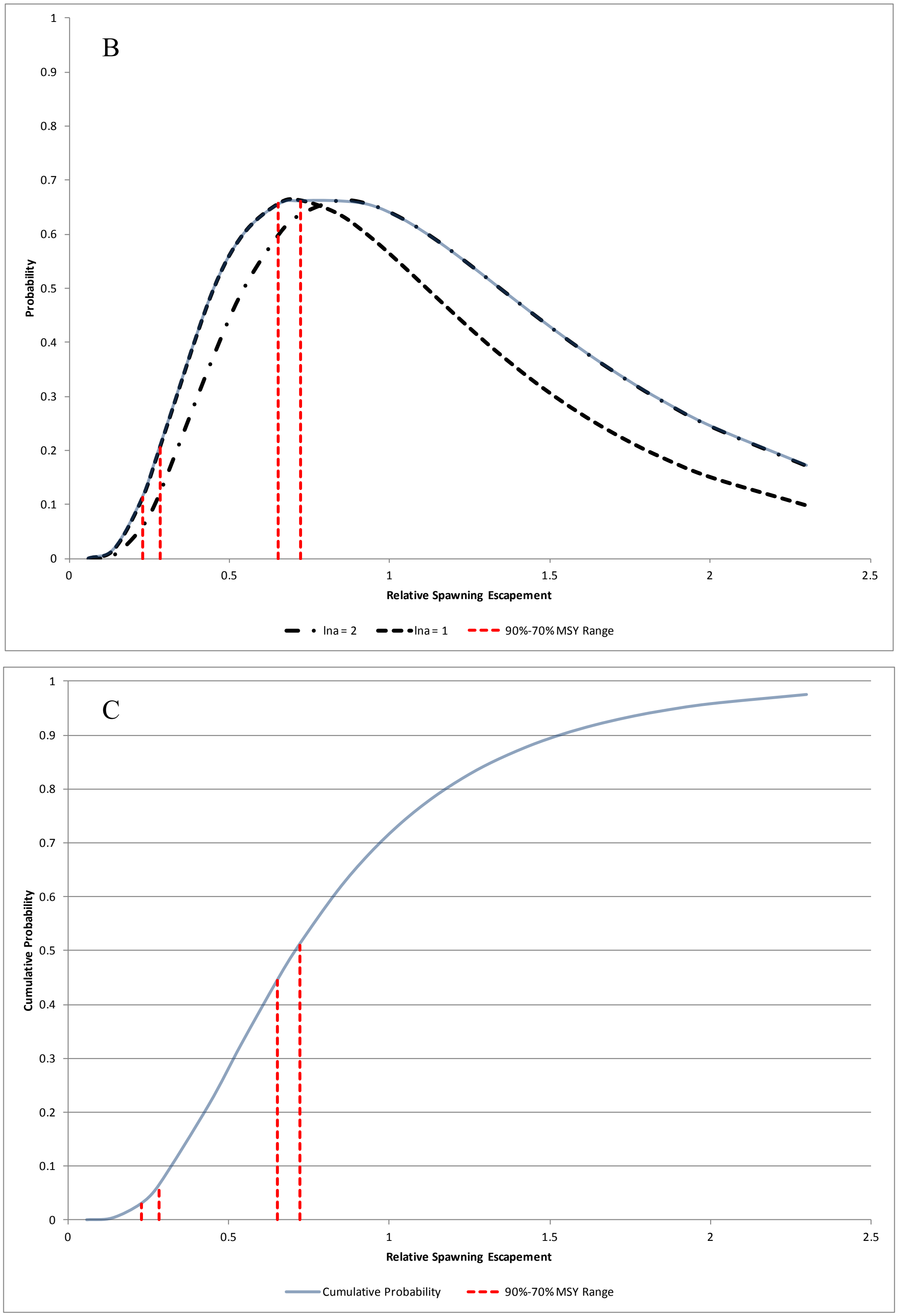

Figure 4.–Page 2 of 2. Panel C: the combined cumulative distribution (solid curve) of the 2 theoretical log-normal distributions in Panel B and the same L90 and U70 lines (vertical dashed lines) from Panel A. Results are for the low measurement error scenario ($\sigma_S = 0.05$).

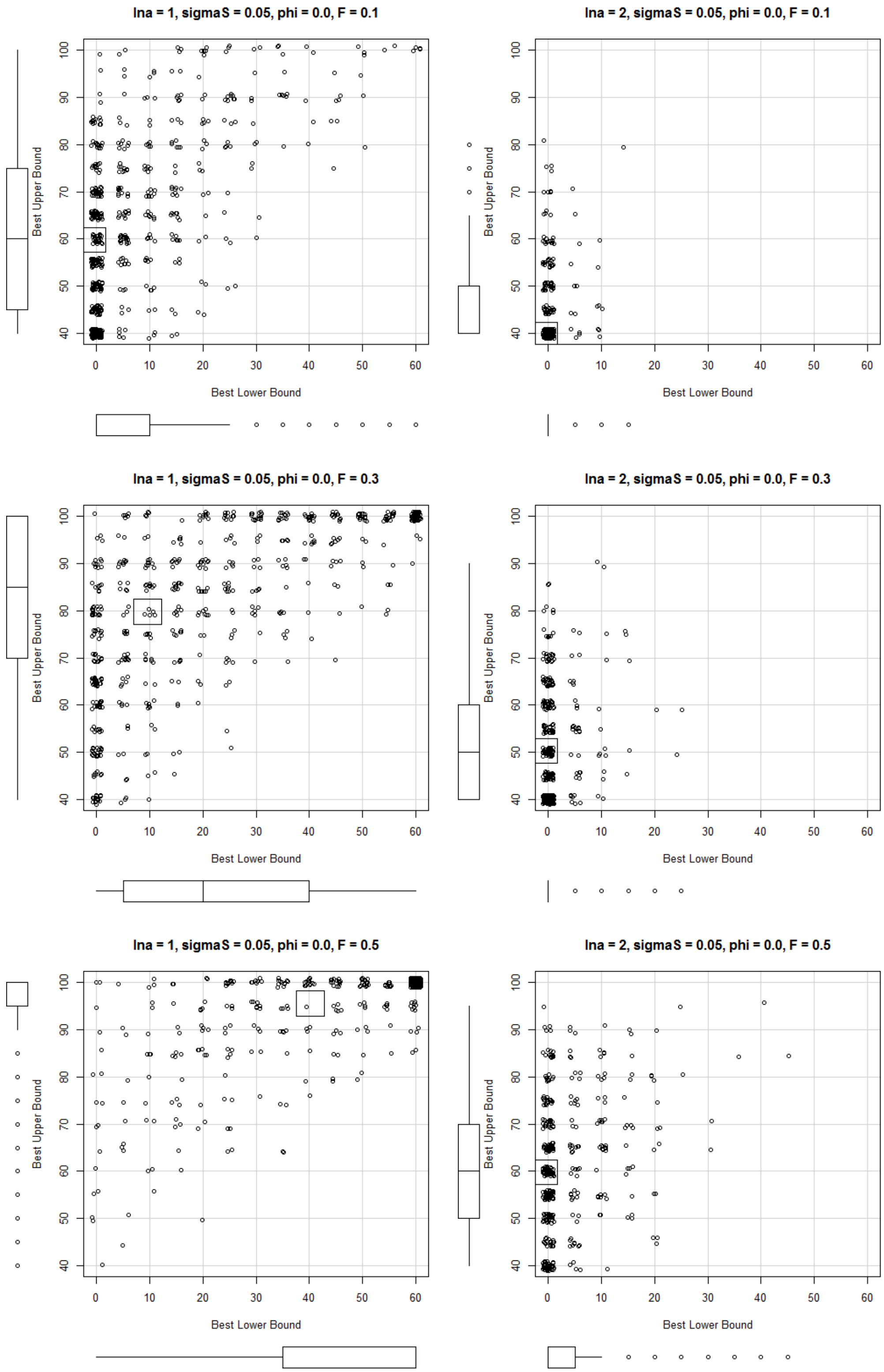

Figure 5(A).–Scatter plots of simulated Best upper against Best lower percentile based on lowest *Rating* for 2 log-productivities and 3 harvest rates; with low measurement error, no serial correlation, and low contrast for 10 years of escapements. Squares indicate the average Best percentile range.

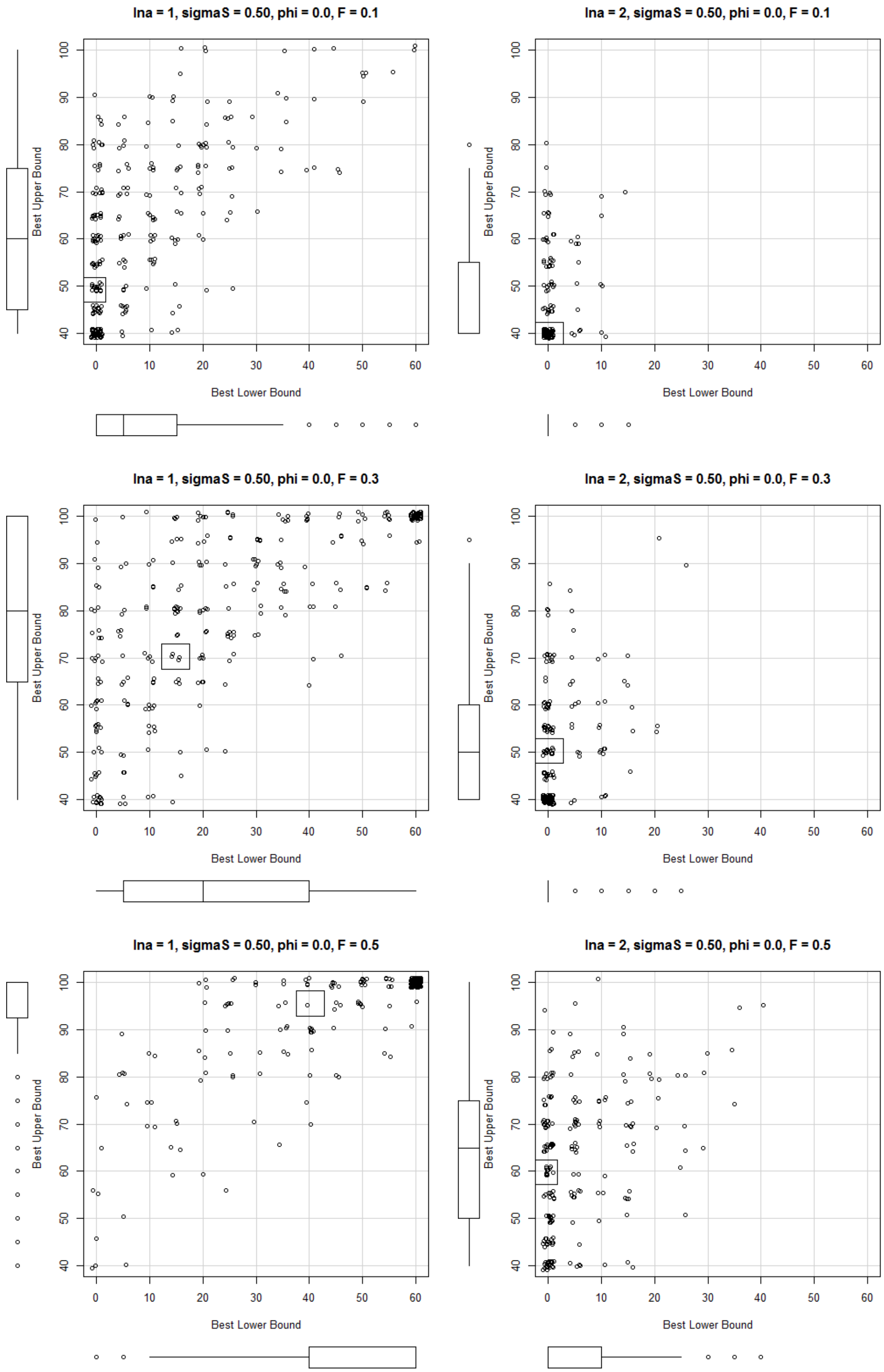

Figure 5(B).–Scatter plots of simulated Best upper against Best lower percentile based on lowest *Rating* for 2 log-productivities and 3 harvest rates; with high measurement error, no serial correlation, and low contrast for 10 years of escapements. Squares indicate the average Best percentile range.

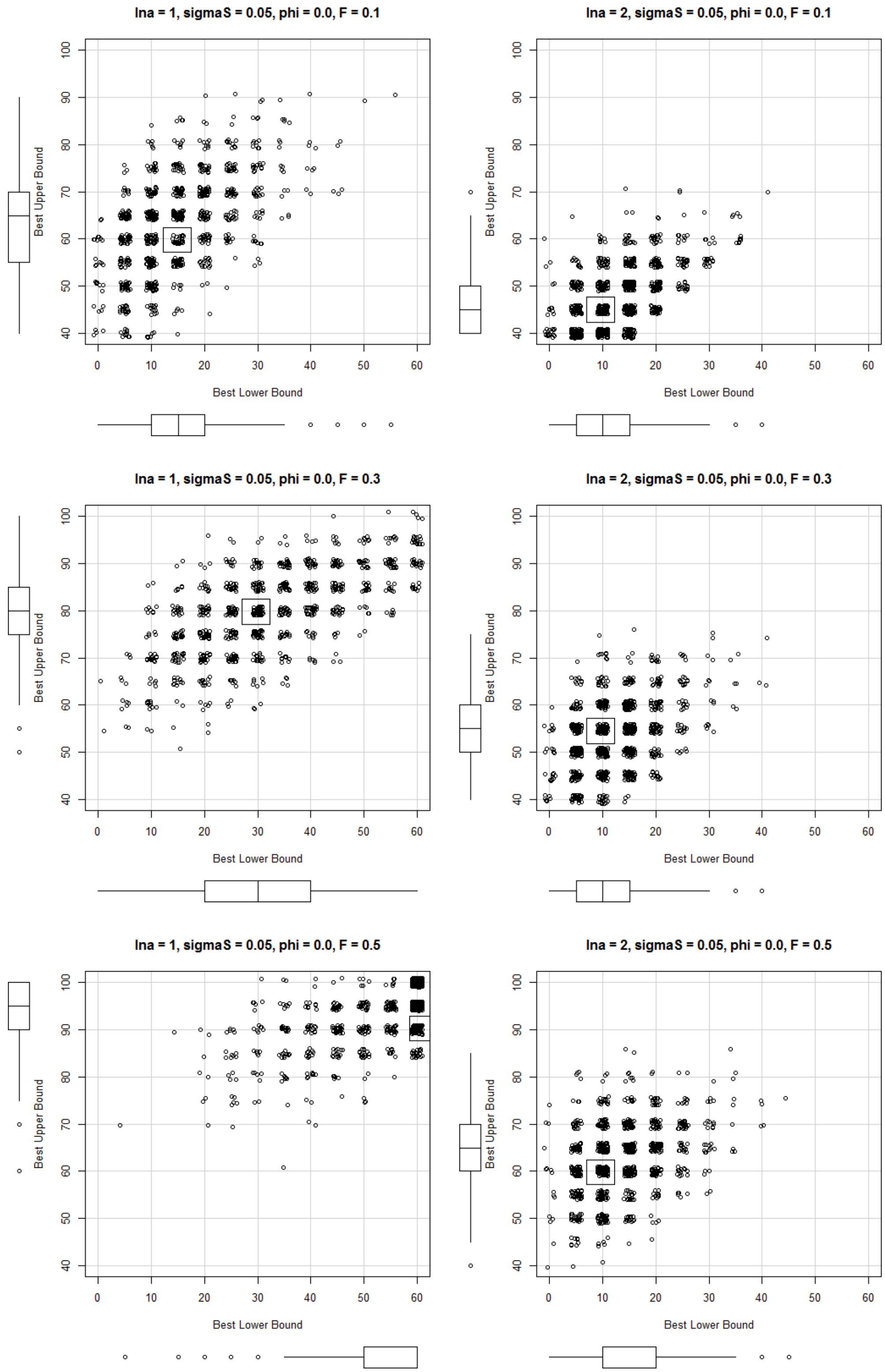

Figure 5(C).–Scatter plots of simulated Best upper against Best lower percentile based on the lowest *Rating* for 2 log-productivities and 3 harvest rates; with low measurement error, no serial correlation, and high contrast for 30 years of escapements. Squares indicate the average Best percentile range.

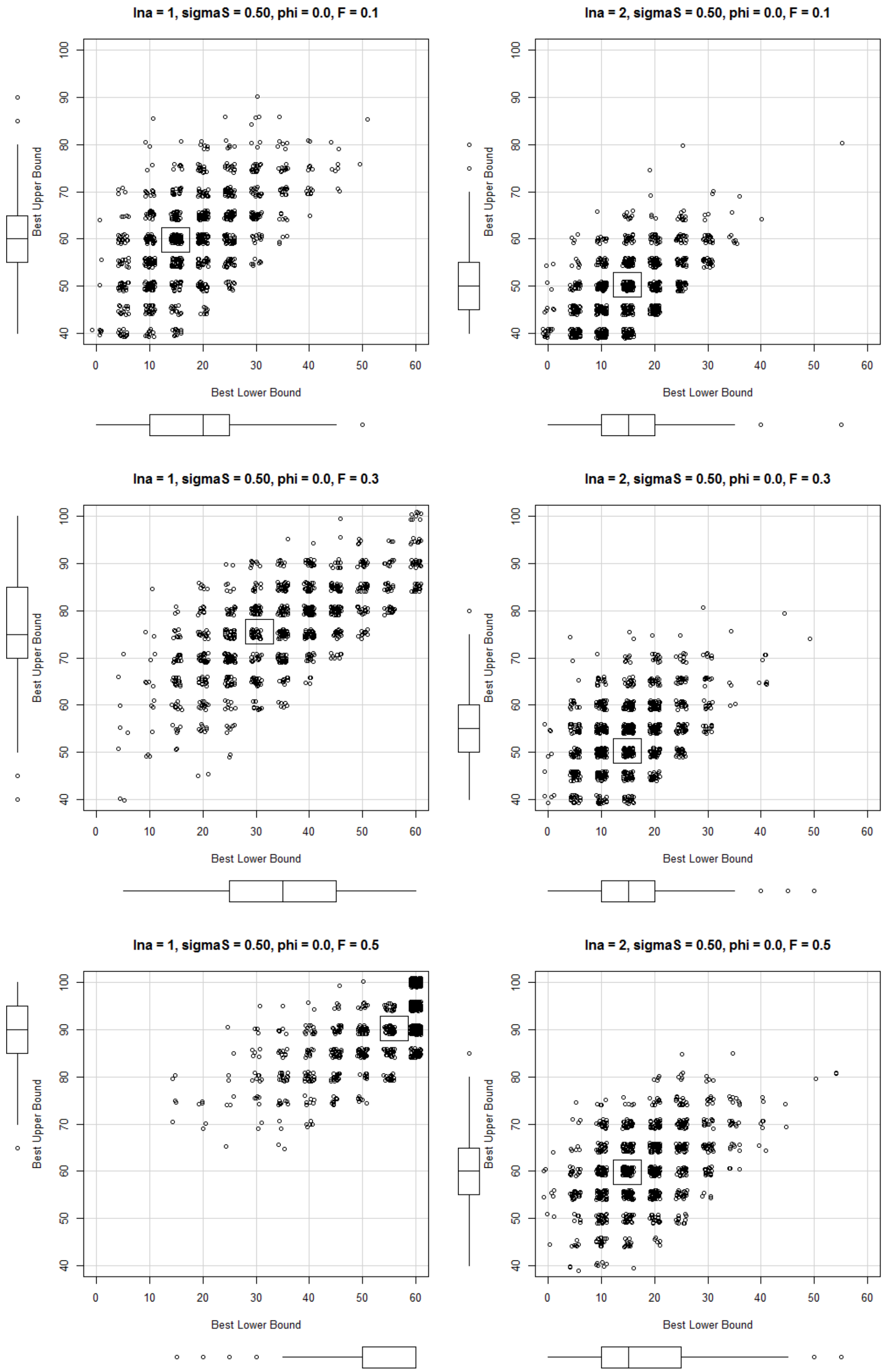

Figure 5(D).–Scatter plots of simulated Best upper against Best lower percentile based on the lowest *Rating* for 2 log-productivities and 3 harvest rates; with high measurement error, no serial correlation, and high contrast for 30 years of escapements. Squares indicate the average Best percentile range.

