RAP

A RISK ASSESSMENT PROCEDURE FOR EVALUATING HARVEST MORTALITY ON PACIFIC SALMONIDS

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INTRODUCTION

Implementation of the ESA in management requires translation of the relevant text of the ESA into quantifiable terms, and a framework for determining the consistency of proposed actions with the requirements of the ESA. The ESA and the joint ESA rules published by the U.S. Fish and Wildlife Service (USFWS) and NMFS (51 Fed. Reg. 19926 (1986)) provide some relevant guidance, as does the Endangered Species Handbook- Procedures for Conducting Consultations and Conference Activities Under Section 7 of the Endangered Species Act (the Handbook). This guidance was developed to be applicable to all listed species of animals, but application to listed species of Pacific salmon can be difficult given salmon are highly migratory. In addition, salmonids are listed at the Evolutionarily Significant Unit (ESU) level rather than at the species level. Each ESU typically consists of several distinct populations. In order to bridge the gap between the general guidance and language of the ESA and management decisions affecting listed Pacific salmon species, management tools are needed that link available biological data about the listed species with quantified standards of acceptable risk to survival and recovery. To address the biological requirements of salmonids, NMFS developed guidance on the characteristics of viable, i.e., recovered, salmonid populations, in its paper, Viable Salmonid Populations and the Recovery of Evolutionarily Significant Units (VSP)(McElhaney *et al.* 2000). It identifies four characteristics of viable salmonid populations: population size, trends in abundance and productivity, diversity, and spatial structure. However, VSP does not provide quantified risk standards, or a framework for assessing risk.

This document describes one such framework, the Risk Assessment Procedure (RAP) used to assess harvest management actions and define population-specific harvest mortality standards. RAP provides a coherent and objective methodology that can be consistently applied for evaluating proposed actions that may be considered under various sections of the ESA including: 4(d) rules, recovery plans, section 7 consultations and section 10 incidental take permits for salmon, utilizing the concepts of VSP. It is just one tool in the NMFS toolbox, and will require additional interpretation and adaptation for specific applications. The RAP defines maximum exploitation rates (Recovery Exploitation Rates, or RERs) for individual populations which are projected to result in a low risk to survival and a moderately high to high probability of recovery *of the population* in the long term. Risk is measured in terms of the frequency that escapements are above or below previously defined benchmark thresholds of abundance. Although, abundance, or population size, is the key standard assessed in the RAP, RAP also addresses the other important characteristics of viable salmonid populations (McElhaney *et al.* 2000).

Development of the risk assessment framework for each ESU is likely to be an iterative process, with the depth and scope of the assessment increasing as information becomes available and analytical tools are refined. To date, RERs have been developed for eight populations from the Puget Sound chinook ESU (North Fork Nooksack early, South Fork Nooksack early, Upper Skagit summer, Lower Skagit fall, Upper Sauk summer, North Fork Stillaguamish summer, South Fork Stillaguamish fall, and the Green River) and one population from the Lower Columbia River chinook ESU (Coweeman))(Table 1).

This paper describes the conceptual structure and procedural steps of RAP and thus provides an opportunity for substantive review and comment. The approach will be revised as appropriate as a result of the review before continuing with further applications of the RAP.

OVERVIEW OF APPROACH

Characteristics of approach

Our premise is that the best way to develop ESA standards for harvest actions is within a risk assessment framework. Broadly, this means a structured process to: 1) identify a measurable goal (e.g., maintenance of a population above a specified level); 2) identify a range of potential strategies to achieve that goal (e.g., reduce exploitation rates); 3) objectively assess the probable range of outcomes of alternative strategies; and 4) determine the strategy or set of strategies most likely to result in achieving of the goal. The requirements of the ESA, salmon biology, and our level of understanding of natural processes suggest that such an approach should possess the following characteristics:

Quantitative. Placing the RAP in a quantitative framework facilitates identification of key information needs and formalizes the decision process. Quantitative analyses typically lead to a repeatable, consistent, and defensible basis for decisions. In addition, the ESA and associated regulations are typically couched in probabilistic terms. A threatened species is one that is *likely* to become endangered; an action is termed jeopardy if it would reasonably be expected to reduce *appreciably* the *likelihood* of both the survival and recovery of a species.

General. The types of analysis and information required are similar under the various sections of the ESA. RAP provides a consistent set of output setting harvest standards, that can be applied across a range of ESA applications including making jeopardy determinations, shaping 4(d) rules or recovery planning. Because RAP is applied at the population level, it is generally applicable to any salmonid population or ESU.

Life Cycle Oriented. A single factor in a single year rarely poses a threat of extinction to an ESU. More likely, it is the cumulative effect of many factors applied over many years that places an ESU at risk. A RAP that incorporates that entire life cycle of salmon can provide the analytic framework required to address the cumulative, long-term, effects of multiple factors on the population dynamics of an ESU.

Harvest mortality inclusive. Similarly, a single fishery rarely poses a threat of extinction to an ESU. However, the cumulative impacts of all fisheries may be sufficiently high to pose significant risk. By evaluating total fishing mortality, the RAP focuses on the biological requirements of the species, thereby providing managers with the necessary information and flexibility to shape fisheries that, in aggregate, are consistent with ESA standards.

Incorporates uncertainty. Significant uncertainty exists in our understanding of the processes affecting the dynamics of salmon populations, particularly at low levels of abundance. The uncertainty is compounded by variability in the environmental conditions that heavily influence salmon populations. The RAP provides a mechanism for explicitly incorporating uncertainty in the risk assessment framework.

Scalable. Although the most useful assessments would encompass all actions affecting the population dynamics of an ESU, jeopardy decisions must often be made at a much finer level of resolution. At the finest scale, this entails an assessment of the effects of a single action on a single population. For each population, RAP defines a total fishing mortality standard (RER) across all fisheries, taking into account the effects of habitat management on productivity and capacity, and the contribution of hatchery fish. Since the population standards are all measured in the same terms, the effects to the ESU can be assessed by examining the effects of the proposed fishing action relative to the RERs for all populations in the ESU.

Flexible. NMFS has three management mandates: 1) implementation of the ESA; 2) treaty trust obligations; and, 3) creating opportunities for sustainable fisheries. In addition, many of the resource users have management objectives aside from conservation, e.g., maximum sustainable catch, agricultural and municipal water allocation. In working with the comanagers and other users, RAP may serve as a tool to assess multiple objectives.

Relationship to VSP

In the development of RAP, we sought to use an approach that was consistent with the concepts developed by the NWFSC for the purpose of defining the conservation status of populations and ESUs, described in the Viable Salmonid Populations (VSP) document (McElhaney *et al.* 2000). Both RAP and VSP operate at the population level. However, although VSP offers general guidelines for biological characteristics of a population at increased risk or robust to risk, it is not population specific and it does not assess an action's effects over time. Consequently, models are needed that look at population-specific population dynamics and the effects of proposed actions over time. The result is a merging of the thresholds of risk, e.g., VSP, with the effects of an action over time to assist in making management decisions, e.g., RAP.

VSP describes four elements that must be considered when determining whether a population could be considered viable: population size, trends in abundance and productivity, diversity and spatial structure. RAP addresses the first three elements. It incorporates abundance and productivity through its use of thresholds, and stock recruit dynamics and addresses diversity, in part, by operating at the population level. Spatial structure, as described by McElhaney *et al.* is primarily a function of habitat management, although is also considers the role of sub-populations.

General approach

There are five steps involved with determining population specific RERs: 1) identify populations, 2) estimate population productivity as indicated by a spawner-recruit relationship, 3) set critical and viable threshold abundance levels, 4) determine risk criteria, and 5) identify, through simulation, the appropriate RER.

Even in relatively data rich assessments, significant scientific judgement will likely be required in evaluating the results and determining which analyses and assumptions should be given the greatest weight. Natural resource management in general, and listed species in particular, rarely benefit from a formulaic approach. The risk assessment must be carefully considered in the context of all biologically relevant information.

1) Identify populations

The intent of the VSP approach is clearly to recognize and protect the diversity of populations that may exist within an ESU and, in assessing the effect of an action, to stratify the ESU adequately to represent the unique population characteristics of the ESU. This includes, for example, unique life history or genetic characteristics, geographic distributions and so on. The objective is to apply the RAP for each population for which sufficient data exist. However, determinations about population structure have not been made for many of the ESUs. The Washington co-managers have suggested a stock structure of Washington salmonids in the Salmon and Steelhead Stock Inventory (SASSI)(WDF *et al.* 1993). Whether or to what degree stocks will be aggregated to form populations is not known at this time, but until the population assessment is complete, SASSI is the best available information. Therefore, in the recent biological opinions relevant to the Puget Sound ESU, RERs were developed for individual SASSI stocks.

2) Determine population-recruit relationship

Estimates of the spawner-recruit parameters for each population are required to both establish the escapement threshold levels and to simulate population dynamics. The RAP is flexible as to what spawner-recruit function is used. The model currently allow the user to choose among several different variations of the Ricker model, a linear or "hockey-stock" model, or a Beverton-Holt model. So far, parameters have been estimated using methods developed by the Chinook Technical Committee and applied on a coast-wide basis (Chinook Technical Committee, in press). A detailed description of the development of the population-recruit parameters is provided later in the Data Inputs and Method section.

