PACIFIC SALMON COMMISSION
JOINT CHINOOK
TECHNICAL COMMITTEE REPORT

RELATING RISK OF MANAGEMENT ERROR TO LOWER BOUNDS OF ESCAPEMENT FOR ADDITIONAL MANAGEMENT ACTION

TCCHINOOK (2002)-2

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LIST OF ACRONYMS WITH DEFINITIONS

AABM	Aggregate abundance based management
AI	Abundance Index
ADF&G	Alaska Department of Fish & Game
AEQ	Adult Equivalent
AWG	Analytical Working Group of the CTC
C&S	Ceremonial & Subsistence
CBC	Central British Columbia Fishing area – Kitimat to Cape Caution
CDFO	Canadian Department of Fisheries & Oceans
CNR	Chinook Nonretention
CR	Columbia River
CRITFC	Columbia River Intertribal Fish Commission
CTC	Chinook Technical Committee
CUS	Columbia Upriver Spring chinook stock
CWT	Coded Wire Tag
ESA	U.S. Endangered Species Act
est+fw	Estuary Plus Fresh Water Area
FR	Fraser River
GS	Strait of Georgia
IDFG	Idaho Department of Fish & Game
IDL	InterDam Loss
ISBM	Individual stock based management
LFR	Lower Fraser River
LGS	Lower Strait of Georgia
mar	Marine Area
mar+fw	Marine Plus Fresh Water Area
MRP	Mark-Recovery Program
MSY	Maximum Sustainable Yield for a stock, in adult equivalents
MSY ER	Exploitation Rate sustainable at the escapement goal for a stock, in AEQs
NA	Not Available
NBC	Northern British Columbia - Dixon Entrance to Kitimat including Queen Charlotte Islands
NMFS	National Marine Fisheries Service
NOC	Oregon Coastal North Migrating Stocks
NPS	North Puget Sound
NPS-S/F	North Puget Sound Summer/Fall chinook stock
NR	Not Representative
NWIFC	Northwest Indian Fisheries Commission
ODFW	Oregon Department of Fish & Wildlife
OTAC	Outside Troll Advisory Committee
PFMC	Pacific Fisheries Management Council
PS	Puget Sound
PSC	Pacific Salmon Commission
PSMFC	Pacific States Marine Fisheries Commission
PST	Pacific Salmon Treaty
QIN	Quinault Nation
QCI	Queen Charlotte Islands
S_{MSY}	Escapement producing maximum sustained yield
SEAK	Southeast Alaska - Cape Suckling to Dixon Entrance
SPS	South Puget Sound
SSRAA	Southern Southeast Regional Aquaculture Association
TBR	Transboundary Rivers
TTC	Transboundary Technical Committee
UFR	Upper Fraser River
UGS	Upper Strait of Georgia
USFWS	U.S. Fish & Wildlife Service
UW	University of Washington
WA/OR	Ocean areas off Washington and Oregon North of Cape Falcon
WAC	North Washington Coastal Area (Grays Harbor northward)
WACO	Washington, Oregon, Columbia River chinook stock
WCVI	West Coast Vancouver Island - excluding Area 20
WDFW	Washington Department of Fisheries and Wildlife

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EXECUTIVE SUMMARY

A decision to implement “additional management actions” in a fishing season will be based on the number of stock groups of chinook salmon “requiring response” as per the Agreement:

Percentage Reduction In Index	*Number of Stock Groups Requiring Response*
10%	*2 stock groups*
20%	*3 stock groups*
30%	*4+ stock groups*

For AABM fisheries on chinook salmon the “index” is the pre-season abundance index from a successful calibration of the CTC (Chinook Technical Committee) coast-wide model for the upcoming season; for ISBM fisheries the “index” is the non-ceiling index as defined in TCChinook (96)-1. For both types of fisheries a reduction of x% implies an approximate x% reduction in fishing effort and subsequently a lower fishing-induced mortality rate (harvest rate).

Whether or not a stock group “requires response” depends upon the number of stocks in the group with escapement below a lower bound and a negotiated set of criteria. There are 12 stock groups with each group comprised of one to seven stocks. By the Agreement, only those stocks with biologically based escapement goals accepted by the CTC will be considered when implementing “additional management action” (AMA). To date the CTC has accepted goals for two stock groups, the Fraser Late group (Harrison stock) and the Far North Migrating Oregon Coastal group (Nehalem, Siletz, and Siuslaw stocks). An interim goal based on outputs from the coast-wide model was developed for the mid-Columbia group (and stock). A goal was accepted for the Lewis stock of the Columbia Falls group, but not for the other two stocks in that group. In the Agreement the CTC was tasked with developing methods by the end of 2001 for establishing lower bounds for all stocks that would be used to trigger AMA.

Possible “interim” methods of calculating lower bounds for stocks prior to 2001 were implied in the Agreement and were investigated for their effectiveness as methods for establishing lower bounds. All of these methods were variants of setting lower bounds as a function of estimated, two-parameter stock-recruit relationships. Lower bounds were judged on how often AMA would be taken, how quickly stock size would “recover,” and the effects of AMA on average harvest and average escapements. Simulations based on information from stock assessment programs, exploitation rate analyses, and estimated, three-parameter stock-recruit relationships were used to answer these questions. The third parameter in simulated stock-recruit relationships represented process error and was stochastic. “Interim” approaches were subsequently abandoned when simulations showed AMA is not needed to protect stocks, so long as average harvest rates are no greater than the optimal rate and stock productivity is as estimated and not lower.

Although stocks do not need protection when harvest occurs at or below optimal rates (rates that produce MSY given stock productivity), stocks do need protection if they are being overfished. Overfishing happens when average harvest rates are greater than optimal rates, usually from stock productivity being lower than expected or harvest rates being higher than estimated. Whichever the cause, the appropriate response is to reduce average harvest rates through AMA. Low escapements can result from overfishing, however, low escapements can also result from natural variation in stock abundance when stocks are under or optimally fished as well. Because we do not know which is so, there are risks of doing the wrong thing in setting a lower bound to trigger AMA. These risks of management error can be estimated and used to establish rational lower bounds.

General methods linking lower bounds and the risk of management error were developed that incorporated unexpected changes in productivity and harvest rates. Management error is defined as an unwarranted AMA (a Type I Error) or no AMA when needed (a Type II Error). The former occurs when one or zero stock groups are unknowingly being overfished (no AMA is needed as per the Agreement), yet by chance enough escapements are below established lower bounds to trigger AMA. A Type II Error occurs when two or more stock groups are unknowingly being overfished (AMA is needed as per the Agreement), but by chance too few escapements are below established bounds to trigger AMA.

The link between lower bounds and risk is a matter of probability as implied in the Agreement. Simulations of the Harrison, mid-Columbia, Oregon coastal, and Lewis stocks can be used to estimate the probability that escapement to each stock would meet the “two-year” criterion in a particular year, that is, escapement below a lower bound in the two previous years. Simulations were similar to those developed to investigate the “interim” methods mentioned earlier. Probabilities of each stock in a group meeting its “two-year criterion” are combined to estimate the probability that a stock group “requires response” in a year, then these probabilities are used to estimate the probability that two or more groups “require a response” and trigger AMA. Productivity of stocks was reduced in some simulations and not others to represent situations when no, one, two, or three groups are being overfished. Estimated probability of triggering AMA when one or no groups are being overfished represents a Type I Risk. Estimated probability of not triggering AMA when two or more groups are overfished represents a Type II Risk.

The link between lower bounds and risk can be exercised to estimate risks from a specific set of lower bounds, or to establish lower bounds from acceptable risks. The former approach is demonstrated by estimating the risks of choosing the accepted and interim goals as lower bounds. Under one interpretation of the Agreement [¶9(a)(i) and Attachments I-V], lower bounds for taking AMA would be established whenever the CTC accepted an escapement goal range as being biologically based. The lower end of this range would be the lower bound for triggering AMA under this interpretation of the Agreement. Since only the goal for the Harrison stock was accepted as a range (75,100 to 98,500), risks were estimated for this demonstration using the lower end of the range for the Harrison stock and the point goals for the other stocks (Table E.1). Risks were estimated when all stocks in no, one, or two groups were being overfished due to a 10, 20, 30, or 40% drop in productivity, while all other stocks were being optimally fished (fished to produce MSY). General results showed:

1) Type I Risk was higher when one stock group was overfished;
2) Type I Risk increased as productivity declined in the one group being overfished; and
3) Type II Risk decreased as more stocks became overfished and/or productivity declined.

Specific results under these same circumstances are that there would be an estimated 98% or greater chance of AMA in a typical year (Table E.2) if the lower bounds in Table E.1 are implemented. If one or no groups are overfished and the others optimally fished, all AMA would be unwarranted as per the Agreement. If two or more groups are overfished and the others optimally fished, management would err only in years with no AMA.

Table E.1. Stock groups, stocks, accepted (or interim) escapement goals, lower bounds as implied in ¶9(a)(i) and Attachments I-V of the Agreement, estimated harvest rates, both optimal and current (average from 1995 – 1999).

Stock Group	Stocks	Accepted (or Interim) Goal	Lower Bound	Optimal Harvest Rate	Current Harvest Rate
Fraser Late	**Harrison**	75,100	75,000	0.61	0.31
Columbia River Summers	**Mid-Columbia Summers**	12,141[a]	12,100	0.76	0.30
Oregon Coastals	**Nehalem**	6,989	7,000	0.72	0.60
	Siletz	2,944	2,900	0.72	0.60
	Siuslaw	12,925	12,900	0.72	0.60
Columbia River Falls	**Lewis**	5,791	5,800	0.79	0.27
	Upriver Brights				
	Deschutes				

[a] Interim goal past Rock Island Dam.

Table E.2. Estimated risks of management error if the low end of “ranges” about accepted (or interim) goals are used as lower bounds. Stock groups are either optimally fished, or are overfished due to reductions in expected productivity of at least 10%. Note that all stocks with accepted goals are currently underfished (see Table E.1).

Error	Type of Risk	Estimated Risk
Unneeded AMA	**I**	³ **0.976**
No AMA when needed	**II**	£ **0.016**

Currently, stocks with accepted goals are being underfished, that is, their average harvest rates as estimated have been significantly below levels that are estimated to produce MSY (Table E.1). In this current situation, estimates of risk based on optimally fished and overfished stocks are over estimates. Under current conditions, AMA is unlikely even if lower bounds in Table E.1 are implemented.

As mentioned above, the process of linking risk and lower bounds can start with the risk of management error. That risk could be a Type I or Type II Risk, but calculations are easier if the Type I Risk is specified first. An acceptable risk is specified and spread evenly across all stock groups giving each the same probability of “requiring response,” provided that all stocks are optimally fished. The probability of a group “requiring response” is then spread among stocks within a group (if needed) to calculate the target probability of a stock meeting the “two-year criterion” in any given year. Next lower bounds are changed in simulations based on optimal fishing until the “predicted” probabilities match “target” probabilities. The result is a set of estimated lower bounds associated with an acceptable Type I Risk. Because a Type I Error also occurs when one stock group is overfished, productivity is lowered for one stock group and risk reestimated from the previously determined set of lower bounds.

Type II Risks are then estimated from this set of lower bounds under conditions when two or more stock groups are overfished due to reductions in productivity, say reductions of 30, 40, or 50%. Simulations are rerun with these now overfished stock groups while other groups are fished optimally. Because the goal is to present lower bounds as a consequence of risk, this process is repeated on different sets of lower bounds to produce a menu or graph.

Figure E.1 is such a graph linking not only Type II Risk to sets of lower bounds, but Type I Risk as well, for the Harrison, mid-Columbia, Nehalem, Siletz, Siuslaw, and Lewis stocks A straight-edge implement is sufficient to show that if a 20% Type I Risk at most is acceptable (for instance), estimated lower bounds for the six stocks in order would be 22,000; 7,700; 3,050; 2,400; 3,600; and 4,100, as determined off the thin curve labeled “I/40/1” (one group overfished due to a 40% reduction in productivity). If overfishing is not as severe as specified for this curve, the estimated Type I Risk is less than 20% for this set of lower bounds. Note that a Type I Error occurs with AMA in a year when one or no stock groups are overfished.

If a 20% Type II Risk is acceptable (as an example), estimated lower bounds from Figure E.1 are 30,000; 8,800; 3,650; 2,800; 4,500; and 4,550, respectively, as determined from the lines labeled “II/40/2” or “II/30/3” (two groups overfished due to 40% reductions in productivity or three groups overfished due to 30% reductions). Note that a Type II Error occurs with no AMA in a year when two or more stocks are overfished. If only concerned with a 50% reduction in productivity in two groups, or a 40% reduction in three, lower bounds would be much lower at the same estimated risk. If concerned with a 30% reduction in two groups, lower bounds would be higher.

Since only one set of lower bounds can be implemented, a compromise is needed to be risk averse. Remembering that:

1) Type I Risk is lower when overfishing is less severe in the one overfished group; and
2) Type II Risk is less as more groups are overfished and overfishing is more severe,

Curves in Figure E.1 can be used to determine a set of lower bounds that represent a range of acceptable risks. A straight edge laid parallel to the y-axis determines a set of lower bounds by bisecting risk curves. The result overstates both types of risk as per the rules above, or if some stocks are underfished. Graphs can be drawn for ranges in risk and lower bounds not covered in Figure E.1.

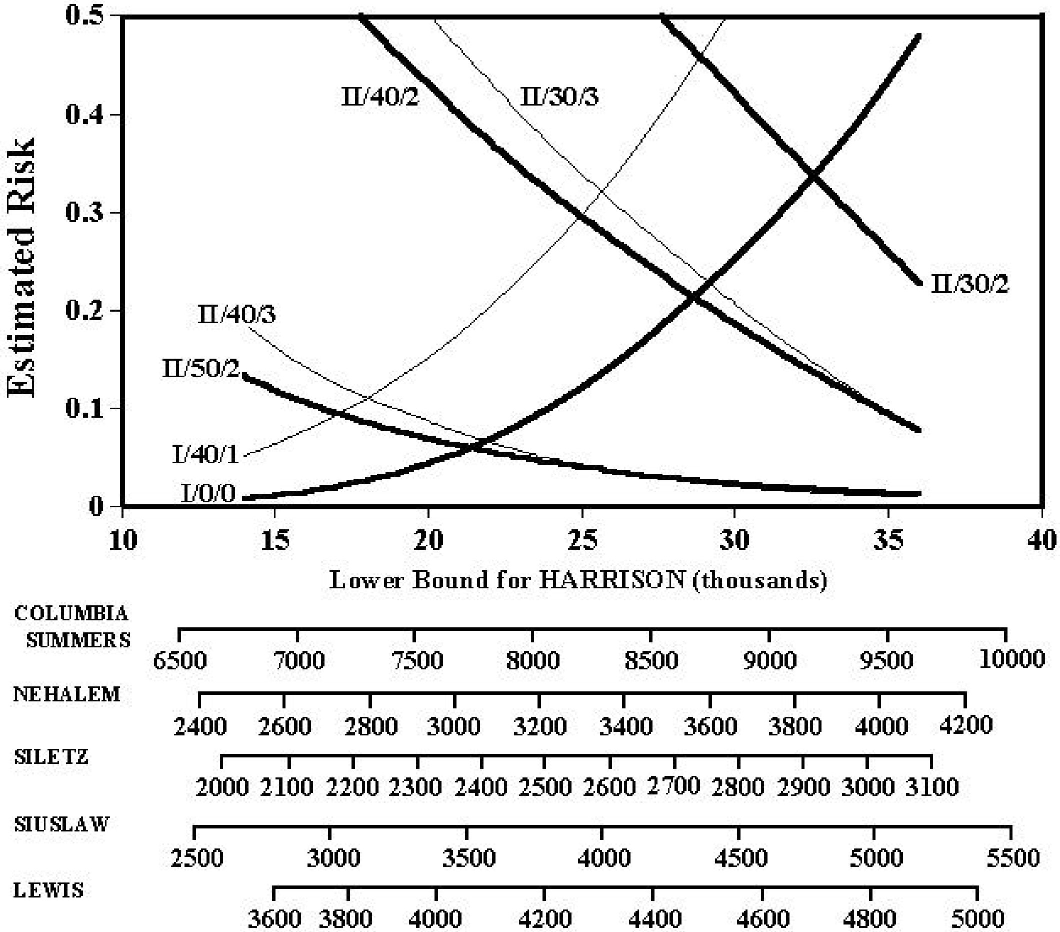

Figure E.1.Estimated risks of management error with sets of lower bounds for the six stocks with accepted or interim escapement goals. Labels on curves have the format “x/y/z” where “x” is the type of risk, “y” is a percent reduction in productivity, and “z” is the number of stock groups being overfished. All stocks not being overfished are assumed to be optimally fished.