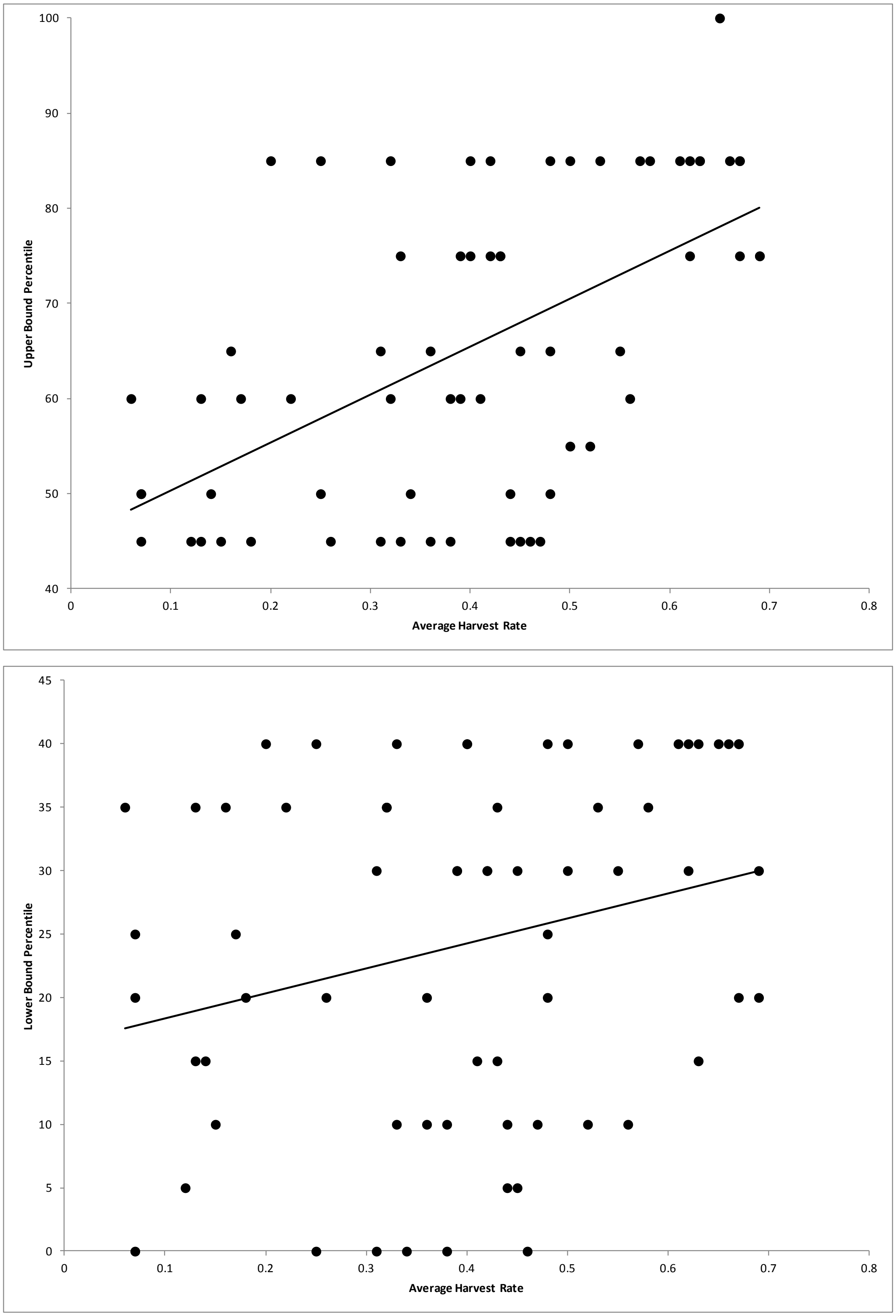

Figure 6.–Best lower bound (lower panel) or upper bound (upper panel) percentile plotted against average harvest rate for 66 Pacific salmon stocks in the empirical meta-analysis. Solid lines are simple least-squared linear regressions.

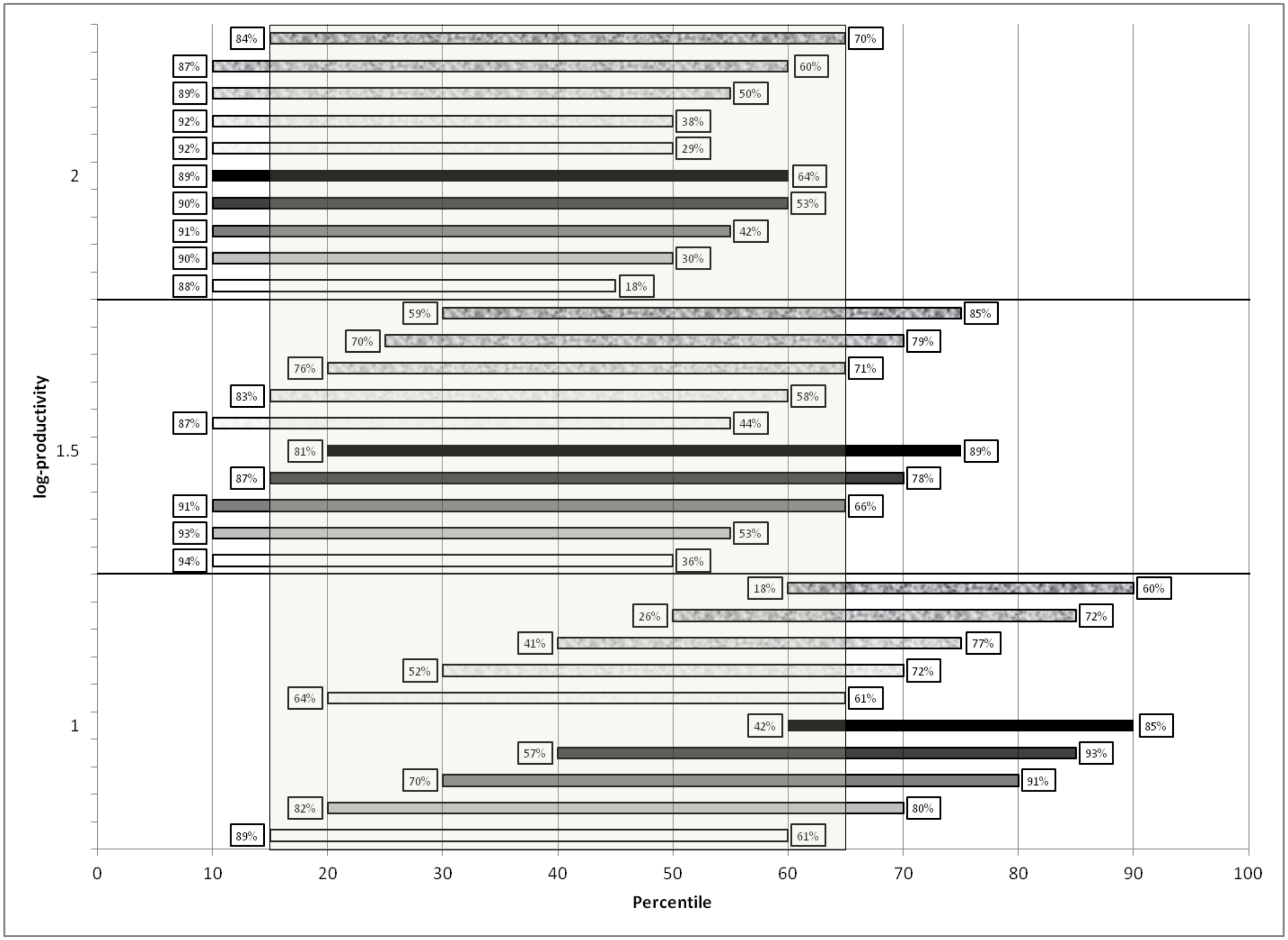

Figure 7(A).–Plots of average Best percentiles (bars) and expected yields as a percentage of MSY (values in boxes) for 3 levels of log-productivity when the recommended 15th-65th percentiles (shaded area) are managed for. Shading represents low (lightest) to moderate (darkest) harvest rate, and fill represents no (solid) to moderate (stippled) serial correlation for simulations with low measurement error and high contrast, with 30 years of escapements.

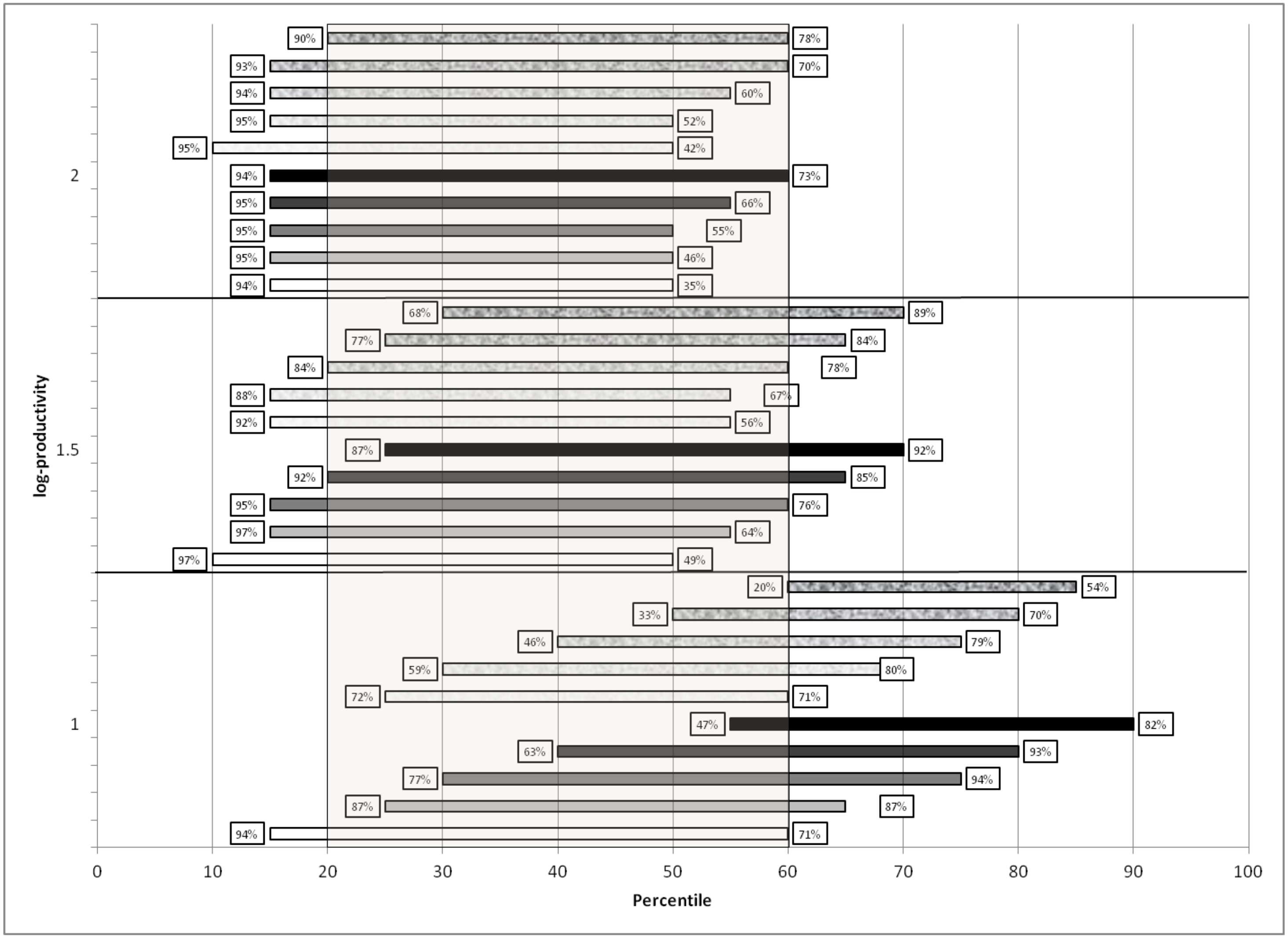

Figure 7(B).–Plots of average Best percentiles (bars) and expected yields as a percentage of MSY (values in boxes) for 3 levels of log-productivity when the recommended 20th-60th percentiles (shaded area) are managed for. Shading represents low (lightest) to moderate (darkest) harvest rate, and fill represents no (solid) to moderate (stippled) serial correlation for simulations with high measurement error and high contrast, with 30 years of escapements.

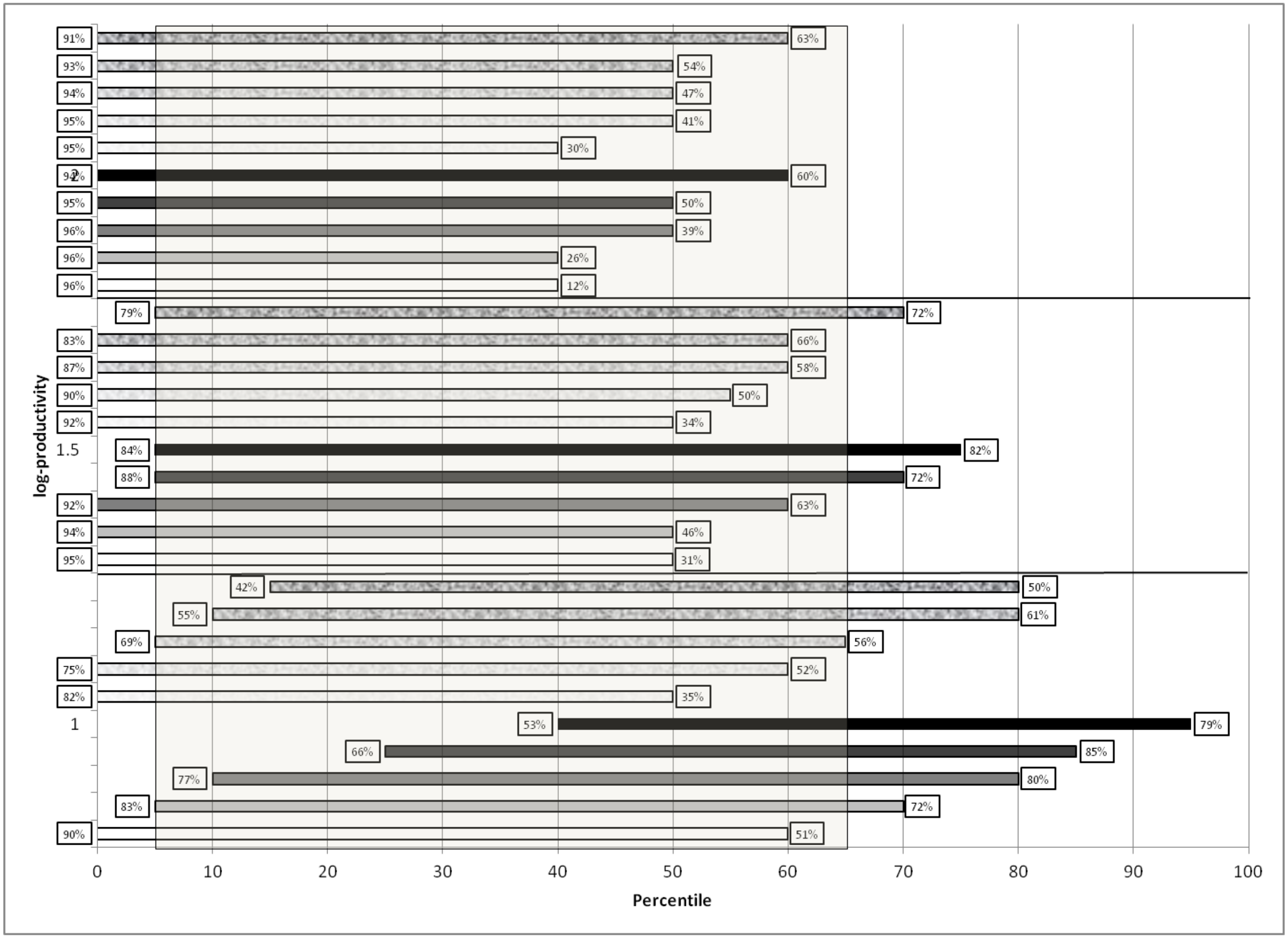

Figure 7(C).–Plots of average Best percentiles (bars) and expected yields as a percentage of MSY (values in boxes) for 3 levels of log-productivity when the recommended 5th-65th percentiles (shaded area) are managed for. Shading represents low (lightest) to moderate (darkest) harvest rate, and fill represents no (solid) to moderate (stippled) serial correlation for simulations with low measurement error and low contrast, with 10 years of escapements.

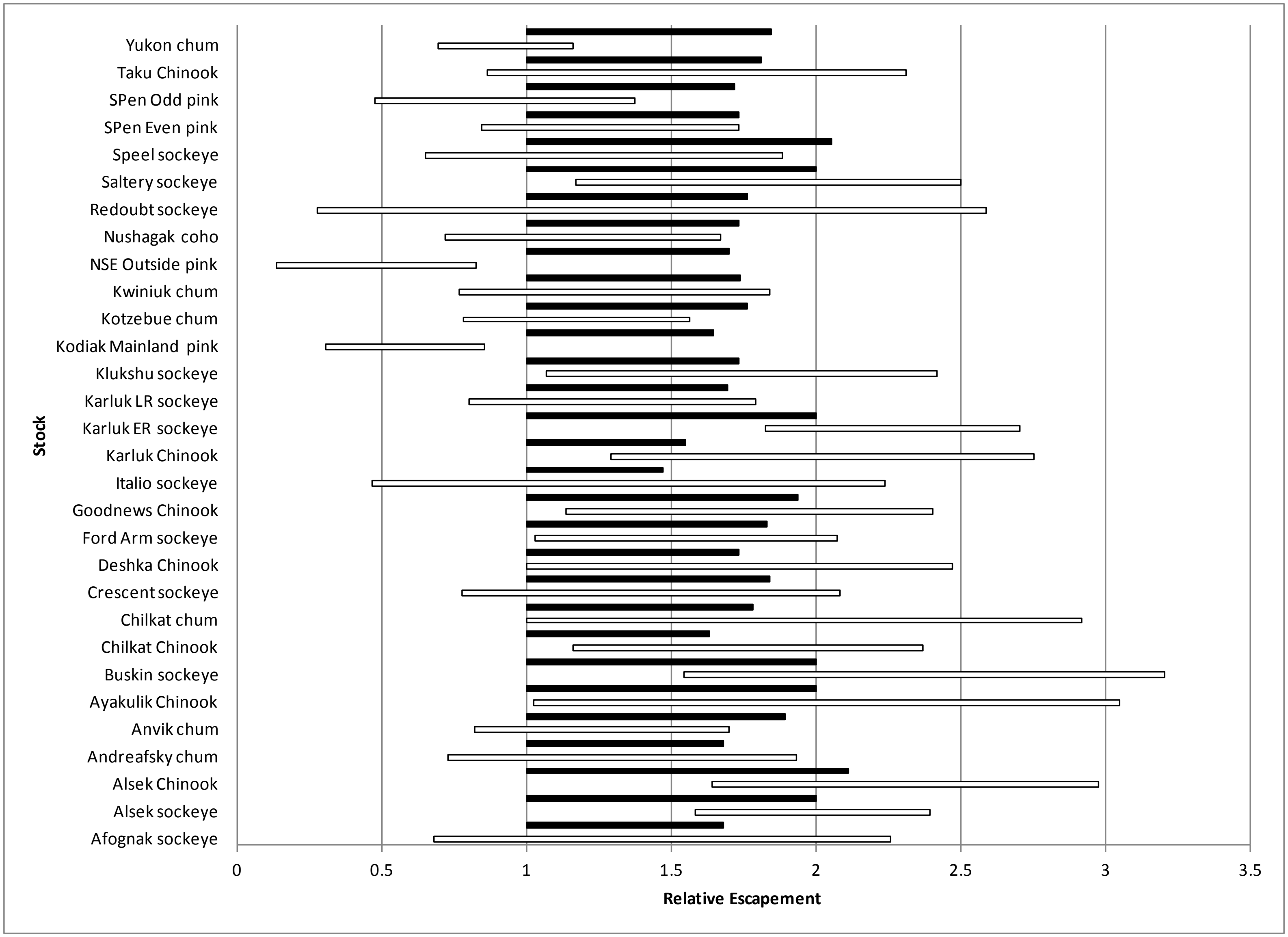

Figure 8.–Comparison of relative escapements (L90 = 1) calculated for the L90-U70 range around S_{MSY} (solid bars) and for the tier level from the recommended Percentile Approach (open bars) for the 30 salmon stocks in the meta-analysis with harvest rates of less than 0.40.

APPENDIX A: ESCAPEMENT GOALS IN ALASKA BASED ON THE PERCENTILE APPROACH

Appendix A1.–Sustainable escapement goals in Southeast Alaska that are based on the Percentile Approach.

Stock	Species	Lower	Upper	Type	Enumeration Method	Lower %tile	Upper %tile	Harvest Rate	Years	Contrast
Southern SE Summer	chum	54,000		lower-bound SEG	Peak Aerial Survey	25		moderate	48	40
Northern SE Inside Summer	chum	119,000		lower-bound SEG	Peak Aerial Survey	25		moderate	48	18
Northern SE Outside Summer	chum	19,000		lower-bound SEG	Peak Aerial Survey	25		moderate	26	10
Cholmondeley Sound Fall	chum	30,000	48,000	SEG	Peak Aerial Survey	25	75	moderate	28	12
Security Bay Fall	chum	5,000	15,000	SEG	Peak Aerial Survey	25	75	moderate	44	12
Excursion River Fall	chum	4,000	18,000	SEG	Peak Aerial Survey	25	75	moderate	44	144
Situk River	pink	33,000		lower-bound SEG	Weir Index	15		low (<25%)	22	87
Lost River	sockeye	1,000		lower-bound SEG	Foot/Boat Survey					

Appendix A2.–Sustainable escapement goals in Southcentral Alaska that are based on the Percentile Approach.