3) Set critical and viable threshold levels

The VSP paper identifies threshold abundance levels as one of several indicators of population status (others being trends in abundance and productivity, spatial structure and diversity). The thresholds described include a critical threshold and a viable population abundance level. The critical threshold generally represents a boundary below which uncertainties about population dynamics increase and therefore extinction risk increases substantially. The viable population threshold is a higher abundance level that would generally indicate recovery or an abundance beyond which ESA type protections are no longer required[1].

The VSP paper provides several rules of thumb that are intended to serve as guidelines for setting population specific thresholds (McElhaney *et al.* 2000). However, since they are general, and not population specific, threshold determinations for selected "populations" should be made by considering both the rules of thumb, and other more population-specific information. The following describes the approach taken to establish thresholds for the RER analysis in the biological opinions on the PST agreement and the 2000 PFMC/Puget Sound fisheries.

The critical threshold was developed from a consideration of genetic, demographic, and spatial risk factors for each population. Genetic risks to small populations include the loss of genetic variation, inbreeding depression, and the accumulation of deleterious mutations. The risk posed to a population by genetic factors is often expressed relative to the effective population size (N_b), or the size of an idealized population that would produce the same level of inbreeding or genetic drift that is seen in an observed population. Guidance from the VSP paper suggests that population sizes of 167-1,667 per generation (N_b = 50-500) are at high to very high risk. The population size range per generation was converted to an annual spawner abundance range of 42-417 by dividing by four, the approximate generation length for chinook and chum stocks.

Factors associated with demographic risks include environmental variability and depensation. Environmental variation presents risks to small populations when conditions reduce survival or reproduction to chronically low levels. The VSP paper suggests that abundance levels of 1,000-10,000 spawners per generation, represent a low risk of extinction, i.e., a viable threshold. Assuming the same 4 year generation length, this converts to a range of 250 - 2,500 spawners per year. Since escapement within this range is considered to be at low risk, the critical escapement level with regard to environmental variation must be somewhat lower. Because most of the populations that were subject to the RER analysis were relatively small, an escapement level of 200 fish was selected from these ranges to represent a generic critical threshold related to genetic and environmental risk factors (method 1).

The Biological Requirements Work Group (BRWG 1994) took genetic considerations and other factors into account in their effort to provide guidance with respect to a lower population threshold for Snake River spring/summer chinook. They recommended that annual escapements of 150 and 300, for small and large populations, represented levels below which survival becomes increasingly uncertain due to various risk factors and a lack of information regarding populations responses at low spawning levels. This provides independent support for the use of 200 (within the range of 150-300) as a critical threshold.

[1] with the caveat that abundance is not the only relevant or necessary indicator of recovery

Depensation, or a decline in the productivity of a population (e.g., smolts per spawner) as the abundance declines, can result from the uncertainty of finding a mate in a sparse population and/or increased predation rates at low abundance. Demographic risks were assessed using a Ricker population-recruit model (method 2)[2]. This method was derived from an analysis of the Ricker population-recruit relationship based on Peterman's work (1977, 1987). He provided a rationale for depensation and suggested relating the escapement level at which depensation occurs to the size of the population in the absence of fishing (equilibrium escapement level). Based on Peterman's work, NMFS set this measure of the critical threshold equal to 5% of the equilibrium escapement level.

For "large populations", the NMFS typically selected a critical threshold based on method 2 to assure a sufficient density of spawners. Method 1 was used for four small populations and two populations for which the NMFS was unable to estimate Ricker functions (Table 1).

Similar methods were used to establish the viable population or recovery level. In this case, the criteria were 1,250 spawners (the VSP genetic guideline range of 1,670 -16,700 spawners per generation or the VSP environmental variance guideline range of 1,000-10,000 spawners per generation, divided by the average generation length of approximately 4 years) (Method 1) or the level of escapement required to achieve the maximum sustainable yield (Method 2). As applied in RAP to date, the MSY level represents a maximum sustainable level given current productivity and capacity restraints on the population, and is not intended to represent a potential recovery level for the population. Method 1 was used for the two populations for which NMFS was unable to estimate the MSY escapement (Table 1). Each of the threshold measures was considered in the context of the types and quality of data available, the characteristics of the watershed, and the biology of the population.

Table 1. Critical and viable abundance thresholds by population

ESU	Population	Critical Threshold	Viable Threshold	RER	Critical/Viable Method
Puget Sound	North Fork Nooksack	200	1,250	0.24	1/1
	South Fork Nooksack	200	1,250	0.30	1/1
	Upper Skagit/S	967	7,454	0.54	2/2
	Lower Skagit/F	251	2,182	0.33	2/2
	Lower Sauk/S	200	681	0.36	1/2
	NF Stillaguamish/S	300	552	0.45	1*/2
	SF Stillaguamish/F	200	300	0.28	1/2*
	Green River S/F	835	5,523	0.62	2/2
L.Columbia River	Coweeman (tule)	200	330	0.65	1/2

* Adjusted for population-specific information

[2] The Dennis model (Dennis et. al. 1991) provides an estimate of the number of spawners required to have a desired level of probability that the population does not go extinct within a defined period of time. It is another tool that might be used to assess demographic risks. However, we did not have a working model available to us during the time of our analysis.

Table 2. Chinook escapement estimates for SASSI populations from Puget Sound.

Year	Dungeness	NF NKS	SF NKS	U. Sauk Spring	Suiattle Spring	U.Cascade Spring	L. Sauk Summer	L. Skagit Falls	U. Skagit Summer	NF Stilly Summer	SF Stilly Fall	Snohom	Cedar	Green	White R	Puyallup	Nisqually	Skok. Total	Skok. Wild
1971				610	1,468							7,822	471	5,832	393	2,220	800	3,423	2,666
1972				150	1,804							3,128	419	4,343	392	925	700	2,119	1,066
1973				1,255	577							4,841	1,025	3,180	137	630	700	3,093	1,572
1974				108	355		1,082	3,116	8,389			6,030	560	5,095	388	1,480	500	779	674
1975				300	326		964	3,185	7,171			4,485	656	3,394	488	1,396	550	1,836	1,673
1976				173	460		1,770	5,590	6,760			5,315	416	3,140	229	1,120	450	1,378	1,134
1977				411	407		926	2,485	5,807			5,565	675	3,804	66	703	220	2,061	1,427
1978				404	548		1,640	2,987	8,448			7,931	890	3,304	140	962	178	485	164
1979				411	344		1,636	3,829	7,841			5,903	1,243	9,704	72	2,359	1,665	1,301	1,251
1980				590	816		2,738	4,921	12,399			6,460	1,360	7,743	61	2,553	1,124	997	479
1981				394	581		1,702	2,348	4,233			3,368	624	3,606	175	518	439	422	117
1982				277	476		1,133	1,932	6,845			4,379	763	1,840	20	851	848	323	248
1983				202	352		375	3,151	5,197			4,549	788	3,679	21	1,184	1,066	1,278	1,007
1984				238	345	113	680	2,306	9,642			3,762	898	3,353	7	1,258	313	2,850	1,394
1985				1,818	716	100	515	1,686	13,801	1,148	75	4,873	766	2,908	27	1,147	112	5,031	2,974
1986	238			737	806	380	1,143	4,584	12,181	980	188	4,534	942	4,792	6	740	302	5,876	2,643
1987	100			815	729		792	2,635	5,982	1,065	148	4,689	1,540	10,338	117	925	85	5,449	2,112
1988	335	450	230	870	740	133	1,052	2,339	8,077	516	72	4,513	559	7,994	127	1,332	1,342	7,596	2,666
1989	88	300	610	668	514	218	449	1,454	4,781	537	207	3,138	558	11,512	83	2,442	2,332	3,760	1,204
1990	310	10	140	557	685	269	1,294	3,705	11,793	575	196	4,209	469	7,035	275	3,515	994	2,828	642
1991	163	110	630	747	354	135	658	1,510	3,656	1,331	128	2,783	508	10,548	194	1,702	953	4,787	1,719
1992	153	490	100	580	201	205	469	1,331	5,548	486	153	2,708	525	5,267	406	3,034	106	1,119	825
1993	43	440	230	323	292	168	205	942	4,654	583	136	3,866	156	2,476	409	1,999	1,655	1,572	960
1994	65	40	120	130	167	173	100	884	4,665	667	96	3,626	452	4,078	392	2,526	1,730	1,152	657
1995	163	230	290	190	440	225	263	666	5,948	599	176	3,707	681	7,939	605	2,701	817	6,594	1,398
1996	183	540	200	408	435	208	1,103	1,521	7,989	993	251	4,850	303	6,026	630	2,440	600	4,095	995
1997	50	620	180	305	428	308	295	409	4,168	930	226	4,300	227	9,967	400	1,550	340	2,337	452
1998	110	366	157	290	473	323	460	2,388	11,761	1,292	248	6,306	432	7,300	316	4,995	834	6,911	1,327
1999	75	911	213	180	208	83	295	1,043	3,586	845	253	4,799	241	9,100	553			10,044	1,817
1988-96 avg	139	176	232	425	382	188	470	1,405	5,963	660	147	3,644	436	6,374	289	2,322	913	3,024	1,110
1997-99 avg	93	578	186	284	368	204	458	1,116	6,122	1,005	242	5,012	291	7,948	458	2,663	554	5,077	1,020
97-99/88-96	0.67	3.29	0.80				0.98	0.79	1.03	1.54	1.64	1.38	0.67	1.25	1.59	1.15	0.61	1.68	0.92

Goal	925	2,000	2,000	----3000----	----14,900----	---2000---	5,300	1,200	5,800	1,0(

4) Determine risk criteria

The next step is to determine the risk criteria appropriate to the ESA objective. Two decisions are required to establish the RER risk criteria: 1) the probabilities for exceeding the two thresholds; and, 2) the time over which this must occur. Unlike the technical exercise used to derive the population dynamic relationship and the population thresholds, the amount of risk and the duration over which it is measured are essentially policy decisions. We looked to past NMFS decisions and common scientific standards to guide us.

