Chapter 1
An Overview of PATH and Retrospective Analyses

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This chapter provides an overview of PATH (Plan for Testing and Analyzing Hypotheses), and the contents of this preliminary report on retrospective analyses. Section 1.1 provides an overview of the background and objectives of PATH, and the set of activities either completed or planned until the end of September 1996 to achieve the stated objectives. It is intended to inform readers who have not been intimately involved with PATH activities over the past few months. Section 1.2 describes the hypotheses framework used to structure the retrospective analyses described in the following chapters. Section 1.3 provides brief summaries of the following chapters, describing their contents and how they relate to the PATH hypothesis framework. These summaries have been drawn from individual chapters, but have not been reviewed by all PATH participants. A consensus document which synthesizes conclusions across all chapters is to be completed by the end of October 1996. Most of the figures and tables in this report are contained at the end of each chapter.

1.1 Background and Objectives of PATH

During the period from 1990 - 1994, the Bonneville Power Administration (BPA), the Northwest Power Planning Council (NPPC), the National Marine Fisheries Service (NMFS), and various state and tribal resource agencies worked together to compare and enhance the models used to evaluate management options intended to enhance recovery of depleted Columbia River Basin salmon stocks. In 1994, a Scientific Review Panel (SRP) completed an interim report in which they concluded that there were three major differences between the modeling systems: 1) the distribution of survival over the life span; 2) the effect of flow on survival; and 3) the benefit of transportation. The panel felt that as long as these differences exist the models were going to give different answers in a fairly predictable fashion, rendering further analysis of the details of model behavior a relatively unproductive activity. The panel concluded that it would be more fruitful to focus on describing and attempting to resolve the fundamental issues, through hypothesis formulation and testing. This was the genesis of the Plan for Analyzing Testable Hypotheses (PATH).

The NMFS 1995 Biological Opinion on the Federal Columbia River Power System (page 124, Recommendation 17) stated that "The BPA shall participate with NMFS in activities to coordinate the regional passage and life cycle models and to test the hypotheses underlying those models." NMFS noted that the emphasis should shift to analyses that test the different assumptions and hypotheses underlying the models, rather than refining our understanding of how the models are different. NMFS concurred with the recommendation of the SRP to conduct an analysis of alternative hypotheses. While PATH was designed to respond to the NMFS 1995 Biological Opinion, it also meets specific needs of the NPPC Fish and Wildlife Program.[1]
Though initiated by written directives (i.e. the SRP, NMFS and NPPC), the direction of PATH responds to periodic meetings with senior management and policy personnel in NMFS, BPA, U.S. Army Corps of Engineers (COE), NPPC, Washington Dept. of Fisheries (WDF), Oregon Dept. of Fish and Wildlife

[1] Section 3.2 (adaptive management; integration of monitoring, evaluation and research into a unified framework to assist decision makers); Section 4.2A (system-wide analysis of major uncertainties); and Section 5.0A (specific hypotheses).

(ODFW), Idaho Dept. of Fish and Game (IDFG), and the Columbia River Intertribal Fisheries Commission (CRITFC). The policy group currently directing PATH is a Subcommittee of the Recovery Plan Implementation Team. PATH's primary objectives were originally defined as:

1. Determine the overall level of support for key alternative hypotheses based on existing information, providing guidance to management agencies. Propose other hypotheses and/or model improvements that are more consistent with the data.

2. Assess the ability to distinguish among competing hypotheses from future information. Advise various institutions (NMFS, NPPC, BPA, USFW) on research, monitoring and adaptive management experiments which would maximize the rate of learning and clarify decisions.[2]

PATH is an iterative process of defining and testing a logical framework of hypotheses relating to the Columbia River anadromous salmon ecosystem, while moving towards stock recovery and rebuilding. Iteration within the PATH process occurs as this logical framework is revised over time in response to improvements in both information and analytical methods. The framework is intended to:

- bound the anadromous salmon ecosystem components under consideration in the Columbia River Basin;

- lay out alternative hypotheses for the functioning of these ecosystem components, their response to management actions, and their ultimate impact on salmonid production;

- compile and analyze information to assess the level of support for alternative hypotheses relevant to key management decisions, identifying knowledge and data gaps that could be filled through management experiments, research and monitoring;

- provide guidance to the development of regional programs that would stabilize, ensure persistence, and eventually restore depressed salmon stocks to self-sustaining levels; and

- provide a structure for an adaptive learning approach to development and implementation of a regional salmonid recovery program.