Stock	Species	Lower	Upper	Type	Enumeration Method	Lower %tile	Upper %tile	Harvest Rate	Years	Contrast
Alexander Creek	Chinook	2,100	6,000	SEG	Single Aerial Survey	15	85		25	6
Chuitna River	Chinook	1,200	2,900	SEG	Single Aerial Survey	25	75	moderate	20	8
Chulitna River	Chinook	1,800	5,100	SEG	Single Aerial Survey	15	85		16	7
Clear (Chunilna) Creek	Chinook	950	3,400	SEG	Single Aerial Survey	15	85		17	6
Crooked Creek	Chinook	650	1,700	SEG	Weir Count	25	75	high	17	20
Goose Creek	Chinook	250	650	SEG	Single Aerial Survey	15	85		19	8
Lake Creek	Chinook	2,500	7,100	SEG	Single Aerial Survey	15	100		17	4
Lewis River	Chinook	250	800	SEG	Single Aerial Survey	15	85		20	6
Little Susitna River	Chinook	900	1,800	SEG	Single Aerial Survey	15	85		14	6
Little Willow Creek	Chinook	450	1,800	SEG	Single Aerial Survey	15	85		20	8
Montana Creek	Chinook	1,100	3,100	SEG	Single Aerial Survey	15	100		20	4
Peters Creek	Chinook	1,000	2,600	SEG	Single Aerial Survey	25	75	moderate	18	13
Prairie Creek	Chinook	3,100	9,200	SEG	Single Aerial Survey	15	85		20	5
Sheep Creek	Chinook	600	1,200	SEG	Single Aerial Survey	25	75	moderate	17	11
Talachulitna River	Chinook	2,200	5,000	SEG	Single Aerial Survey	15	85		19	6
Theodore River	Chinook	500	1,700	SEG	Single Aerial Survey	15	85		21	6
Willow Creek	Chinook	1,600	2,800	SEG	Single Aerial Survey	25	75	moderate	21	9
Deep Creek	Chinook	350	800	SEG	Single Aerial Survey	25	75	moderate	24	19

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Stock	Species	Lower	Upper	Type	Enumeration Method	Lower %tile	Upper %tile	Harvest Rate	Years	Contrast
Ninilchik River	Chinook	550	1300	SEG	Weir Count	15	100			
Clearwater Creek	chum	3,800	8,400	SEG	Peak Aerial Survey	25	75	moderate	28	28
Port Graham River	chum	1,450	4,800	SEG	Multiple Foot Surveys	25	75		26	29
Dogfish Lagoon	chum	3,350	9,150	SEG	Multiple Foot Surveys	25	75		26	25
Rocky River	chum	1,200	5,400	SEG	Multiple Foot Surveys	25	75		25	350
Port Dick Creek	chum	1,900	4,450	SEG	Multiple Aerial or Foot Surveys	25	75		26	9
Island Creek	chum	6,400	15,600	SEG	Multiple Aerial or Foot Surveys	25	75		26	36
Big Kamishak River	chum	9,350	24,000	SEG	Multiple Aerial Surveys	25	75		22	18
Little Kamishak River	chum	6,550	23,800	SEG	Multiple Aerial Surveys	15	85		23	7
McNeil River	chum	24,000	48,000	SEG	Multiple Aerial Surveys					
Bruin River	chum	6,000	10,250	SEG	Multiple Aerial Surveys	25	75		26	11
Ursus Cove	chum	6,050	9,850	SEG	Multiple Aerial Surveys	25	75		26	32
Cottonwood Creek	chum	5,750	12,000	SEG	Multiple Aerial Surveys	25	75		26	10
Iniskin Bay	chum	7,850	13,700	SEG	Multiple Aerial Surveys	25	75		26	7
Fish Creek (Knik)	coho	1,200	4,400	SEG	Weir Count	25	75	moderate	30	32
Jim Creek	coho	450	700	SEG	Single Foot Survey	25	75		16	174
Little Susitna River	coho	10,100	17,700	SEG	Weir Count	25	75	moderate	14	10
Copper River Delta	coho	32,000	67,000	SEG	Peak Aerial Survey	15	85		20	4
Bering River	coho	13,000	33,000	SEG	Peak Aerial Survey	25	75		17	13

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Stock	Species	Lower	Upper	Type	Enumeration Method	Lower %tile	Upper %tile	Harvest Rate	Years	Contrast
Humpy Creek	pink	21,650	85,550	SEG	Multiple Foot Surveys	25	75		26	22
China Poot Creek	pink	2,900	8,200	SEG	Multiple Foot Surveys	25	75		26	13
Tutka Creek	pink	6,500	17,000	SEG	Multiple Foot Surveys	25	75		16	20
Barabara Creek	pink	1,900	8,950	SEG	Multiple Foot Surveys	25	75		26	84
Seldovia Creek	pink	19,050	38,950	SEG	Multiple Foot Surveys	25	75		26	9
Port Graham River	pink	7,700	19,850	SEG	Multiple Foot Surveys	25	75		26	11
Port Chatham	pink	7,800	21,000	SEG	Multiple Foot Surveys	25	75		25	142
Windy Creek Right	pink	3,350	10,950	SEG	Multiple Foot Surveys	25	75		26	115
Windy Creek Left	pink	3,650	29,950	SEG	Multiple Foot Surveys	25	75		26	374
Rocky River	pink	9,350	54,250	SEG	Multiple Foot Surveys	25	75		26	61
Port Dick Creek	pink	18,550	58,300	SEG	Multiple Aerial or Foot Surveys	25	75		26	28
Island Creek	pink	7,200	28,300	SEG	Multiple Aerial or Foot Surveys	25	75		25	836
S. Nuka Island Creek	pink	2,700	14,250	SEG	Multiple Aerial or Foot Surveys	25	75		24	114
Desire Lake Creek	pink	1,900	20,200	SEG	Multiple Aerial Surveys	25	75		23	169
Bruin River	pink	18,650	155,750	SEG	Multiple Aerial Surveys	25	75		26	414
Sunday Creek	pink	4,850	28,850	SEG	Multiple Aerial Surveys	25	75		26	545
Brown's Peak Creek	pink	2,450	18,800	SEG	Multiple Aerial Surveys	25	75		26	133

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Stock	Species	Lower	Upper	Type	Enumeration Method	Lower %tile	Upper %tile	Harvest Rate	Years	Contrast
Eastern District (even year)	pink	250,000	580,000	SEG	Multiple Aerial Surveys	25	75		46	
Eastern District (odd year)	pink	310,000	640,000	SEG	Multiple Aerial Surveys	25	75		46	
Northern District (even year)	pink	140,000	210,000	SEG	Multiple Aerial Surveys	25	75		46	
Northern District (odd year)	pink	90,000	180,000	SEG	Multiple Aerial Surveys	25	75		46	
Coghill District (even year)	pink	60,000	150,000	SEG	Multiple Aerial Surveys	25	75		46	
Coghill District (odd year)	pink	60,000	250,000	SEG	Multiple Aerial Surveys	25	75		46	
Northwestern District (even year)	pink	70,000	140,000	SEG	Multiple Aerial Surveys	25	75		46	
Northwestern District (odd year)	pink	50,000	110,000	SEG	Multiple Aerial Surveys	25	75		46	
Eshamy District (even year)	pink	3,000	11,000	SEG	Multiple Aerial Surveys	25	75		46	
Eshamy District (odd year)	pink	4,000	11,000	SEG	Multiple Aerial Surveys	25	75		46	
Southwestern District (even year)	pink	70,000	160,000	SEG	Multiple Aerial Surveys	25	75		46	
Southwestern District (odd year)	pink	70,000	190,000	SEG	Multiple Aerial Surveys	15	85		46	
Montague District (even year)	pink	50,000	140,000	SEG	Multiple Aerial Surveys	25	75		46	
Montague District (odd year)	pink	140,000	280,000	SEG	Multiple Aerial Surveys	25	75		46	
Southeastern District (even year)	pink	150,000	310,000	SEG	Multiple Aerial Surveys	25	75		46	
Southeastern District (odd year)	pink	270,000	620,000	SEG	Multiple Aerial Surveys	25	75		46	
Fish Creek (Knik)	sockeye	20,000	70,000	SEG	Weir Count	25	75	moderate	37	113
Packers Creek	sockeye	15,000	30,000	SEG	Weir Count	25	75	moderate	16	18
Russian River - Late Run	sockeye	30,000	110,000	SEG	Weir Count	15	85		38	6

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Stock	Species	Lower	Upper	Type	Enumeration Method	Lower %tile	Upper %tile	Harvest Rate	Years	Contrast
Chelatna Lake	sockeye	20,000	65,000	SEG	Weir Count	15	85		10	5
Judd Lake	sockeye	25,000	55,000	SEG	Weir Count	15	85		7	5
Larson Lake	sockeye	15,000	50,000	SEG	Weir Count	15	85		12	7
English Bay	sockeye	6,000	13,500	SEG	Peak Aerial Survey, Weir Count	25	75		25	9
Delight Lake	sockeye	7,550	17,650	SEG	Weir Count	25	75	~30%	13	11
Desire Lake	sockeye	8,800	15,200	SEG	Peak Aerial Survey	15	85		26	5
Bear Lake	sockeye	700	8,300	SEG	Weir Count	25	75		17	128
Aialik Lake	sockeye	3,700	8,000	SEG	Peak Aerial Survey	25	75		26	12
Mikfik Lake	sockeye	6,300	12,150	SEG	Peak Aerial Survey, Video	15	85		26	7
Chenik Lake	sockeye	3,500	14,000	SEG	Peak Aerial Survey, Video	25	75	~40%	15	22
Amakdedori Creek	sockeye	1,250	2,600	SEG	Peak Aerial Survey	25	75		26	22
Upper Copper River	sockeye	360,000	750,000	SEG	Sonar	15	100		23	3
Copper River Delta	sockeye	55,000	130,000	SEG	Peak Aerial Survey	25	75		31	7
Bering River	sockeye	15,000	33,000	SEG	Peak Aerial Survey	15	85		22	6

Appendix A3.–Sustainable escapement goals in the Arctic–Yukon–Kuskokwim region of Alaska that are based on the Percentile Approach.

Stock	Species	Lower	Upper	Type	Enumeration Method	Lower %tile	Upper %tile	Harvest Rate	Years	Contrast
North (Main) Fork Goodnews River	Chinook	640	3,300	SEG	Single Aerial Survey	15	85		17	6
Kanektok River	Chinook	3,500	8,000	SEG	Single Aerial Survey	25	75	moderate	24	24
Kogrukluk River	Chinook	5,300	14,000	SEG	Weir Count	15	85		24	6
Kwethluk River	Chinook	6,000	11,000	SEG	Weir Count	25	75	moderate to high	12	14
Tuluksak River	Chinook	1,000	2,100	SEG	Weir Count	15	85	moderate	16	4
George River	Chinook	3,100	7,900	SEG	Weir Count	15	100		9	3
Kisaralik River	Chinook	400	1,200	SEG	Single Aerial Survey	25	75	moderate	13	38
Aniak River	Chinook	1,200	2,300	SEG	Single Aerial Survey	25	75	moderate	19	45
Salmon River (Aniak River)	Chinook	330	1,200	SEG	Single Aerial Survey	25	75	moderate	23	83
Holitna River	Chinook	970	2,100	SEG	Single Aerial Survey	25	75	moderate	12	9
Cheeneetnuk River (Stony River)	Chinook	340	1,300	SEG	Single Aerial Survey	15	85		12	5
Gagarayah River (Stony River)	Chinook	300	830	SEG	Single Aerial Survey	25	75	moderate	12	15
Salmon River (Pitka Fork)	Chinook	470	1,600	SEG	Single Aerial Survey	15	85		19	7
East Fork Andreafsky River	Chinook	2,100	4,900	SEG	Weir Count	25	75	moderate	36	42
West Fork Andreafsky River	Chinook	640	1,600	SEG	Peak Aerial Survey	25	75	moderate	28	12
Anvik River	Chinook	1,100	1,700	SEG	Peak Aerial Survey	25	75	moderate	24	11
Nulato River (forks combined)	Chinook	940	1,900	SEG	Peak Aerial Survey	25	75	moderate	18	15
Fish River/Boston Creek	Chinook	100		lower-bound SEG	Peak Aerial Survey	25		moderate	11	43
North River (Unalakleet River)	Chinook	1,200	2,600	SEG	Tower Count	15	85		10	4

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Stock	Species	Lower	Upper	Type	Enumeration Method	Lower %tile	Upper %tile	Harvest Rate	Years	Contrast
Middle Fork Goodnews River	chum	12,000		lower-bound SEG	Weir Count	15			23	6
Kanektok River	chum	5,200		lower-bound SEG	Single Aerial Survey	15		moderate	19	56
Kogrukluk River	chum	15,000	49,000	SEG	Weir Count	15	85		24	8
Aniak River	chum	220,000	480,000	SEG	Sonar	25	75	moderate to high	25	105
Middle Fork Goodnews River	coho	12,000		lower-bound SEG	Weir Count	15			7	4
Kogrukluk River	coho	13,000	28,000	SEG	Weir Count	25	75	moderate	22	12
Delta Clearwater River	coho	5,200	17,000	SEG	Boat Survey	25	75	moderate	31	54
Niukluk River	coho	2,400	7,200	SEG	Tower Count	15	85		13	11
North (Main) Fork Goodnews River	sockeye	5,500	19,500	SEG	Single Aerial Survey	25	75	moderate	16	29
Kanektok River	sockeye	14,000	34,000	SEG	Single Aerial Survey	25	75	moderate	23	24
Kogrukluk River	sockeye	4,440	17,000	SEG	Weir Count	25	75	moderate	29	36

Appendix A4.–Sustainable escapement goals in the Westward region of Alaska that are based on the Percentile Approach.

Stock	Species	Lower	Upper	Type	Enumeration Method	Lower %tile	Upper %tile	Harvest Rate	Years	Contrast
Southeastern District	Chum	106,400	212,800	SEG	Peak Aerial Survey	15	85	high	17	7
South Central District	Chum	89,800	179,600	SEG	Peak Aerial Survey	15	100	high	17	3
Southwestern District	Chum	133,400	266,800	SEG	Peak Aerial Survey	15	100	high	18	3
Kodiak Archipelago Aggregate	Chum	151,000		lower-bound SEG	Peak Aerial Survey	15			30	6
Cinder River	Sockeye	12,000	48,000	SEG	Peak Aerial Survey	15	75	low	16	9
Meshik River	Sockeye	25,000	100,000	SEG	Peak Aerial Survey	15	75	low	19	367
Sandy River	Sockeye	34,000	74,000	SEG	Weir Count	15	75	low	36	15
Swanson Lagoon	Sockeye	6,000	16,000	SEG	Peak Aerial Survey	15	75	low	36	329
North Creek	Sockeye	4,400	8,800	SEG	Peak Aerial Survey	25	75	high	30	31
Orzinski Lake	Sockeye	15,000	20,000	SEG	Weir Count	25	75	high	34	59
Mortensen Lagoon	Sockeye	3,200	6,400	SEG	Peak Aerial Survey	25	75	high	34	21
McLees Lake	Sockeye	10,000	60,000	SEG	Weir Count	15	75	low	8	12
Malina Creek	Sockeye	1,000	10,000	SEG	Peak Aerial Survey	15	75	low	36	64
Uganik Lake	Sockeye	24,000		lower-bound SEG	Peak Aerial Survey	25			31	31
Pasagshak River	Sockeye	3,000		lower-bound SEG	Peak Aerial Survey	15			42	116

APPENDIX B: STOCK-RECRUITMENT DATA SETS USED IN THE EMPIRICAL META-ANALYSIS

Appendix B1.–Source citations for the 76 stock-recruitment data sets evaluated for use in the empirical meta-analysis. Stocks preceded with an asterisk are those not used in the meta-analysis due to an unreliable estimate of S_{MSY}.

Stock (brood years)	Species	Citation
Afognak (1982-2000)	sockeye	Nelson et al. 2005
Akwe (1973-1987)	sockeye	Geiger and McPherson 2004
*Alagnak (1956-2004)	sockeye	ADF&G Bristol Bay brood tables
Alsek (1976-2005)	sockeye	Eggers and Bernard 2011
Alsek (1976-2001)	Chinook	Bernard and Jones 2010
Andreafsky (1972-2003)	chum	Fleischman and Evenson 2010
Anvik (1976-1994)	chum	Clark and Sandone 2001
Auke (1980-2001)	coho	Clark et al. 1994
*Ayakulik (1996-2002)	sockeye	Nelson et al. 2005
Ayakulik (1977-2003)	Chinook	Nemeth et al. 2010b
Bear late run (1980-2004)	sockeye	Witteveen et al. 2009
Berners (1987-2005)	coho	Clark et al. 1994
Buskin (1990-2003)	sockeye	Schmidt and Evans 2010
Chena (1986-1994)	Chinook	Evenson 2002
Chignik (1978-1997)	Chinook	Nemeth et al. 2010
*Chignik early run (1952-2002)	sockeye	Nemeth et al. 2010
Chignik late run (1952-2002)	sockeye	Nemeth et al. 2010
Chilkat (1979-2002)	sockeye	Eggers et al. 2010
Chilkat (1991-2002)	Chinook	Ericksen and McPherson 2004
Chilkat (1994-2002)	coho	Ericksen and Fleischman 2006
Chilkat fall run (1994-2003)	chum	Eggers and Heinl 2008
Chilkoot (1976-2003)	sockeye	Eggers et al. 2009
Coghill (1962-1998)	sockeye	Evenson et al. 2008
Copper (1961-1999)	sockeye	Evenson et al. 2008
Crescent (1968-2005)	sockeye	Fair et al. 2007
Deshka (1974-2002)	Chinook	Fair et al. 2010
East Alsek (1972-1997)	sockeye	Clark et al. 2004
*Egegik (1956-2004)	sockeye	ADF&G Bristol Bay brood tables
Eshamy (1970-1997)	sockeye	Evenson et al. 2008
Frazer (1966-2000)	sockeye	Nelson et al. 2005
Ford Arm (1982-2005)	Coho	Clark et al. 1994
Ford Arm (1983-2005)	sockeye	ADF&G SEAK brood tables
Goodnews (1981-2002)	sockeye	Taylor and Clark 2010
Goodnews (1981-2001)	Chinook	Taylor and Clark 2010
Hugh Smith (1982-2003)	Coho	Shaul et al. 2008
Igushik (1956-2004)	sockeye	ADF&G Bristol Bay brood tables
Italio (1972-1997)	sockeye	Geiger and McPherson 2004
Karluk (1976-2002)	Chinook	Nemeth et al. 2010
Karluk early run (1981-2003)	sockeye	Nemeth et al. 2010
Karluk late run (1981-2003)	sockeye	Nemeth et al. 2010
Kasilof (1968-2005)	sockeye	Fair et al. 2007
Kenai (1968-2005)	sockeye	Fair et al. 2007
Klukshu (1976-2005)	sockeye	Eggers and Bernard 2010
Kodiak Archipelago (1976-2009)	Pink	Nemeth et al. 2010
Kodiak Mainland (1976-2009)	Pink	Nemeth et al. 2010

-continued-

Appendix B1.–Page 2 of 2.

Stock (brood years)	Species	Citation
Kotzebue (1962-1998)	chum	Eggers and Clark 2006
*Kvichak (1956-2004)	sockeye	ADF&G Bristol Bay brood tables
Kwiniuk (1965-1995)	chum	Clark 2001
Lost (1972-1988)	sockeye	Geiger and McPherson 2004
McDonald (1980-2001)	sockeye	Eggers and Heinl 2009
*Naknek (1956-2004)	sockeye	ADF&G Bristol Bay brood tables
Nelson (1975-2003)	sockeye	Witteveen et al. 2009
Nelson (1981-1996)	Chinook	Nelson et al. 2005
Northern SE Inside (1960-2010)	pink	Piston and Heinl 2011
Northern SE Outside (1960-2010)	pink	Piston and Heinl 2011
Nushagak (1966-1999)	Chinook	Baker et al. 2006
Nushagak (1956-2004)	sockeye	ADF&G Bristol Bay brood tables
Nushagak (1980-1998)	coho	Baker et al. 2006
Redoubt (1982-1996)	sockeye	Geiger and McPherson 2004
*Russian early run (1965-2003)	sockeye	Fair et al. 2010
Salcha (1986-1994)	Chinook	Evenson 2002
Saltery (1976-2003)	sockeye	Nemeth et al. 2010
Situk (1976-1997)	sockeye	Clark et al. 1995
Speel (1983-1996)	sockeye	Geiger and McPherson 2004
South Peninsula even (1968-2002)	pink	Nelson et al. 2006
South Peninsula odd (1969-2003)	pink	Nelson et al. 2006
Southern SE (1960-2010)	pink	Piston and Heinl 2011
Taku (1973-2001)	Chinook	McPherson et al. 2010
Taku (1989-2003)	coho	Unpublished analysis
Togiak (1956-2004)	sockeye	ADF&G Bristol Bay brood tables
*Ugashik (1956-2004)	sockeye	ADF&G Bristol Bay brood tables
*Upper Station early run (1969-2002)	sockeye	Nemeth et al. 2010
*Upper Station late run (1969-2002)	sockeye	Nemeth et al. 2010
Unuk (1981-1998)	Chinook	Hendrich et al. 2008
Wood (1956-2004)	sockeye	ADF&G Bristol Bay brood tables
Yukon fall run (1974-2003)	chum	Fleischman and Borba 2009

APPENDIX C: RESULTS OF THE EMPIRICAL META-ANALYSIS OF 66 SALMON STOCKS

Appendix C1.–Stock-recruitment parameter estimates, management parameters, and Best *Rating* percentiles and values for 66 stocks of Pacific salmon in Alaska. Column headings are defined in Table 1.