For jeopardy determinations, the standard is to not "...reduce appreciably the likelihood of survival and recovery ..." (50 CFR section 402.2). NMFS' 1995 biological opinion on the operation of the Columbia River hydropower system (NMFS 1995) considered the biological requirements for Snake River spring/summer chinook to be met if there was a high likelihood, relative to the historic likelihood, that a majority of populations were above lower threshold levels[3] and a moderate to high likelihood that a majority of populations would achieve their recovery levels in a specified amount of time. High likelihood was considered to be a 70% or greater probability, and a moderate-to-high likelihood was considered to be a 50% or greater probability (NMFS 1995). The Cumulative Risk Initiative (CRI) has used a standard of 5% probability of absolute extinction in evaluating the risks of management actions to Columbia River ESUs. The different standards of risk, i.e., 50% vs 5%, were based primarily on the thresholds that the standard was measured against. The CRI threshold is one of absolute extinction, i.e., 1 spawning adult in a brood cycle. The BRWG threshold is based on a point of potential population destabilization, i.e., 150-300 adult spawners, but well above what would be considered extinction. In fact, several of the populations considered by the BWRG had fallen below their thresholds at some point and rebounded, or persisted at lower levels. Since the consequences to a species of the CRI threshold are much greater than the consequences of the BWRG thresholds, the CRI standard of risk should be much higher (5%). Scientists commonly define high likelihood to be ≥95%. For example, tests of significance typically set the acceptable probability of making a Type I error at 5%. The basis of the RAP critical threshold is more similar to the BWRG lower threshold in that it represents a point of potential population destabilization. However, given the uncertainties in the data, especially when projected over a long-period of time, we chose a conservative approach both for falling below the critical threshold, i.e., 5%, and exceeding the recovery threshold, i.e., 80%.

We set this within the context of the jeopardy standard. It measures the effect of the proposed action against the baseline condition, and requires that the proposed action cannot result in a significant negative effect on the status of the species over the conditions that already exist. We

[3] The BRWG defined these as levels below which uncertainties about processes or population enumerations are likely to become significant, and below which qualitative changes in processes are likely to occur (BRWG 1994). They accounted for genetic risk, and some sources of demographic and environmental risk.

determined that the risk criteria consistent with the jeopardy standard would be that 1) the percentage of escapements below the critical threshold differs no more than 5% from that under baseline conditions; and, 2) the viable threshold must be met 80% of the time, or the percentage of escapements less than the viable threshold differs no more than 10% from that under baseline conditions. Said another way, these criteria seek to identify an exploitation rate that will not appreciably increase the number of times a population will fall below the critical threshold and also not appreciably reduce the prospects of achieving recovery. For example, if under baseline conditions, the population never fell below the critical threshold, escapements must meet or exceed the critical threshold 95% of the time under the proposed harvest regime.

The second element of the risk criteria is the time period over which risk is measured. The time period should be biologically relevant to the life-cycle of the species, and encompass a time period over which we have confidence in the relevance of the model assumptions and our management tools and strategies. With regard to life-history, Puget Sound chinook typically exhibit a four to five year life cycle with three to four years spent in the marine environment. So it would take a minimum of 5 years to begin to assess the long-term effects of changes in management. The same is true about the effects of environmental conditions. Recent evidence suggests that marine survival of salmon species fluctuates in response to 20-30 year cycles of climatic conditions and ocean productivity (Mantua 1997). This has been referred to as the Pacific Decadal Oscillation (PDO). Since declines in marine survival began to be detected in the early 1990's, marine survival may continue to be low for the next 10-20 years. The effects of land use generally take decades to detect. Therefore, the effect of changes in land use and the improvements from current restoration efforts won't be measurable for at least another 20 years. So it is reasonable to assume that conditions in the next twenty to thirty years might be similar to those observed over the past 10-15 years. In addition, we want to develop long-term harvest regimes that are protective of the resource. To do that we need to assess its effects over several generations.

Conversely, management and technology are changing rapidly, and management plans can be expected to be revised periodically to incorporate new information. For example, Genetic Stock Identification techniques were unknown in the field of applied fishery management twenty years ago, but are commonly used in management today. So it is likely that management twenty or thirty years from now may differ significantly from what we do now.

We again looked to previous NMFS decisions to guide us. The 1995 opinion looked at the likelihood that populations would remain above lower threshold levels over periods of 24 and 100 years, and the likelihood that populations would achieve recovery levels within 48 years. It recognized the same concerns described above when noting that "...based on comments from the [life-cycle] model review panel regarding potential propagation of discrepancies between projections and reality (Barnthouse et al. 1994), where conclusions from the two approaches differ (24 years vs 100 years), greater weight may be given to the 24-year assessments."(NMFS 1995).

Taking all these factors into account, we chose a 25 year period over which to evaluate our risk criteria. In doing this, we assumed model assumptions would be evaluated every 5-10 years and the RERs adjusted as necessary.

5) Identify population specific RER

The final step in determining RERs is to use a simulation model to iteratively solve for an exploitation rate that meets the risk criteria associated with the particular ESA objective, given the specified thresholds and estimated spawner/recruit parameters as follows:

1) Did the percentage of escapements less than the critical threshold value increase by less than 5 percentage points relative to the baseline?

and, either

2a) Does the escapement at the end of the 25 year simulation exceed the recovery level at least 80% of the time?

or

2b) Does the percentage of escapements less than the recovery level at the end of the 25 year simulation differ from the baseline by less than 10 percentage point?

The RER is the highest exploitation rate that can meet criterion 1 and criterion 2a or 2b (Figure 1). Since the RERs represent total fishing mortality standards, the baseline condition used for comparison in this context assumes zero harvest everywhere.

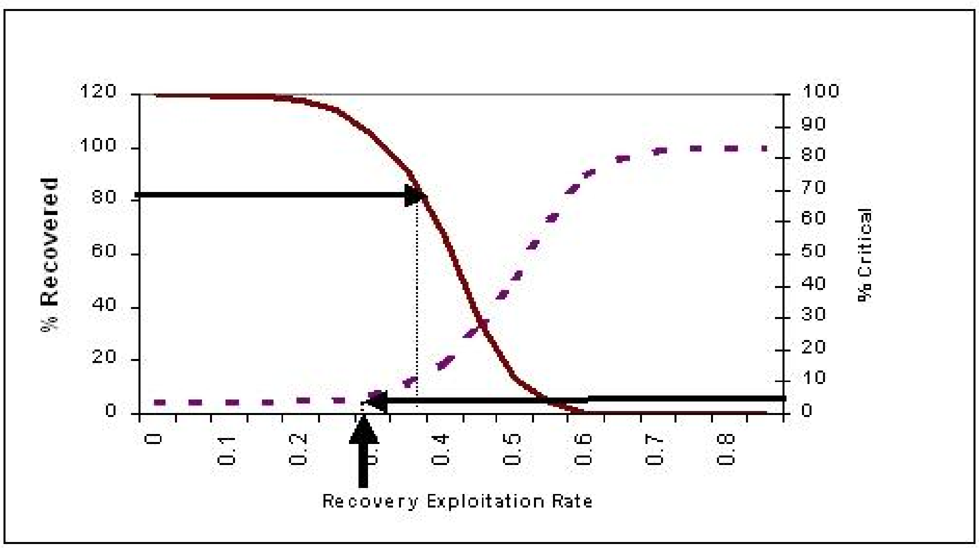


Figure 1. Example of RER application

Once identified, proposed fisheries are evaluated by considering the likelihood that they will meet the RERs. It is again important to emphasize that the RER analysis is made with respect to populations, while jeopardy determinations must be made with respect to the anticipated impacts to the ESU. That is, the failure to meet the RER standards for one population in an ESU with multiple populations does not necessarily indicate jeopardy to the ESU as a whole.

The approach combines the use of both measures of population abundance such as escapement, with exploitation rates in setting management objectives. Exploitation rates are used as the primary management objective for several reasons. They 1) represent a single measure of fishing related mortality across all fisheries; 2) are sensitive to population productivity; 3) are more robust to uncertainty in parameter estimates than calculations of escapement estimates; 4) separate harvest from other sources of mortality; 4) can be managed over a wide range of abundances; 5) better balance multiple resources needs, i.e., some proportion of the abundance always escapes and some proportion is harvested. Under fixed escapement management, all abundance above the goal is considered surplus and considered available for harvest (CCW 1994).