Curves in Figure E.1 do not represent the probable, current situation in AABM and ISBM fisheries. As indicated in Table E.2, current average harvest rates for the Fraser Late, mid-Columbia, Oregon Coastal groups, and the Lewis stock are well below their estimated optimal rates. To the extent that these and other stocks are underfished, curves in Figure E.1 overstate both types of risks.

1. INTRODUCTION

Annexes to the Pacific Salmon Treaty revised in 1999 (hereafter called the Agreement) provide for reductions in harvest rates of chinook salmon if escapement levels of stock groups fall below threshold levels (Pacific Salmon Commission 2000). Specifically, the Agreement reads that a decision to implement "additional management actions" in a fishing season will be based on the number of stock groups of chinook salmon "requiring a response":

Percentage Reduction in Index	***Number of Stock Groups Requiring Response***
No Reduction	*0 stock groups*
No Reduction	*1 stock group*
10%	*2 stock groups*
20%	*3 stock groups*
30%	*4+ stock groups*

For AABM fisheries the "index" is the pre-season abundance index from a successful calibration of the CTC (Chinook Technical Committee) coast-wide model for the upcoming season; for ISBM fisheries the "index" is the non-ceiling index as defined in TCChinook (96)-1. For both types of fisheries a reduction of x% implies an approximate x% reduction in fishing effort and subsequently a lower fishing-induced mortality rate (harvest rate).

Whether a stock group requires a response depends upon the number of stocks in the group with escapement below a lower bound and a negotiated set of criteria. There are 12 stock groups defined in the Agreement (Table 1.1) with each group comprised of one to seven stocks. By the Agreement, only those stocks with biologically based escapement goals accepted by the CTC will be considered when implementing "additional management actions" (AMAs). To date the CTC has accepted goals for six stocks outside of Alaska; these stocks, their stock groups, and their criteria for "requiring response" are listed in Table 1.2.

A series of scenarios can be used to demonstrate how AMAs would be implemented under the Agreement. Decisions regarding AMAs occur in the first few months of each calendar year. Say the current year is calendar year y:

> **Scenario 1:** If estimated escapements to the Harrison River were below its lower bound in calendar years $y-1$ and $y-2$, the Fraser Late stock group would meet the criteria for "requiring a response." If the Fraser Late stock group is the only group "requiring response," there would be no AMA in any fishery in year y.

Scenario 2: Escapements in years *y* – 1 and *y* – 2 were below lower bounds for the Harrison, Siletz, and Nehalem rivers, meeting the criteria for declaring two stock groups, the Fraser Late and the Far North Migrating Oregon Coastal Falls, as "requiring response." Additional management actions, a 10% reduction in indices, would be taken in all three AABM and both ISBM fisheries, since one or both of these groups are exploited in each fishery.

Table 1.1. Stock groups and the fisheries in which their stocks are exploited as per the Agreement.

Stock Group	**Fishery**				
	SEAK AABM	**North BC AABM**	**WCVI AABM**	**BC ISBM**	**South US ISBM**
Upper Strait of Georgia	*Yes*	*Yes*	*No*	*Yes*	*No*
Lower Strait of Georgia	*No*	*No*	*No*	*Yes*	*No*
West Coast Vancouver Island	*Yes*	*Yes*	*No*	*Yes*	*No*
North/Central British Columbia	*Yes*	*Yes*	*No*	*Yes*	*No*
Far North Migrating Oregon Coastal Falls	*Yes*	*Yes*	*No*	*No*	*Yes*
Columbia River Falls	*Yes*	*Yes*	*Yes*	*No*	*Yes*
Columbia River Summers	*Yes*	*Yes*	*Yes*	*No*	*Yes*
Washington Coastal Falls	*Yes*	*Yes*	*No*	*No*	*Yes*
Fraser Early (Spring & Summers)	*Yes*	*Yes*	*No*	*Yes*	*No*
Fraser Late	*No*	*No*	*Yes*	*Yes*	*Yes*
Puget Sound Natural Summer/Falls	*No*	*No*	*Yes*	*Yes*	*Yes*
North Puget Sound Natural Springs	*No*	*No*	*No*	*Yes*	*Yes*

Scenario 3: Escapements in years *y* – 1 and *y* – 2 were below lower bounds for the Harrison and Nehalem rivers, meeting the criteria for only one group, the Fraser Late, as "requiring response." No AMA would be taken in any fishery.

Scenario 4: Escapements in years *y* – 1 and *y* – 2 were below lower bounds for the Siuslaw and Nehalem rivers and for the mid-Columbia summers, meeting the criteria for two groups, the Far North Migrating Oregon Coastal Falls and the Columbia River Summers, as "requiring response." Additional management actions, a 10 % reduction in indices, would be taken in four fisheries. The British Columbia ISBM fishery would be exempt from AMA in this instance because no stock in the two groups "requiring response" is exploited in this fishery.

Scenario 5: Escapements in years $y – 1$ and $y – 2$ were below lower bounds for the Harrison, Siuslaw, and Nehalem rivers and for the mid-Columbia summers, meeting the criteria for three groups, the Fraser Late, the Far North Migrating Oregon Coastal Falls, and the Columbia River Summers, as "requiring response." Additional management actions would be taken in all three AABM fisheries (10% reduction in indices) and in the US ISBM fishery (20% reduction in its index). No AMA would occur in the Canadian ISBM fishery.

Table 1.2. Stock groups, their stocks, and criteria for "concern" and "stock status" for groups containing stocks (underlined) with accepted, biologically based escapement goals.

Stock Group	Criteria for Stock Group Concern	Escapement Indicator Stocks	Escapement Objective	Criteria for Stock Status
Fraser Late	Below lower bound of goal	Harrison River	Escapement goal range by stock	Spawning escapement below lower bound of escapement range for 2 consecutive years
Columbia River Summers	Below lower bound of goal	Mid-Columbia Summers	Escapement goal range by stock	Spawning escapement below lower bound of escapement range for 2 consecutive years
Far North Migrating Oregon Coastal Falls	Two or more stocks below lower bound of goal	Nehalem, Siletz, Siuslaw rivers	Escapement goal range by stock	Spawning escapement below lower bound of escapement range for 2 consecutive years
Columbia River Falls	Two or more stocks below lower bound of goal	Upriver Brights, Deschutes, Lewis rivers	Escapement goal range by stock	Spawning escapement below lower bound of escapement range for 2 consecutive years

The CTC was tasked in the Agreement to establish methods by the end of year 2001 for determining lower bounds in escapements for use in implementing AMAs. As per entry (7) on p. 49 of the Appendix to Annex IV, Chapter 3 of the Agreement:

> "For those stocks for which the escapement goals have been recommended by the CTC, …. the CTC will, prior to the end of 2001, review and recommend for adoption to the Commission, criteria defining the lower bound of escapement for the purposes of taking additional management action pursuant to paragraph 9 of this chapter."

The apparent latitude given the CTC in establishing a method for determining lower bounds was reinforced in footnote (3) to ¶9(b) on p. 40 of the Agreement:

> “[3] … By the end of 2001, the CTC will recommend for adoption by the Commission, criteria defining a lower bound of escapement for the purposes of taking additional management action pursuant to this paragraph. Until the end of 2001, the escapement level at which MSY production is reduced by more than 15% will be defined as the lower bound of escapement.”

The footnote also contained an interim method for establishing lower bounds in escapements. Although there was some confusion as to the meaning of the phrase “MSY production” in the footnote, the CTC focused its initial efforts on investigating this “interim” method as a possible means of establishing lower bounds (Chapter 3). These and subsequent efforts to establish a method of determining lower bounds are based on stochastic simulations of stocks, fisheries, and stock assessment programs as described in Chapter 2.

While the instructions above appear to contain a method for establishing interim lower bounds, and to give the CTC latitude in recommending how lower bounds would be established after 2001, other passages in the Agreement appear to contradict these instructions. As per ¶9(a)(i) and Attachments I-V of the Agreement:

> 9(a)(i): “Beginning in 1999, (there will be additional management action) if stock groups …. listed in Attachments I-V … are below the agreed escapement objectives.” [1]

Under these passages, lower bounds for taking AMAs would be established whenever the CTC accepted an escapement goal as being biologically based. Such lower bounds could be established as early as 1999, obviating the need for the interim method described in footnote (3).

After considering these contradictions and results from initial investigations (Chapter 3), the CTC developed a method of evaluating lower bounds based on estimating the risk involved with additional management action (Chapter 4). In this context risk is defined as the probability of making the wrong management decision by either disrupting fisheries with AMA when none is needed to protect stocks, or by not implementing an AMA when protection is needed. The method links lower bounds to risk such that risk of management error can be estimated for a particular set of lower bounds (Chapter 5), or that lower bounds can be established that entail an acceptable level of estimated risk (Chapter 6).

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[1] In the Attachments, “escapement objectives” are defined as “escapement goal ranges” and the lower bound as being literally the “lower bound of (an) (accepted) escapement (goal) range.”

2. STOCK-SPECIFIC SIMULATIONS

2.1 Fraser Late

The Fraser Late stock group is comprised of a single stock spawning in the Harrison River. This fall run of chinook salmon has an ocean-type life history with fry smolting to the estuary of the Fraser River to rear before heading out to sea. Adults mature at ages 2 – 5 with adults ages 3 – 5 years in the escapement considered the spawning population in any one year. Chinook salmon released from the Chilliwack Hatchery constitute the indicator stock for the Fraser Late group. Salmon from that hatchery are caught in the AABM fishery along the West Coast of Vancouver Island (WCVI) and in both the British Columbia and South US ISBM fisheries. Brown et al. (*in prep*) describe the Harrison stock in detail along with its fisheries, stock assessment programs, and an analysis to determine a biologically based escapement goal. The CTC accepted that goal of 75,100 – 98,500 spawners in December 2001.

Simulations involving the Harrsion stock used the same model as found in Brown et al. (*in prep*, Model 3). Transformed for use in the simulation, this model is:

$$R'_{by} = S'_{by} \exp\left[\, \ln a + g \ln[M'_{by}]_{\text{dev}} - bS'_{by} + e'_{by} \,\right] \qquad 2.1$$

where S'_{by} is predicted abundance of parents in simulated brood year *by* and R'_{by} their subsequent predicted production in the form of adults (this and all subsequent notation are defined in Table 2.1). The stochastic element $1\text{n}[M'_{by}]_{\text{dev}}$ represents deviation from the mean of log marine survival rates for smolts to age 2 such that $1\text{n}[M'_{y}]_{\text{dev}}$ ~ N(0, $s^2_{1\text{n}M}$) where $s^2_{1\text{n}M}$ is the variance of the log of the rates labeled SR in Table 9 of Brown et al. (*in prep*). The other stochastic element in the basic model, e'_{by}, represents the remaining process error in the relationship and is distributed N(0, s^2_e) where s^2_e is estimated from the residuals resulting from regressing eq. 2.1. to data on the Harrison stock. This regression also provided values for fixed parameters ln α, β, and γ, and for derived statistics $\boldsymbol{S_{MSY}}$ and $\boldsymbol{U_{MSY}}$ (from Brown et al. *in prep*. as listed in Table 2.2).

Stochastic elements in the simulations outside of the basic stock-recruit model involved variation in:

1) fishing-induced mortality (harvest) rate;
2) measurement error in estimating future escapements; and
3) return rates for adults.

Simulated fishing was set to be optimal fishing, that is, the average simulated harvest rate would approximate U_{MSY} while the average simulated spawning abundance would approximate S_{MSY}. Values for the optimal harvest rate U_{MSY} and the optimal stock size S_{MSY} were determined by regressing eq. 2.1 against data for the Harrison stock as per methods in TCCHINOOK (99)-3 (values in Table 2.2). Harvest rate for calendar year *cy* was simulated as:

F'_{cy} ~ N[-ln(1-U_{MSY}), s_F^2] 2.2

$U'_{cy} = 1 - \exp(-F'_{cy})$ 2.3

Table 2.1. Definitions and explanations of notation used in simulations.

Statistic:	**Explanation:**
β	Fixed parameter representing effects of density-dependent mortality in freshwater.
ε'_{by}	Predicted (stochastic), density-independent process error for brood year *by* that is "unexplained" and is distributed N(0, s_e^2).
F'_{cy}	Predicted (stochastic) instantaneous harvest rate during simulated calendar year *cy* and is distributed N[-ln(1-U_{MSY}), s_F^2] or N[-ln(1-U_{MAX}), $\bar{s}_F^2$].
γ	Fixed parameter representing that part of process error "explained" by variation in marine survival rates from smolts to age 2.
κ	Reduction in stock productivity as a fraction of exp(ln α).
ln α	Fixed parameter representing intrinsic, density-independent productivity of the stock.
$\ln[M'_{by}]_{\text{dev}}$	Predicted (stochastic) part of process error "explained" by variation in marine survival rates from smolts to age 2. The stochastic element is the deviation between the natural logarithm of the survival rate for brood year *by* and the natural logarithm of the mean survival rate over all brood years; this deviation is distributed N(0, s_{1nM}^2).
p	Probability that a stock group "requires response."
π	Probability that a stock meets the "two-year" criterion in a specific year.
φ	Fixed parameter representing effects of "unexplained" process error in brood year *by* - 1 on process error for brood year *by*.
R'_{by}	Predicted production in the form of adult equivalents for brood year *by*.
σ_ε^2	Fixed parameter representing variation (variance) in "unexplained" process error. The square root σ_e is a standard deviation.
σ_F^2	Fixed parameter representing variation (variance) in the instantaneous rate of fishing mortality.
$\bar{\sigma}_F^2$	Fixed parameter representing variation (variance) in the instantaneous rate of fishing mortality averaged over several stocks.
S_{LB}	The lower bound in adult spawning abundance (escapement) for a stock that is the first trigger for taking additional management action pursuant to paragraph 9 of Chapter 3 of the Agreement.

Table 2.1. Definitions and explanations of notation used in simulations (cont.).

Statistic:	**Explanation:**
$\sigma^2_{\ln M}$	Fixed parameter representing variation (variance) in “explained” process error due to marine survival rates for smolts to age 2 as expressed as deviations from the mean of log survival rates. The square root $\sigma_{\ln M}$ is a standard deviation.
S_{MSY}	Adult spawning abundance (escapement) that on average produces maximum sustained yield, i.e., the optimal stock size.
S'_{by}	Predicted, adult spawning abundance of parents to brood year *by*.
S''_{by}	Predicted, adult spawning abundance of parents to brood year *by* plus measurement error from stock assessment programs in calendar year *cy* (=*by*) [$= S'_{by} + S'_{by} t\ Z$].
τ	Fixed parameter representing the coefficient of variation (CV) divided by 100 for estimates of spawning abundance from stock assessment programs.
U_{MAX}	Annual harvest rate that maximizes sustained yield from more than one stock simultaneously
U_{MSY}	Annual harvest rate that on average produces maximum sustained yield, i. e. the optimal rate.
U'_{cy}	Predicted harvest rate for calendar year *cy* [=1- exp(- F'_{cy})].
Z	Predicted (stochastic) standard normal variate distributed N(0, 1).

Table 2.2. Parameters used to simulate the dynamics of the Harrison stock. Definitions of parameters are in Table 2.1.

ln a	b	g	s_e	$s_{\mathbf{lnM}}$	$\boldsymbol{S_{MSY}}$	$\boldsymbol{U_{MSY}}$
1.55935[a]	0.00000815	0.954	0.5373	0.83	75,100	0.61

$s_{\mathbf{F}}$	t
0.20	0.11

[a] This value is larger than reported in Brown et al. (*in prep*), Table 21 by $s_e^2/2$; this difference adjusts the parameter value to describe average instead of median production given an escapement.

where s_F^2 = 0.039 and is the variance of annual harvest rates on the Harrison stock estimated across years 1995 – 1999 in the CTC exploitation rate analysis of 2001.

Because a lower bound will be compared against an estimated escapement instead of the actual escapement, simulations needed to incorporate situations when estimates and actual escapements straddle the lower bound. For the Harrison stock, simulated measurement error in estimates of future escapement had the same coefficient of variation (11%) as did estimates of escapement as calculated from statistics reported in the sixth and seventh columns in Table 9 of Brown et al. (*in prep*.). Measurement error was modeled as:

$$S''_{cy} = S'_{cy} + S'_{cy} t\ Z \qquad 2.4$$

with τ the coefficient of variation (CV) divided by 100, Z a standard normal variate, and S''_{cy} measured against a lower bound.