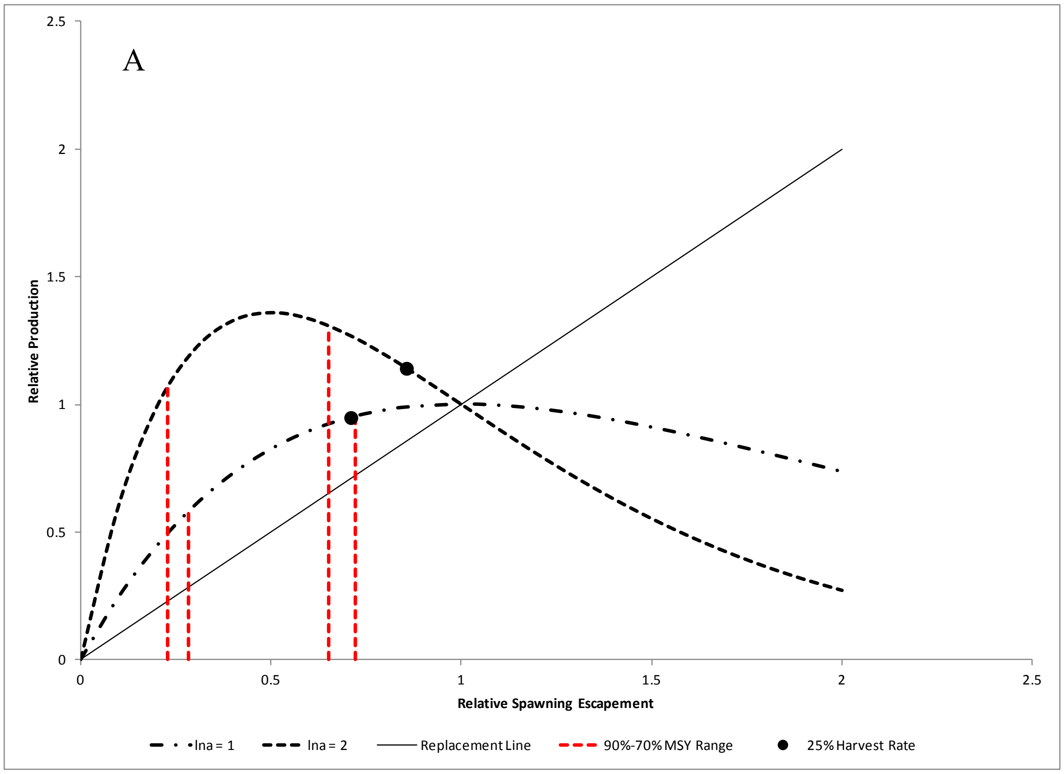
Stock	Species	n	ln(α)	σ_ε	ϕ	L90	S_{MSY}	U70	SEQ	Best	P_L	P_U
Afognak	sockeye	28	1.43	0.75	0.72	34	48	57	128	25-50	27	53
Akwe	sockeye	19	1.55	0.59	0.44	10	12	16	31	25-75	6	17
Alsek	sockeye	30	1.35	0.29	0.22	21	28	42	71	Min-45	29	47
Alsek	Chinook	32	1.28	0.45	0.21	4	5	8	12	5-45	4	9
Andreafsky	chum	38	1.21	0.72	0.52	50	66	84	163	25-60	52	78
Anvik	chum	38	1.44	0.55	0.32	360	481	680	1,239	20-65	360	611
Auke	coho	30	1.78	0.26	0.28	0.51	0.64	0.96	1.72	25-75	0.47	0.80
Ayakulik	Chinook	33	1.79	0.61	0.49	4.2	5.5	8.4	15.0	15-50	4.3	8.4
Bear late run	sockeye	31	2.37	0.61	0.43	108	145	195	439	20-75	108	197
Berners	coho	28	2.02	0.36	0.69	8	10	14	29	25-85	5	15
Buskin	sockeye	20	2.60	0.49	0.35	5	6	10	19	Min-45	6	11
Chena	Chinook	23	2.64	1.02	0.25	2.9	3.6	5.3	12.3	5-45	2.9	5.6
Chignik	Chinook	32	2.15	0.29	0.49	1.4	1.8	2.3	5.3	10-50	1.4	3.0
Chignik late run	sockeye	58	2.07	0.44	0.42	204	255	384	721	15-85	208	371
Chilkat	sockeye	31	1.38	0.61	0.54	94	122	154	316	25-65	84	147
Chilkat	Chinook	18	1.21	0.63	0.47	1.9	2.4	3.1	6.1	Min-45	2.0	3.7
Chilkat	coho	15	1.89	0.30	0.73	38	50	77	139	15-60	39	73
Chilkat	chum	17	2.09	0.49	0.50	96	119	171	343	20-45	96	219
Chilkoot	sockeye	34	2.23	0.78	0.66	40	53	72	158	20-50	41	72
Coghill	sockeye	48	2.33	1.03	0.39	49	63	90	190	25-85	27	75
Copper	sockeye	50	1.96	0.36	0.62	370	461	670	1,267	20-75	354	632
Crescent	sockeye	41	1.59	0.43	0.63	38	47	69	122	10-60	38	71
Deshka	Chinook	36	1.37	0.46	0.63	15	19	26	46	15-45	15	29
East Alsek	sockeye	38	1.64	0.57	0.65	41	54	70	142	25-85	37	69
Eshamy	sockeye	38	2.25	0.77	0.20	17	21	31	62	25-75	12	34
Ford Arm	coho	27	1.87	0.30	0.46	2.4	3.0	4.6	8.2	25-85	2.1	4.8
Ford Arm	sockeye	27	1.60	0.83	0.20	1.5	1.8	2.7	4.8	20-50	1.5	2.7
Frazer	sockeye	44	2.12	0.94	0.20	111	136	207	388	25-75	79	202
Goodnews	sockeye	29	1.67	0.53	0.43	21	26	36	69	5-45	21	34
Goodnews	Chinook	29	1.52	0.47	0.10	1.5	1.9	2.9	4.8	Min-50	1.4	2.9
Hugh Smith	coho	28	1.90	0.44	0.64	1.1	1.4	1.9	3.9	25-85	0.9	1.8

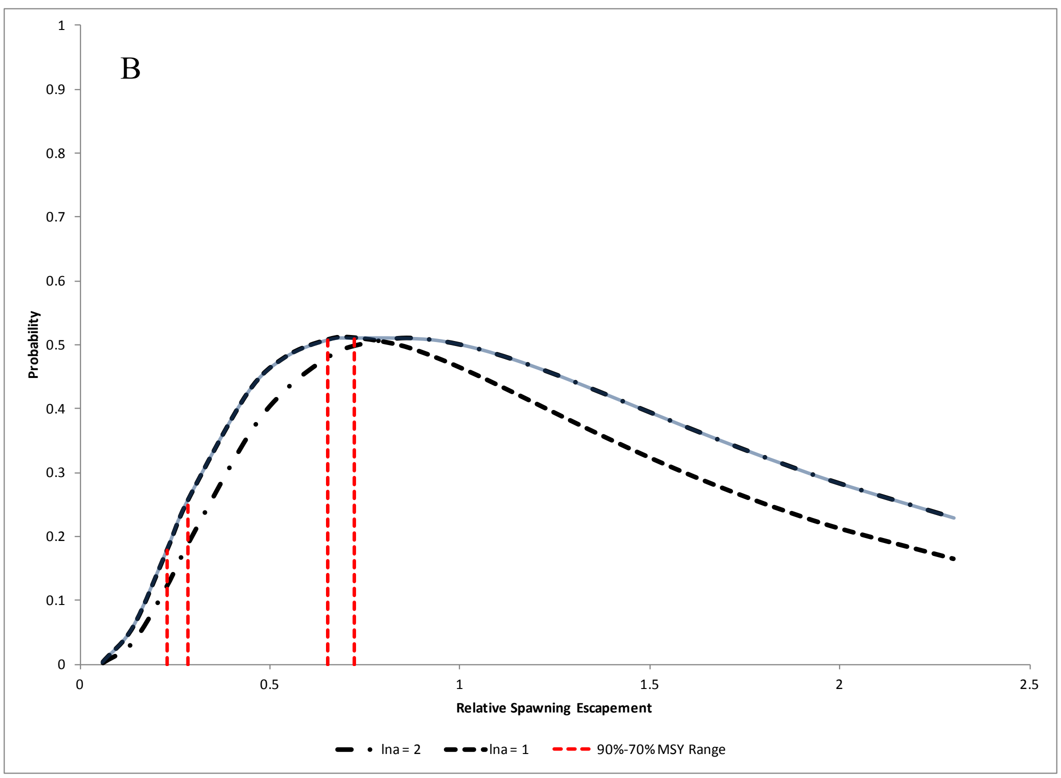
-continued-

Appendix C1.–Page 2 of 2.

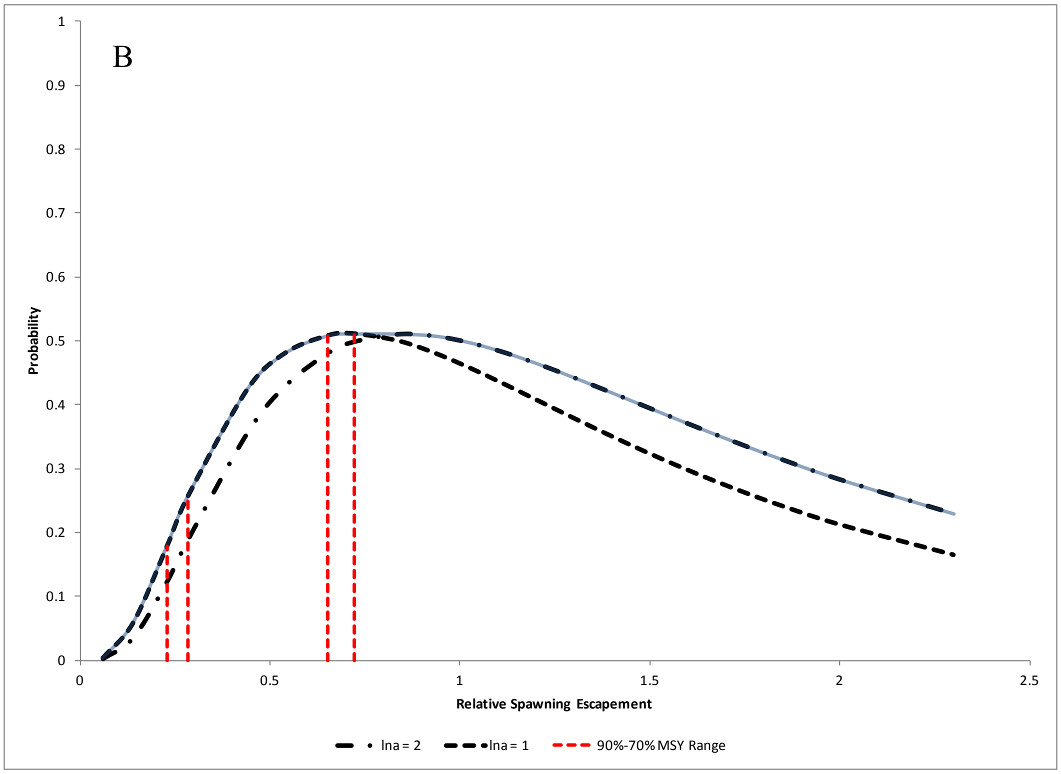
Stock	Species	n	ln(α)	σ_ε	ϕ	L90	S_{MSY}	U70	SEQ	Best	P_L	P_U
Igushik	sockeye	54	2.16	0.79	0.57	344	430	624	1,241	25-85	180	512
Italio	sockeye	31	1.58	0.55	0.85	6.0	7.6	8.8	19.8	25-55	3.7	8.5
Karluk	Chinook	34	1.32	0.41	0.85	3.3	4.2	5.1	10.2	10-45	3.2	7.5
Karluk early run	sockeye	29	2.17	0.48	0.53	108	138	216	409	10-45	118	258
Karluk late run	sockeye	29	1.80	0.66	0.76	288	394	488	1,095	25-60	282	493
Kasilof	sockeye	42	2.19	0.61	0.84	140	180	272	517	25-75	139	267
Kenai	sockeye	42	1.92	0.52	0.00	1,040	1,318	1,800	3,615	25-Max	509	2,027
Klukshu	sockeye	30	1.61	0.59	0.59	7.5	9.1	13.0	24.1	10-45	7.0	13.8
Kodiak Archipelago	pink	43	1.50	0.54	0.25	7.8	9.9	14.7	25.1	40-85	7.7	14.5
Kodiak Mainland	pink	41	1.22	0.90	0.43	1.9	2.5	3.1	6.1	40-85	1.1	2.5
Kotzebue	chum	37	1.36	0.63	0.23	250	304	440	755	25-75	232	472
Kwiniuk	chum	44	1.35	0.60	0.52	15	19	26	48	25-65	13	28
Lost	sockeye	37	1.73	0.45	0.50	2.2	2.8	4.0	7.5	25-65	1.8	4.0
McDonald	sockeye	30	2.01	0.70	0.28	56	69	99	196	25-50	52	92
Nelson	sockeye	36	2.02	0.41	0.25	123	153	237	427	10-60	131	251
Nelson	Chinook	29	1.66	0.42	0.19	2.2	2.8	4.3	7.3	10-45	2.1	4.5
Northern SE Inside	pink	50	1.00	0.58	0.35	11.7	17.8	19.8	41.3	40-85	6.5	15.3
Northern SE Outside	pink	50	0.80	0.63	0.34	4.6	6.7	7.8	15.0	40-85	1.3	6.7
Nushagak	Chinook	44	2.00	0.47	0.46	38	50	78	138	10-55	40	80
Nushagak	coho	22	1.03	0.61	-0.10	60	79	104	189	25-60	45	100
Nushagak	sockeye	31	1.76	0.44	0.41	630	797	1,200	2,121	25-85	471	763
Redoubt	sockeye	28	2.47	1.21	0.43	15	19	24	62	25-50	10	24
Salcha	Chinook	23	2.97	0.87	0.35	2.8	3.7	5.8	13.3	Min-45	2.7	7.8
Saltery	sockeye	34	1.64	0.64	0.09	18	24	36	62	Min-50	17	37
Situk	sockeye	34	1.34	0.38	0.32	45	55	82	138	15-75	46	84
Speel	sockeye	27	3.16	1.22	0.20	6.0	7.5	12.3	27.5	25-65	4.6	12.6
South Pen. even	pink	24	1.71	0.91	0.29	4.9	6.2	8.5	16.5	35-60	4.7	8.5
South Pen. odd	pink	23	1.57	0.97	0.24	5.9	8.3	10.1	21.8	40-75	5.5	8.9
Southern SE	pink	50	1.39	0.56	0.22	16	21	27	51	40-85	13	28
Taku	Chinook	35	1.28	0.60	0.28	20	25	35	60	20-45	21	37
Taku	coho	21	1.89	0.37	0.78	57	72	102	198	25-65	57	96
Togiak	sockeye	54	1.94	0.52	0.35	156	187	279	515	25-85	118	290
Unuk	Chinook	18	1.38	0.51	0.58	3.8	6.2	6.6	16.4	25-75	3.6	6.3
Wood	sockeye	54	1.77	0.49	0.57	1,000	1,230	1,750	3,254	25-85	855	1,653
Yukon	chum	36	0.98	0.55	0.52	480	757	885	1,792	25-85	377	890

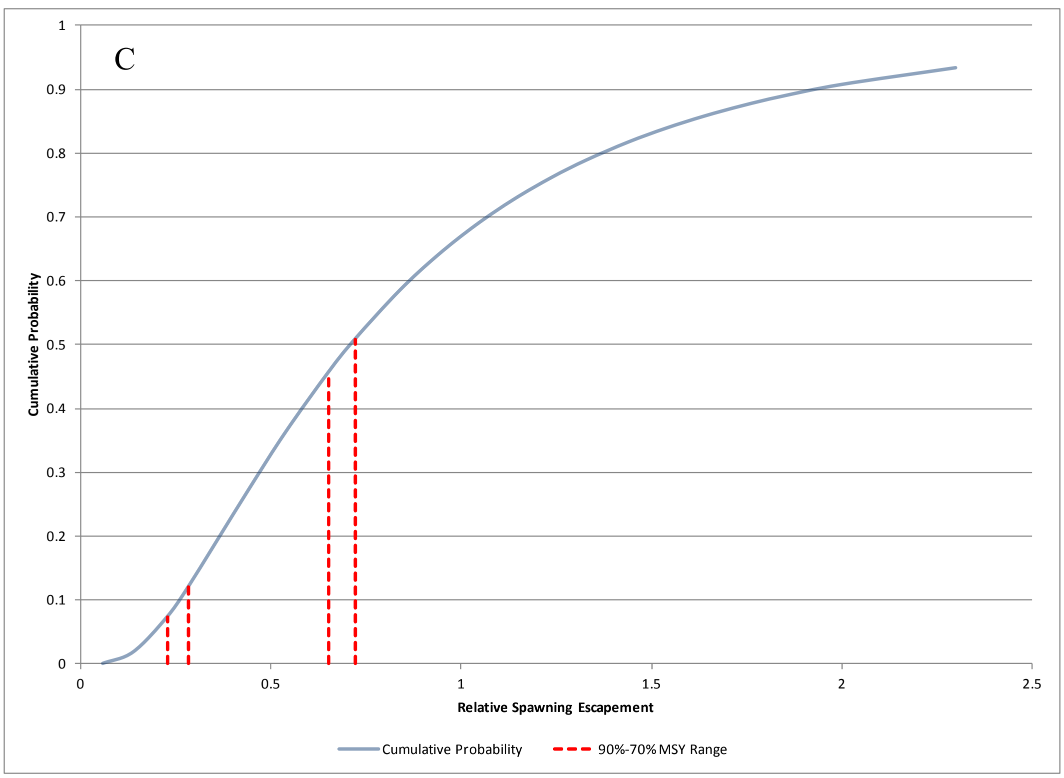
APPENDIX D: GRAPHICAL RESULTS OF THE THEORETICAL ANALYSIS



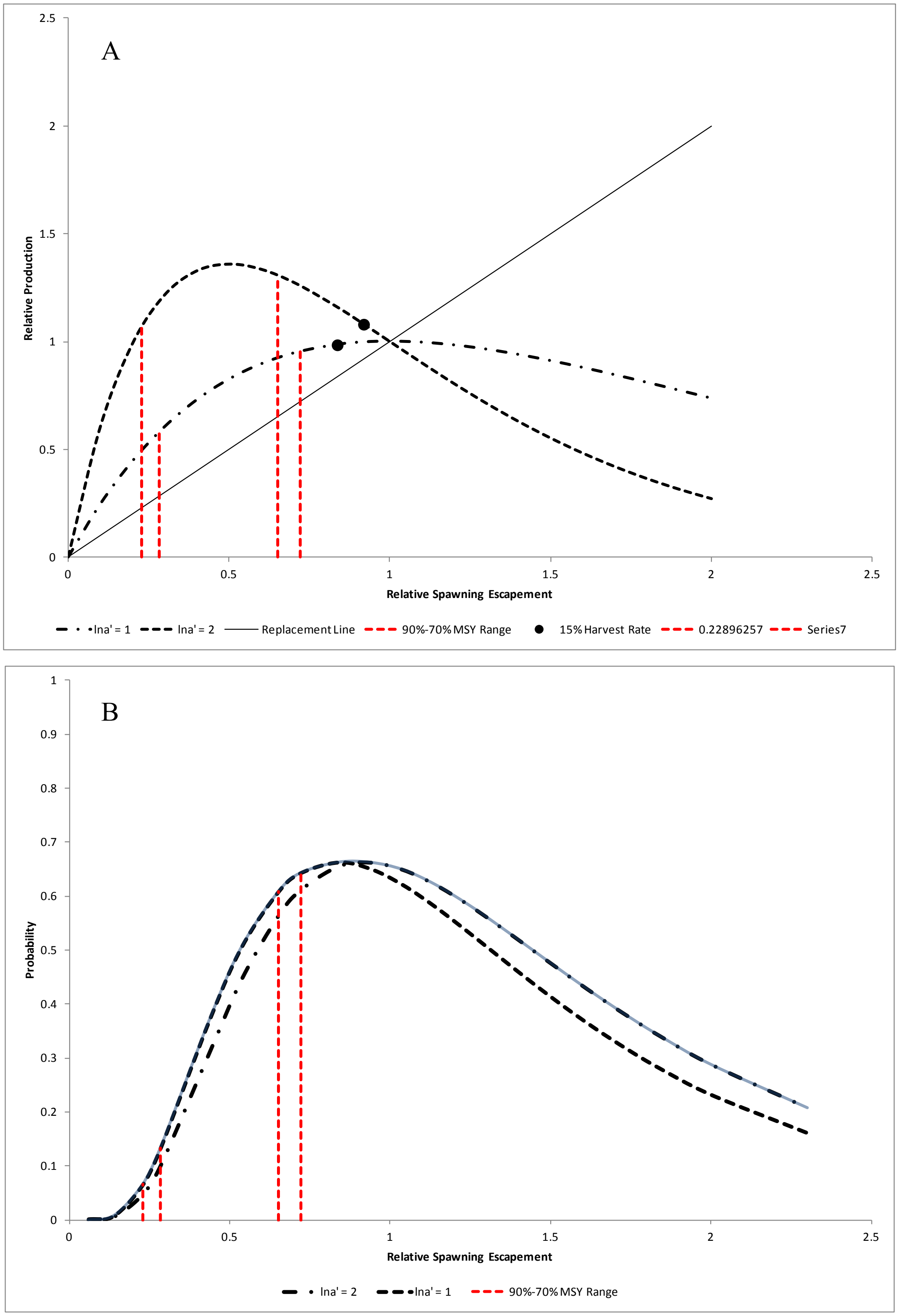


Appendix D1.–Panel A: 2 hypothetical stock-recruitment relationships (dashed curves), the L90 and U70 lines (vertical dashed lines) for each relationship, and equilibrium points (black circles) based on a fixed harvest rate of 0.25. Panel B: 2 hypothetical log-normal distributions (dashed curves) around the 2 equilibrium spawning escapements from Panel A, and the same L90 and U70 lines from Panel A.