However, the RER is dependent on the escapement thresholds, and conditioned on achieving given levels of escapement with a certain frequency over a given time period. The integration with an abundance measure is important because it provides a better measure of the population's resilience to demographic and genetic risks. Post season assessments of escapement provide information on the temporal and spatial distribution of spawners and an evaluation of the model's predictions, i.e., are escapements occurring above or below the thresholds at the frequency that the model predicted? Escapement is also a better indicator of population status and progress towards recovery than exploitation rates.

DATA INPUT AND METHODS

The following section describes the model inputs, data sources, parameter estimation methods and mechanics of the RAP model, the implementation tool for the approach described previously. The RAP model is a Quick Basic[4] model that simulates population abundance, catch and escapement over time, and generates the probabilities of falling below the critical escapement threshold and meeting or exceeding the viable escapement threshold at the end of a given time period (e.g., 25 years) for a range of target total exploitation rates. The model does this for a user determined number of simulations (we've used 1000) and calculates the percentage of the total simulations for which the escapement falls below the critical threshold, and achieves viability by the end of the specified time period. The user may then assess the risks corresponding to the various exploitation rates. A sample input file is given in Table 5.

[4] Originally written by Bob Hayman and Jim Scott, minor adaptions by Norma Jean Sands.

Input Parameters:

Biological parameters that need to be estimated for model input include (information in brackets refers to corresponding text in Table 2 for easy identification):

- Variation in the Ricker c parameter (escapement); MSE from regression or dynamic model estimation [line 8 and 8a].
- Spawner/recruit parameters (could include two normal Ricker or Beverton-Holt parameters plus one for marine survival and one for freshwater flow [line 10, 10a].
- Gamma parameters for generating the marine survival index and freshwater flow variables [lines 10c and 10d].
- A critical escapement threshold, which is used to test risk assessment [line 16.
- A viable escapement threshold, which is used to test risk assessment [line 17].
- Gamma parameters for generating management error [line 18 and 18a].
- Starting population size for a calendar year by age [lines 19-23].
- Natural mortality per age group (is applied prior to fisheries mortalities and maturation in given year) [lines24-28].
- Maturation rate by age group (proportion that start migration to spawning grounds) [lines 29-32].
- Fishing rates on age group by preterminal and terminal fisheries (fisheries on mixed maturity fish and mature fish, respectively) [lines 33-36].

Parameter Estimation

Natural Mortality

Natural mortality per age group is considered to be a constant. Natural mortality is assumed to be 0.5 for 1-year olds, 0.4 for 2-year olds, 0.3 for 3-year olds, 0.2 for 4-year olds, and 0.1 for 5-year olds, after the practice of the Chinook Technical Committee (CTC 1999). These constants are also used in the Dynamic Population Recruit Model described below and used to estimate many of the parameters needed by the RAP model.

Spawner-Recruit Parameters

In order to use RAP to predict escapements over a period of years given target harvest rates, one first needs to determine the parameters for a spawner-recruit relationship for the population. For the current jeopardy analysis, the Ricker function (Ricker 1975) was modified, incorporating additional parameters for effects of marine survival and freshwater flow on survival:

$$\mathbf{R = e^{a} M^{b} S e^{(cS + dF)}}$$

Where R = recruits (i.e., harvest mortalities plus escapement),

a = productivity Ricker parameter,

M = marine survival index (indicates good to poor marine conditions),

b = marine survival parameter,

S = spawners,
c = density dependent Ricker parameter,
d = flow parameter, and
F = freshwater winter flow index.

Two methods were used for determining the Ricker spawner-recruit parameters: 1) standard ln regression which minimizes the difference between the observed recruits and predicted recruits for a cohort (Ricker 1975), and 2) dynamic equilibrium cohort reconstruction which minimizes the difference between predicted and observed spawners in a calendar year (Walters in press). Where information is available on stray rates, it minimizes the difference between predicted and observed natural-origin recruits.

Both of these methods require escapement estimates. Escapement is expressed in adult (age 3 and greater) spawners per population. Escapement data was obtained from the co-managers either through the Puget Sound Chinook fishery plan (WDFW/Tribes 2000)(Table 3) or directly through agency staff. Analyses were conducted at the SASSI population level (WDF *et al.* 1993). In order to relate the number of wild recruits resulting from the total spawners (including strays), an estimate of hatchery strays was need to subtract from escapement before adding to harvest mortalities and an estimate of straying of wilds to hatcheries was needed to add to the return. Where available, estimates of hatchery strays to spawning grounds and returns to the hatchery racks were obtained from coded-wire-tag recovery data. Estimates of straying by wild populations to hatcheries was 1-proportion hatchery origin.

Recruits were determined as catch plus indirect harvest mortalities plus escapement and are expressed as adult equivalents, i.e., the number of fishery mortalities reduced to the number of fish that would have made it to the spawning grounds in the absence of fishing. Exploitation rates estimated from indicator coded-wire-tagged hatchery populations were used to derive catches. Exploitation rates were expanded by the Chinook Technical Committee of the Pacific Salmon Commission to include indirect mortalities as well as landed mortalities (CTC 1999). Separate exploitation rates were derived for the terminal fisheries, in which all mortalities are assumed to be mature fish on their way back to the spawning grounds, and mixed population fisheries.

Standard ln(R/S) regression

Standard multiple regression was used incorporating the marine index variable and the flow variable. The linear regression equation was:

$$\mathbf{Ln\ (R/S) = a + b\ ln(M) + c\ S + d\ F}$$

Since this is done on a cohort basis, age composition of the escapement is needed to distribute the annual escapements to cohort escapements. Estimates of the percentage of the annual escapement that were from fingerling and yearling smolts were taken, as well as age composition within each group were derived from scale data collected from escapement surveys or fishery sampling. The escapement estimates by age are then used to reconstruct cohorts for each brood year for which data was available. Flow estimates were retrieved from the USGS database. Marine survival indices were taken from Chinook Technical Committee (CTC) analyses and are calculated as the proportion of the releases of hatchery index populations that survive to recruit to fisheries (CTC 1999). Multiple regression was used to derive estimates of the a-d parameters.

Dynamic Population Recruitment Model

The dynamic population recruitment model uses an iterative approach to fit population recruit parameters by solving for values that result in the least sum-square-error between predicted and observed annual total escapement. It does this by using the spawner recruit parameters to estimate cohort recruits and then uses CTC estimates of age specific harvest rates and maturation rates to determine harvest and escapement by age for the cohort. Escapements are then added up over ages in a calendar year to compare against observed escapement counts.

Input includes estimates of total spawning escapement, total wild spawners returning to system (by subtracting hatchery strays and adding wild strays to hatcheries), indices of marine survival and freshwater flow (optional), exploitation rates by age and fishery type (mixed or terminal), and natural mortality. Marine survival indices and flow estimates are derived as explained above.

Exploitation rates are estimated from index hatchery population recoveries (using coded-wire-tags to identify populations) as designated by the CTC. Coded-wire-tag recovery data comes from the Pacific States Marine Fisheries Commission (PSMFC) database (PSMFC 2000). Expansions of these tag recoveries to account for incidental mortalities are also taken from CTC reports (CTC 1999). Expansions are gear and fishery specific.

The model then uses an iterative process to determine which spawner-recruit parameters result in calendar year total escapements being closest to the observed values. For each set of spawner-recruit parameters, the model reconstructs the cohort by brood year, then applies the natural mortality, maturation and mortality rates by fishery (preterminal and terminal) and age to derive the escapements by age. Escapements are then added across ages to calculate calendar year escapement. These are then compared to the observed calendar year escapements. The model selects the set of spawner-recruit parameters that minimize the sum of $[\ln(\text{observed age 3-5 escapement}) - \ln(\text{predicted age 3-5 escapement})]^2$ across calendar years.

Variability in Recruits per Spawner Estimate

Variability in recruits per spawner is determined by multiplying the estimated ln(R/S) by a standard normal variate times the square root of the mean square error (MSE). The MSE is calculated from the regression ANOVA for the multiple regression method and from the difference between the natural log values of predicted and observed escapements in the Dynamic Population Recruitment Model.

Maturation Rates

Using the assumed values of natural mortality by age and exploitation rates by age and year, maturation rates by age and cohort are calculated by assuming that all age 5 fish mature and that all fish caught in the terminal fish are mature fish returning to spawn. This is done within the Dynamic Population Recruit Model. The maturation rate for a given cohort and age is calculated as:

$$\mathbf{MR_i = (TFM_i + E_i)/(TFM_i + E_i + NE_i)}$$

$$\mathbf{NS_i = MFM_i + TFM_i + E_i + NE_i}$$

$$\mathbf{NE_{i-1} = NS_i /(1-NM_i)}$$

Where MR_i = maturation rate of age i fish
TFM_i = terminal total fishing mortality of age i fish
E_i = escapement of age i fish
NE_i = cohort size at end of calendar year
NS_i = cohort size at beginning of calendar year, after natural mortality for that age as occuured
MFN_i = mixed population total fishing mortality of age i fish
NM_i = natural mortality for age i fish.

Maturation rates by age are calculated by starting with age 5 and the assumption $NE_5 = 0$. This assumes that all natural mortality for a give age occurs in winter between NE_i and NS_{i+1}.