The logical framework developed in PATH is driven by the management questions of interest, the alternative hypotheses relevant to these questions, and the data available to test these hypotheses. The purpose of this exercise is not to simply compare the existing belief systems embodied in the various models, though modeling plays a role. Instead, the hope is to lay out a framework without reference to existing models with the expectation that this will provide a novel foundation for learning, decision-making and action. This has already started to develop improved analytical tools.

1.2 Activities Planned to Achieve PATH Objectives

Procedurally PATH consists of a series of workshops, technical meetings, analytical activities and reporting/review steps. These steps are repeated several times in essentially successive orbits on an upward

[2] Barnthouse, L.W. and D. Marmorek; April 5, 1995. A new direction for Columbia River Basin Salmonid Model Evaluation and Use.

spiral towards greater understanding and better decision making. The workshops and reports force participants to complete tasks, and provide for fruitful exchange, feedback and internal peer review. Both a core set of 25 PATH participants, and an extended set of 15 - 20 occasional participants, provide input to analytical activities. Progress toward specific tasks is motivated by a PATH Planning Group, consisting of five representatives of each of the major institutional groups (NMFS, States, Tribes, NPPC, power system operating agencies), and the PATH facilitator.

1.2.1 Progress to date

In its first year of existence, PATH has already made considerable progress. Specific achievements include:

- clarification of management decisions with senior personnel in the major institutions;
- development of hypothesis frameworks and sets of alternative hypotheses relevant to management decisions;
- considerable data reconnaissance, acquisition and refinement prior to completion of retrospective analyses of specific hypotheses;
- detailed retrospective analyses for Level 1, Level 2, and Level 3 Hypotheses related to hydrosystem, habitat and hatchery management decisions (Figure 1-1);
- two workshops, each involving about 30 research scientists, to plan retrospective and prospective analyses, review the results of preliminary analyses and assess their implications for management decisions;
- a series of technical meetings of task work groups to advance progress on specific retrospective analyses;
- novel development and/or application of analytical tools to assist in decision making [e.g. three-level hypothesis framework; decision trees for hydrosystem, habitat and hatchery management decisions; a Bayesian maximum likelihood estimation (MLE) framework to evaluate ability of different models to predict stock-recruitment patterns; several different statistical analyses (cluster analyses, multiple regression, analysis of variance and covariance) to assess patterns implied by spatial and temporal contrasts in stock-recruitment; a method for evaluating survival trends in the freshwater spawning and rearing life stage; an approach towards prospective analyses for determining the required improvements in life cycle survival; a plan for formal decision analysis to assess through a variety of performance measures the effects of different combinations of actions in each of the four H’s (hydrosystem, hatcheries, habitat, harvest) under different future climate scenarios.];

Figure 1-1: Progress made to date on key hypotheses. Chapter numbers refer to this document. The diagram is a simplified representation which excludes delayed effects.

- a set of recommendations for future research, monitoring and experimentation that arise out of the retrospective analyses conducted in FY 96 (partly complete);

- a set of eight reports describing: 1) the conceptual direction and general hypothesis framework for PATH; 2) the results of a workshop at Camp Cascade, Oregon in October 1995 to design retrospective analyses; 3) a preliminary report on retrospective analyses; 4) a set of four peer reviews of the preliminary analyses; 5) a summary of the peer reviews, sent to members of the Implementation Team; 6) a summary of the second workshop held at Warm Springs, Oregon in April 1996 to develop plans to complete retrospective analyses and plan future prospective analyses; 7) a draft final report on retrospective analyses for internal review (distributed August 1996); and 8) this final retrospective report, distributed to the review panel September 11, 1996; and

- a set of presentations on progress by PATH participants to the Implementation Team (IT) Committee on PATH, other IT representatives, members of the NPPC, and the public; meetings with the Research Review Group of the IT; and meeting with the Independent Scientific Group (now the Independent Scientific Advisory Board) to coordinate our activities.