Return rates in simulations were used to describe the fraction of a brood year that survived to mature at ages 2 – 5 years for brood years 1984 – 1995. These rates were estimated from Table 8 in Brown et al. (*in prep*.) by dividing estimated total adult production by the brood year into adult production by age for that brood year. Return rates sum to one across a brood year. Average age of maturity was also estimated from Table 8 for each brood year and proved to be poorly correlated (r = -0.049 over years 1984-1995) with estimated abundance of their parents (Table 9 in Brown et al.). Neither was there evidence that average age of maturity was autocorrelated across brood years (P > 0.05 for autocorrelation and partial autocorrelation functions). With this lack of evidence for temporal or parental relationships with return rates, these rates were treated as independent across years. Return rates were treated as "pseudo-stochastic" in simulations in that sets of estimated return rates were concatenated to produce simulated rates for all brood years.

2.2 Columbia Summers

The Columbia River Summers stock group is comprised of a single stock (the Mid-Columbia Summers) spawning mostly in the Okanagon, Wenatchee, and Methow rivers. The group and the stock are hereafter referred to as the Columbia Summers. This summer run of chinook salmon has an ocean-type life history with fry moving through the Columbia river. Adults mature at ages 2 – 6 and escapement used in analysis is comprised of ages 3 – 6. Chinook salmon released from the Wells Hatchery on the Columbia River constitute the indicator stock for the Columbia Summers. Salmon from that hatchery are caught in the SEAK, North BC, and WCVI AABM and in the South US ISBM fisheries. The fisheries, stock assessment programs, and an analysis to determine an optimal escapement goal for this stock are described in Chapter 3 of TCCHINOOK (99)-3. In 1999, the CTC "accepted" that goal of 12,141 spawners past Rock Island Dam (17,857 past Bonneville Dam). Because the "stock-recruit data" used to establish these goals are not estimates from stock assessment programs, but predictions from the CTC coast-wide model, the subsequent goal is not considered to be biologically based and is labeled as "interim."

Simulations involving the Columbia Summers used a model that incorporated an autoregressive lag of one brood year in its process error. Transformed for use in the simulation, this model is:

$$R'_{by} = S'_{by} \exp\left[\ln a - bS'_{by} + fe'_{by} + (\sqrt{1-f^2})e'_{by-1}\right] \qquad 2.5$$

Table 2.3. Parameters used to simulate the dynamics of the Columbia Summers taken from TCCHINOOK (99)-3. Definitions of parameters are in Table 2.1.

ln a	b	f	s_e	S_{MSY}	U_{MSY}	s_F	t
2.16596[a]	0.000062	0.808	0.5373	12,143	0.756	0.19	0.15

[a] This value is larger that reported TCCHINOOK (99)-3 by $\sigma_{\varepsilon}^{2}/2$; this difference adjusts the parameter value to describe average instead of median production given an escapement.

where ϕ is the estimated coefficient for autocorrelation between process error in production across two consecutive brood years (a one-year lag). Values for fixed parameters and derived statistics (Table 2.3) were calculated by regressing production against escapement, both as predicted by the CTC coast-wide Model Calibration 98-12 for brood years 1979 – 1995 [as reported in TCCHINOOK (99)-3].

Simulations of the Columbia Summers stock also included stochastic elements describing annual harvest rates, measurement error in estimating future escapements, and return rates for adults. As with the Harrison stock, simulated fishing was optimal with stochastic annual harvest rates as calculated using eq. 2.2 – 3 above. Variance in the instantaneous fishing rate used in the simulations was again estimated across years 1995 – 1999 from statistics resulting from the CTC exploitation rate analysis. Estimates of escapements were simulated as per eq. 2.4 to incorporate measurement error in future estimates of escapements, this time using variation in inter-dam loss for brood years 1979 – 1995 to calculate τ [see Table 3.5 in TCCHINOOK (99)-3 for rates of inter-dam loss]. Return rates for ages 2 – 6 years were estimated for brood years 1989 – 1995 (Table 2.4). Average age of maturity was estimated for each brood year and proved to be poorly correlated (r = -0.23) with predicted abundance of their parents [Table 3.5 in TCCHINOOK (99)-3]. Neither was there evidence that average age of maturity was autocorrelated across brood years (P > 0.05 for autocorrelation and partial autocorrelation functions). With this lack of evidence for temporal or parental relationships with return rates, these rates were treated as "pseudo-stochastic" in simulations, in that sets of estimated return rates were concatenated to produce simulated rates for all simulated brood years.

Table 2.4. Estimated return rates for the Columbia Summers.

Brood	**Age in Years**				
Year	**2**	**3**	**4**	**5**	**6**
1989	0.038	0.096	0.430	0.396	0.040
1990	0.035	0.135	0.321	0.455	0.054
1991	0.006	0.141	0.371	0.402	0.080
1992	0.034	0.120	0.440	0.355	0.050
1993	0.002	0.072	0.556	0.349	0.020
1994	0.000	0.057	0.390	0.545	0.009
1995	0.008	0.088	0.412	0.405	0.087

2.3 Oregon North Coastals

The Far North Migrating Oregon Coastal Falls (hereafter called Oregon North Coastal) stock group is comprised of three stocks spawning each in the Nehalem, Siletz, and Siuslaw rivers. These fall runs of chinook salmon have an ocean-type life history with fry smolting to rear in estuaries before heading out to sea. Adults mature at ages 2 – 6 with adults ages 3 – 6 years in the escapement considered the spawning population in any one year. Chinook salmon released from the Salmon River Hatchery constitute the indicator stock for the Oregon North Coastal group. Salmon from that hatchery are caught in SEAK and North BC AABM fisheries and in the South US ISBM fishery. These stocks are described in detail in Chapter 4 of TCCHINOOK (99)-3 along with an analysis to determine biologically based escapement goals for these stocks. In 1999, the CTC accepted goals of 6,989 for the Nehalem stock, 2,944 for the Siletz stock, and 12,925 for the Siuslaw stock.

Simulations involving the Oregon North Coastal group used the same model as found in TCCHINOOK (99)-3 for each of three stocks. Transformed for use in simulations, this model is:

$$R'_{by} = S'_{by} \exp\left[\ln a - bS'_{by} + e'_{by}\right] \qquad 2.6$$

Values for fixed parameters in eq. 2.6 along with derived parameters (Table 2.5) resulted from regressing estimated production against estimated escapements separately for all three stocks. Although stocks within the stock group were initially thought to have similar variation in brood-year strengths, evidence in support of this hypothesis is lacking. Correlations among residuals in estimated stock-recruit relationships across stocks are weak and contradictory (Table 2.6). Because of this lack of evidence for linked production, the ε'_{by} were drawn independently for each stock.

In simulations all three stocks had the same harvest rates in the same calendar year because all three stocks are assumed to be equally exploited in the same fisheries. This assumption is stated in TCCHINOOK (99)-3 as the justification for using ocean exploitation rates for releases from the Salmon River Hatchery (as estimated for calibration 98-12 of the CTC coast-wide model) to generate statistics on production for all three wild stocks in the group. All three stocks do support independent freshwater sport fisheries, however, these fisheries have been relatively small and

Table 2.5. Parameters used to simulate the dynamics of stocks in the Oregon North Coastal group. Information on production and escapements reported in TCCHINOOK (99)-3 was used to calculate these values. Definitions of parameters are in Table 2.1.

	ln a[a]	b	s_e	S_{MSY}	U_{MSY}
Nehalem	1.972213	0.000097656	0.432980	7,310	0.714
Siletz	2.527041	0.000273235	0.261277	2,988	0.817
Siuslaw	1.787735	0.000044342	0.648949	15,113	0.670

[a] These values are larger than reported in TCCHINOOK (99)-3 by $\sigma_\varepsilon^2/2$; this difference adjusts the parameter value to describe average instead of median production given an escapement.

Table 2.6. Correlation matrixes for residuals in estimated stock-recruit relationships for brood years 1973-1991 among stocks within the Oregon North Coastal group. Residuals were generated from regressing data in Tables 4.4, 4.9, and 4.14 in TCCHINOOK (99)-3.

Stock	**Nehalem**	**Siletz**	**Siuslaw**
Nehalem	1	-0.296	0.236
Siletz		1	-0.226
Siuslaw			1

harvest rates in them are significantly positively correlated (Table 2.7). For these reasons, the simulated harvest rate U'_{cy} was the same for each simulated stock within the group each calendar year. This common harvest rate was estimated as per eq. 2.3 with:

$$F'_{cy} \sim \text{N}[-\ln(1-U_{MAX}),\ \bar{\sigma}_F^2] \qquad 2.7$$

Overall, average harvest rate U_{MAX} (= 0.72) is the harvest rate that on average produces maximum sustained yield from all three stocks taken as a unit. The stochastic element $\bar{s}_F^2$ (= 0.09; $\bar{s}_F$ = 0.30) is the sum of the variance of the common marine instantaneous harvest rate estimated for 1995 – 1999 and the average of the three variances for the separate instantaneous freshwater harvest rates estimated for years 1989 – 1996.

Measurement error in future estimates of escapement had the same relative magnitude across stocks, but was simulated independently. No estimates of variance are available for past estimates of escapement for any of the stocks in the group. However, current

LOA projects funded through the CTC have provided estimates of variance from mark-recapture experiments on some of these stocks. Since these projects have striven towards (and reached) estimates with CVs of 12-13%, a CV of 13% ($\tau = 0.13$) was used to model measurement error in estimated escapement in the simulations for all three stocks as per eq. 2.4. Since mark-recapture experiments on stocks within the group would be based on independent sampling programs, vectors of standard normal variates (Z) were generated independently for each stock.

Table 2.7. Correlation matrix for estimated freshwater harvest rates for stocks within the Oregon North Coastal group for calendar years 1969 – 1996. Correlations were based on instantaneous fishing rates generated from data in Tables 4.3, 4.8, and 4.13 in TCCHINOOK (99)-3.

Stock	Nehalem	Siletz	Siuslaw
Nehalem	1	0.375	0.636
Siletz		1	0.406
Siuslaw			1

Return rates in simulations were specific to each stock and were used to describe the fraction of a brood year that survived to mature at ages 2 – 6. These rates were estimated from Tables 4.4, 4.9, and 4.14 in TCCHINOOK (99)-3 by dividing estimated recruitment for the brood year into recruitment estimated by age for that brood year. Average age of maturity was also estimated from these tables for each brood year and proved to be poorly correlated with estimated abundance of their parents ($r = 0.17$, 0.40, and 0.27 for the Nehalem, Siletz, and Siuslaw stocks). Neither was there evidence that average age of maturity was autocorrelated for any of these stocks across brood years ($P > 0.05$ for autocorrelation and partial autocorrelation functions). With this lack of evidence for temporal or parental relationships with return rates, these rates were treated as independent across years. Sets of estimated return rates were concatenated to simulate rates for all simulated brood years.

2.4 Columbia Falls

The Columbia River Fall stock group is comprised of three stocks: Upriver Brights, Deschutes River, and Lewis River. These fall runs of chinook salmon have an ocean-type life history with fry moving downstream into the Columbia River to rear before heading out to sea. Adults mature at ages 2 – 5 with adults ages 3 – 5 in the escapement considered the spawning population in any one year. All three stocks are indicator stocks and are caught in SEAK, North BC, and WCVI AABM fisheries and in the Southern US ISBM fishery. To date the CTC has not been presented with biologically based escapement goals for the Upriver Brights or the Deschutes stock. Analysis to determine a biologically based escapement goal for the Lewis stock is described in Chapter 3 of TCCHINOOK (99)-3. The CTC accepted that goal of 5,791 spawners in 1999.

Simulations involving the Columbia Falls stock group were restricted to the Lewis River using the same model as found in TCCHINOOK (99)-3. Transformed for use in the simulation, this model is the same as that used to describe productivity for stocks in the Oregon North Coastal group, eq. 2.6 above. Information on production and escapements reported in Table 3.2 of TCCHINOOK (99)-3 was used to calculate values for fixed and derived parameters (Table 2.8).

Table 2.8. Statistics relevant to simulations of the Lewis stock. Definitions of parameters are in Table 2.1.

ln a	b	s_e	S_{MSY}	U_{MSY}	s_F	t
2.37620[a]	0.0001313	0.6115	6,038	0.793	0.23	0.11

[a] This value is larger that reported TCCHINOOK (99)-3 by $s_e^2/2$; this difference adjusts the parameter value to describe average instead of median production given an escapement.

The average harvest rate in simulations was set at the estimated optimal rate U_{MSY} (Table 2.8) with the annual harvest rate calculated as per eq. 2.2 – 3 with σ_F^2 = 0.052 from the variance of annual harvest rates on the Lewis stock estimated across years 1995 – 1999 in the CTC exploitation rate analysis for 2000. Simulated measurement error in estimates of future escapement had the same coefficient of variation (τ x 100%, Table 2.8) as did estimates of escapement as calculated from statistics given in completion reports for stock assessment programs funded though the LOA process. Eq. 2.4 was used to simulate escapement as estimated in each calendar year.

Return rates in simulations were estimated as fractions of a brood year that survived to mature at ages 2 – 5 years from brood years 1964 – 1994. These rates were calculated from estimates of production by age obtained from Washington Department of Fisheries and Wildlife (Cindy LeFleur, personnel communication). Estimated total adult production by brood year was divided into adult production by age for that brood year to produce a return rate by age. These return rates by age sum to one across ages within a brood year. Average age of maturity was also estimated from these return data for each brood year and proved to be poorly correlated (r = 0.31 over years 1962-1991) with estimated abundance of their parents [Table 3.2 in TCCHINOOK (99)-3]. Neither was there evidence that average age of maturity was autocorrelated (P > 0.05 for autocorrelation and partial autocorrelation functions). With this lack of evidence for temporal or parental relationships with return rates, these rates were treated as independent across years and sets of return rates were concatenated to produce simulated rates for each brood year in simulations.

3. INVESTIGATION OF "INTERIM" METHODS

3.1 Questions

An "interim" method, one that was to be used to establish lower bounds for triggering AMA until the end of 2001, is explicitly given in footnote (3) to ¶9(b) on p. 40 of the Agreement:

> "[3] … Until the end of 2001, the escapement level at which MSY production is reduced by more than 15% will be defined as the lower bound of escapement."

Interim methods may become established methods given that investigation shows them to be efficient and efficacious in protecting productivity of stocks with minimal disruption to fisheries. With that thought in mind, a set of interim methods laid out in the footnote was so investigated with stock-specific simulations.

The investigation focused on finding answers to the following questions for specific lower bounds for specific stocks:

1) What would be the long-term, average escapement across simulations with AMA?

2) What would be the long-term, average harvest with AMA?

3) How many additional management actions could be expected with a specific lower bound?

4) How quickly would simulated escapements "recover" to S_{MSY} once the lower bound had been breeched? How long with AMA? How long without AMA?

The trajectory of simulated escapements was used to determine the length of "recovery," that is the length of time in years (seasons) to return simulated escapements to S_{MSY} once action had been taken. A "recovery period" began with the first year of AMA after simulated escapement had slipped below the lower bound for two consecutive years after first falling below S_{MSY}. The recovery period ended when simulated escapement reached or surpassed S_{MSY}. An example of how the lengths of "recovery periods" were calculated can be found in the Appendix 9.1. Lengths of "recovery periods" were averaged over each simulation, as were the harvests and escapements over simulated years. Numbers of AMAs taken were simple tallies over simulated years.

Because some confusion was generated when lower bounds were to be set according to "the" interim method, three lower bounds were investigated for each stock, set at regular intervals at or below S_{MSY}. In the footnote, the lower bound is explicitly related to MSY production. A literal interpretation of the footnote makes the lower bound S_{LB} a solution to the following equation:

$$0.85(MSY + S_{MSY}) = S_{LB} \exp[\ln \alpha - \beta S_{LB}] \qquad 3.1$$

Another interpretation of footnote (3) is that the lower bound was intended to be the escapement that produces a sustained yield 15% less than MSY. In this case, S_{LB} is a solution to the equation:

$$(0.85)MSY = S_{LB} \exp[\ln\alpha - \beta S_{LB}] - S_{LB} \qquad 3.2$$

A third interpretation resulted in a third equation to be solved for S_{LB}:

$$(0.85)MSY = S_{LB} \exp[\ln\alpha - \beta S_{LB}] - S_{MSY} \qquad 3.3$$

Initial analysis showed the lower bounds as calculated with the equations above would have the relationship $S_{MSY} > S_{LB(3.3)} > S_{LB(3.1)} > S_{LB(3.2)}$. Since this relationship is monotonic, insight on the relative effects of these three methods could be, and was, obtained by investigating a range of escapements to make the simulation investigation more useful. Each range covered three prospective lower bounds with the highest equal to estimated S_{MSY} (rounded) and the other two with a reasonable chance of being breached by escapements under optimal fishing.