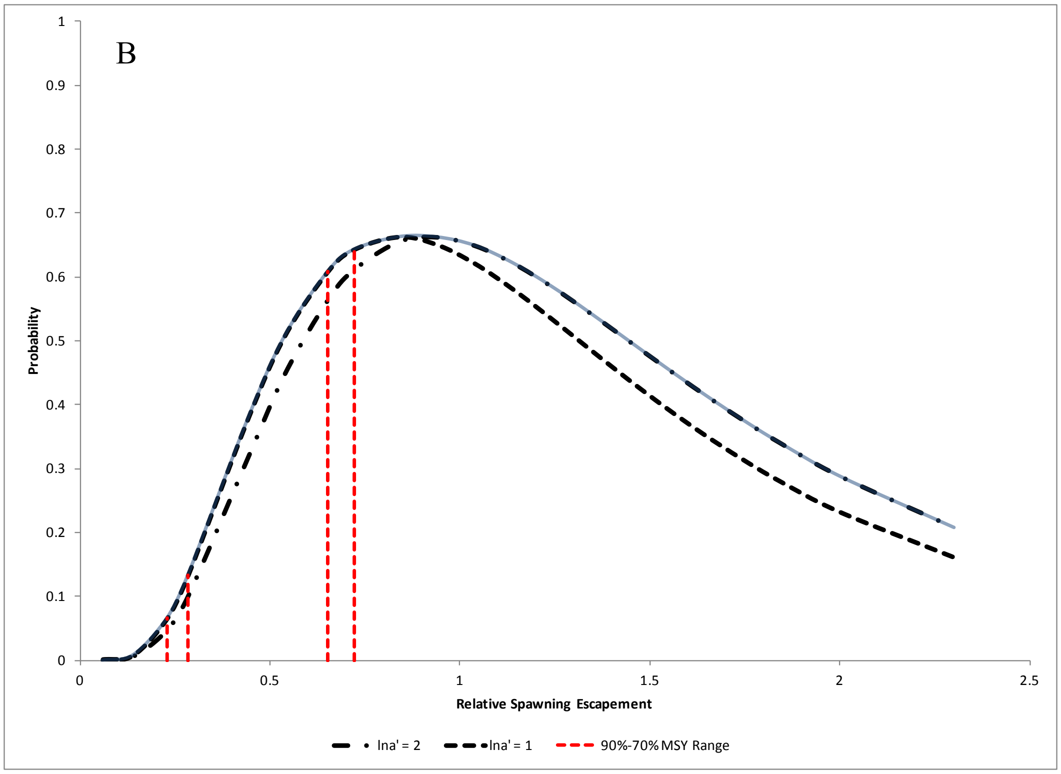


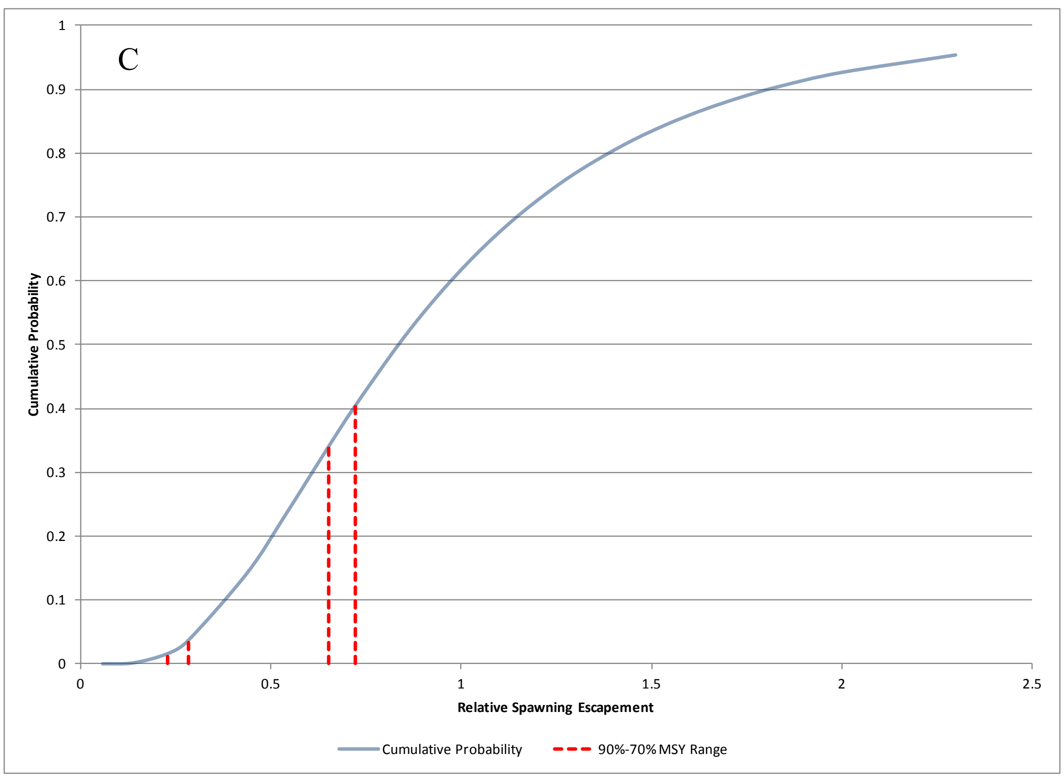


Appendix D1.–Page 2 of 2. Panel C: the combined cumulative distribution (solid curve) of the 2 theoretical log-normal distributions in Panel B and the same L90 and U70 lines (vertical dashed lines) from Panel A. Results are for the fixed harvest rate of 0.25 and high measurement error (σ_S = 0. 50) scenario.

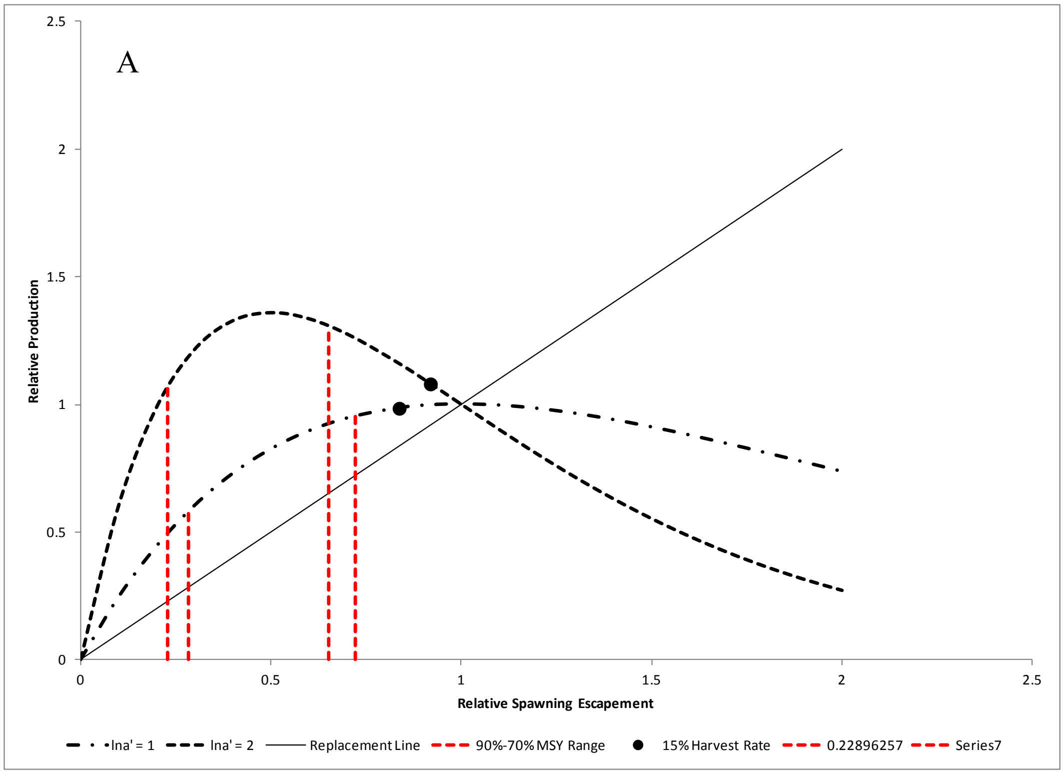


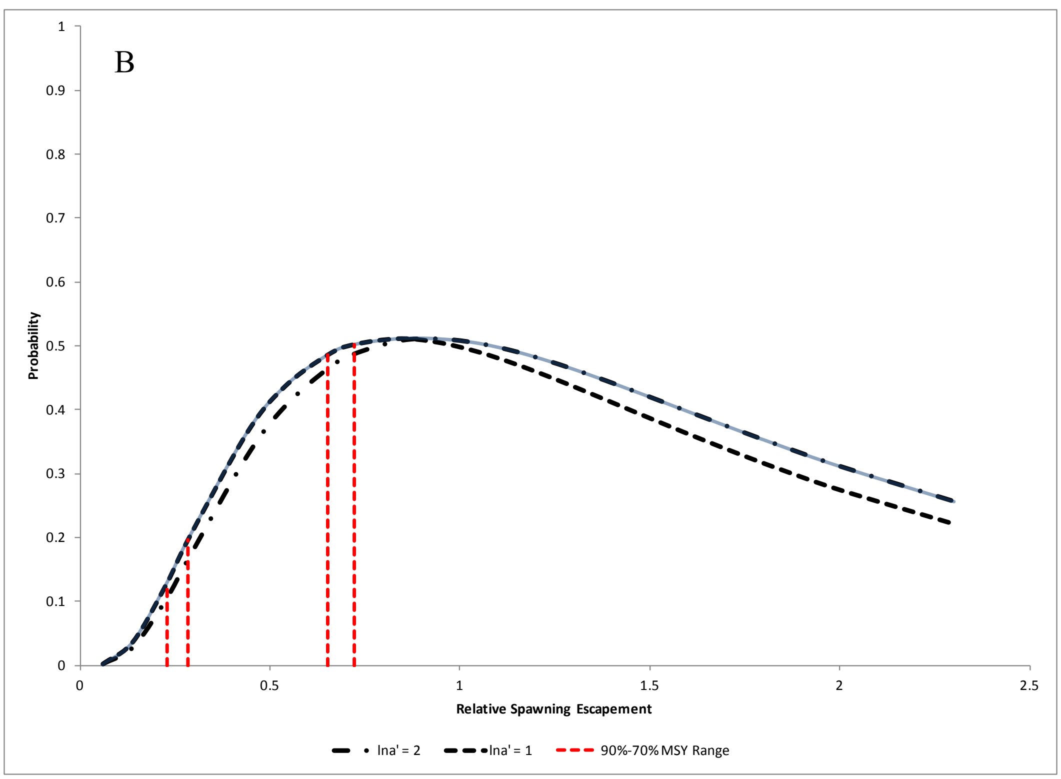
Appendix D2.–Panel A: 2 hypothetical stock-recruitment relationships (dashed curves), the L90 and U70 lines (vertical dashed lines) for each relationship, and equilibrium points (black circles) based on a fixed harvest rate of 0.15. Panel B: 2 hypothetical log-normal distributions (dashed curves) around the 2 equilibrium spawning escapements from Panel A and the same L90 and U70 lines from Panel A.



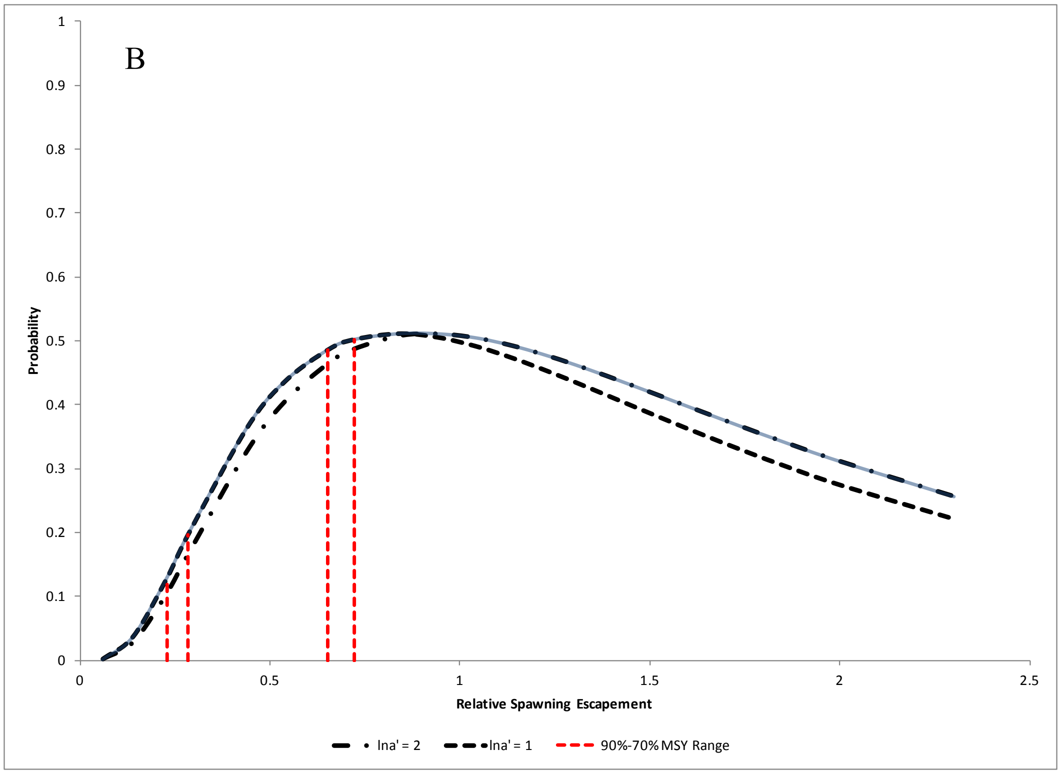


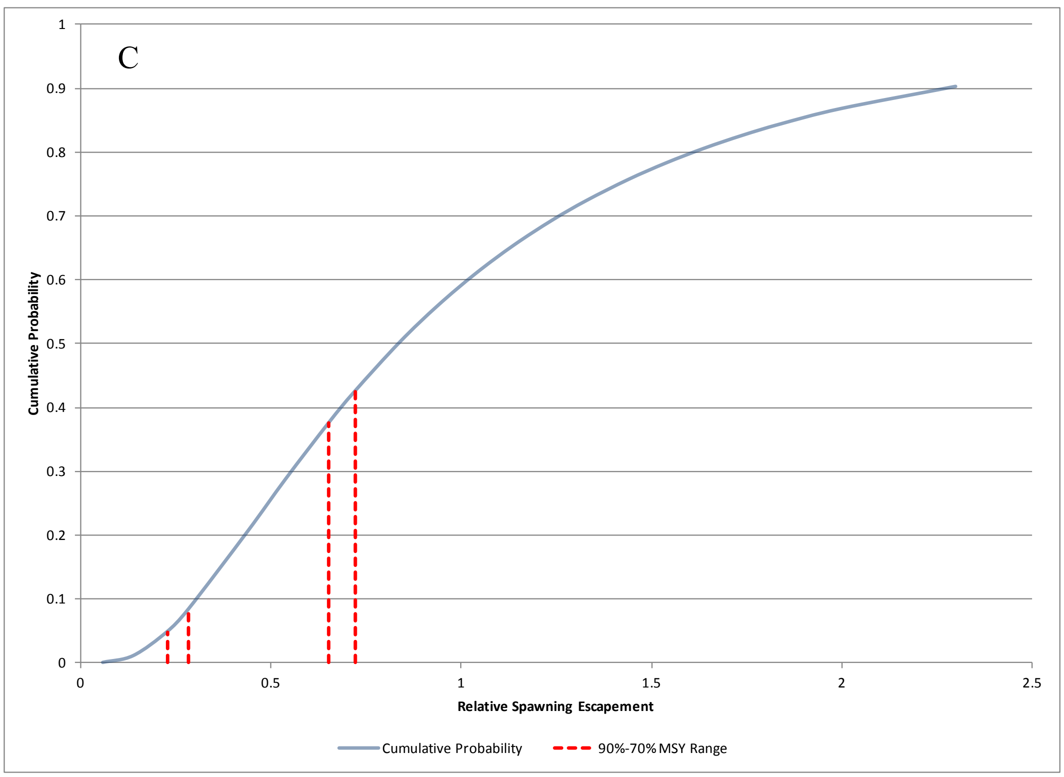
Appendix D2.–Page 2 of 2. Panel C: the combined cumulative distribution (solid curve) of the 2 theoretical log-normal distributions in Panel B and the same L90 and U70 lines (vertical dashed lines) from Panel A. Results are for the fixed harvest rate of 0.15 and low measurement error (σ_S = 0.05) scenario.



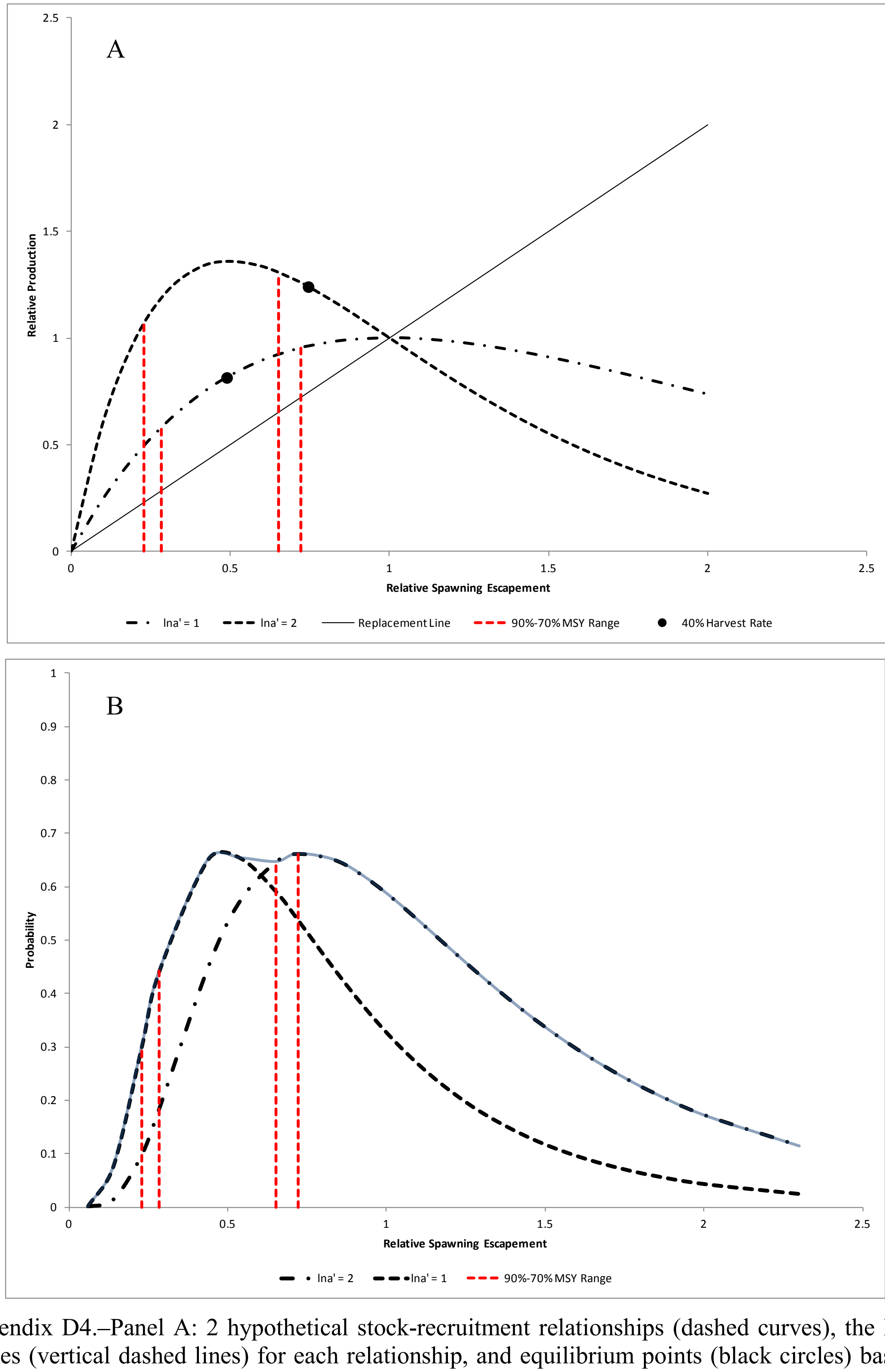


Appendix D3.–Panel A: 2 hypothetical stock-recruitment relationships (dashed curves), the L90 and U70 lines (vertical dashed lines) for each relationship, and equilibrium points (black circles) based on a fixed harvest rate of 0.15. Panel B: 2 hypothetical log-normal distributions (dashed curves) around the 2 equilibrium spawning escapements from Panel A and the same L90 and U70 lines from Panel A.

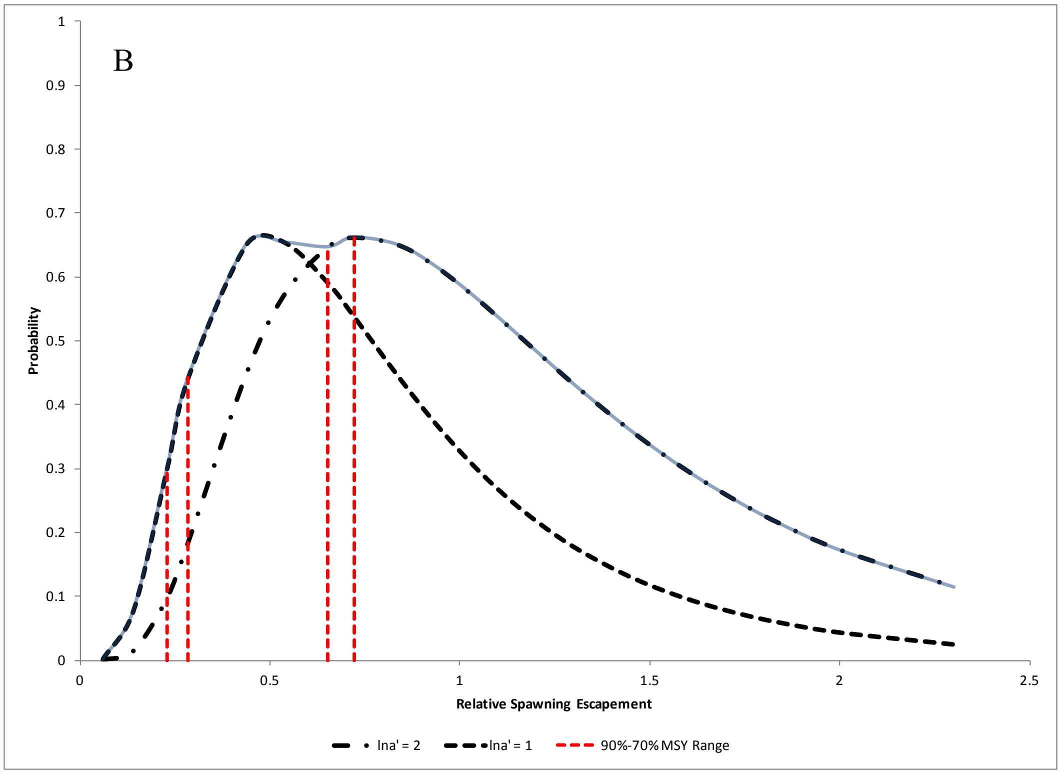


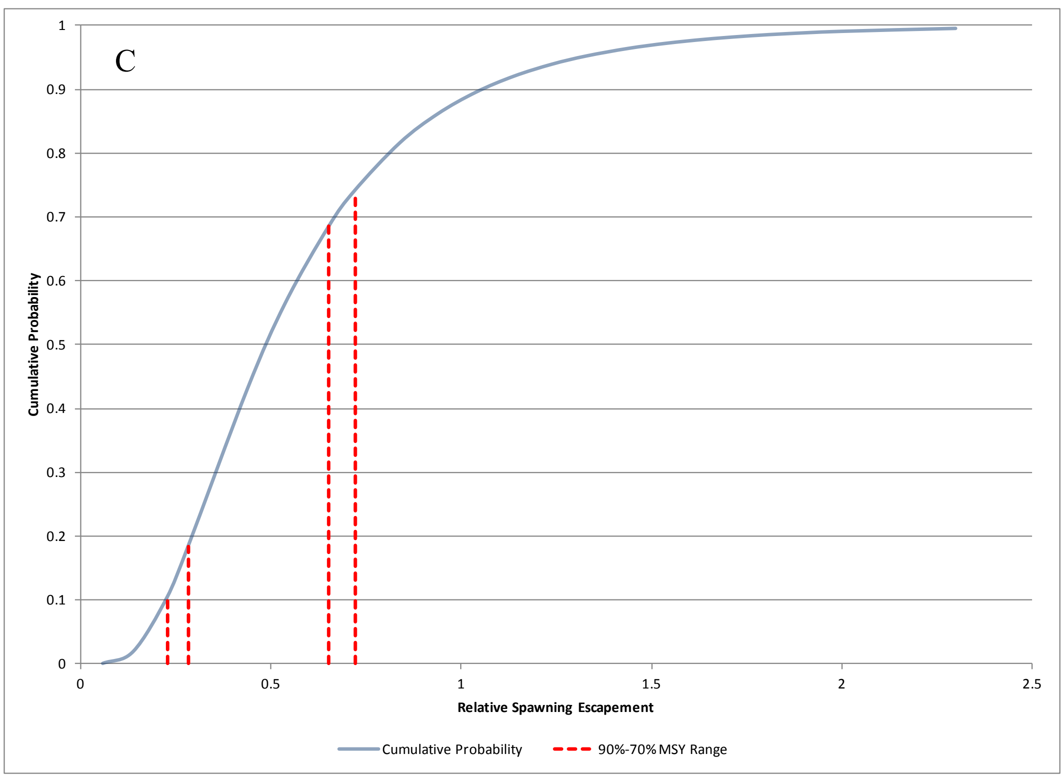


Appendix D3.–Page 2 of 2. Panel C: the combined cumulative distribution (solid curve) of the 2 theoretical log-normal distributions in Panel B and the same L90 and U70 lines (vertical dashed lines) from Panel A. Results are for the fixed harvest rate of 0.15 and high measurement error (σ_S = 0.50) scenario.