Virtually all of the above work has focused on spring-summer chinook. In addition to advancing this work to the prospective domain, major goals for the next fiscal year are to complete similar analyses for fall chinook and steelhead.

1.2.2 Future Activities

The federal government's 1997 fiscal year extends from October 1, 1996 to September 30, 1997. For FY 97, PATH has five goals concerned with retrospective analyses:

R1. Publish the results of retrospective analyses on spring/summer chinook completed in FY 96 in the peer-reviewed literature.

R2. Complete a consensus document describing the main conclusions of the FY 96 retrospective analyses and the implied research and monitoring priorities.

R3. Follow-up retrospective analyses for hydrosystem, hatchery, habitat, and harvest impacts, so as to better define quantitatively the impact each of these have had on spring/summer chinook stock indicators

R4. Complete data acquisition and run reconstructions for fall chinook and steelhead stocks within the Columbia River Basin, as well as spring/summer stocks outside of the Basin (e.g. Alaska, Canada).

R5 Design and complete retrospective analyses for fall chinook and steelhead stocks.

PATH's FY 97 goals for prospective analyses are as follows:

P1. Estimate the improvement in life cycle survival required to reach various salmon objectives (survival, recovery, rebuilding) and the uncertainty associated with these estimates.

P2. Develop a formal decision analysis framework, which provides a common framework for incorporating alternative management action packages, alternative passage models (with their respective posterior probabilities based on retrospective analyses), and a variety of performance measures.

P3. Use of the decision analysis approach and other methods to assess the rate of learning associated with alternative sets of management actions, research and monitoring activities, and adaptive management experiments.

This set of goals obviously will mean concurrent efforts on retrospective and prospective analyses, and concerted efforts at integration and coordination.

Third PATH Workshop 3 and Follow-up Activities

The third PATH workshop (planned for the week of October 7, 1996) will complete the consensus document (goal R2) and develop detailed plans for each of the other retrospective goals. The external peer review of this document will be an important input to the workshop. With respect to prospective analyses, the workshop will review progress already made on required improvements in life cycle survival (goal P1), and consider in greater detail plans for the decision analysis framework (goal P2). The decision analysis framework will permit the calculation of the expected value of various performance measures (e.g. probability of survival, probability of recovery, expected rates of learning), given a number of different hypotheses about key processes and life history stages, and their associated probabilities. In some cases these probabilities may be computed from retrospective analyses, whereas in other cases they may need to be more subjectively assigned.

The third workshop will be followed by a number of task group activities, on both retrospective and prospective analyses, with occasional technical meetings to review progress. It is intended at this time to find a journal interested in publishing some of the retrospective analysis papers contained within this report.

Fourth PATH Workshop and Follow-up Activities

As occurred in the past year, we intend to have a mid-course workshop to review progress, near the end of March, 1997, preceded by an external peer review of new analyses. This meeting (PATH Workshop #4) will serve to review the pilot analyses completed to date on fall chinook and steelhead stocks, and to determine the remaining steps required to complete retrospective analyses of these species. For spring/summer chinook, the workshop will focus on both the follow-up retrospective analyses completed in the previous quarter, as well as the draft prospective analyses. These two components are closely interdependent, as estimates of the effects on stock indicators from retrospective analyses will be used in the prospective work.