Simulations were conducted with EXCEL© spreadsheets LBSimFLX and LBSimLewis2.0 for the Harrison and the Lewis stocks, respectively (more detail on simulations is provided in Appendix 9.2). All simulated AMA produced 10% reductions in abundance indices resulting in an 11% reduction in harvest rates. The relationship between indices and harvest rates were derived from Table 1 in Chapter 3 of the Agreement (see Appendix 9.3). Only this level of reduction in indices was investigated (other than no reduction at all), because this is currently the highest level of reduction possible with accepted goals only for two stock groups (Fraser Late and Oregon North Coastal). If these two groups both "require response" under ¶9, all fisheries would be affected. The Harrison and Lewis stocks were chosen to investigate the "interim" method because they represent the range of productivity among the five stocks with accepted goals. Simulated fishing was optimal, that is the average harvest rate equaled the rate that produces estimated MSY. Each simulation began with spawning escapement at S_{MSY} for one generation, then continued forward for 9,994 simulated years (iterations). Because results showed little sensitivity to these initial conditions, no "burn-in" period at the start of a simulation was involved in tabulating results. Stochastic elements of simulations were generated independently, then pasted into the spreadsheets as fixed constants. Comments on cells in spreadsheets give particulars concerning calculations. These spreadsheets can be obtained upon request.

3.2 Answers

Addressing the first and second questions together, "What would be the long-term, average escapement (and annual harvest) across simulations with AMA?," simulations of the Harrison and Lewis stocks showed:

1) Average escapement trends higher than S_{MSY} with a higher, lower bound; while

2) Average harvest remains similar to MSY (Figure 3.1).

Under optimal fishing, reduction of the harvest rate in some years through AMA has the effect of reducing the average rate over all years, subsequently causing average escapement to rise. How great the rise depends upon how frequent the AMA. Simultaneously, average harvest should decrease with an increase in escapement beyond S_{MSY} ; that didn't happen for the simulated Harrison stock. Investigation into this counter-intuitive result indicated that there is some modest "drift" upward in simulated S_{MSY} beyond its expected value when variation beyond process error is modeled. Because stock-recruit relationships in the vicinity of S_{MSY} are relatively flat (Figure 3.2), average simulated harvest is little affected with modest changes in escapement. The expected trend in average harvests was disrupted because the expected, not the effective value of S_{MSY} was used in comparisons.

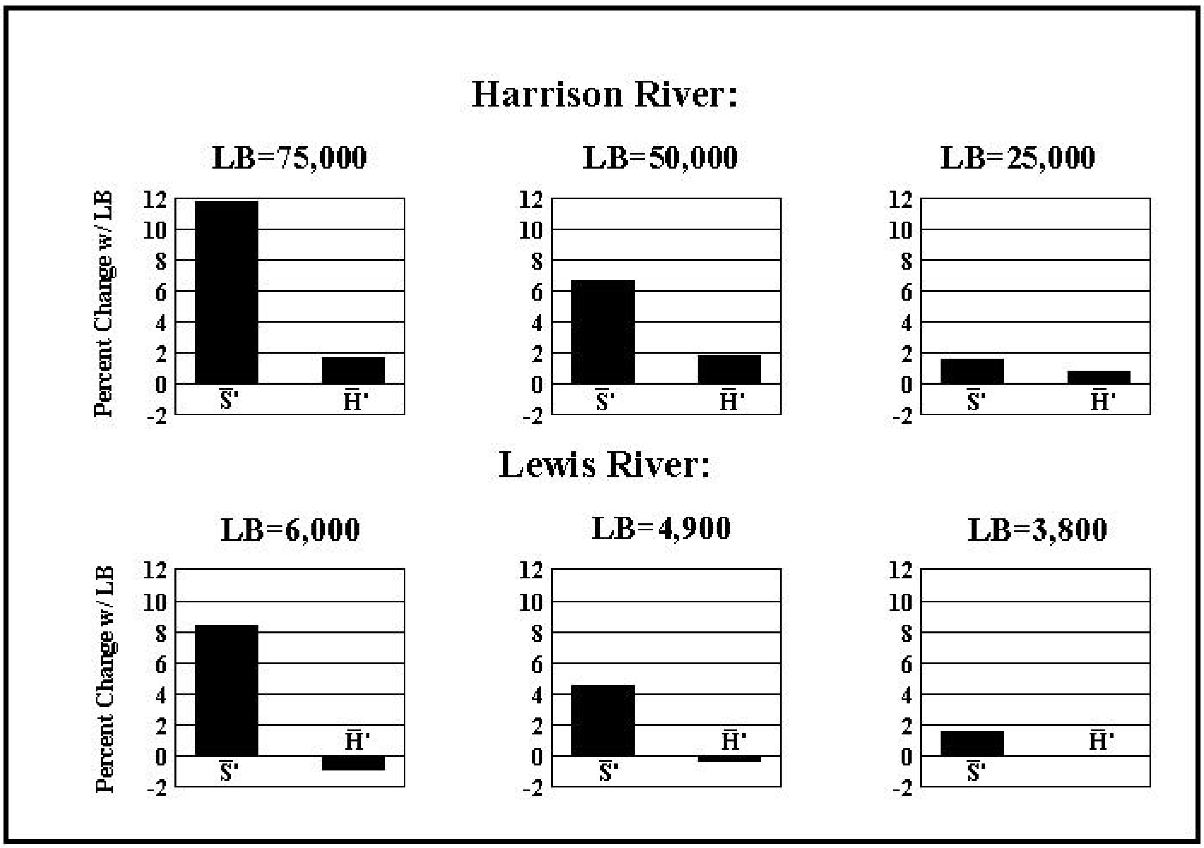


Figure 3.1. Percentage changes in average escapements and average harvests for different simulated lower bounds (LB) for the Harrison and Lewis stocks. Changes were measured against simulated values of S_{MSY} and MSY, simulated values being averages of escapements $\overline{S}'$ and of harvests $\overline{H}'$ in simulations with no lower bounds (no AMA) and with the average harvest rate set at U_{MSY}. All AMA produced 10% reductions in abundance indices in all fisheries.

In answer to the second question, “How many additional management actions could be expected ....?”given a specific lower bound, simulations showed:

1) The lower the lower bound, the fewer the number of actions taken; or
2) The higher the lower bound, the more frequent the actions.

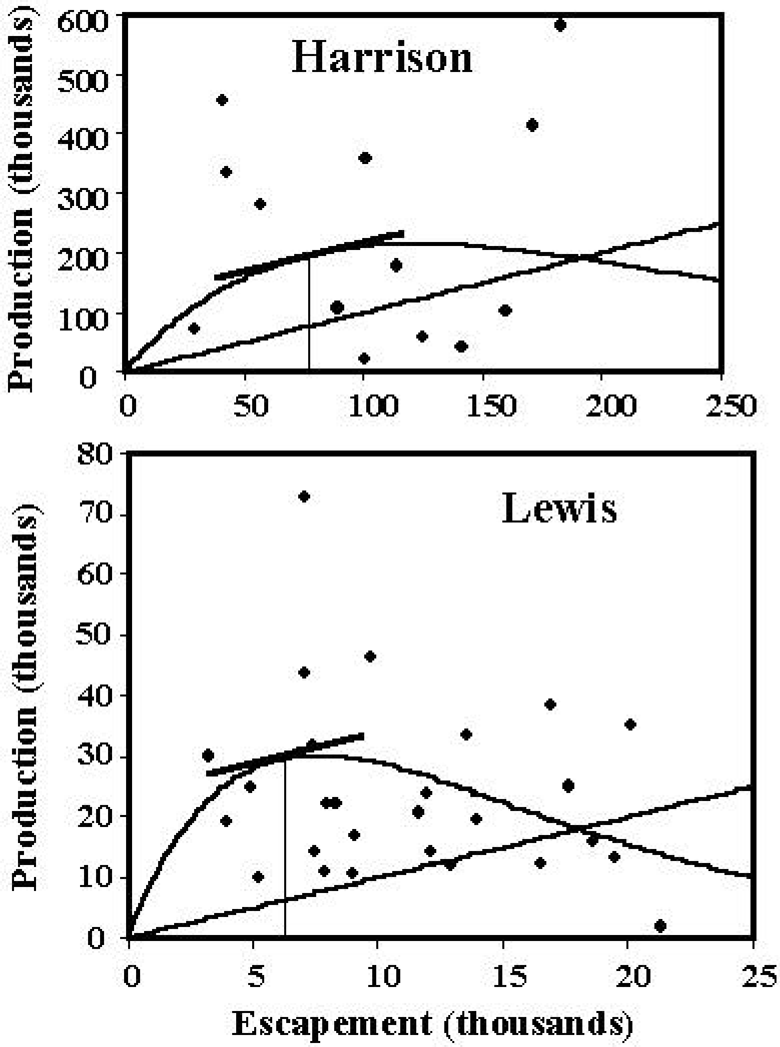


Figure 3.2. Estimated data on stock and recruitment for the Harrison and Lewis stocks along with predicted production from the resulting estimated stock-recruit relationships and the replacement and tangent lines at the estimated escapement producing MSY. Axes are scaled to give both curves the same perspective.

While these results are axiomatic for both stocks (Figure 3.3), the phenomenon is far more pronounced for the less productive Harrison stock. The rate of AMA is about the same when the lower bound for the Harrison stock is about a third of its estimated S_{MSY} (25 of 75 thousand) and for the Lewis stock when its lower bound is set at its estimate of S_{MSY} (six thousand). The reason for this discrepancy can be seen in the much longer (about three times longer) “recovery” periods for the less productive Harrison stock (Figure 3.4). For the Harrison stock, “recovery” is more a matter of vagaries in marine survival rates than density-dependent feedback from AMA. The inference from these results is that the productivity of the individual stocks and the amount of variation left unexplained by the stock-recruitment relationship greatly affects the consequences of picking a particular lower bound.

Reasons that the simulated Harrison stock has longer “recovery” periods and more AMA are evident in Figure 3.2. The estimated stock-recruit relationship for the Harrison stock is flatter with greater process error than for the Lewis stock. The result is that “recovery” for the former is due more to factors other than escapement. Without a strong density-dependent “signal,” the simulated time trace of escapements for the Harrison stock “wanders” somewhat erratically within a “recovery” period, triggering more AMA without greatly increasing the chances of “recovery.”

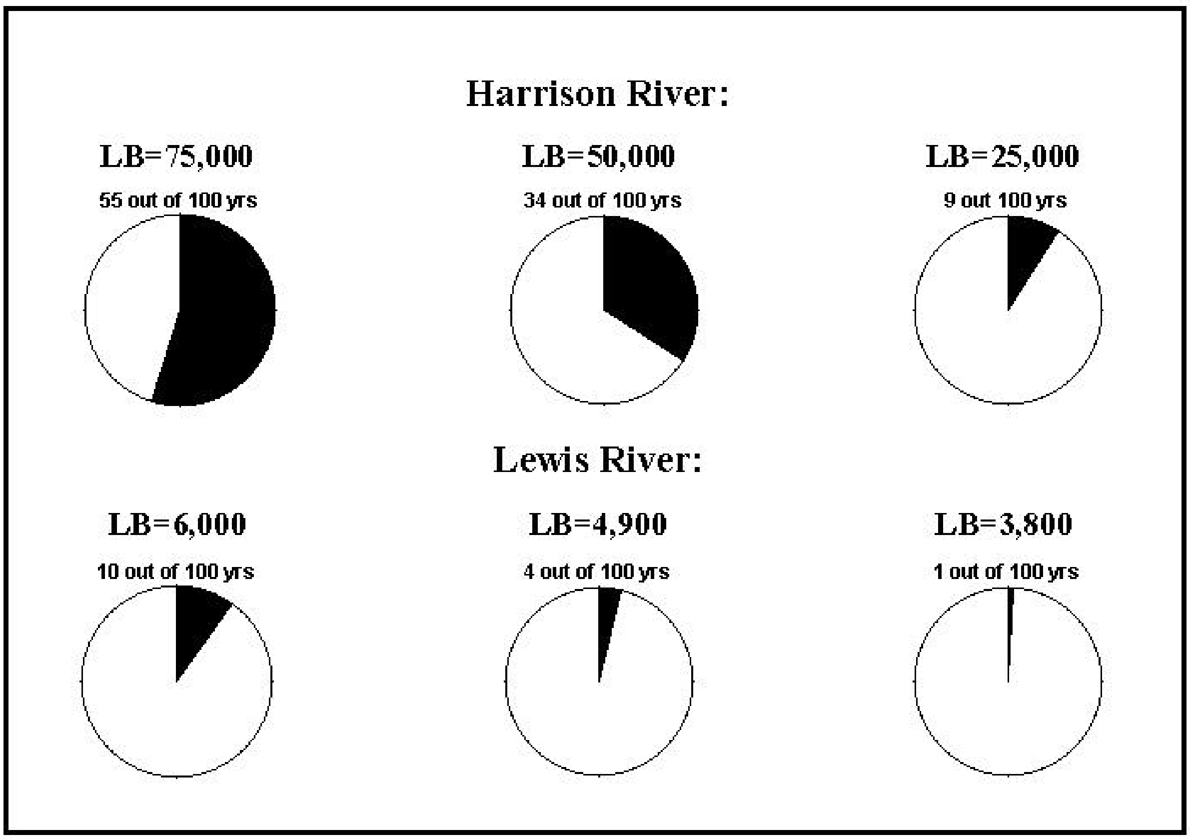


Figure 3.3. Number of simulated years out of 100 that the two-year criterion had been met for simulated stocks of the Harrison and Lewis Rivers with AMA resulting in 10% reductions in abundance indices in all fisheries.

Some parts of the last question, “How quickly would simulated escapements “recover” to S_{MSY} once the lower bound had been breeched? How long with AMA?,” have been answered above in that “recovery” periods are longer for the less productive Harrison stock. As for the remaining parts:

1) Simulated “recovery” periods were shorter with higher, lower bounds (and vice versa) regardless of the productivity of the stock; and
2) Simulated “recovery” was about 0 – 1 season quicker with AMA that reduced abundance indices by 10% than with no AMA.

In no simulation on either stock did escapement fail to “recover” back to S_{MSY} once it dipped below the specified lower bound regardless of the magnitude of that lower bound.

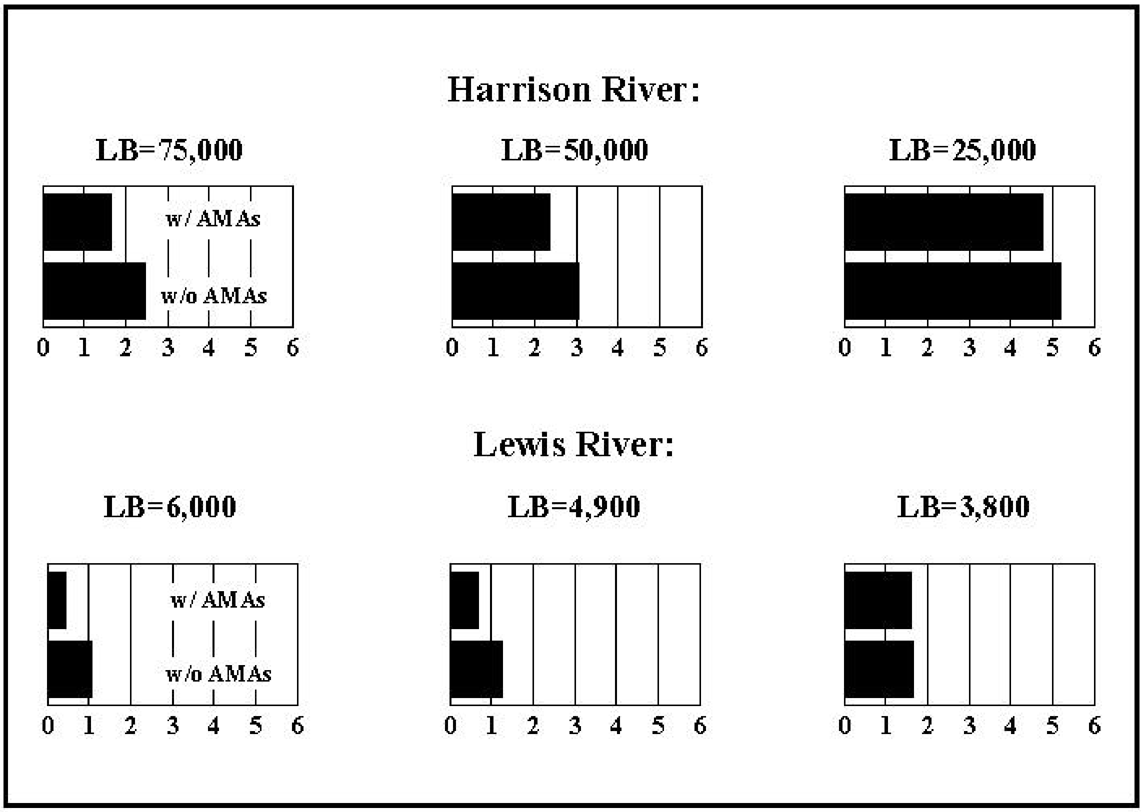


Figure 3.4. Average length of simulated “recovery” periods for the Harrison and Lewis stocks. Length is the number of seasons taken for simulated escapement to return to S_{MSY} once it has slipped below the lower bound for two consecutive years. Averages were calculated with and without taking AMA resulting in 10% reductions in abundance indices in all fisheries.