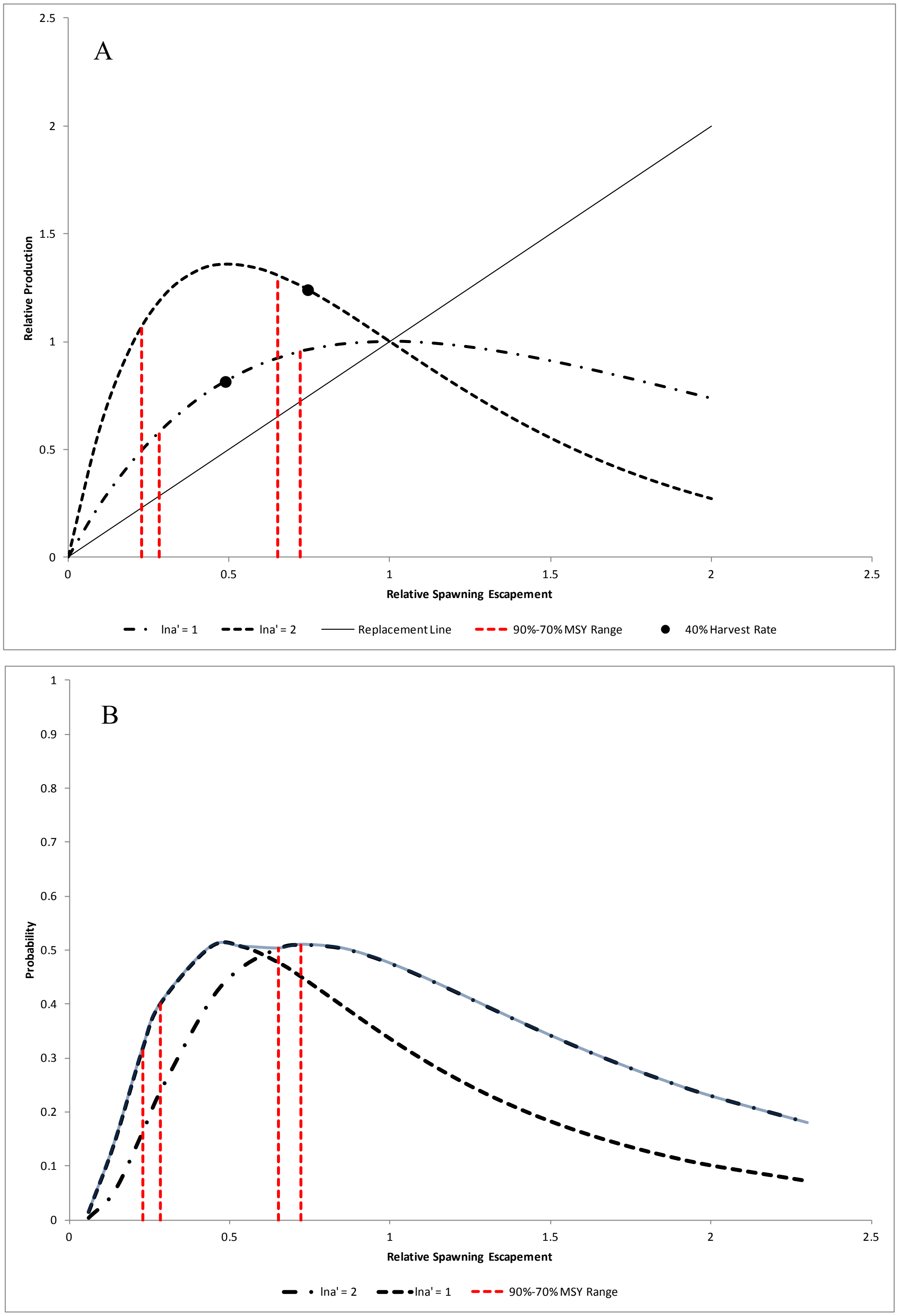


Appendix D4.–Panel A: 2 hypothetical stock-recruitment relationships (dashed curves), the L90 and U70 lines (vertical dashed lines) for each relationship, and equilibrium points (black circles) based on a fixed harvest rate of 0.40. Panel B: 2 hypothetical log-normal distributions (dashed curves) around the 2 equilibrium spawning escapements from Panel A and the same L90 and U70 lines from Panel A.

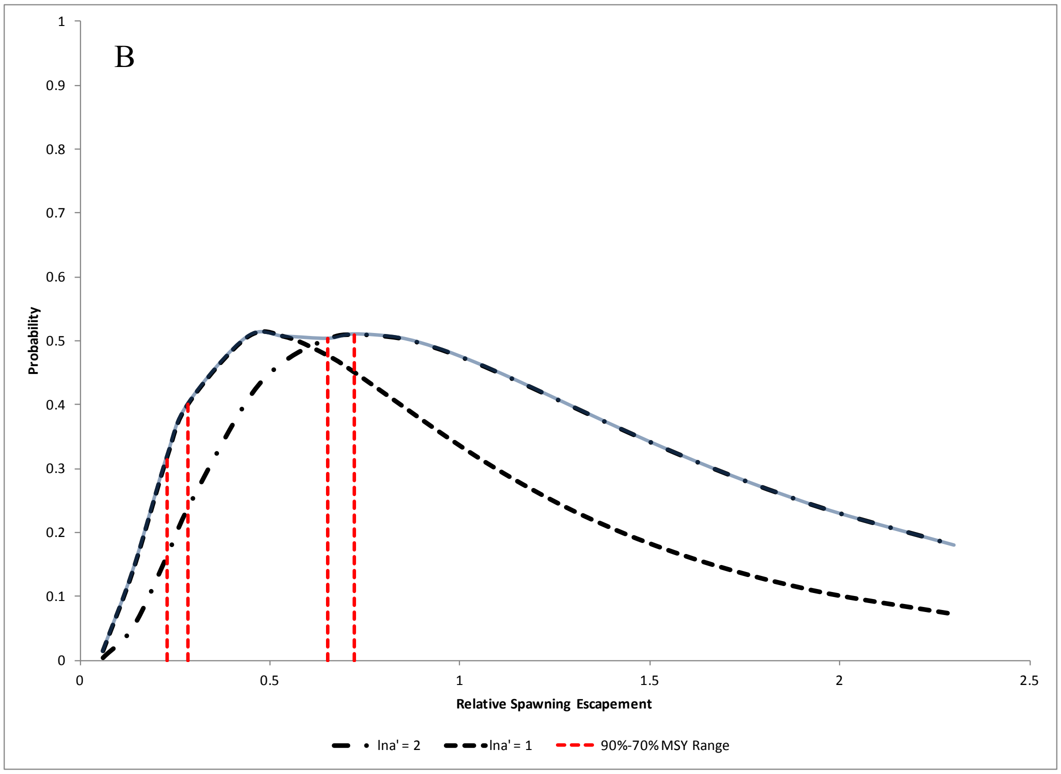


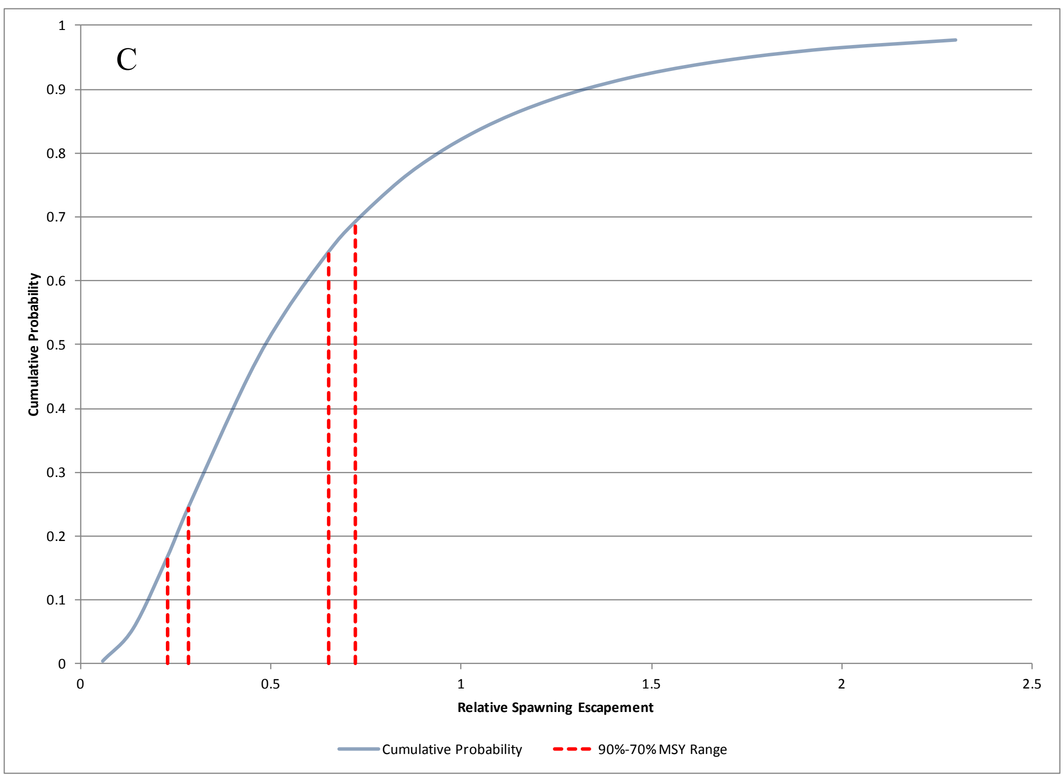


Appendix D4.–Page 2 of 2. Panel C: the combined cumulative distribution (solid curve) of the 2 theoretical log-normal distributions in Panel B and the same L90 and U70 lines (vertical dashed lines) from Panel A. Results are for the fixed harvest rate of 0.40 and low measurement error (σ_S = 0.05) scenario.



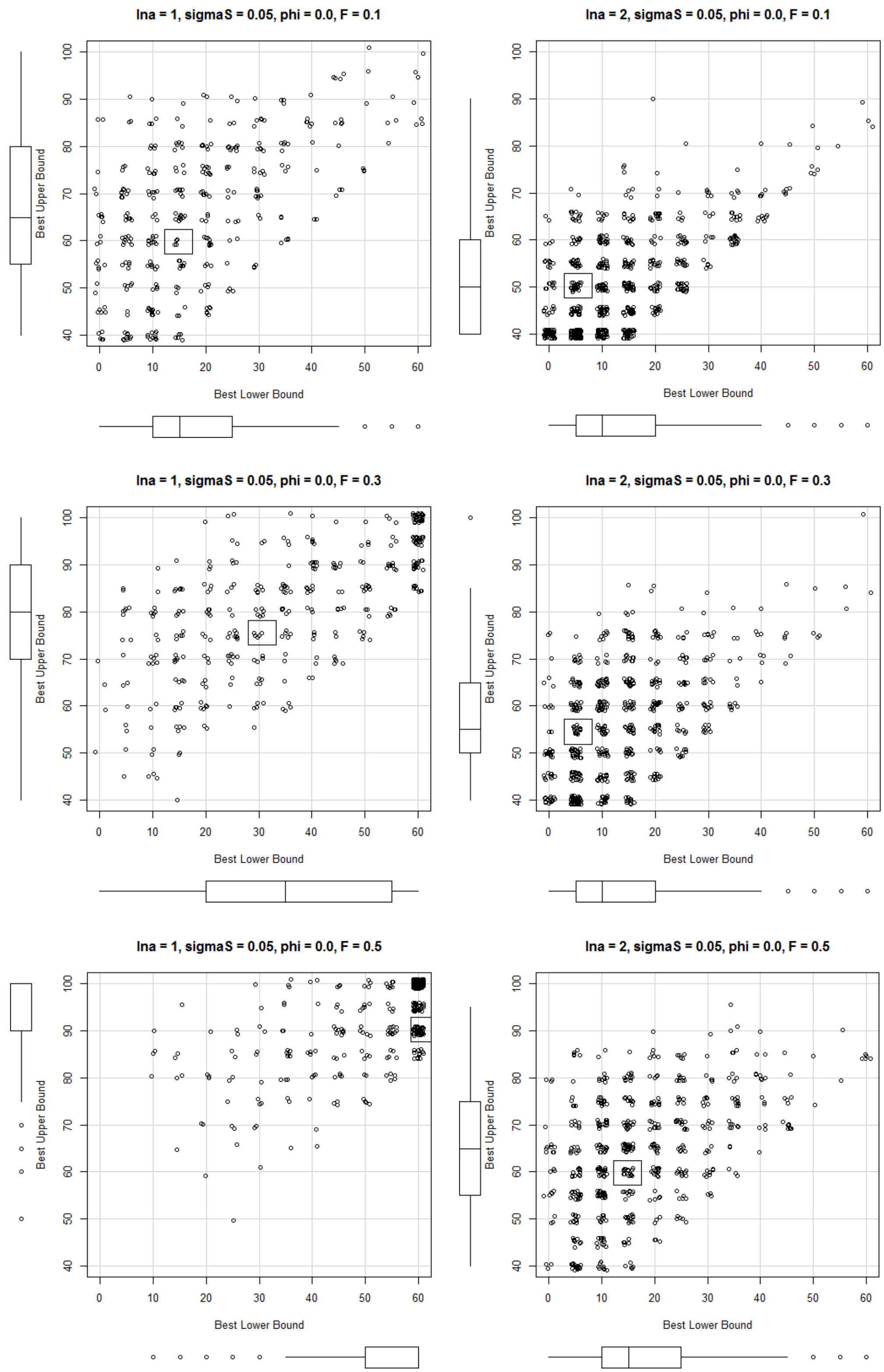
Appendix D5.–Panel A: 2 hypothetical stock-recruitment relationships (dashed curves), the L90 and U70 lines (vertical dashed lines) for each relationship, and equilibrium points (black circles) based on a fixed harvest rate of 0.40. Panel B: 2 hypothetical log-normal distributions (dashed curves) around the 2 equilibrium spawning escapements from Panel A and the same L90 and U70 lines from Panel A.



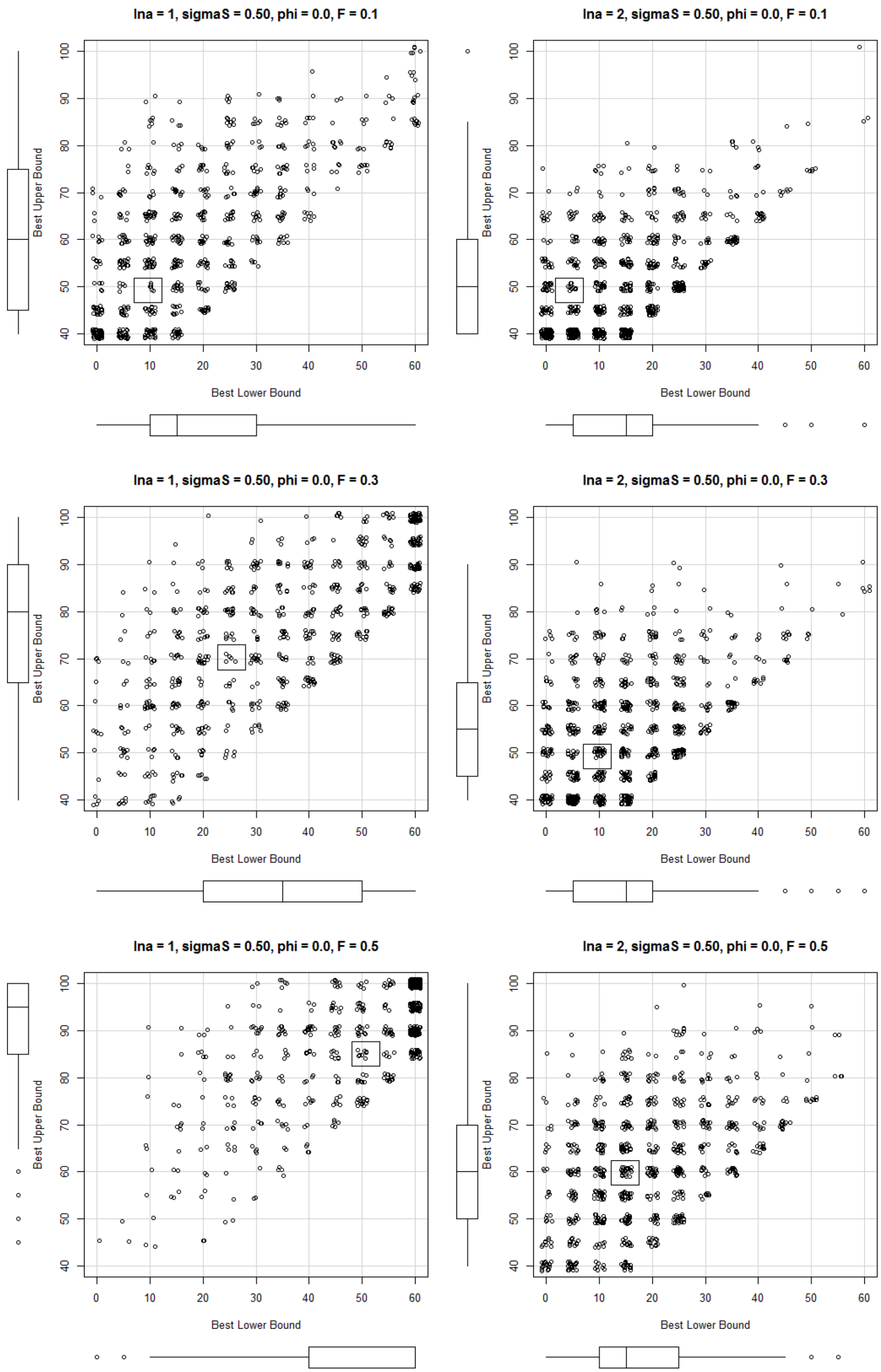


Appendix D5.–Page 2 of 2. Panel C: the combined cumulative distribution (solid curve) of the 2 theoretical log-normal distributions in Panel B and the same L90 and U70 lines (vertical dashed lines) from Panel A. Results are for the fixed harvest rate of 0.40 and high measurement error ($\sigma_S = 0.50$) scenario.