A major component of this workshop will be an examination of the pilot decision analysis framework and discussion on how to further improve it. We will explore alternative research designs and adaptive management strategies, and consider formal methods to assess the expected amount of learning associated with each option. The workshop will conclude with a set of clear assignments, deliverables and deadlines, for both retrospective and prospective analyses. These assignments will be incorporated into a short workshop report, which would also summarize the workshop’s discussions and conclusions. This workshop report will serve as a quarterly work plan for PATH, to be reviewed by the Implementation Team Committee responsible for PATH.

After Workshop 4, we intend to formally assess the benefits of different management and research directions (Goal P3). This analysis would be linked to ongoing research, monitoring and evaluation programs, to assess both how existing activities could be modified to better answer key uncertainties, and also to suggest new activities which could be added to those already planned. A component of this goal is to define performance measures which could be used in-season to improve learning, and ultimately increase the likelihood of reaching survival improvement objectives.

All of the year's activities will be integrated into a Draft Final Report completed by the end of August, 1997, and peer-reviewed in September.

PATH Workshop 5: Consolidation of Results

This workshop (scheduled for late September 1997) will review and finalize reports on the previous activities and prepare a succinct set of recommendations regarding both management actions and future research and monitoring activities. It will include responses to the Draft Final Report by the Scientific Review Panel.

1.3 Background to the Retrospective Analyses: The Three Level Hypothesis Framework

This section summarizes the hypothesis framework used to organize the PATH approach to the retrospective analyses. These hypotheses are used to clarify the rationale for different management decisions and ultimately should assist in defining an adaptive management framework. The hypotheses represent an evolving frame of reference for organizing information, structuring hypothesis tests, and planning applied research. A detailed discussion of these hypotheses can be found in Sections 4 and 5 of Marmorek et al, 1995a, which is summarized below.

Representation of life histories is an important organizing structure for management questions, hypotheses, data sources and ultimately, model revisions. One can consider three different levels of detail of representation of the Columbia River stocks' life histories. Development of hypotheses proceeds from the most general at Level 1 (overall patterns in stock recruitment) to the most specific at Level 3 (responses of components of life stages, such as reservoir survival, to individual management actions). Hypotheses at a greater level of specificity must be consistent with the more general hypotheses previously examined (e.g. life stage specific conclusions must be consistent with overall life cycle patterns). While many analyses span more than one level of hypothesis (particularly between levels 1 and 2), the following definitions help to place each analysis in context, and bound the management inferences which it can or can't support.

Level 1 hypotheses represent exploratory analyses to determine if there are differences in trends of standardized abundance, productivity, and associated variance among a wide array of Pacific Northwest species and stocks over a period that is relevant to the condition of Snake River stocks. Hypotheses at this level seek to identify differences in trends among species/stocks, but do not propose mechanisms to explain those differences. However, these Level 1 analyses may suggest hypotheses that could be more formally tested with a more detailed analysis of component measurements at a Level 2 or Level 3 representation (e.g. marine survival separated out). They can also help to "screen" hypotheses to reduce the number examined in detail. The Level 1 representation, though extremely simple, has the benefit that many more data sets can be employed to address a variety of questions. While examination of stocks from a broad geographical area will be necessary to test hypotheses, the hypotheses related to Snake River stocks listed under the Endangered Species Act receive highest priority.

Level 2 hypotheses seek to explain trends in stock indicators (i.e. standardized abundance, productivity, or associated variance) in terms of spatial contrasts and temporal changes in: a) survival during particular life history stages; or b) pressure/stressor indicators associated with survival in one or more life history stages. Hypotheses at this level do not propose specific mechanisms to explain the changes in survival during each life stage, but must potentially provide inferences on where to focus management actions. There are two types of Level 2 hypotheses: 1) life stage composite hypotheses; and 2) life cycle aggregate hypotheses. These two terms are explained below.

Level 3 hypotheses seek to explain the life-stage specific mechanisms associated with observed trends, for each life history stage identified at Level 2 as most closely associated with the population trends. For listed Snake River stocks, Level 3 hypotheses link directly to key management decisions. Since the key management questions relate to the degree of various effects (e.g. changes in survival with increased flow) rather than whether or not an effect occurs, Level 3 hypotheses need to focus on the quantitative strength of hypothesized effects.