3.3 Abandonment of “Interim” Methods

Evidence from this investigation of “interim” methods to establish lower bounds is inconclusive. The magnitude of the lower bound will affect escapements by increasing them when increasing them is not needed to protect the stock (at least not with AMA at the lowest level). The magnitude of the lower bound will increase AMA, but will not meaningfully affect harvest. The magnitude of the lower bound will affect the length of “recovery” periods when “recovery” is not an issue. In short, so long as fishing is on average optimal or stocks on average are underfished, no lower bound and no AMA are needed to protect stocks.

In retrospect the results from this investigation of “interim” methods should not be surprising. Theory for stock-recruit relationships is that when fishing is optimal, that is harvest rates are on average at U_{MSY}, the stock will provide on average MSY from an escapement that is on average S_{MSY} ... so long as the form and the parameters of the relationship remain unchanged. Because simulations reported here are based on just such an unchanging stock-recruit relationship, results only confirm the consistency of the theory under stochastic return rates and errors in estimating future escapements. Although stocks do not need protection when fishing is optimal, they do need protection when harvest rates are beyond optimal levels. Such “overfishing” can occur by design or by circumstance. The former is a matter of conscious decision, one that has not been made for stocks listed in the Agreement. Overfishing from circumstance occurs when average harvest rates are higher than estimated, or productivity of stocks is less than expected. Regardless of the cause, the appropriate response to overfishing would be to reduce harvest rates. But how is overfishing recognized? The only immediate sign is a series of low escapements, but, is such a series evidence of overfishing; or evidence of the expected variation in brood year strengths for optimally fished stocks? This dilemma sets up the risk of making a management error, either:

1) Reducing harvest rates when fishing is optimal (or stocks are underfished); or
2) Doing nothing when stocks are being overfished.

The risk of both types of management error can be estimated to provide a rational basis for AMA. The remainder of this report describes the development of a method that links estimated risk of management error to lower bounds as per the Agreement. The method can be used to estimate the risk of management error given a lower bound, or to determine a lower bound that has an acceptable risk of management error.

4. LOWER BOUNDS AND RISK

4.1 The Dilemma of Low Escapements

There are three circumstances why escapement from an exploited stock of salmon is frequently lower than expected, assuming that escapement data provide unbiased estimates of the number of spawning fish:

1) harvest rates have been higher than thought;
2) productivity has been lower than expected; or
3) chance resulting from natural variation around a mean production (process error).

The appropriate management response to the first and second circumstances is the same: reduce harvest rates such as is the result from AMA. The appropriate response to the third circumstance is to do nothing.

A lower bound can be used as a threshold below which a high frequency of low escapements would be an unlikely event, given what we know of harvest rates and productivity. If such an unlikely event occurs, we would conclude, more probably, that either harvest rates have been consistently higher than measured, or productivity consistently lower than expected. Our knowledge of fishing mortality rates and productivity are both based on parameters estimated with uncertainty, meaning that our knowledge may be faulty. Also, past productivity could have been accurately assessed, but current productivity of the stock may have declined due to changes in environment. Regardless of the circumstance, the logical response to unexpectedly low escapements would be to lower harvest rates (implement AMA). Otherwise, the stock might suffer recruitment overfishing and be placed at higher risk of further declines in abundance.

However logical, lowering harvest rates as a response to low escapements might be the wrong thing to do. Low escapements can and do occur from chance alone with no shift in productivity or average harvest rates. Restricting harvest under this circumstance would be unnecessary, pushing average escapements above the level that produces maximum sustained yield (MSY) and the average yields below MSY.

This dilemma defines the two types of risk associated with management based on escapement. The first (Type I Risk) is the risk of unnecessarily restricting fishing-induced mortality when escapements are <u>below</u> a threshold, that is, when chance alone has lowered escapements. The second (Type II Risk) is the risk of not restricting fishing-induced mortality even though productivity has declined, but chance has kept escapements <u>above</u> the threshold. Fortunately, the tradeoff between these two types of risk can be quantified and used to set a rational lower bound using available information and reasonable intuition.

4.2 Estimating Risk

Estimating risk of management error through AMA begins with the probability that two or more stock groups "require response" in a particular year, that is, they meet their group-specific criteria (Table 1.2). If probabilities of each stock group "requiring response" are independent across groups (assumed when there is no evidence of dependence), the probability that 0 or 1 group would "require response" is:

$$\text{Prob(No or One Group "Requires Response")} = \prod_{i=1}^{12}(1-p_i) + \sum_{j=1}^{12}\left[p_j \prod_{\substack{i=1 \\ i \neq j}}^{12}(1-p_i)\right] \quad 4.1$$

where p_i is the probability that the ith (or the jth) group "requires response." Therefore, the probability of AMA is the complement of the equation above:

$$\text{Prob(Two or More Groups "Requires Response")} = 1-\prod_{i=1}^{12}(1-p_i) - \sum_{j=1}^{12}\left[p_j \prod_{\substack{i=1 \\ i \neq j}}^{12}(1-p_i)\right] \quad 4.2$$

By implication of the Agreement, there should be no AMA when no or one stock group is overfished, and AMA when two or more groups are overfished. Accordingly:

1) ***Type II Risk is zero and Type I Risk equals eq. 4.2 whenever no or one stock group is overfished; or***
2) ***Type I Risk is zero and Type II Risk equals eq. 4.1 whenever two or more groups are overfished.***

If the p_i were known for all stock groups, risk would be known. However, risk of both types must be estimated because the p_i must be estimated for each group. Because each group contains one or more stocks, estimating p_i for each group begins with the probability that individual stocks within that group meet their "two-year" criterion.

The probability π that a stock would meet the "two-year" criterion (as specified in the right column of Table 1.2) in a given year can be estimated with simulations similar to those described in Chapter 2 and used in the investigation of "interim" methods described in Chapter 3. To recap, these simulations would:

1) be based on an estimated stock-recruit relationship;
2) be stochastic with variation in:

   2a) process error;
   2b) return rates (combination of survival and maturation rates);
   2c) harvest rates; and
   2d) measurement error in estimates of future escapement;

3) have an optimal harvest rate as estimated when the CTC accepted the escapement goal for the stock;
4) have many iterations;
5) be robust to initial conditions; and
6) have a specific lower bound for future escapements.

Average harvest rate in each simulation is set to the estimated optimal rate to be consistent with the management goal of MSY as stated in ¶1 in Chapter 3 of the Agreement. Influence of initial conditions on the simulations is reduced by disregarding results from earlier iterations (a "burn-in" period). Probability π is estimated from the remaining iterations (M "years" in the simulations) by dividing the number of years in which the "two-year" criterion was met (m) by M. While this calculation ignores that "years" in each simulation are not independent, this dependence should be inconsequential with large numbers of iterations. Figure 4.1a is a graphical representation of the results of a series of such simulations of an optimally fished stock across a spectrum of lower bounds.

With one modification, simulations as described above can represent overfished stocks. If all other factors are as before, including the average harvest rate, overfishing can be simulated by reducing the density-independent parameter α in the estimated stock-recruit relationship. Remembering that overfishing occurs with a reduction in productivity, a reduction of κ (x100%) in productivity is represented as a change in ln α as follows:

$$\ln \alpha_a = \ln[(1-\kappa)\exp(\ln \alpha)] \qquad 4.3$$

where ln α_a is used in simulations instead of ln α. Figure 4.1b shows the effect on of reducing productivity by 50% on an estimated relationship between π and a lower bound.

Note that for each lower bound and each stock there are two values of π. The first value, call it π', is the probability of meeting the "two-year" criterion under optimal fishing. The second value, call it π'', is the probability of meeting the "two-year" criterion with overfishing. In the example in Figure 4.1b, overfishing represents a 50% reduction in estimated productivity, while simulated harvest rates remained at levels estimated to optimally harvest a stock with 100% of estimated productivity.

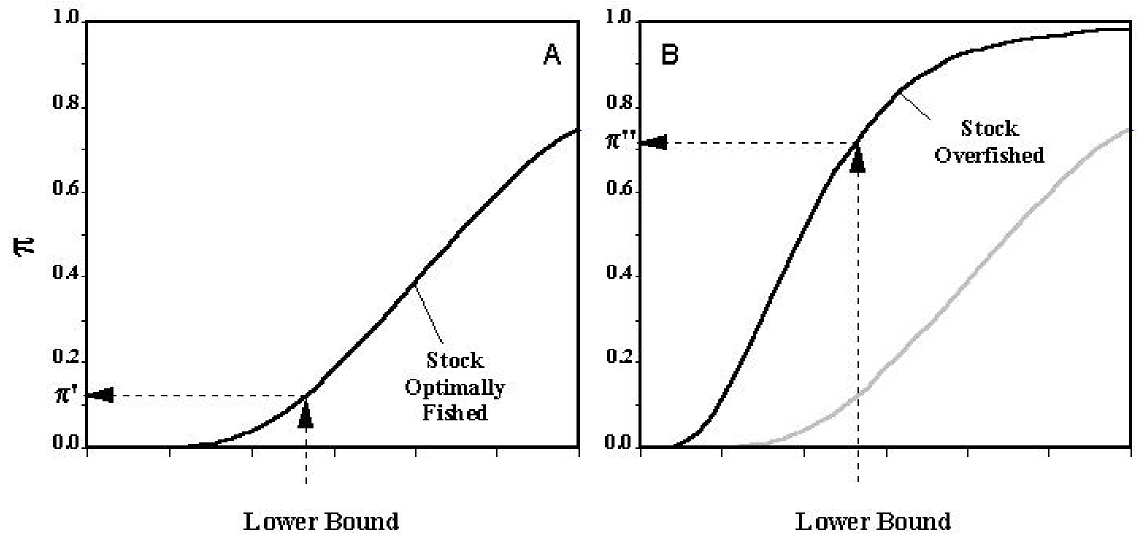


Figure 4.1. Estimated probability π of a stock meeting the "two-year" criterion in a particular calendar year as a function of a lower bound in escapement under optimal fishing (Panel A) and under overfishing (Panel B) in which productivity has been reduced 50%. Curves are based on interpolations from individual simulations.

4.2.1. Stock Groups with One Stock.

For those stock groups with one stock, such as the Fraser Late group with the Harrison stock as its sole member, estimating the probability p_i that the group "requires response" is a matter of simple substitution:

$$\hat{p}_i = \begin{cases} \pi_i' & \text{if simulated stock is optimally fished} \\ \pi_i'' & \text{if simulated stock is overfished} \end{cases} \qquad 4.4$$

The estimate $\hat{p}_i \rightarrow p_i$ into eq. 4.1 and 4.2 for estimating both types of risk.

4.2.2. Stock Groups with Two or More Stocks.

With two or more stocks in a group, simulation of the dynamics of individual stocks can still be used to link *p* with lower bounds for all stocks in the group, but in this case, simulations might be linked. Implicitly stocks within the same group should experience similar harvest rates and vagaries in brood-year strengths. To the extent that they do, simulations of each stock should have the same stochastic elements for process error and harvest rates. To the extent that they do not, process error or exploitation rates should be simulated independently. Regardless of how closely stochastic elements are linked across simulations, status of predicted escapements in all stocks relative to meeting the stock-specific "two-year" criterion for each are compared in the same iteration ("calendar year") and are flagged if they collectively meet a group-specific criterion (second column Table 1.2).

There are two general, group-specific criteria in the Agreement for flagging a stock group as "requiring response" when the group consists of more than one stock . The first is when at least "*k* of *n*" stocks in the group meet the "two-year" criterion. The Oregon North Coastal is such a group (Table 1.2), containing 3 (= *n*) stocks (Siletz, Nehalem, and Siuslaw) in which at least 2 (= *k*) must meet the "two-year" criterion in the same year to flag this group as "requiring response." Flagged "years" would be tallied, and the tally (*m*) divided by the number of simulated "years" (*M*) to calculate π_i' (or π_i''). Calculations would proceed as per eq. 4.4.

The second general type of group-specific criteria is based on a single lower bound for all stocks combined. The lower bound is for the group, not individual stocks. Simulations of individual stocks are run in tandem as described previously, only in this situation, predicted escapements for each "year" are summed across stocks in the group. If this "aggregated" escapement meets the "two-year" criterion, the year is flagged. Calculations proceed at this point as for a one-stock group.

Two additional constraints may be required whenever there is more than one stock in a group:

1) a compromise in optimal harvest rates if estimated optimal rates are different across stocks and all stocks experience the same harvest rate; and/or
2) a rule as to the relationship among lower bounds across stocks.

Both constraints are needed for the "*k* of *n*" group-specific criterion. A compromise consistent with the Agreement (the first constraint) is to use a harvest rate that would produce MSY for the group. As for the second constraint, any stock or group of stocks can be favored over others in setting a lower bound. Only the first constraint need be considered for the "aggregate," group-specific criterion.

5. RISK FROM LOWER BOUNDS

5.1 Estimating Probabilities

Procedures in the previous chapter linking estimated risk to lower bounds can be used either forwards or backwards: estimating risk incurred from a set of lower bounds, or setting lower bounds that provide acceptable risks, at least as estimated. The first approach is demonstrated in this chapter.

As per ¶9(a)(i) and Attachments I-V of the Agreement, one interpretation of the Agreement on how to establish lower bounds for AMA is to use the lower end of the escapement goal range as accepted by the CTC to encompass biologically based goals. To date the CTC has accepted only one such range, that is, the range of 75,100 to 98,500 three-year olds and older in the escapement to the Harrison River. For the sake of this demonstration, rounded versions of the point goals accepted by the CTC are used as lower bounds for other stocks (Table 5.1).

Simulations were conducted with EXCEL© spreadsheets LBSimFL1.1 for the Harrison stock, LBSimCS1.0 for the mid-Columbia Summers, LBSimOC1.1 for the Oregon North Coastal group,

Table 5.1. Stock groups, stock-group specific criteria for labeling a group as "requiring response," stocks, accepted values of S_{MSY}, lower bounds used to determine risks of management error, and optimal harvest rates used in simulations.

Stock Group	Group-Specific Criterion	Stocks	Accepted S_{MSY}	Lower Bound	Optimal Harvest Rate
Fraser Late	Below lower bound of goal	**Harrison**	75,100	75,000	0.61
Columbia Summers	Below lower bound of goal	**Mid-Columbia Summers**	12,141	12,100	0.76
Oregon North Coastals	Two or more stocks below lower bound of goal	**Nehalem** **Siletz** **Siuslaw**	6,989 2,944 12,925	7,000 2,900 12,900	0.72 0.72 0.72
Columbia Falls	Two or more stocks below lower bound of goal	**Lewis** Upriver Brights Deschutes	5,791	5,800	0.79

and LBSimLew3.1 for the Lewis stock. Each simulation began with spawning escapement at S_{MSY} for one generation (7 years), then continued forward for 9,993 simulated calendar years (iterations). Although results showed little sensitivity to initial conditions, a "burn-in" period was used, meaning flags to calculate π were tallied for iterations 1,000 through 10,000. Stochastic elements in simulations were generated independently, then pasted into the spreadsheets as fixed constants. All spreadsheets have single worksheets except LBSimOC1.1 which has four, one for each of the three stocks in the group and a summary worksheet. Comments on cells in spreadsheets give particulars concerning calculations. Spreadsheets can be obtained upon request.

With one exception, probabilities of a stock group "requiring response," the p_i, were estimated as per eq. 4.4 (Table 5.2). The Columbia Falls group is the exception because only the Lewis stock has an accepted goal in that group. Two assumptions were used to estimate p_i for the Columbia Falls group:

1) the π_i estimated for the Lewis stock also represents the Upriver Bright and Deschutes stocks without meaningful bias; and
2) all stochastic processes are independent across all three stocks.