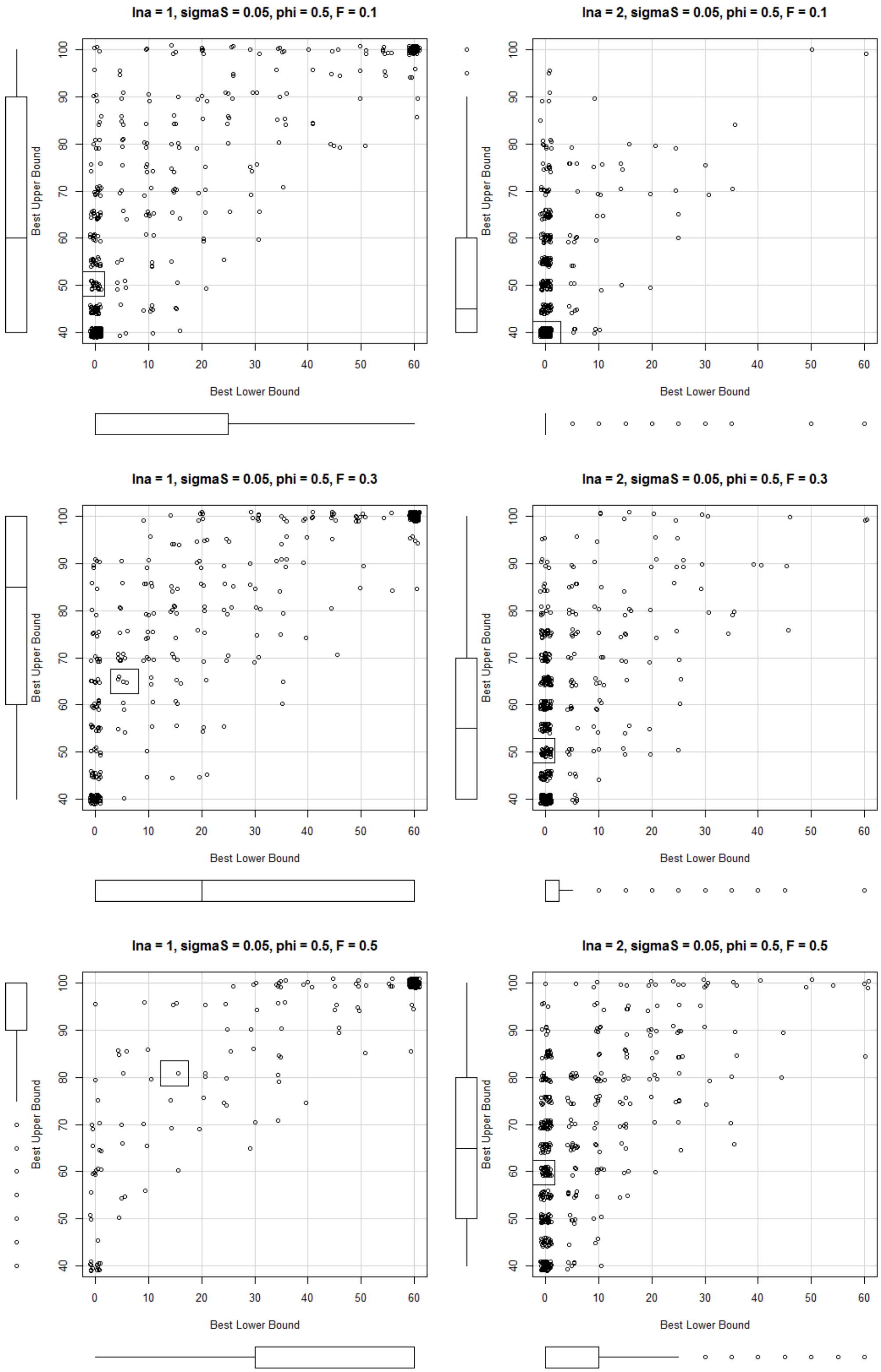
APPENDIX E: PLOTS OF UNCERTAINTY IN ESTIMATION OF THE BEST PERCENTILE RANGE FROM THE SIMULATION ANALYSIS



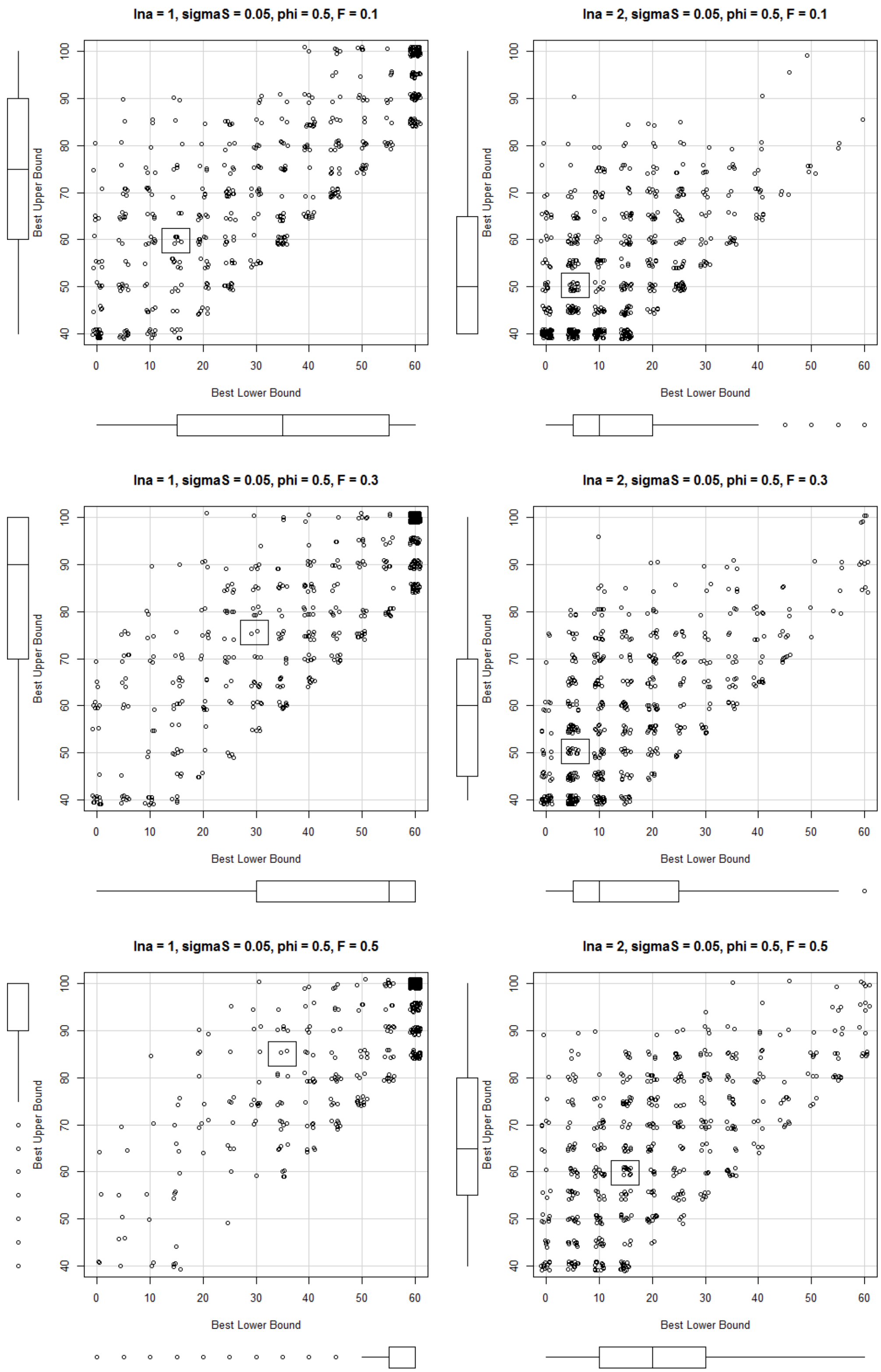
Appendix E1.–Scatter plots of simulated Best upper against Best lower percentile based on the lowest Rating for 2 log-productivities and 3 harvest rates; with low measurement error, no serial correlation, and high contrast for 10 years of escapements. Squares indicate the average Best percentile range.



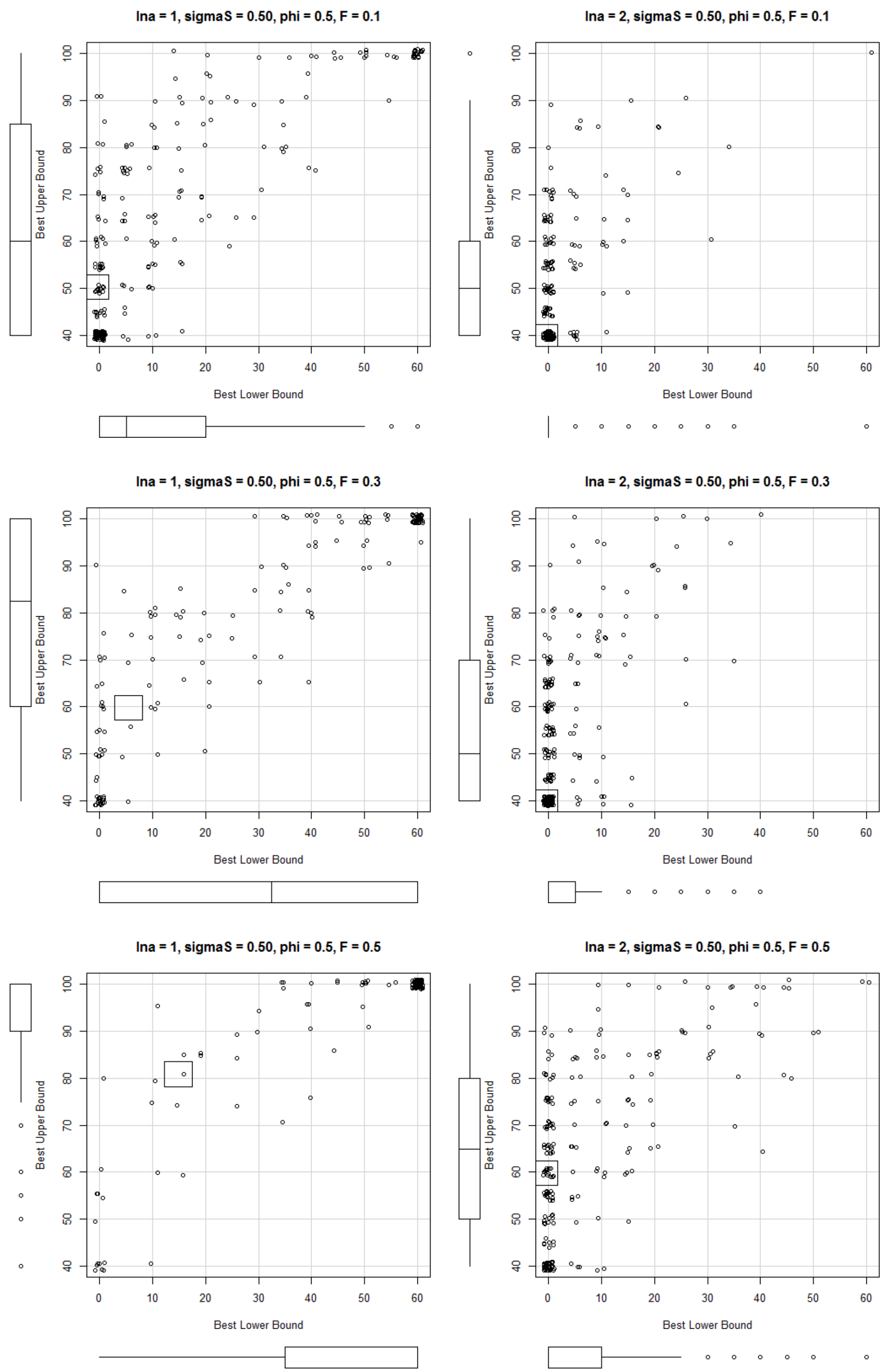
Appendix E2.–Scatter plots of simulated Best upper against Best lower percentile based on the lowest Rating for 2 log-productivities and 3 harvest rates; with high measurement error, no serial correlation, and high contrast for 10 years of escapements. Squares indicate the average Best percentile range.



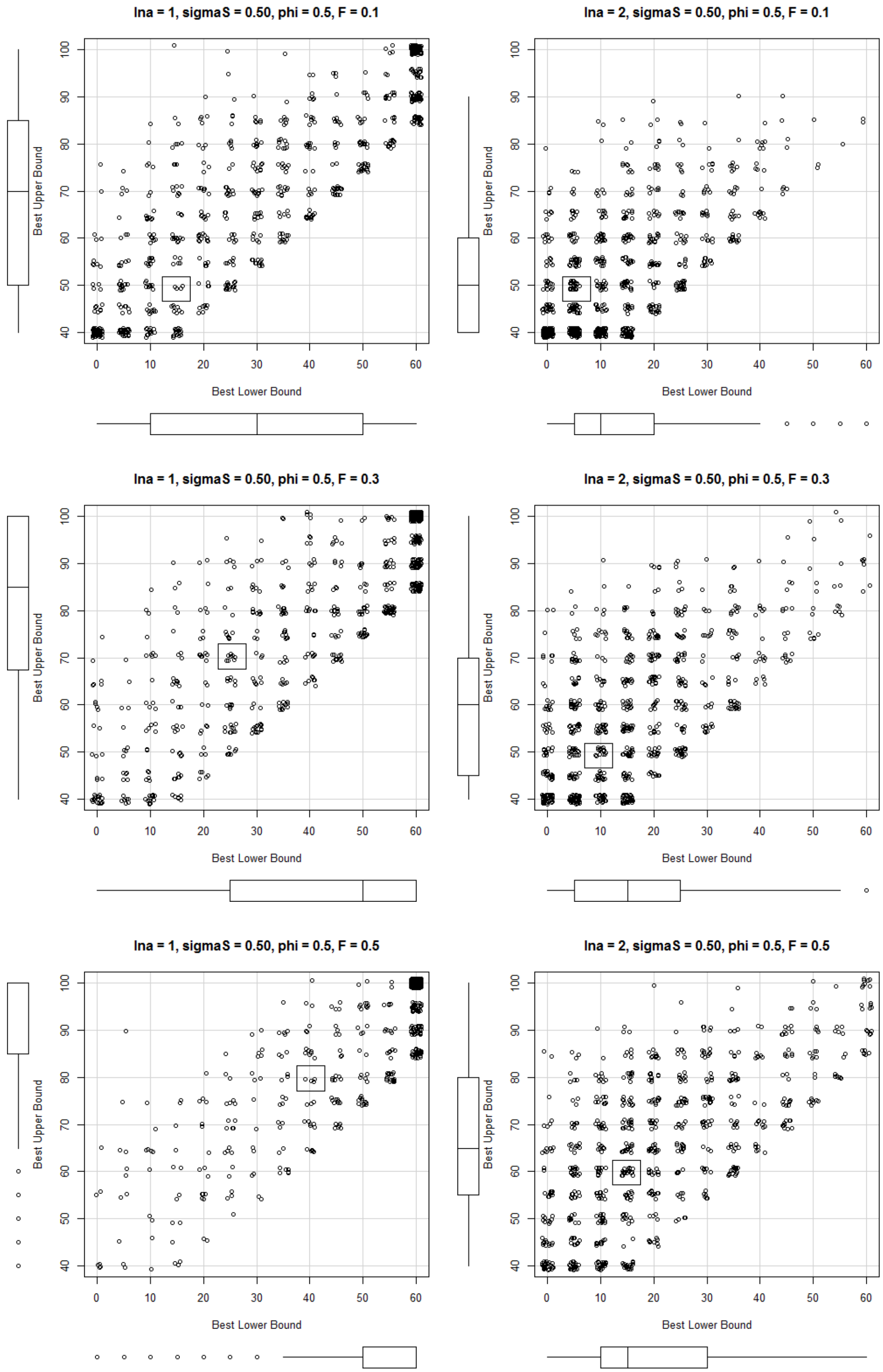
Appendix E3.–Scatter plots of simulated Best upper against Best lower percentile based on the lowest Rating for 2 log-productivities and 3 harvest rates; with low measurement error, moderate serial correlation, and low contrast for 10 years of escapements. Squares indicate the average Best percentile range.



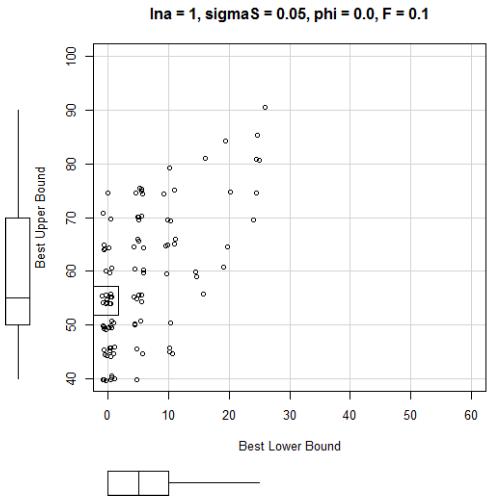
Appendix E4.–Scatter plots of simulated Best upper against Best lower percentile based on the lowest Rating for 2 log-productivities and 3 harvest rates; with low measurement error, moderate serial correlation, and high contrast for 10 years of escapements. Squares indicate the average Best percentile range.

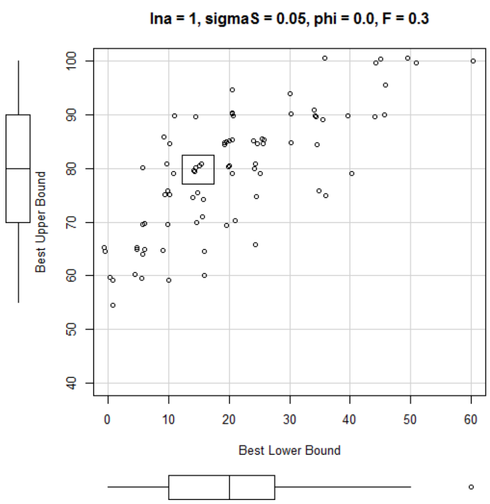


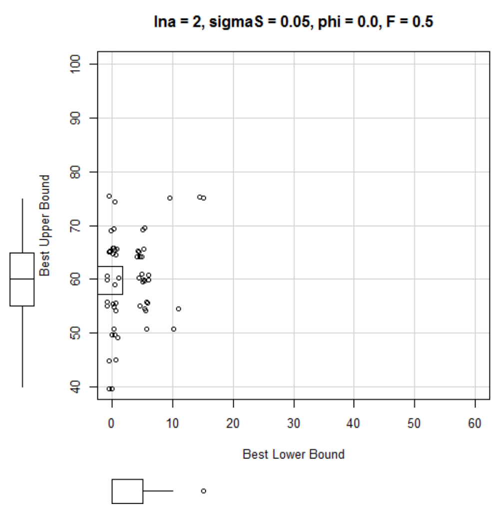
Appendix E5.–Scatter plots of simulated Best upper against Best lower percentile based on the lowest Rating for 2 log-productivities and 3 harvest rates; with high measurement error, moderate serial correlation, and low contrast for 10 years of escapements. Squares indicate the average Best percentile range.



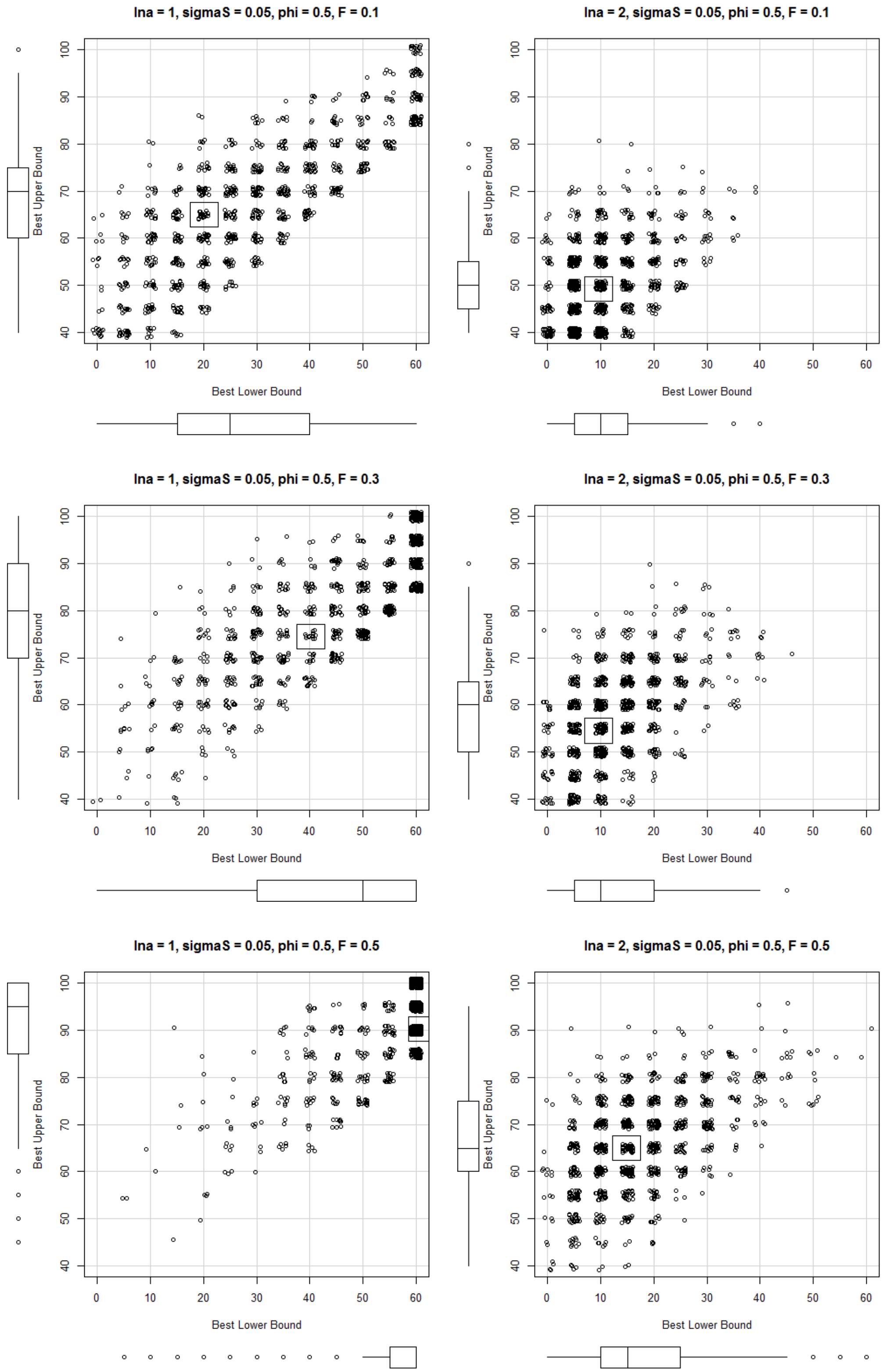
Appendix E6.–Scatter plots of simulated Best upper against Best lower percentile based on the lowest Rating for 2 log-productivities and 3 harvest rates; with high measurement error, moderate serial correlation, and high contrast for 10 years of escapements. Squares indicate the average Best percentile range.



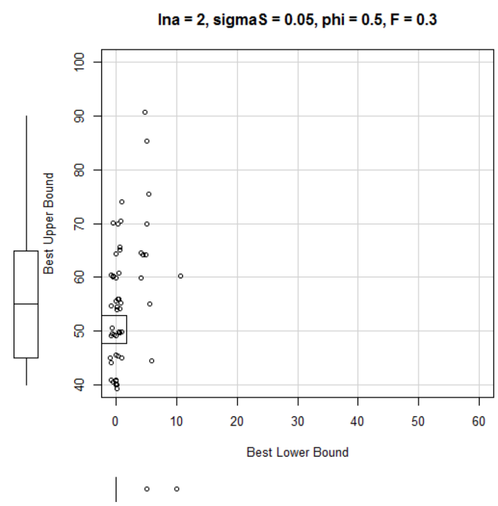


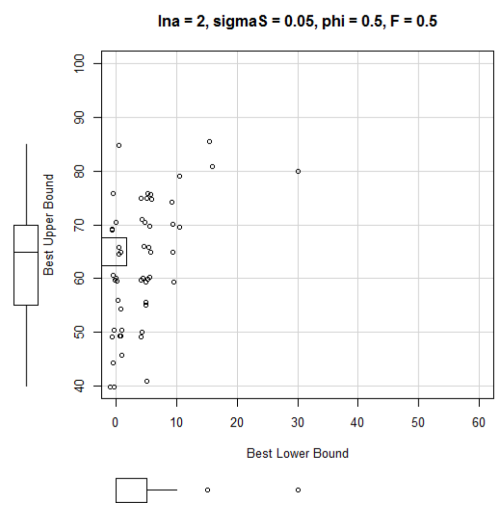


Appendix E7.–Scatter plots of simulated Best upper against Best lower percentile based on the lowest Rating for 2 log-productivities and 3 harvest rates; with low measurement error, no serial correlation, and low contrast for 30 years of escapements. Squares indicate the average Best percentile range.