Distribution parameters for determining the marine survival variable

The marine survival variable was assumed to be gamma distributed based on observed distribution of marine survival indices. The gamma parameters were derived from the mean and variance of the annual estimated marine survival index values for brood years 1983-1992. In general marine survival was high for 1973-1979 broods and low for 1983 to current broods (Figure 2). The distribution was drawn from marine survivals observed in brood years 1983 to 1992 to be consistent with our conservative assumptions about future marine survivals (Figures 3 and 4). The gamma parameters are derived from the mean and variance as:

$$\text{Gamma}\alpha = \text{mean-sq / variance}$$
$$\text{Gamma}\beta = \text{variance / mean}$$

The gamma parameters varied depending on the available information. For example, the gamma parameters used to generate the annual marine survival values for the Skagit stocks was: α = 1.5374 and β = 0.8661. An average North Puget Sound survival for those years was used since population specific information was not available.

Figure 2. Marine survival index for various Puget Sound fall hatchery populations

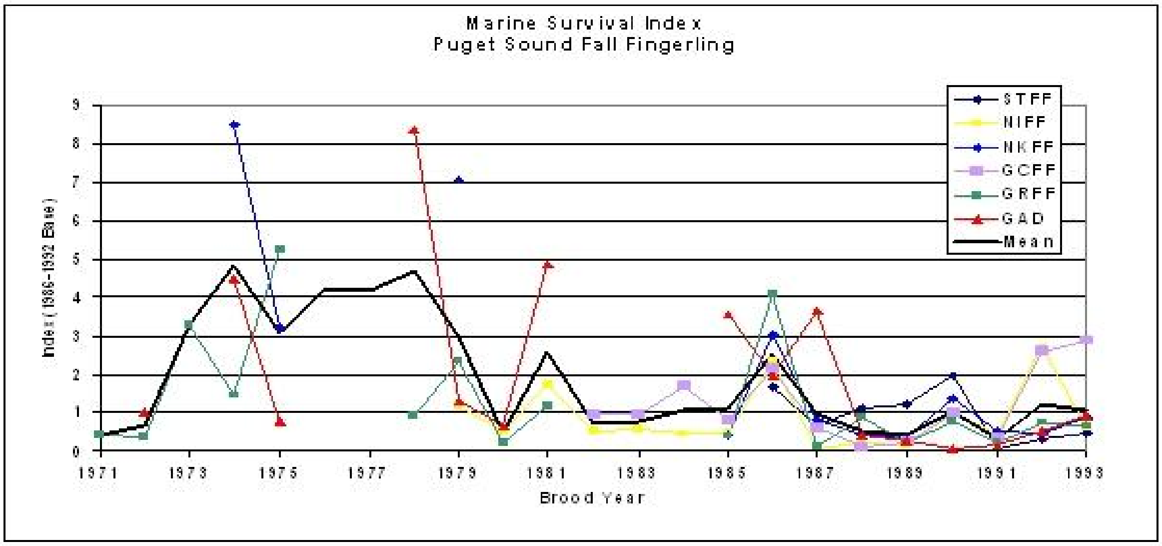
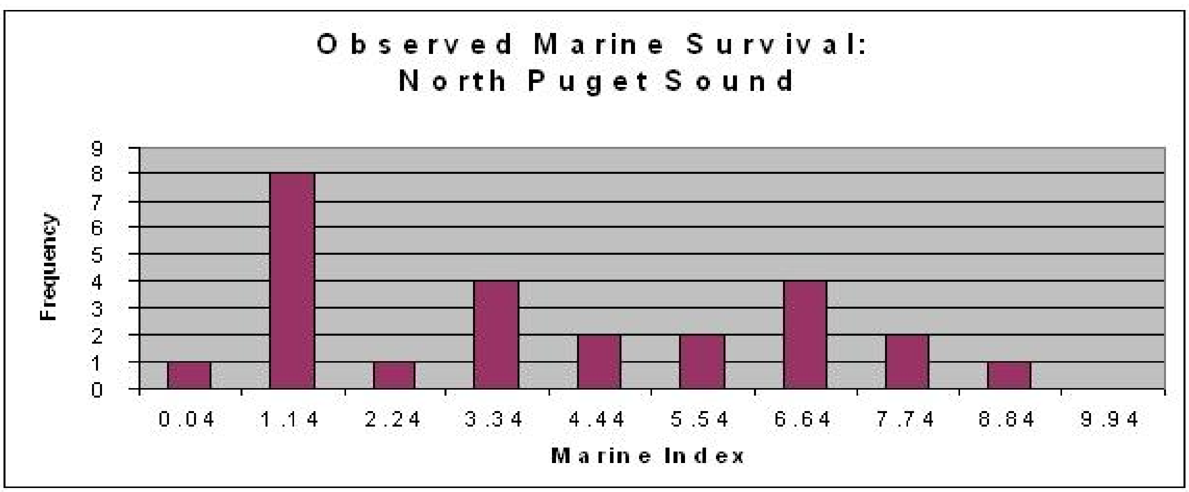
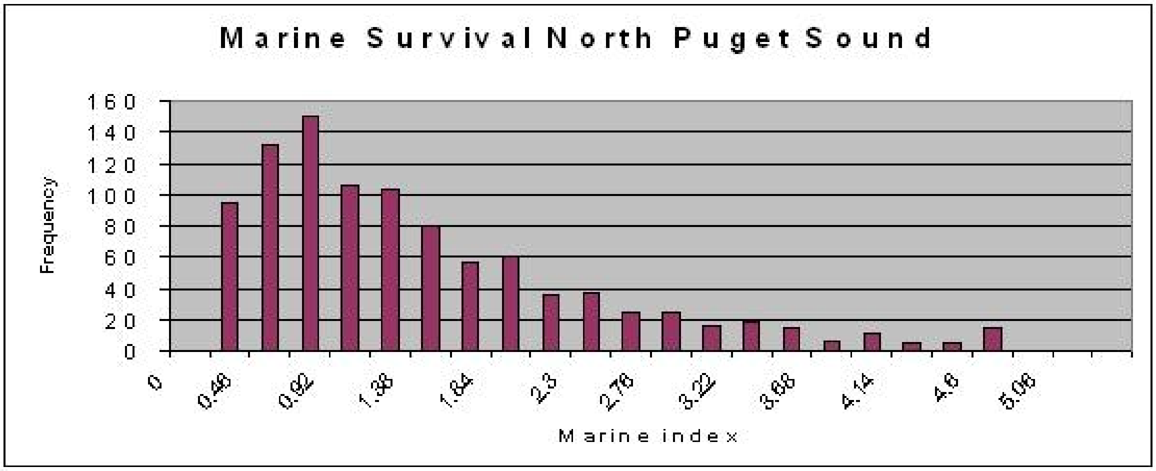


Figure 3. Distribution of observed North Puget Sound chinook marine index



Other environmental variables such as peak winter flows were treated similarly.

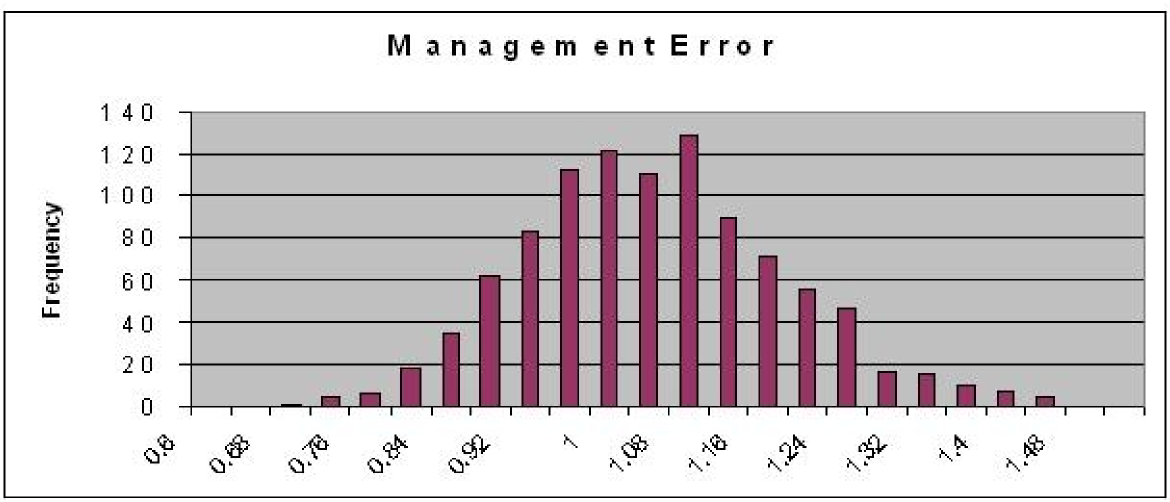
Figure 4. Gamma distribution of North Puget Sound chinook marine index



Gamma parameters for management error

Management error, the difference between target and actual exploitation rate, was also assumed to be gamma distributed. The parameters were derived by comparing postseason exploitation rate estimates with preseason FRAM ER targets for five Puget Sound populations for the years 1988-1993 (J. Gutman memo 2/24/98). The percent error (actual vs target) varied from –25% to +51.0% for Puget Sound Chinook populations. The gamma parameters used to express this variability were: $\alpha = 65.39$ and $\beta = 0.0158$ (Figure 5).

Figure 5. Gamma distribution for management error



Critical and Viable Escapement Levels
See discussion in Approach Overview.