Table 5.2. Estimated probabilities that stock groups "require response" when lower bounds equal estimated values of S_{MSY} and average harvest rates are at levels estimated to produce MSY. Estimated values of α were used to calculate the $\hat{p}_i'$, but were reduced per eq. 4.3 by 10, 20, 30, and 40% to calculate the $\hat{p}_i''$.

Stock Group	$\hat{p}_i'$	$\hat{p}_i''$			
		10%	**20%**	**30%**	**40%**
Fraser Late	**0.502**	**0.603**	**0.720**	**0.838**	**0.944**
Columbia Summers	**0.325**	**0.497**	**0.725**	**0.916**	**0.995**
Oregon North Coastals	**0.424**	**0.578**	**0. 755**	**0.910**	**0.988**
Columbia Falls	**0.295**	**0.481**	**0.731**	**0.923**	**0.994**
Average	**0.387**	**0.540**	**0.725**	**0.897**	**0.980**

If these assumptions hold, the probability p_i is the probability that all three stocks independently meet the "two-year" criterion plus the probability that only two of the three do so. Under these circumstances, the following equation was used instead of eq. 4.4:

$$\hat{p}_i = \begin{cases} (\pi_i')^3 + 3(\pi_i')^2(1-\pi_i') & \text{if simulated stock is optimally fished} \\ (\pi_i'')^3 + 3(\pi_i'')^2(1-\pi_i'') & \text{if simulated stock is overfished} \end{cases} \qquad 5.1$$

Because at this time no biologically based goals have been proffered to the CTC for stocks in eight of the stock groups in the Agreement, information with which to conduct simulations for stocks in those groups is not available. Without simulation of at least one stock within a group, p_i can not be directly estimated for the group. This problem was circumvented for this demonstration by averaging the $\hat{p}_i$ across the four groups with accepted goals and substituting the average for the missing values in the other eight groups.

5.2 Estimating Type I Risk

There are two circumstances to consider when estimating Type I Risk (AMA is unwarranted): no or one stock group is being overfished. When no stock groups are overfished, the estimated probabilities that each group would "require response" are in bold for the lower bounds in Table 5.1:

	Fraser Late	**Columbia Summers**	**Oregon North Coastals**	**Columbia Falls**	**Group 5**	**...**	**Group 12**
$\hat{p}_i'$	**0.502**	**0.325**	**0.424**	**0.295**	**0.387**	**...**	**0.387**
$\hat{p}_i''$	0.603	0.497	0.587	0.481	0.540	...	0.540

From eq. 4.1, Prob(No or One Group "Requires Response") =

(1-0.502)(1-0.325)(1-0.424)(1-0.295)(1-0.387) ... (1-0.387) +

0.502(1-0.325)(1-0.424)(1-0.295)(1-0.387) ... (1-0.387) +
(1-0.502)**0.325**(1-0.424)(1-0.295)(1-0.387) ... (1-0.387) +
(1-0.502)(1-0.325)**0.424**(1-0.295)(1-0.387) ... (1-0.387) +
(1-0.502)(1-0.325)(1-0.424)**0.295**(1-0.387) ... (1-0.387) +
(1-0.502)(1-0.325)(1-0.424)(1-0.295)**0.387** ... (1-0.387) +
(1-0.502)(1-0.325)(1-0.424)(1-0.295)(1-0.387) ... **0.387** = 0.023

From eq. 4.2:

Estimated Type I Risk = Prob(Two or More Groups “Require Response”) = 1- 0.023 = **0.977**

When one group is being overfished, the estimate of Type I Risk depends on which group is being overfished and by how much. Below in bold are the probabilities that a specific stock group “requires response” with the stocks in the Oregon North Coastal group overfished due to a 10% reduction in productivity:

	Fraser Late	**Columbia Summers**	**Oregon North Coastals**	**Columbia Falls**	**Group 5**	**...**	**Group 12**
$\hat{p}_i'$	**0.502**	**0.325**	0.424	**0.295**	**0.387**	...	**0.387**
$\hat{p}_i''$	0.603	0.497	**0.587**	0.481	0.540	...	0.540

From eq. 4.1 and 4.2:

Estimated Type I Risk = Prob(Two or More Groups “Requires Response”) = 1- 0.018 = **0.982**

Calculations with one group being overfished at a time each with a 10% reduction in productivity produced estimated risks between 0.980 and 0.985. Minimal estimates of Type I Risk when one stock group is overfished due to a drop in productivity up to 40% are provided in Table 5.3.

5.3 Estimating Type II Risk

When two or more stock groups are being overfished, the estimate of Type II Risk, the risk of no AMA when needed, depends on which group is being overfished and by how much. Below in bold are the probabilities that a specific stock group “requires response” with the stocks in the Fraser Late and Oregon North Coastal groups overfished due to a 10% reduction in productivity:

	Fraser Late	**Columbia Summers**	**Oregon North Coastals**	**Columbia Falls**	**Group 5**	**...**	**Group 12**
$\hat{p}_i'$	0.502	**0.325**	0.424	**0.295**	**0.387**	...	**0.387**
$\hat{p}_i''$	**0.603**	0.497	**0.587**	0.481	0.540	...	0.540

From eq. 4.1 is the estimated Prob(No or One Group "Requires Response") =

(1-0.603)(1-0.325)(1-0.587)(1-0.295)(1-0.387) ... (1-0.387) +

0.603(1-0.325)(1-0.587)(1-0.295)(1-0.387) ... (1-0.387) +
(1-0.603)**0.325**(1-0.587)(1-0.295)(1-0.387) ... (1-0.387) +
(1-0.603)(1-0.325)**0.587**(1-0.295)(1-0.387) ... (1-0.387) +
(1-0.603)(1-0.325)(1-0.587)**0.295**(1-0.387) ... (1-0.387) +
(1-0.603)(1-0.325)(1-0.587)(1-0.295)**0.387** ... (1-0.387) +
(1-0.603)(1-0.325)(1-0.587)(1-0.295)(1-0.387) ... **0.387 = 0.015**

Table 5.3. Minimum estimates of Type I Risk (risk of an unwarranted AMA) when lower bounds equal estimated values of S_{MSY} and average harvest rates are at levels estimated to produce MSY. Overfishing results from drops in productivity (reduction in α) of 10, 20, 30, and 40%.

No Group Overfished	**One Group Overfished**				**Two or More Groups Overfished**
	10%	**20%**	**30%**	**40%**	
0.976	**0.980**	**0.984**	**0.989**	**0.992**	**0**

Table 5.4. Maximum estimates of Type II Risk (risk of no AMA when needed) when lower bounds equal estimated values of S_{MSY} and average harvest rates are at levels estimated to produce MSY at optimal fishing. Overfishing results from drops in productivity (reduction in α) of 10, 20, 30, and 40%.

No or one Group Overfished	**Two Groups Overfished**			
	10%	**20%**	**30%**	**40%**
0	**0.016**	**0.008**	**0.003**	**0.001**

Since eq. 4.1 defined Type II Risk when two groups are being overfished, the estimated Type II Risk under these circumstances is 0.015. Depending on which two groups are being overfished, due to 10% reductions in productivity, the estimated Type II Risk run with lower bounds set at S_{MSY} ranges from 0.014 to 0.016. Maximum estimates of Type II Risks when productivity has been reduced up to 40% in stocks in two groups are given in Table 5.4. Further calculations with eq. 4.1 show that when three or more groups are overfished, the estimated Type II Risk declines from the values listed in Table 5.4.

6. LOWER BOUNDS FROM RISK

6.1 Spreading the Risk

As mentioned at the start of the previous chapter, the link between lower bounds and risk can be exercised either forwards or backwards. In this chapter the second approach, defining lower bounds that provide acceptable risks of management error, is the topic of discussion.

Before lower bounds can be determined from risk, some decision is needed on how to spread that risk across the 12 stock groups. The decision most consistent with the Agreement is not to favor one stock group over another, in which case all the p_i are the same (= p), and eq. 4.2 simplifies to:

$$\text{Type I Risk} = \begin{cases} 0 & \text{if } \geq 2 \text{ groups overfished} \\ 1-(1-p)^{12} - \binom{12}{1} p^{1}(1-p)^{11} & \text{if } \leq 1 \text{ groups overfished} \end{cases} \qquad 6.1$$

Say that the acceptable Type I Risk, the risk of an unneeded AMA, is 0.10 (AMA in one of every ten years). Solving the relationship in eq. 6.1 with one or fewer groups being overfished gives $p = 0.0452$. A set of lower bounds for individual stocks is determined through simulation as described in Chapter 5 such that each stock group has the probability p of "requiring response" under optimal conditions (fishing at the optimal harvest rate for expected productivity). This set of lower bounds is then associated with a specific Type I Risk, such as 0.10. The relationship between Type I Risk and sets of lower bounds can be estimated by repeating this procedure with different values of risk. This estimated relationship is easily graphed as an aid to decision making.

6.2 Lower Bounds by Type I Risk

Lower bounds are selected through trial and error using the same simulation software described in section 5.1 with average harvest rates set to emulate optimal fishing. Prospective lower bounds for a stock are changed and the simulation rerun until a lower bound is found with a "predicted" p that matches the "target" p. For a Type I Risk of 0.10, the "target" p for a stock group is 0.0452 as calculated above. How a "predicted" p is produced depends on the membership of the stock group:

> **For stock groups with one stock**, such as the Fraser Late or Columbia Summers groups, where $p = \pi$ (the probability of the stock meeting the "two-year" criterion), "predicted" π is compared directly against the "target" p.
>
> **For stock groups with several members and simultaneous simulations**, such as the Oregon North Coastal group, "predicted" p is the result of a tally of the number of years in which two or more stocks meet the "two-year" criterion. In

this case, more than one combination of lower bounds across the three stocks in the group produces the same "predicted" *p*. Some rule is needed to provide a unique set of lower bounds. Two rules that extend the policy of spreading the risk are proffered here:

1) Frequencies of meeting the "two-year" criterion are similar across all stocks in the group; or
2) Lower bounds for all stocks represent the same fraction of their estimated S_{MSY}.

The first rule was used to determine lower bounds in the tables and figures below.

For stock groups with several members, only one of which has an accepted goal, such as the Columbia Fall group, "target" and "predicted" *p* are compared, but:

$$\text{predicted } p = (\text{predicted } \pi)^3 + 3(\text{predicted } \pi)^2\ (1\text{-predicted } \pi)$$

This adjustment is based on the assumption that productivity and harvest rates for the other two stocks in the group, Deschutes and Upriver Bright stocks, vary independently of one another and against the Lewis stock. If so, the adjustment is the result of the group-specific criterion that at least two of these stocks meet their "two-year" criterion before the group "requires response."

For stock groups with no members with accepted goals. Eight stock groups in the Agreement, have no members with accepted escapement goals at this time. While no lower bounds can be determined for these stocks, the policy of spreading the risk does assign a probability *p* of each group "requiring response."

Lower bounds associated with a Type I Risk of 0.10 (10%) are listed in Table 6.1 for stocks in the Agreement that have accepted, biologically based escapement goals. Lower bounds were rounded to the nearest 50 fish for all stocks. Bounds were relatively lower for less productive stocks, such as the Harrison stock, than for more productive stocks, such as the Lewis stock. Values of "predicted p" were the same to the nearest hundredth regardless of whether calculation began with iteration 8, 108, or 1,000; iterations 1,000 to 10,000 were used to calculate "predicted" *p*.

The relative divergence of lower bounds among stocks within the Oregon North Coastal group occurred because of the compromise in the average harvest rate. At an average rate of 0.72, the Siletz stock is underfished while the Nehalem and Siuslaw stocks are overfished. Low escapements are less frequent for the Siletz stock (as they would be for any underfished stock), so the lower bound for this stock must be higher to represent the same "target" probability as the other two stocks. Conversely, low escapements are more frequent in overfished stocks, so their lower bound must be lower to represent the same "target" probability.

This divergence among the Oregon stocks lessens if lower bounds are kept a fraction of estimated S_{MSY} (the second rule). Lower bounds for the Nehalem, Siletz, and Siuslaw stocks associated with a 10% Type I Risk would be 3300, 1400, and 6100, or about 47.5% of their estimated values for S_{MSY}. In this approach, the Nehalem stock meets the "two-year" criterion in about 9 of every simulated 100 years and the Siuslaw stock about 24 of every 100; the simulated Siletz stock meets the criterion less than one year in a simulated century. In contrast, these three simulated stocks meet the "two-year" criterion about 8 years out of 100 years when the frequency is constrained to be equal across stocks (the first rule).

Lower bounds were calculated as described above for Type I Risks of 0.010, 0.05, 0.075, 0.100, 0.125, 0.150, and 0.200 for all six stocks with accepted goals under optimal fishing and the result graphed (Figure 6.1). The relationship at these points was transformed to a curve with exponential or logarithmic regression (all regressions had coefficient of determination greater than 99%). Since all six curves are the same curve, only scaled for the differences in the relative sizes of escapements among stocks, curves were rescaled to produce a single display of risk. Six x-axes are provided in this figure corresponding to the six stocks with accepted (or interim) goals. The dashed line in the figure represents the lower bounds for these stocks that produce an estimated 10% Type I Risk when that risk is spread evenly across all stock groups and no stock group is overfished.

Table 6.1. Stock groups, stocks, optimal harvest rates, "predicted" probability of the group "requiring response," accepted escapement goals, and lower bounds associated with a Type I Risk of 0.10 (risk of an unneeded AMA). For this level of risk, the "target" *p* is 0.0452.

Stock Group	**Stocks**	**Optimal Harvest Rate**	**"Predicted" *p***	**Accepted S_{MSY}**	**Lower Bound**
Fraser Late	**Harrison**	0.612	0.0458	75,100	24,000
Columbia Summers	**Mid-Columbia Summers**	0.746	0.0486	12,141	8,100
Oregon North Coastal	**Nehalem Siletz Siuslaw**	} 0.720	} 0.0458	6,989 2,944 12,925	3,200 2,500 3,750
Columbia Falls	**Lewis Upriver Brights Deschutes**	0.804	} 0.0458	5,791 - -	4,200 - -

Figure 6.1 contains two lines. As per the Agreement a Type I Risk is incurred whenever no or one stock is being overfished. The thick curve in Figure 6.1 represents the former situation while the thin curve the latter, the case when only one stock is overfished. The thin curve was calculated by reducing the productivity of the Harrison stock by 40%. New values of *p* were estimated for this stock at the same lower bounds as before. New and old values for all stocks were then plugged into eq. 4.2 to estimate the Type I Risk for each set of lower bounds, and the results "smoothed" through regression. The Harrison stock was chosen for this demonstration because its selection had the most dramatic effect on risk. Thin curves so generated for other stocks or for less severe reductions in productivity would move the thin curve down and to the right towards the thick curve in Figure 6.1.

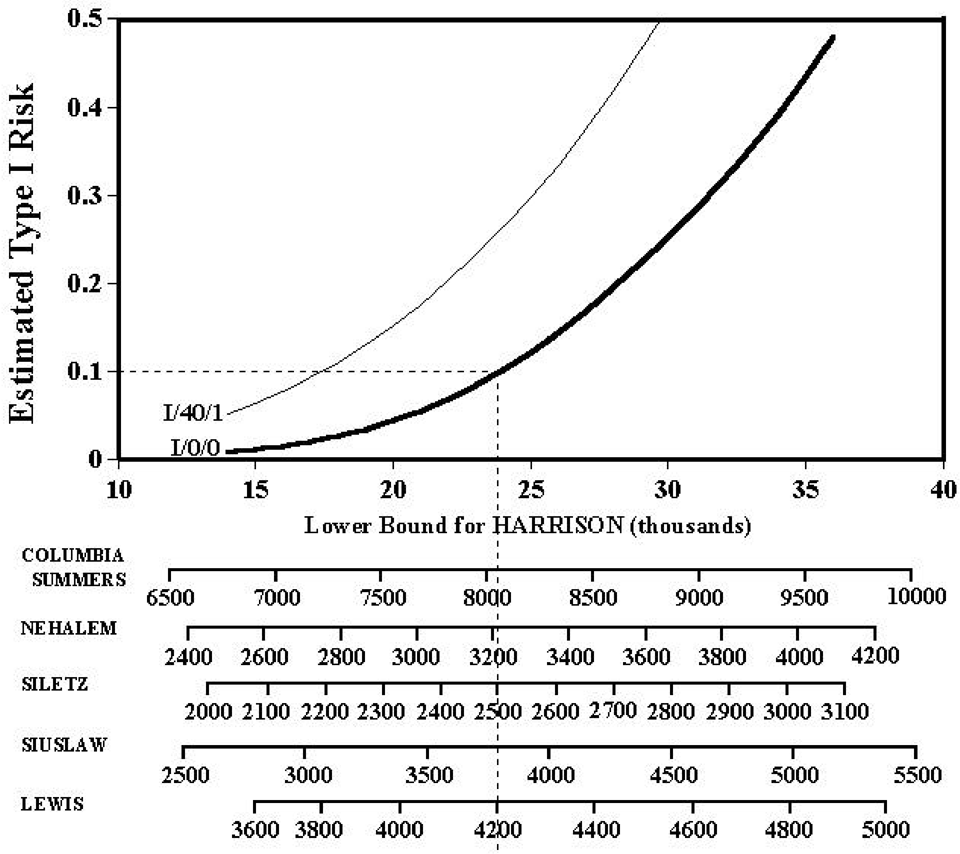


Figure 6.1. Lower bounds associated with estimated Type I Risk of management error for the six stocks with accepted escapement goals. The thick curve represents the situation when all stocks are being optimally fished; the thin curve represents when the Harrison stock is being overfished due to a 40% reduction in productivity. Dashed lines reflect information in Table 6.1. Label "I/40/1" signifies a Type I Risk when there has been a 40% drop in the productivity of 1 stock causing it to be overfished; "I/0/0" signifies a Type I Risk when all stocks are optimally fished. The x-axis for the Lewis stock is asymmetric because of a change in the relationship between *p* and π at lower values.