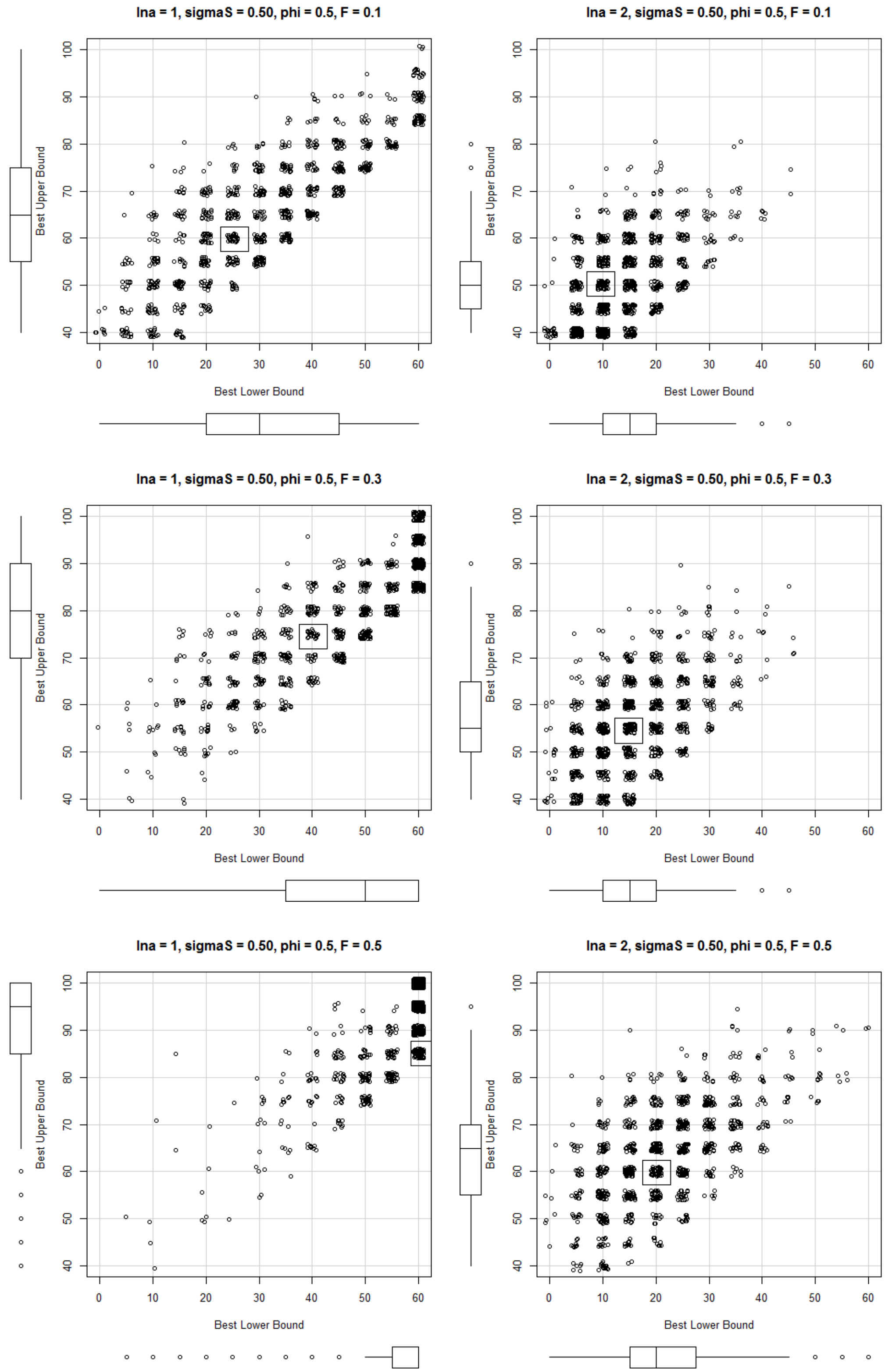


Appendix E8.–Scatter plots of simulated Best upper against Best lower percentile based on the lowest Rating for 2 log-productivities and 3 harvest rates; with low measurement error, moderate serial correlation, and high contrast for 30 years of escapements. Squares indicate the average Best percentile range.



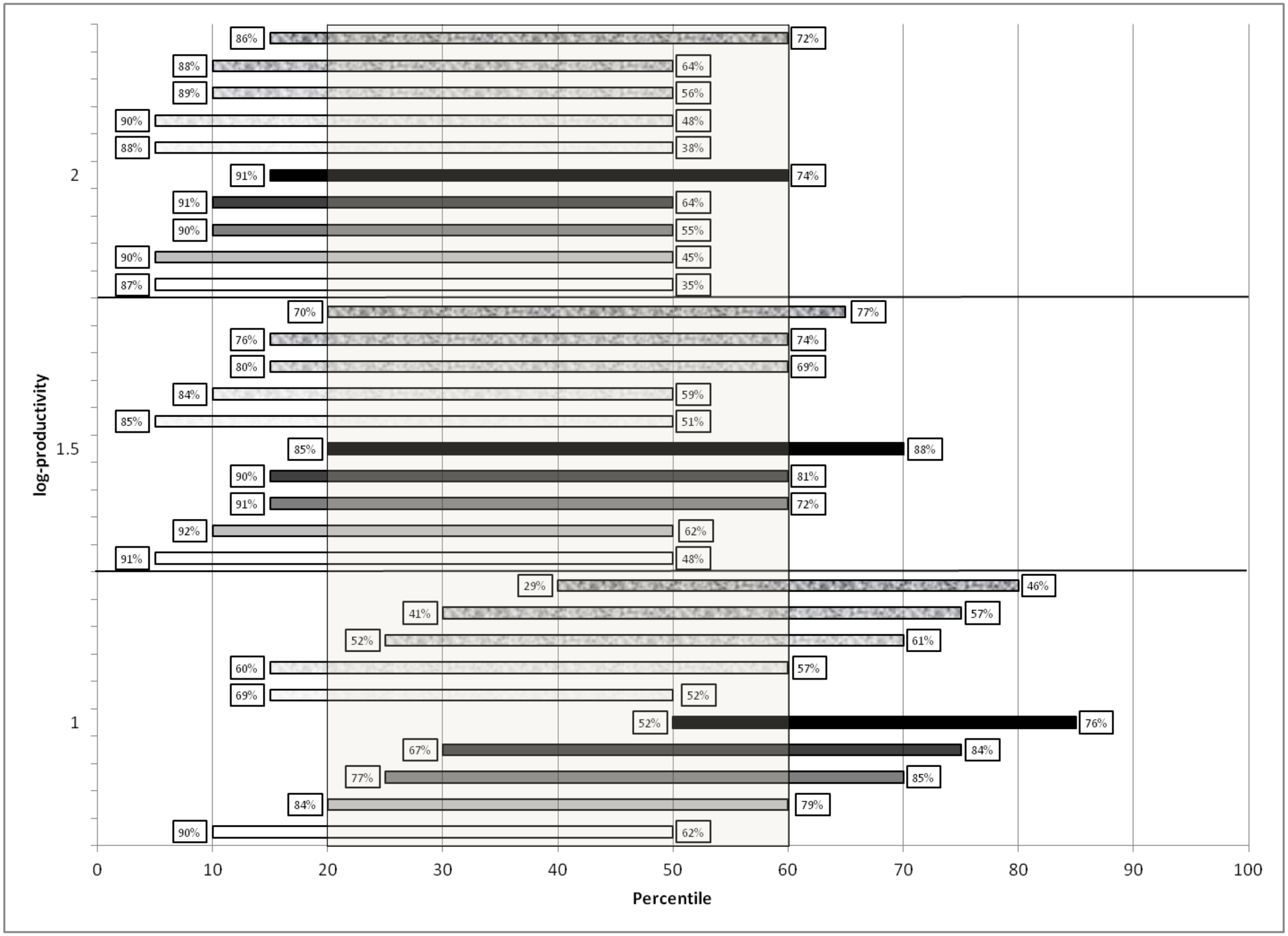


Appendix E9.–Scatter plots of simulated Best upper against Best lower percentile based on the lowest Rating for 2 log-productivities and 3 harvest rates; with low measurement error, moderate serial correlation, and low contrast for 30 years of escapements. Squares indicate the average Best percentile range.

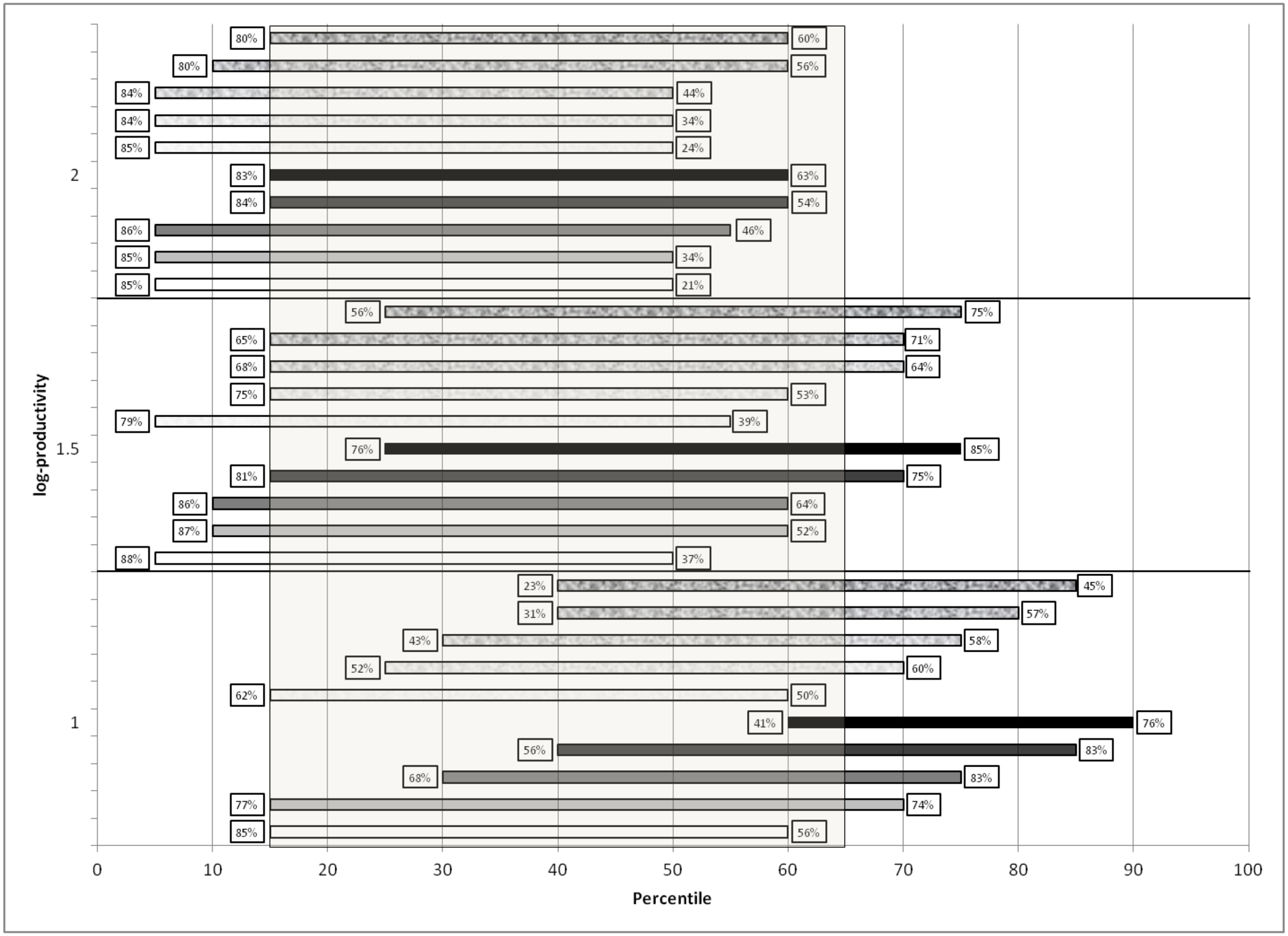


Appendix E10.–Scatter plots of simulated Best upper against Best lower percentile based on the lowest Rating for 2 log-productivities and 3 harvest rates; with high measurement error, moderate serial correlation, and high contrast for 30 years of escapements. Squares indicate the average Best percentile range.

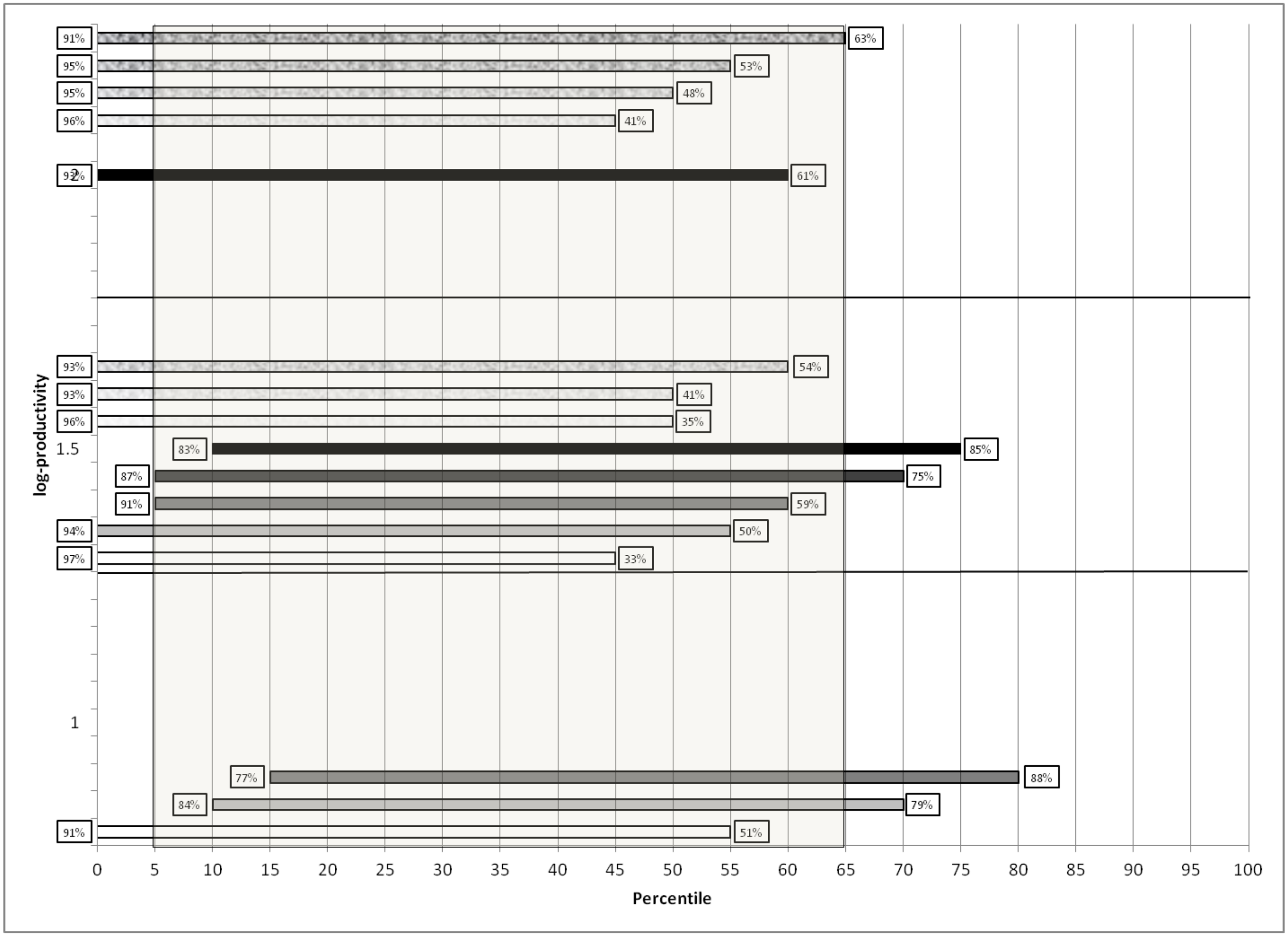
APPENDIX F: PLOTS OF PERFORMANCE OF RECOMMENDED TIERS BASED ON THE SIMULATIONS ANALYSIS



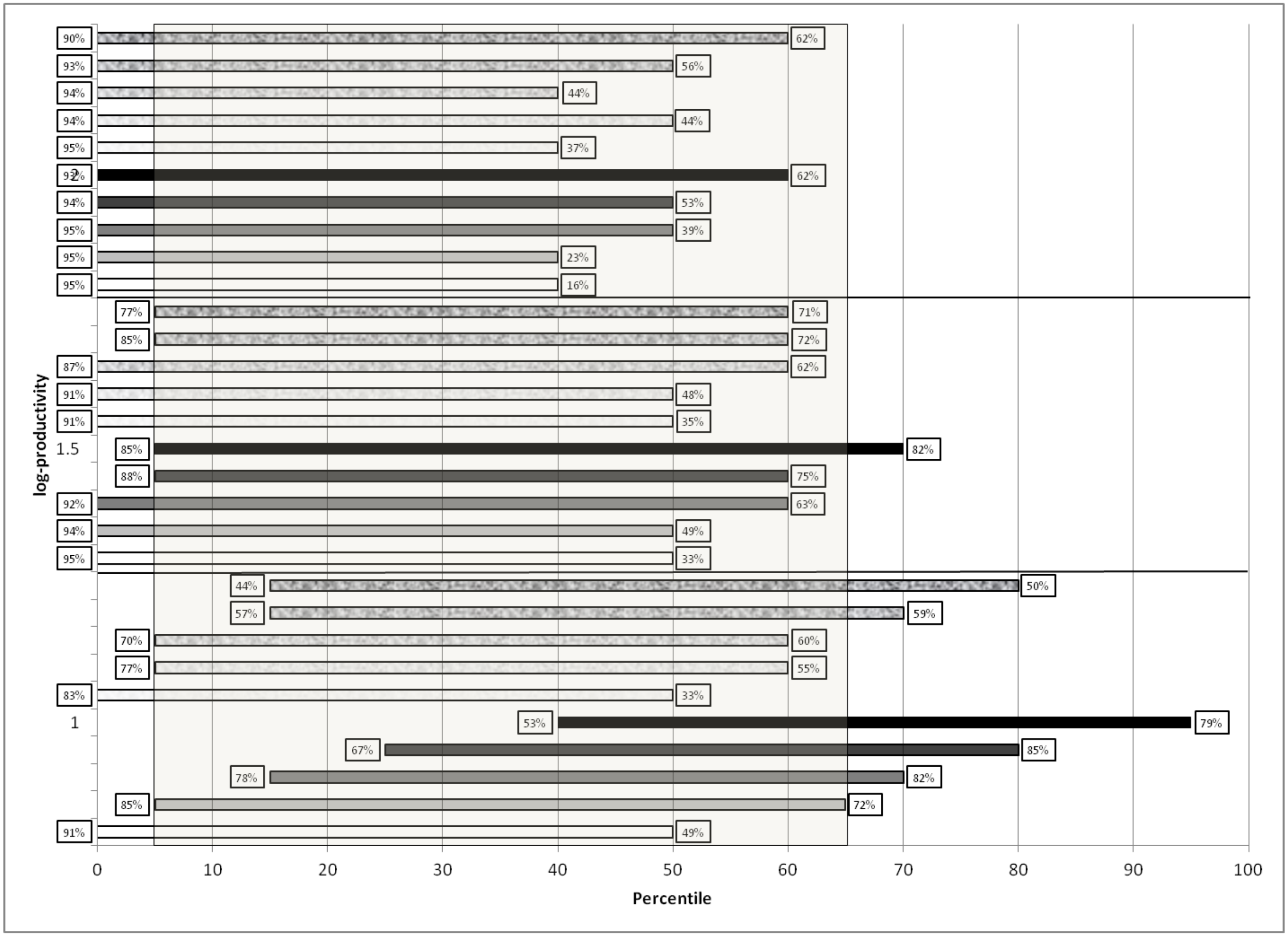
Appendix F1.–Plots of average Best percentiles (bars) and expected yields as a percentage of MSY (values in boxes) for 3 levels of log-productivity when the recommended 20th-60th percentiles (shaded area) are managed for. Shading represents low (lightest) to moderate (darkest) harvest rate, and fill represents no (solid) to moderate (stippled) serial correlation for simulations with high measurement error and high contrast, with 10 years of escapements.



Appendix F2.–Plots of average Best percentiles (bars) and expected yields as a percentage of MSY (values in boxes) for 3 levels of log-productivity when the recommended 15th-65th percentiles (shaded area) are managed for. Shading represents low (lightest) to moderate (darkest) harvest rate, and fill represents no (solid) to moderate (stippled) serial correlation for simulations with low measurement error and high contrast, with 10 years of escapements.



Appendix F3.–Plots of average Best percentiles (bars) and expected yields as a percentage of MSY (values in boxes) for 3 levels of log-productivity when the recommended 5th-65th percentiles (shaded area) are managed for. Shading represents low (lightest) to moderate (darkest) harvest rate, and fill represents no (solid) to moderate (stippled) serial correlation for simulations with low measurement error and low contrast, with 30 years of escapements.



Appendix F4.–Plots of average Best percentiles (bars) and expected yields as a percentage of MSY (values in boxes) for 3 levels of log-productivity when the recommended 5th-65th percentiles (shaded area) are managed for. Shading represents low (lightest) to moderate (darkest) harvest rate, and fill represents no (solid) to moderate (stippled) serial correlation for simulations with high measurement error and low contrast, with 10 years of escapements.