Annual Fishing Rates by Age and Type of Fishery

Annual fishing rates on the recruits in the ocean, not taking into account subsequent natural morality and maturation, are estimated from the Dynamic Population Recruitment Model, since the total number of fish present in the ocean at each age is determined in the process of this analysis. The average rates by age and fishery type (mixed and terminal) over all years are used. These rates are used to partition target harvest rates in RAP by age and fishery.

Starting Population Size for Simulation Runs

The model uses an initial calendar year population size partitioned by age to seed the simulations. The average number of fish in each age class contributing to the last three years of runs are used. This seeds the model at current levels of population abundance.

RAP Model Description

The RAP model was written in Quick Basic. In executing the program, the model queries the user for an input file name. The file must have an extension of .SSD and the root name is used to identify output files, a summary file *.SUM, an escapement file *.ESC, and a brood year exploitation rate file?? *.BYR. The format of the input file is given in Table 2 (first two columns). The model has gone through several adaptations for current use and is still under development for full generality. The description given here is for the current Puget Sound Chinook RER analysis.

Since the spawner-recruit parameters predict recruits as total returns of a cohort contributing to the catch (including indirect mortalities) and escapement, a factor is needed to determine the number of age-1 recruits required to produce that adult return. The age-1 recruits can then be partitioned by age into catch and escapement, taking into account natural mortality and maturation rates. The cohort returns by age can then be added up over calendar years to give catches, exploitation rates, and escapements by calendar year for use in fisheries management risk assessment. The recruits at age-1 factor (f) is calculated as:

$$f = \mathbf{(1-N_1)(1- N_2)\{M_2+(1-M_2)(1- N_3)[\ M_3+(1-M_3)(\ldots\ldots)\quad]\}}$$

extending out to age 5 when all remaining fish mature. $\mathbf{N_i}$ = natural mortality at age i, $\mathbf{M_i}$ = maturation rate at age i.

Since management exploitation rates are expressed as adult equivalent (AEQ) ERs, AEQ factors must be calculated for each age group. The AEQ factor for age 5 fish is 100%, for the others it is calculated as:

$$AEQ_i = M_i + (1 - M_i)(1 - N_{i+1}) AEQ_{i+1}$$

Calculations of the model are done for each target exploitation rate as defined by the minimum, maximum and step values for the exploitation rate (see Table 1 lines 13-15). Each run is done for a set number of repetitions (e.g., 1000) and is done over a set number of years (e.g., 25). Each repetition starts with the initial population size given in the input file (lines 20-23). The initial population size will influence the risk assessment of falling below the critical level, so it should represent the current population status.

Within a year, natural mortality is applied first before any fishing mortality or maturation. Management error is applied as a multiplicative factor to the target exploitation rate. The exploitation rate is confined to be less than or equal to 0.99. Monte Carlo simulation is used to converge the input fisheries rates to result in a combined exploitation rate equal to the target rate. Thus, the input fisheries rates are used to distribute the fishing mortalities among the age groups and fisheries. Escapement is calculated for both total escapement and total adult escapement. For the next year, the cohort at age is advanced to the next age and a new age-1 cohort is calculated from the previous year's escapement.

When the 1000 repetitions of the 25-year runs have been completed, statistics are compiled for each target exploitation rate giving average observed exploitation rates per calendar year and per brood year, the minimum, maximum, and average escapement, the number of time escapement was below critical over 1000x25 years, and the number of times during the 1000 runs that the average escapement for the last 5 years was greater than the viable level.

Model Output

The output of the model gives the fishing mortality, percent of simulations below the critical threshold and the percent of escapements above the viable threshold at the end of 25 years, over a range of exploitation rates (Table 4). The user then finds the exploitation rates in the output table that satisfies the specified risk criteria.

EXAMPLE APPLICATION

The following is an of the application of the Dynamic Spawner-Recruit Model and the RAP model using the North Fork Stillaguamish fall chinook population as an example.

Two populations are distinguished in the Stillaguamish River, both have been chronically depressed. There is a summer chinook population in the North Fork Stillaguamish and a fall chinook population in the South Fork. The geometric mean aggregate escapement to the system over the last five years has been 1,174 (range 822-1,544) compared to an combined escapement goal of 2,000 (Table 2). However, the distribution of escapement has been uneven with most fish returning to the North Fork. Escapements of both the North Fork and South Fork populations have increased in recent years by 54% and 64%, respectively, over the long-term average. Escapements to the North Fork have averaged 904 over the last five years (range 599-1,292), compared with the 1988-1996 average of 651 (range = 466-1,331). The increases in escapements may have resulted, in part, from corresponding decreases in exploitation rates (67% to 48%), and as a result of returns from the supplementation program on the North Fork. Production in both systems is limited substantially by poor habitat conditions.

The supplementation program for the North Fork Stillaguamish is considered essential for recovery. The program was initiated in 1980. There is no on-station release program; rather brood population is collected annually from the river (the collection goal is 65 pairs) to provide for a release of 200,000 juveniles. The hatchery-origin fish are all marked and also serve as a harvest and survival indicator population. The marking also means that returning hatchery fish can be distinguished from natural-origin spawners for assessment purposes. Juveniles are acclimated and released volitionally from a large, spring-fed rearing pond. The program contributes a significant proportion of the annual escapement of North Fork summers.

A slightly higher proportion of the total harvest occurs in Canada than in Puget Sound. The majority of harvest in Puget Sound sport fisheries, and pre-terminal net and troll fisheries. The RER for the North Fork Stillaguamish summer population is 0.45, at the lower end of past exploitation rates (range 0.41-0.88). The projected 2000 FRAM ER for the Stillaguamish Management Unit is 0.15, well below the FRAM equivalent RER (0.32)[5].

[5]The Fishery Regulation Assessment Model (FRAM) is used by the co-managers and the PFMC to assess impacts from proposed harvest actions. Conversion to a FRAM equivalent RER was necessary so that a determination could be made as to whether the exploitation rates from the proposed harvest regimes were consistent with the RERs.

Table 3. Observed Stillaguamish age 3-5 escapement and hatchery contribution.

	Age 3-5 Total Escapement		
Return Year	Observed	% Supplemental	Natural Origin
1974	837		837
1975	990		990
1976	1,768		1,768
1977	1,218		1,218
1978	1,018		1,018
1979	861		861
1980	678		678
1981	520		520
1982	638		638
1983	320		320
1984	309		309
1985	1,148		1,148
1986	980		980
1987	1,065		1,065
1988	516		516
1989	537		537
1990	575	21.4%	452
1991	1,331	39.2%	809
1992	486	13.6%	420
1993	583	36.4%	371
1994	667	34.2%	439
1995	599	29.7%	421
1996	993	31.8%	677
1997	930		930

Table 4. Input data for Dynamic model

			Age 2			Age 3			Age 4			Age 5			Calculated AEQ			
Brood Year	Escpmnt	Marine Index	Mixed Maturity Fishing Rate	Maturation Rate	Mature Fishing Rate	Mixed Maturity Fishing Rate	Maturation Rate	Mature Fishing Rate	Mixed Maturity Fishing Rate	Maturation Rate	Mature Fishing Rate	Mixed Maturity Fishing Rate	Maturation Rate	Mature Fishing Rate	Age 2	Age 3	Age 4	Age 5
1974	837	8.50	0.12	0.01	0.95	0.32	0.22	0.90	0.56	0.89	0.22	0.40	1.00	0.06	0.58	0.84	0.99	1.00
1975	990	3.20	0.12	0.01	0.95	0.41	0.22	0.90	0.49	0.89	0.22	0.49	1.00	0.06	0.58	0.84	0.99	1.00
1976	1,768	7.20	0.13	0.01	0.95	0.35	0.22	0.90	0.43	0.89	0.22	0.49	1.00	0.06	0.58	0.84	0.99	1.00
1977	1,218	6.06	0.14	0.01	0.95	0.32	0.22	0.90	0.43	0.89	0.22	0.49	1.00	0.06	0.58	0.84	0.99	1.00
1978	1,018	6.34	0.15	0.01	0.95	0.30	0.22	0.90	0.37	0.89	0.22	0.49	1.00	0.06	0.58	0.84	0.99	1.00
1979	861	7.08	0.10	0.01	0.95	0.29	0.22	0.90	0.61	0.89	0.22	0.44	1.00	0.06	0.58	0.84	0.99	1.00
1980	678	4.67	0.12	0.01	0.95	0.42	0.22	0.90	0.40	0.89	0.22	0.33	1.00	0.06	0.58	0.84	0.99	1.00
1981	520	5.20	0.26	0.01	0.72	0.43	0.22	0.29	0.45	0.89	0.02	0.47	1.00	0.01	0.58	0.84	0.99	1.00
1982	638	3.83	0.08	0.01	0.95	0.24	0.22	0.55	0.38	0.89	0.04	0.77	1.00	0.00	0.58	0.84	0.99	1.00
1983	320	3.27	0.14	0.01	0.56	0.28	0.22	0.31	0.35	0.89	0.02	0.00	1.00	0.00	0.58	0.84	0.99	1.00
1984	309	2.64	0.11	0.01	0.82	0.25	0.22	0.43	0.48	0.89	0.01	0.33	1.00	0.01	0.58	0.84	0.99	1.00
1985	1,148	0.41	0.07	0.01	0.61	0.20	0.22	0.30	0.35	0.89	0.04	0.56	1.00	0.01	0.58	0.84	0.99	1.00
1986	980	2.35	0.08	0.01	0.62	0.23	0.22	0.76	0.49	0.89	0.05	0.48	1.00	0.00	0.58	0.84	0.99	1.00
1987	1,065	0.74	0.09	0.01	0.57	0.27	0.22	0.24	0.43	0.89	0.01	0.41	1.00	0.00	0.58	0.84	0.99	1.00
1988	516	0.78	0.08	0.01	0.49	0.23	0.22	0.72	0.60	0.89	0.02	0.35	1.00	0.00	0.58	0.84	0.99	1.00
1989	537	0.80	0.07	0.01	0.50	0.30	0.22	0.27	0.58	0.89	0.01	0.20	1.00	0.00	0.58	0.84	0.99	1.00
1990	575	1.66	0.11	0.01	0.23	0.37	0.22	0.24	0.22	0.89	0.01	0.28	1.00	0.02	0.58	0.84	0.99	1.00
1991	1,331	0.29	0.06	0.01	0.12	0.16	0.22	0.04	0.33	0.89	0.08	0.30	1.00	0.00	0.58	0.84	0.99	1.00
1992	486	0.37	0.07	0.01	0.10	0.21	0.22	0.16	0.29	0.89	0.01	0.37	1.00	0.00	0.58	0.84	0.99	1.00
1993	583	0.00	0.08	0.01	0.00	0.20	0.22	0.00	0.35	0.89	0.00	0.00	1.00	0.00	0.58	0.84	0.99	1.00
1994	667														0.50	0.72	0.90	1.00