Once built the graphic relationship between risk and sets of lower bounds is easy to use. A straight-edge implement is sufficient to show that if a 20% Type I Risk at most is acceptable, estimated lower bounds for the six stocks in order are 22,000; 7,700; 3,050; 2,400; 3,600; and 4,100 as determined off the thin curve. If more protection for the one stock being overfished is desired, lower bounds can be determined off the thick curve in Figure 6.1. For at least a 20% Type I Risk under this circumstance, estimated lower bounds are 28,000; 8,650; 3,500; 2,700; 4,200; and 4,400, respectively.

6.3 Lower Bounds by Type II Risk

Once sets of lower bounds for stocks with accepted goals have been established, the easiest way to estimate Type II Risk for each set is to use eq. 4.1 and proceed as in section 5.3. Remembering that a Type II Risk is the probability that one or no stock groups "require response" when two or more are overfished:

$$\text{Type II Risk} = \begin{cases} \prod_{i=1}^{12}(1-p_i) + \sum_{j=1}^{12}\left[p_j \prod_{\substack{i=1 \\ i\neq j}}^{12} (1-p_i) \right] & \text{if } \geq 2 \text{ groups overfished} \\ 0 & \text{if } \leq 1 \text{ groups overfished} \end{cases} \qquad 6.2$$

Like Type I Risk, the degree of overfishing and the number of stocks overfished affects Type II Risk. Below in bold are the probabilities that a specific stock group "requires response" given the lower bounds in Table 6.1 with the stocks in the Fraser Late and Oregon North Coastal groups being overfished due to a **50%** reduction in productivity:

50% Redux	**Fraser Late**	**Columbia Summers**	**Oregon North Coastals**	**Columbia Falls**	**Group 5**	**...**	**Group 12**
$\hat{p}_i'$	0.045	**0.045**	0.045	**0.045**	**0.045**	...	**0.045**
$\hat{p}_i''$	**0.930**	0.999	**0.999**	0.999	0.982	...	0.982

The $\hat{p}_i' \rightarrow p_i$ or $\hat{p}_i'' \rightarrow p_i$ depending on whether or not a group is overfished, making eq. 6.2:

(1-0.930)(1-0.045)(1-0.893)(1-0.045)(1-0.045) ... (1-0.045) +

0. 930 (1-0.045)(1-0.999)(1-0.045)(1-0.045) ... (1-0.045) +
(1-0.930)**0.045**(1-0. 999)(1-0.045)(1-0.045) ... (1-0.045) +
(1-0.930)(1-0.045)**0.999** (1-0.045)(1-0.045) ... (1-0.045) +
(1-0.930)(1-0.045)(1-0.999)**0.045**(1-0.045) ... (1-0.045) +
(1-0.930)(1-0.045)(1-0.999)(1-0.045)**0.045** ... (1-0.045) +
(1-0.930)(1-0.045)(1-0.999)(1-0.045)(1-0.045) ... **0.045 = 0.045**

These two stock groups were chosen for this demonstration because they are the only two groups for which all stocks have accepted goals. Across all stock groups with goals, estimated risk ranges from **0.001** to **0.045** with a 50% reduction in productivity in two groups. If three or more groups are overfished, the Type II Risk is lower.

Below in bold are the probabilities that a specific stock group "requires response" given the lower bounds in Table 6.1 with the stocks in the Fraser Late and Oregon North Coastal groups being overfished due to a **40%** reduction in productivity:

40% Redux	**Fraser Late**	**Columbia Summers**	**Oregon North Coastals**	**Columbia Falls**	**Group 5**	**...**	**Group 12**
$\hat{p}'_i$	0.045	**0.045**	0.045	**0.045**	**0.045**	...	**0.045**
$\hat{p}''_i$	**0.565**	0.929	**0.893**	0.850	0.809	...	0.809

The $\hat{p}'_i \rightarrow p_i$ or $\hat{p}''_i \rightarrow p_i$ depending on whether or not a group is being overfished, making eq. 6.2:

(1-0.565)(1-0.045)(1-0.893)(1-0.045)(1-0.045) ... (1-0.045) +

0.565(1-0.045)(1-0.893)(1-0.045)(1-0.045) ... (1-0.045) +
(1-0.565)**0.045**(1-0.893)(1-0.045)(1-0.045) ... (1-0.045) +
(1-0.565)(1-0.045)**0.893**(1-0.045)(1-0.045) ... (1-0.045) +
(1-0.565)(1-0.045)(1-0.893)**0.045**(1-0.045) ... (1-0.045) +
(1-0.565)(1-0.045)(1-0.893)(1-0.045)**0.045** ... (1-0.045) +
(1-0.565)(1-0.045)(1-0.893)(1-0.045)(1-0.045) ... **0.045 = 0.326**

If the Fraser Late group and the Columbia Falls group (instead of the Oregon North Coastal group) are overfished by 40%, the estimated Type II Risk rises to **0.367**, the maximum when two groups are overfished. If stocks in the Columbia Summers and Oregon North Coastals group are so overfished, estimated Type II Risk is the minimum at **0.110**. If three groups are being overfished, say the Fraser Late, Columbia Fall, and Oregon North Coastal group:

40% Redux	Fraser Late	Columbia Summers	Oregon North Coastals	Columbia Falls	Group 5	...	Group 12
$\hat{p}_i'$	0.045	**0.045**	0.045	0.045	**0.045**	...	**0.045**
$\hat{p}_i''$	**0.565**	0.929	**0.893**	**0.850**	0.809	...	0.809

and the estimated Type II Risk drops to **0.077** given the lower bounds in Table 6.1. Per eq. 6.2:

(1-0.565)(1-0.045)(1-0.893)(1-0.850)(1-0.045) ... (1-0.045) +

0.565(1-0.045)(1-0.893)(1-0.850)(1-0.045) ... (1-0.045) +
(1-0.565)**0.045**(1-0.893)(1-0.850)(1-0.045) ... (1-0.045) +
(1-0.565)(1-0.045)**0.893**(1-0.850)(1-0.045) ... (1-0.045) +
(1-0.565)(1-0.045)(1-0.893)**0.850** (1-0.045) ... (1-0.045) +
(1-0.565)(1-0.045)(1-0.893)(1-0. 50)**0.045** ... (1-0.045) +
(1-0.565)(1-0.045)(1-0.893)(1-0.045)(1-0.850) ... **0.045 = 0.077**

This is the highest estimated risk for any combination of three overfished groups without involving groups lacking accepted goals (ignoring that only one of three stocks of the Columbia Fall group has an accepted goal).

Below in bold are the probabilities that a specific stock group "requires response" given the lower bounds in Table 6.1 when stocks are optimally fished ($\hat{p}_i'$) or are overfished due to a **30%** reduction in productivity $\hat{p}_i''$:

30% Redux	Fraser Late	Columbia Summers	Oregon North Coastals	Columbia Falls	Group 5	...	Group 12
$\hat{p}_i'$	**0.045**	**0.045**	**0.045**	**0.045**	**0.045**	...	**0.045**
$\hat{p}_i''$	**0.297**	**0.608**	**0.518**	**0.641**	**0.516**	...	**0.516**

As per eq. 6.2, estimated Type II Risk is a maximum **0.635** when two groups are overfished (Fraser Late and Oregon North Coastal) and is a maximum at **0.378** with three overfished groups (add the Columbia Falls group).

Again, graphical representation can be a useful aid for making decisions. The scenarios described above for Type II Risk with:

1) two stock groups overfished due to a 50% reduction in productivity,
2) two stock groups overfished due to a 40% reduction;
3) three groups overfished due to the same reduction;
4) two groups overfished from a 30% reduction; and
5) three groups with the same 30% reduction in productivity.

are expanded across sets of lower bounds in Figure 6.2. Risks were calculated for the same sets of lower bounds used to build Figure 6.1, then their relationships were smoothed into curves by fitting exponential, logarithmic, or linear models of risk against lower bounds. Smoothing models were chosen for different relationships or parts of relationships such that all fits had coefficients of determination greater than 99%.

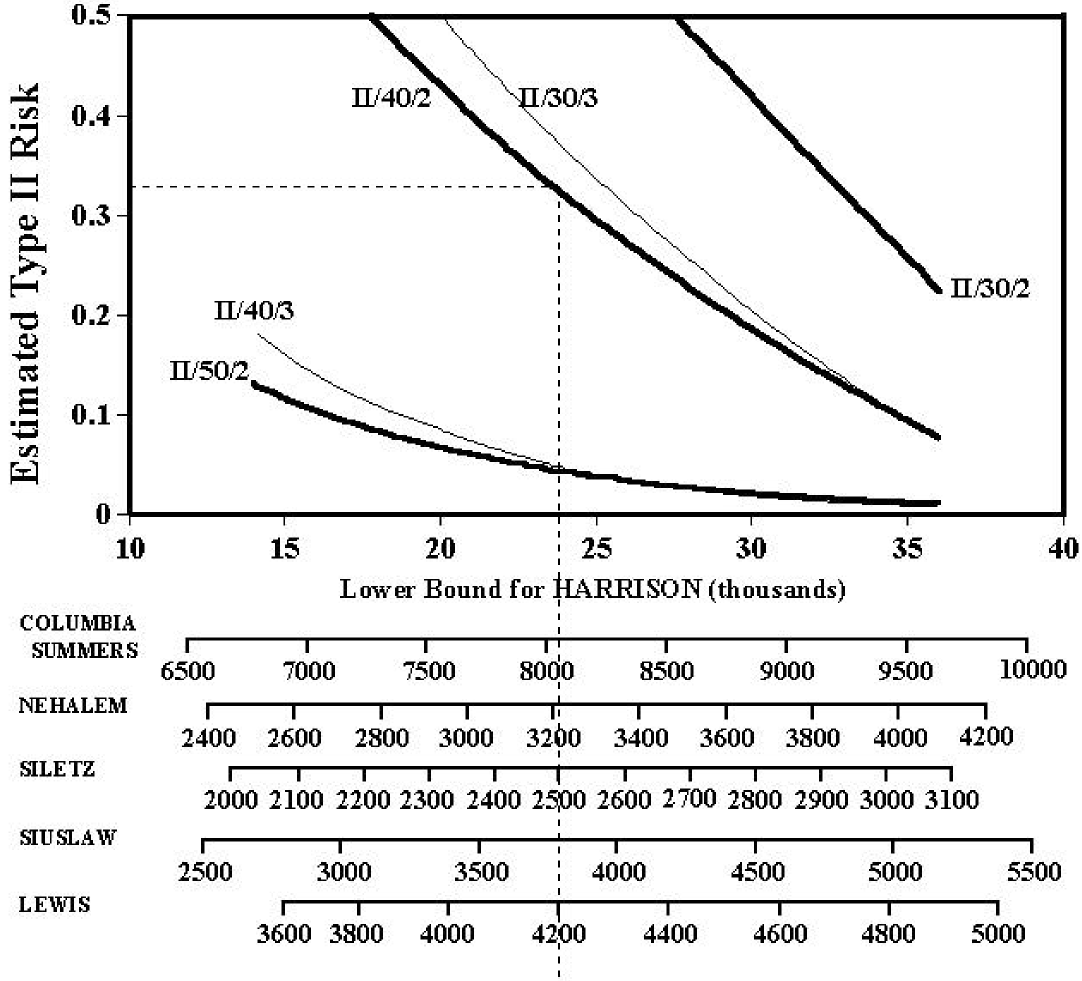


Figure 6.2. Lower bounds associated with estimated Type II Risk of management error for the six stocks with accepted escapement goals. Thick curves represents situations when two stocks are overfished, and thin curves when three stocks are overfished. Dashed line reflects lower bounds in Table 6.1. Label “II/40/2” signifies a Type II Risk when a 40% drop in the productivity in two stocks have caused them to be overfished. Other labels follow the same format. The x-axis for the Lewis stock is asymmetric because of a change in the relationship between p and π at lower values.

7. DISCUSSION

7.1 Assumptions

Optimal Fishing. Most simulations were based on optimal fishing, that is fishing at a rate that on average produces MSY, because these optimal rates provide a natural divide for fisheries managers. A stock with harvest at that rate or below does not need protection, at least not from fishing. This belief is ensconced in the Agreement with references to "harvest regimes" that will "achieve (meet) MSY or other biologically-based escapement objectives" in ¶1 of Chapter 3 of the Agreement.

If stock groups are underfished, as is currently so for the stocks with accepted goals (see Table E.1), risk estimated on the condition of optimal fishing will be overstated (too high). Risk wanes along with the probability of observing low escapements. If all stocks are underfished, the Type II Risk remains at zero because no AMA is needed, and the Type I Risk becomes negligible with lower harvest rates as all the p_i (probability of a stock group requiring response) drop towards zero.

What if all stock groups but two are underfished, and those two are overfished? In this scenario, estimated Type II Risk will be understated (too low) if conditioned on optimal fishing. However, estimation of risk does not have to be conditioned on optimal fishing. Current harvest rates on underfished stocks could be used to provide better estimates of this risk, provided these stocks along with the overfished stocks have accepted goals. However, this scenario is unlikely given the mixed-stock nature of AABM and ISBM fisheries, and if it occurred, could be more readily addressed with special management actions focused on the specific stocks being overfished.

Overfishing from a Change in Productivity. Overfishing was simulated in this analysis as caused by a drop in productivity because of convenience. Overfishing is caused when the average harvest rate is greater than the harvest rate associated with MSY. Such an imbalance can occur either through a drop in productivity or a rise in harvest rates. The basic model used in simulations to predict production from an escapement S can be modified to produce the following relationship between productivity (α) and harvest rate U:

$$(1-\overline{U})\alpha = \exp(\beta\overline{S})$$

showing that either productivity or harvest rate can be manipulated to reach the same situation with escapements. For example, in three simulations regarding the Lewis stock where κ is the fraction reduction in productivity:

k	$\overline{U}$	$\overline{S}$	$\overline{H}$	$\hat{p}$ S_{LB} = 2,000
0	0.804	6,078	24,937	-
0.5	0.804	1,013	4,157	0.934
0	0.902	1,013	9,328	0.934

Note that the top row represents optimal fishing and the lower two overfishing. Simulated overfishing to the same degree was achieved by reducing productivity by 50% or by increasing the average harvest rate by about 0.10. The term "same degree" means that average escapement and the estimated probability that the stock group "requires response" are equal.

Also note that equality in result does not hold for average harvest. As would be expected, overfishing caused by a drop in productivity results in lower average harvest than does overfishing caused by an increase in harvest rate. While this reality has implications for the consequences of a management error, it does not for the risk of them.

Uncertainty. The information we used to estimate probabilities through simulation is not known with certainty. Density-dependent and density-independent parameters used in simulated stock-recruit relationships, variation in estimated escapements, process error, and other parameters are themselves estimates derived from data collected in the past, a past that might not be representative of the present or of the future. Imprecisely estimated parameters may be functionally inaccurate, or precise parameter estimates may be inaccurate because they are no longer relevant. Under these circumstances, modeling estimated uncertainty directly from "old" data is not sufficient to understanding how uncertainty in parameter estimates might affect AMA. "New" information is needed.