Table 5. Dynamic population recruit model

		Age 2									Age 3							
Brood Year	Recruits	Recruits	Post Natural Mortality	Mixed Maturity Mortality	Post Mortality Cohort	Mature Run	Mature Mortality	Prespawn Mortality	Escpmnt	Post Maturation Cohort	Post Natural Mortality	Mixed Maturity Mortality	Post Mortality Cohort	Mature Run	Mature Mortality	Prespawn Mortality	Escpmnt	Post Maturation Cohort
1974	3,978	11,458	6,875	826	6,049	74	71	0	4	5,975	4,182	1,320	2,862	627	564	0	63	2,235
1975	2,601	7,492	4,495	524	3,971	49	46	0	2	3,922	2,746	1,131	1,615	354	318	0	35	1,261
1976	3,048	8,780	5,268	709	4,559	56	53	0	3	4,503	3,152	1,115	2,037	446	402	0	45	1,591
1977	3,386	9,752	5,851	840	5,011	62	59	0	3	4,950	3,465	1,125	2,340	513	461	0	51	1,827
1978	3,534	10,179	6,107	932	5,176	64	60	0	3	5,112	3,578	1,058	2,520	552	497	0	55	1,968
1979	2,279	6,563	3,938	409	3,529	43	41	0	2	3,485	2,440	696	1,743	382	344	0	38	1,361
1980	2,730	7,862	4,717	561	4,156	51	49	0	3	4,105	2,873	1,197	1,677	367	331	0	37	1,309
1981	3,022	8,704	5,223	1,348	3,875	48	34	0	13	3,827	2,679	1,147	1,532	336	97	0	238	1,196
1982	2,735	7,877	4,726	371	4,356	54	51	0	3	4,302	3,011	709	2,303	505	277	0	227	1,798
1983	1,855	5,342	3,205	444	2,761	34	19	0	15	2,727	1,909	527	1,382	303	94	0	209	1,079
1984	2,253	6,488	3,893	423	3,470	43	35	0	8	3,427	2,399	600	1,799	394	170	0	225	1,405
1985	992	2,858	1,715	112	1,603	20	12	0	8	1,583	1,108	220	888	195	58	0	136	693
1986	2,266	6,526	3,916	300	3,616	44	28	0	17	3,571	2,500	577	1,923	421	320	0	101	1,502
1987	1,293	3,725	2,235	194	2,041	25	14	0	11	2,015	1,411	387	1,024	224	54	0	170	799
1988	1,307	3,766	2,260	176	2,083	26	13	0	13	2,058	1,440	330	1,110	243	175	0	68	867
1989	1,094	3,150	1,890	127	1,764	22	11	0	11	1,742	1,219	368	851	186	50	0	136	665
1990	1,910	5,501	3,301	360	2,941	36	8	0	28	2,904	2,033	750	1,283	281	67	0	214	1,002
1991	889	2,561	1,536	94	1,442	18	2	0	16	1,424	997	159	838	184	7	0	176	655
1992	793	2,285	1,371	99	1,273	16	2	0	14	1,257	880	188	692	152	24	0	127	540
1993	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1994	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 6. Observed and predicted escapement, resulting spawner-recruit parameters

	Estimate
a - Intercept	1.4432
b - Spawners	1.0089E-03
c - Marine	0.4486
d - Flow	0.0000E+00
SSE	3.3076E+00

	Age 3-5 Total Escapement				Age 3	Age 4	Age 5	SSE ln(obs)-ln(pred)
Return Year	Observed	% Supplemental	Natural Origin	Predicted	Predicted	Predicted	Predicted	
1974	837		837					
1975	990		990					
1976	1,768		1,768					
1977	1,218		1,218		63			
1978	1,018		1,018		35	547		
1979	861		861	304	45	215	44	1.0840
1980	678		678	580	51	504	25	0.0244
1981	520		520	669	55	579	35	0.0632
1982	638		638	765	38	687	40	0.0328
1983	320		320	377	37	293	47	0.0266
1984	309		309	693	238	432	22	0.6517
1985	1,148		1,148	722	227	456	39	0.2150
1986	980		980	1,003	209	767	27	0.0005
1987	1,065		1,065	732	225	486	21	0.1406
1988	516		516	705	136	513	56	0.0975
1989	537		537	449	101	309	39	0.0323
1990	575	21.4%	452	702	170	516	16	0.1941
1991	1,331	39.2%	809	419	68	319	32	0.4328
1992	486	13.6%	420	399	136	242	21	0.0025
1993	583	36.4%	371	430	214	198	18	0.0217
1994	667	34.2%	439	745	176	551	18	0.2806
1995	599	29.7%	421	458	127	287	44	0.0072
1996	993	31.8%	677	294	0	270	24	

1997	930		930					

Table 7. Example input file for the Risk Assessment Procedure model (North Fork Stillaguamish summer example).

Values, comma separated	Description	How used in our analyses	Line no.
"NF Stillaguamish summer" ,	Title	Described population and variations being run.	1
1,	Random seed	Constant for all runs	2
1000,	Number of runs	Constant for all runs	3
25,	Number of years	Constant for all runs	4
2,5,	Minimum and maximum age (must be 2 and 5 for current version of model)	Constant for all runs	5
0.001,	Convergence criterion (percent error) for target exploitation rate	Constant for all runs	6
"NO",	Debug file flag	NO (except for debugging)	7
"YES",	Stock-recruit variation ("YES" or "NO")	YES	8
0, 0.23625	Parameters for stock-recruit variation (ln normal distribution) and correlation parameter between successive years.	First (and last) parameters are zero; 2^{nd} is MSE for the density dependent variable for given stock.	8a
"NO",	Marine survival variation ("YES" or "NO"); used to determine marine survival when spawner recruit relationship is expressed in spawners to smolts. If Yes provide beta A and B values.	Always NO	9
"Ric4",	Form of spawner recruit function: Ric1=S exp(a(1-S/b)) where b=S-replacement; Ric2=a S exp(-bS); Ric3=exp(a) S exp(cS+dF) M^b; Ric4=exp(a) S exp(cS) M^b	Ric3 or Ric4	10
1.4432,0.4486,-1.00891e-3,	Ricker a; b (Marine); c (Escapement); d (Flow)	Determined by S/R analysis	10a
1.5374, 0.8661,	Gamma A and B parameters for generating marine survival index	Based on variability in estimated survival indices for 1977-1992.	10b
0,	Gamma A and B parameters for generating flow index	Based on variability in estimated survival indices for period	10c
0,	Number of breakpoints	Constant	11
1,	Level to use as base regime	Constant	12
0.25,	Base exploitation rate (ER)	Varied depending on range and precision desired. With numbers given here the range would be from 0 (0*0.5) to 1 (2*0.5) with a step of 0.1 (0.2*0.5)	13
0.04,	Step size for ER as percent of base		14
0, 3.5,	Minimum and maximum ER as percent of base		15
300,	Critical escapement level	Stock specific based on VSP guidance	16

Values, comma separated	Description	How used in our analyses	Line no.
552,	Recovery escapement level	Determined from S/R analysis; a MSY level for recent years.	17
"YES",	Include error ("YES" or "NO") in exploitation rate management	Constant	18
65.3946,0.0158,	Gamma parameters for management error (All except STL and WRS)	Constant, from MES analysis (J. Gutmann)	18a
15966,	Age 1 initial cohort	Based on most recent forecast or most recent three brood year information.	19
4968,	Age 2 initial cohort		20
1188,	Age 3 initial cohort		21
1000,	Age 4 initial cohort		22
106,	Age 5 initial cohort		23
0.50,	Age 1 natural mortality	Constant, taken from CTC use	24
0.40,	Age 2 natural mortality		25
0.30,	Age 3 natural mortality		26
0.20,	Age 4 natural mortality		27
0.10,	Age 5 natural mortality		28
0.01, 0.58,	Age 2 maturation rate and AEQ	From CTC	29
0.22, 0.84,	Age 3 maturation rate and AEQ		30
0.89, 0.99,	Age 4 maturation rate and AEQ		31
1.0000, 1.0000	Age 5 maturation rate and AEQ		32
0.11,0.65,	Age 2 preterminal and mature exploitation rates	From CTC	33
0.29,0.53,	Age 3 preterminal and mature exploitation rates		34
0.43,0.09,	Age 4 preterminal and mature exploitation rates		35
0.38,0.02,	Age 5 preterminal and mature exploitation rates		36
"Test.Out",	Name of output file	Constant	37

Table 8. Example output from the RAP model.

Title: NF Stillaguamish summer; Marine Survival (1983-1992); Mgmt Error

Input File: NSTL831

Date: 2-13-2000

Basic Simulation Parameters:
Number of Years= 25
Number of Repetitions= 1000
HR Convergence Criteria= .001

Population Recruit Function Parameters:
Function Type: RIC4
a= 1.4432
b= .4486
c=-.0010089

Stock-Recruit Variability Parameters:
MSE= .232625
Res Cor= 0

Marine Survival Rate Parameters:
Gamma A= 1.5374
Gamma B= 0.8661

Fishery Regime Parameters:
Fixed HR= .25

Management Variability Parameters:
Gamma A= 65.3946
Gamma B= .0158

Regime Evaluation Parameters:
Critical Escapement Level= 300
Recovery Escapement Level= 552

SUMMARY STATISTICS
All statistics are average over repetitions

Tgt Rate	CYr Rate	BYr Rate	Mortality	% Critical	% Recovered
0.000	0.000	0.000	0	0.3	96.1
0.050	0.052	0.051	80	0.3	96.5
0.100	0.103	0.103	163	0.3	94.2
0.150	0.155	0.155	249	0.3	95.1
0.200	0.207	0.207	337	0.3	94.4
0.250	0.258	0.258	429	0.3	93.7
0.300	0.310	0.310	516	0.4	90.8
0.350	0.362	0.362	609	0.5	88.9
0.400	0.414	0.415	701	0.8	83.5
0.450	**0.465**	**0.466**	**789**	**1.2**	**79.7**
0.500	0.516	0.516	862	2.5	69.4
0.550	0.568	0.570	921	6.0	56.1
0.600	0.620	0.616	953	13.3	39.2
0.650	0.672	0.674	925	30.7	19.1
0.700	0.723	0.722	856	54.7	3.8
0.750	0.774	0.768	702	77.7	0.6
0.800	0.823	0.819	535	88.7	0.0
0.850	0.869	0.869	412	95.5	0.0

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APPENDIX A

Basic Concepts
Implementation of the ESA requires an understanding of a number of key procedures, concepts, and phrases. The complexities of the ESA, and of conservation biology, can make gaining that understanding difficult. While it is well beyond the scope of this report to provide a general review of the Act, it is essential to have a basic understanding of the Act and associated regulations prior to embarking on the development of an assessment framework for Pacific salmon.

Definitions
Four sections of the Act that are particularly relevant were previously introduced:

> Section 4(d) provides the Secretary the discretion for species listed as threatened to issue such regulations as he deems necessary and advisable to provide for the conservation of such species. *Conservation* is defined by the ESA to mean:
>
> > "...to use and the use of all methods and procedures which are necessary to bring any endangered species or threatened species to the point at which the measures provided pursuant to this Act are no longer necessary."
>
> Section 4(f) directs the Secretary to develop and implement recovery plans for the conservation and survival of listed species unless he finds that such a plan will not promote the conservation of the species.
>
> Section 7(a)(2) requires each Federal agency, in consultation with the Secretary, to insure that any action they authorize, fund, or carry out is not likely to jeopardize the continued existence of a listed species or result in the destruction or adverse modification of designated critical habitat. NMFS evaluates the effects of proposed federal actions on listed species by applying the standards of section 7(a)(2) of the ESA as interpreted by the NFMS/FWS joint consultation regulations (50 CFR Part 402). The consultation regulations define *"jeopardize the continued existence"* of to mean:
>
> > "...to engage in an action that reasonably would be expected, directly or indirectly, to reduce appreciably the likelihood of both the survival and recovery of a listed species in the wild by reducing the reproduction, numbers, or distribution of that species" (50 CFR section 402.2).
>
> The term *"survival"* is defined by the Handbook for section 7 consultations as follows:
>
> > "For determination of jeopardy/adverse modification: the species' persistence as listed or as a recovery unit, beyond the conditions leading to its endangerment, with sufficient resilience to allow for potential recovery form endangerment. Said another way, survival is the condition in which a species continues to exist into the future while retaining the potential for recovery. This condition is characterized by a species with a sufficient population, represented by all necessary age classes, genetic heterogeneity, and number of sexually mature individuals producing viable offspring, which exists in an environment providing all requirements for completion of the species' entire life cycle, including reproduction, sustenance and shelter."
>
> The consultation regulations define *"recovery"* to mean:
>
> > "improvement in the status of listed species to the point at which listing is no longer

appropriate under the criteria set out in section 4(a)(1) of the Act".

Section 10(a)(2)(b)(iv) requires that one condition for granting an individual an exception to section 9 take prohibitions is that "the taking will not appreciably reduce the likelihood of the survival and recovery of the species in the wild." Note the similarities with the NMFS/FWS regulatory definition of jeopardy associated with section 7 consultations.

Section 7 Formal Consultation
A section 7 formal consultation is a process to determine if a proposed Federal agency action is likely to jeopardize the continued existence of a listed species or destroy or adversely modify critical habitat. The consultation results in a biological opinion, "setting forth the Secretary's opinion, and a summary of the information on which the opinion is based, detailing how the agency action affects the species or its critical habitat. If jeopardy or adverse modification is found, the Secretary shall suggest those reasonable and prudent alternatives which he believes would not violate subsection (a)(2) and can be taken by the Federal agency or applicant in implementing the agency action" (section 7(b)(3) of the ESA). Contents of a biological opinion are identified in the joint consultation regulations, and additional guidance is provided in the Handbook. The joint consultation regulations require a biological opinion to include: 1) a summary of the information on which the opinion is based; 2) a detailed discussion of the effects of the action on listed species or critical habitat (50 CFR 402.14(f)). The Handbook elaborates on these requirements, and provides an outline for a standard biological opinion. Major topics are: 1) description of the proposed action; 2) status of the species/critical habitat; 3) environmental baseline; 4) effects of the actions; 5) cumulative effects; 6) conclusion; and, in the event of a jeopardy conclusion, 7) reasonable and prudent alternatives.

The conclusion of the biological opinion contrasts the potential status of the species under two scenarios, with and without the proposed action. Scenario 1 (no action baseline) includes:

1) the Environmental Baseline, consisting of : a) past and ongoing human and natural factors leading to the current status of the species; b) State, tribal, local, and private actions within the action area already affecting the species or that will occur contemporaneously with the consultation in progress; c) unrelated Federal actions within the action area affecting the same species or critical habitat that have completed formal or informal consultations; and d) Federal and other actions within the action area that may benefit listed species or critical habitat; and,

2) Cumulative Effects, consisting of future State, tribal, local and private actions, not involving a Federal action, that are reasonably certain to occur within the action area.

Scenario 2 (action effect) includes all components of Scenario 1 plus the direct and indirect effects of the proposed action. If relative to Scenario 1, Scenario 2 appreciably reduces the likelihood of both survival and recovery, then the opinion would conclude that the proposed action is likely to jeopardize the continued existence of the species.

Section 10 Incidental Take Permits
Section 10(a)(1)(B) of the Act provides for the "incidental take" of endangered and threatened species of wildlife by non-Federal entities. Incidental take is defined by the Act as take that is "incidental to, and not the purpose of, the carrying out of an otherwise lawful activity." A permit for incidental take may be issued if the Secretary authorizing any taking determines that:

1) the taking will be incidental
2) the applicant will, to the maximum extent practicable, minimize and mitigate the impacts of such taking;
3) the applicant will ensure that adequate funding for the plan will be provided
4) the taking will not appreciably reduce the likelihood of the survival and recovery of the

species in the wild; and,

5) other measures identified by the Secretary as being necessary and appropriate for the purpose of the plan will be met.

Issuance of an incidental take permit is also a Federal action subject to the section 7 consultation process previously discussed. It is the policy of the Services to integrate from the time of application, the section 7 and section 10 processes, and to regard them as concurrent and related, not independent and sequential, processes. As a consequence, the definitions and framework established for section 7 consultations are equally applicable to a section 10 incidental take permit.

Recovery Plans

Section 4(f) of the Act directs the Secretary to develop and implement recovery plans for the conservation and survival of listed species unless he finds that such a plan will not promote the conservation of the species. The plan, which is applicable to all Federal agencies, includes:

1) a description of such site-specific management actions as may be necessary to achieve the plan's goal for the conservation and survival of the species;

2) objective, measurable criteria which, when met, would result in a determination, in accordance with the provisions of this section, that the species no longer be listed; and

3) estimates of the time required and the cost to carry out those measures needed to achieve the plan's goal and to achieve intermediate steps toward that goal.