Uncertainty in estimated parameters used in our simulations was addressed indirectly, much as is done in a non-parametric statistical test. Differences between two populations can be detected in such tests, however, differences when found could be due to differences in central location and/or to differences in dispersion. If subsequent action does not depend on why the null hypothesis was rejected, no consideration of the cause is needed. The null and alternative hypotheses represent "old" information while samples used to calculate a test statistic represent "new" information.

A series of low escapements in the future (new information) is an unusual event given what we know (old information). The probability of that event can be estimated accurately if what we think we know about stock-recruitment relationships and other relevant phenomena is true, just as is done with samples in a hypothesis test. If an event (low escapements) with low estimated probability actually occurred, a more likely explanation is that our estimate of probability is lower than the actual probability. Such a discrepancy would occur because parameter values used in the simulated stock-recruit relationship or to describe other important phenomena are wrong, either through uncertainty in parameter estimates derived from data collected in the past, or that past data are no longer representative of current circumstances. Either cause implies that productivity is lower than was thought relative to current harvest rates. The subsequent action from this "rejection" of the "null hypothesis" on productivity is an AMA. Why escapements are low would be interesting to know, but in the year of AMA, specific knowledge of the cause would be irrelevant to subsequent action.

Independence among Stock Groups. Models used to describe the probability of no, one, two, or more stock groups "requiring response" are derived from the assumption that each stock group is acting independently from all the others. Other models could be used that incorporate a degree of dependence among stock groups if warranted.

These other models were not used because there is no evidence of dependence among stock groups at this time. As noted in section 2.3, variation in relative brood-year strengths were not correlated among stocks within the Oregon North Coastal group. Log of marine survival rates for fish from the Chillawack Hatchery was shown to be an important factor in brood-year strength for the Harrison stock; this same variable was poorly correlated (r = 0.012) to residuals from the log-transformed model describing the stock-recruit relationship for the Lewis stock. Correlations across stocks (Oregon North Coastals, Harrison, Lewis, and Columbia Summers) among instantaneous rates of harvest as estimated from the 2000 exploitation rate analysis for years 1995 through 1999 are equivocal:

	Harrison	**Columbia Summers**	**Oregon North Coastal**	**Lewis**
Harrison	1	0.512	0.154	0.065
Columbia Summers		1	0.518	-0.799
Oregon North Coastal			1	-0.467
Lewis				1

No correlation is statistically significant, not surprising given that only five years are covered. Negative correlations are interesting, especially between the Columbia Summer and Columbia Fall groups that are exploited in the same fisheries, albeit at different times.

Perhaps evidence supporting dependence among stock groups will be found as more goals are proffered to the CTC and are accepted. If new information shows a dependence among groups, that dependence can be modeled to estimate management risks involved with setting lower bounds.

Independence in Simulated Escapements. Calculations of the probability π of a stock meeting the "two-year criterion" in a particular year was estimated in simulations by assuming that each year represented an independent "trial." Obviously, these "trials" are not the same as "flipping a coin" or "rolling a die." If the two-year criterion is met in calendar year *y*-1, the probability should be higher of meeting that criterion in year y than not, and vice versa. In short, the probability π for the current year is "conditioned" on the whether or not the criterion had been met in the previous year.

While this dependence would be an important consideration when estimating risk of management error in the year 2002, it's not when risk is to be estimated in general, as is the case when establishing a lower bound. The general probability π for any year is found by integrating over all possible two-year scenarios in escapement in accordance with their relative frequency. While simulations did not represent all possible scenarios, almost all of the most likely scenarios were probably included in the 10,000 iterations used in each simulation.

Table 7.1. Probability *p* of a stock group "requiring response" when Type I Risk is set at 10%.

Number of Stock Groups	Two Groups Trigger AMA	One Group Triggers AMA
12	0.0452	0.0087
15	0.0360	0.0070
20	0.0270	0.0052

7.2 Sensitivity to Criteria and Groups

Risk of management error is in part related to the Agreement. Suppose:

1) additional management actions would be taken if only one stock group "requires response" or;
2) there are more than 12 stock groups.

Under these circumstances, lower bounds on individual stocks determined from risk of management error would be lower than reported above. If the acceptable risk of a Type I Error (an unneeded AMA) is 10%, Table 7.1 contains the probabilities *p* corresponding to each group "requiring response." As mentioned before, risk can be spread evenly across all groups, making *p* the same for all. As *p* declines, so too would stock-specific lower bounds under the Agreement. This results in less "protection" for individual stocks or stock groups if risk is fixed at 10% across all stock groups.

7.3. Status

In February 2002, the Pacific Salmon Commission instructed the CTC to postpone further work on establishing lower bounds for AMA until such time that the CTC has accepted escapement goals for additional stocks of chinook salmon. No instruction was given as to how many goals must be accepted before stock-specific lower bounds could be established. Until goals have been accepted for a sufficient number of additional stocks, the CTC will forgo further work on developing methods for establishing lower bounds. As such, this report serves as documentation of past investigations, of descriptions of two methods for establishing lower bounds as per risk of management error, and of a means of evaluating that risk for lower bounds established by any other methods.

8. LITERATURE

Brown, G., B. Riddell, D. Chen, and M. Bradford (*in prep*). A spawning escapement goal for Harrison River fall chinook based on stock-recruit analysis. PSARC Research Document, Department of Fisheries and Oceans, Nanaimo, British Columbia, Canada.

Pacific Salmon Commission. 2000. Pacific Salmon Treaty, 1999 Revised Annexes, Memorandum of Understanding (1985), and Exchange of Notes. Vancouver, B.C. Canada

TCChinook (96)-1. 1994 annual report, February, 1996. Report of the Chinook Technical Committee of the Pacific Salmon Commission, Vancouver, British Columbia, Canada.

TCCHINOOK (99)-3. 1999. Maximum sustained yield or biologically based escapement goals for selected chinook salmon stocks used by the Pacific Salmon Commission's Chinook Technical Committee for escapement assessment, vol. 1, December, 1999. Report of the Chinook Technical Committee of the Pacific Salmon Commission, Vancouver, British Columbia, Canada.

9. APPENDIX

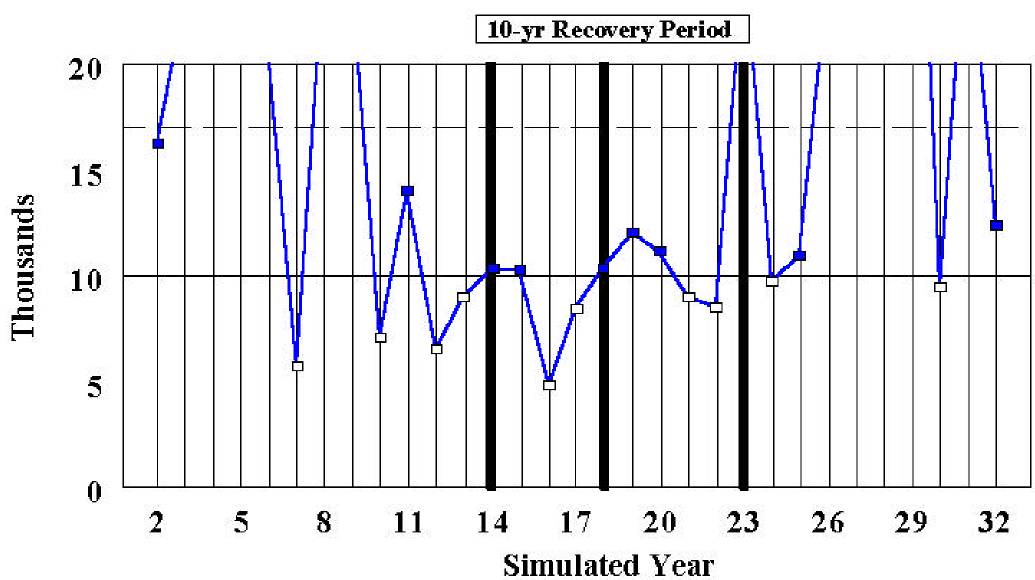
9.1 Example of a Recovery Period

The figure below provides an example of the history of a recovery period. No AMA was taken until year 14 because the first two consecutive years in which $S'_{by} < S_{LB}$ are years 12 and 13 (S_{LB} = 10,000). This started the recovery period in year 14. Escapement rose above S_{LB} in years 14 and 15, so no additional action was taken in years 15 and 16. Because the increase in simulated escapements in years 14 and 15 did not push to or beyond S_{MSY} (S_{MSY} = 17,368), these years are still part of the recovery period. Simulated escapement again dipped below S_{LB} in years 16 and 17, so additional action was taken in year 18, a year in which simulated escapement again rose above S_{LB} but not above S_{MSY}. The simulated population was still in the same recovery period. Simulated escapements remained above S_{LB} and below S_{MSY} in years 19 and 20, then plunged below S_{LB} in years 21 and 22, triggering additional action in year 23. In year 23, escapement finally increased beyond S_{MSY}, ending the recovery period at 10 years of length. Even though escapement dropped to below S_{LB} in later years (years 24 and 30), no second recovery period occurred because no drop lasted longer than one year.

The measure of time for the simulated population to recover is expressed in the simulation as the expected length of recovery periods in seasons. Frequency of recovery periods by their lengths *r* in years F(*r*) was calculated. The expected value in seasons is:

$$E[r'] = (r-1)\frac{F(r-1)}{\sum_{x=1}^{\max r} F(x)}$$

where *r*¢ = *r* – 1 to change units from years to seasons. For instance, a recovery period of length one year (*r* = 1) means that escapement in year y was below the lower bound but above S_{MSY} in



year y_{i+1}, that is the escapement recovered in the same season in which additional action was taken. By subtracting one, recovery was scaled to seasons with “0” denoting near “instantaneous” recovery, “1” recovery in the next season after a year has passed, “2 “ in the third season after two years have passed, etc.

9.2 Simulations

Stock-Recruit Relationships. Simulations were based on standard stock-production relationships for chinook salmon as described in eq. 3.1-4:

$$R_i' = S_i' \exp\left[\ln a + g \ln[M_{(i)}]_{\text{dev}} - bS_i' + e_{(i)}\right] \qquad 9.1(2.1)$$

$$R_{by}' = S_{by}' \exp\left[\ln a - bS_{by}' + fe_{by}' + (\sqrt{1-f^2})e_{by-1}'\right] \qquad 9.2(2.2)$$

$$R_i' = S_i' \exp\left[\ln a - bS_i' + e_{(i)}\right] \qquad 9.3(2.3\text{-}4)$$

where “ ′ “ signifies predictions from the simulation, the subscript *i* the simulated year, and the subscript *i* in parentheses a stochastic input for simulated year *i*. Notation for the variables and parameters in these equations is defined in Table 9.1.

Escapements and harvests (fishing-induced mortality) in simulated year *i* were predicted as functions of surviving production from extant broods and harvest rates:

$$S_i' = (1 - U_{(i)}) \sum_{a=\ddot{a}}^{7} R_{i\text{-a}}' \lambda_{a(i-a)} \qquad 9.4$$

$$H_i' = U_{(i)} \sum_{a=\dot{a}}^{7} R_{i\text{-a}}' \lambda_{a(i-a)} \qquad 9.5$$

where $\lambda_{a(i-a)}$ is the return rate for chinook salmon of age *a* for brood year *i* - *a* in simulated year *i*, that is the fraction of progeny that survive (or would have survived fishing as juveniles) in that brood year to mature at age a, $\dot{a}$ the age of first recruitment to retention fishing for that stock, $\ddot{a}$ the age of first recruitment to what is considered the spawning population for that stock, and $U_{(i)}$ is the harvest rate for adults in simulated year *i*. Note that $\sum_{a=2}^{7} l_{a(i)} = 1$ with return rates for some ages possibly zero depending on the specific stock and its life history.

Iterations. Simulations were used to establish a lower bound based on a target probability p (or π). If there is only one stock in a stock group, the calculated probability is the sum of the number of simulated years in which the “two-year” criterion was met divided by the number of simulated years (9,993; 9,893; or 8,999). The “two-year” criterion for a simulated stock is met when simulated escapement to the stock is below the current lower bound in the previous two simulated years.

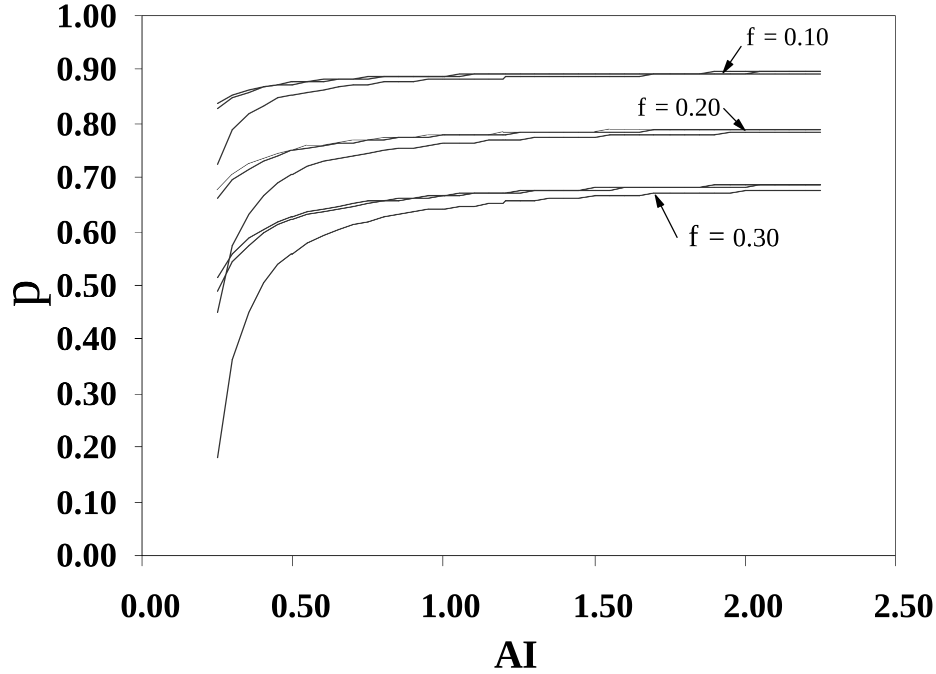
9.3 Harvest Rates from AMA

From Table 1, p. 42 of the Agreement, the allowed fishing-induced mortality *H* measured as landed fish for each AABM fishery is a "near" linear function of an abundance index *AI*. Although the actual functions follow what is called "the broken stick model," linear relationships of the form $H = a + b(AI)$ are good approximations ($R^2 > 0.98$ for all AABM fisheries). These linear relationships were used to determine reductions in fishing-induced mortality from AMA as follows. If *N* is the abundance in a fishery, *U* the fishing mortality rate without AMA (the base rate), and *U¢* with an AMA, the "shrinkage" factor π in the effective fishing mortality rate given an additional action reducing *AI* by φ x 100% is :

$$\theta = \frac{U'}{U} = \frac{H'/N}{H/N} = \frac{H'}{H} = \frac{a + b(AI)(1-\phi)}{a + b(AI)}$$

(Note that some of the notation in section 9.3 has been redefined for use here.) The following figure illustrates θ as functions of *AI* for all three AABM fisheries given AMAs where $\phi = 0.10$, 0.20, or 0.30. Although θ drops off dramatically where $AI < 0.75$ for all three fisheries (especially the SEAK fishery), θ are relatively constant when $AI > 0.75$ (see the figure on the next page). Because *AI*s from calibrations of the coast-wide model historically have been above 0.75, averages of θ over that range and over all three fisheries were used to adjust mortality rates downward when AMAs were required in the simulation (see the table on the next page). These average values are: $\bar{\theta} = 0.89$ when $\phi = 0.10$; $\bar{\theta} = 0.78$ when $\phi = 0.20$; or $\bar{\theta} = 0.67$ when $\phi = 0.30$.

Values of $\bar{\pi}$ were used in simulations to express reductions in fishing-induced mortality not just in AABM fisheries, but in ISBM fisheries as well. As per the Agreement (Chapter 3, paragraph 7(e), p. 41), AMAs for AABM fisheries apply to ISBM fisheries so long as the general obligations have been met. While non-ceiling indices do not follow a "broken stick" model, a reduction in indices of 10, 20, or 30% would imply "shrinkage" in fishing mortality rates on par with those calculated for AABM fisheries.



θ	Additional Management Action		
	10%	20%	30%
SEAK	0.886	0.773	0.659
NBC	0.892	0.783	0.675
WCVI	0.892	0.784	0.677
Averages	0.890	0.780	0.670