The following simplified example may help to operationalize these definitions:

A Level 1 hypothesis may propose that *Snake River spring chinook stocks exhibit a different trend in productivity than other northwest Pacific stocks*.

A consistent hypothesis at Level 2 may be: *changes in survival during juvenile and adult mainstem migration correspond to changes in overall productivity and abundance, while changes in survival during other life stages do not*.

A consistent Level 3 hypothesis may be that *a decrease in water velocity during the spring is one mechanism that can explain the trend in juvenile mainstem survival, and that certain minimum spring flows are required to maintain sufficient mainstem survival*. This Level 3 hypothesis, when combined with additional Level 3 hypotheses, would relate directly to key management decisions, such as the need for flow augmentation or reservoir drawdowns.

PATH participants developed the following terms to distinguish among hypotheses:

Life Stage Component Hypothesis: A hypothesis describing one factor affecting survival in one life stage (e.g. reservoir predation reduces smolt survival in the juvenile migratory stage by X%). These hypotheses are addressed in Level 3.

Life Stage Composite Hypothesis: A hypothesis regarding the relative influence of a particular life history stage on population trends (Level 2). Implicitly, this consists of a linked set of Level 3 component hypotheses describing the factors controlling survival in one life stage, and their relative importance.

Life Cycle Aggregate Hypothesis: A linked set of life stage composite hypotheses, describing the belief system of what is controlling the salmon’s life cycle (Level 2). These hypotheses explicitly highlight the relative significance of particular life history stages and associated stressors in determining the historical trends in stock indicators.

State or Stock Indicators: Measures of a population's status, such as standardized productivity, abundance, or the variance associated with either measure.

Pressure/Stressor Indicators: Factors that may influence state or stock indicators. Examples include indicators of climatic effects, such as annual precipitation or ocean weather indices, or indicators of human influence, such as volume of agricultural water diversions, acres of logged forest, miles of impounded river, commercial harvest levels, or number of hatchery fish released.

1.3.1 Summary of Retrospective Aggregate Hypotheses

Aggregate hypotheses serve to integrate each of the more detailed retrospective analyses. One of the major driving reasons for creating PATH was to make progress on assessing key hypotheses that underlie differences in recommended management actions. Retrospective aggregate hypotheses describe the belief system of what has historically controlled the salmon's life cycle. These hypotheses highlight the relative significance of particular life history stages and associated stressors in determining the historical trends in stock indicators.

Figure 1-2 is an attempt to summarize three alternative aggregate hypotheses to describe the historically observed declines in Snake River chinook. Hypothesis 1 (in Figure 1-2) explains most of the recent trends in chinook abundance as a consequence of decreased survival in the juvenile migratory corridor (JMC) stage and upstream passage (UP) stages due to the creation of the Snake River dams. Estuarine and ocean survival is believed to have affected year-to-year variation in spawner abundance and recruits per spawner, but is not responsible for the overall trends in escapement. Hypothesis 3 attributes the decline in chinook abundance to a number of factors: changes in habitat, the effects of harvest prior to dam construction, the construction of other dams prior to 1970, the effects of dam construction in the 1970s, the effects of spill on survival through increased dissolved gas concentrations in the 1980s, and perhaps most importantly the change in estuarine and ocean survival from a cool/wet period generating high survival to a warm/dry period associated with low/natural survival around 1976 and 1977. Hypothesis 2 is intermediate between Hypotheses 1 and 3; it places more blame on the JMC and UP stage than does hypothesis 3, but also considers estuarine and ocean survival to be the main cause of decline in spawners during the 1980s. Each of these retrospective aggregate hypotheses have different implications for future actions, as described in Chapter 4.

An alternative way to consider the retrospective aggregate hypotheses is illustrated in Table 1-1. Here each of the five major forcing factors (hydro, habitat, hatcheries, harvest, and climate) can have low, moderate, or high effects on each of the life history stages (though only habitat and hatcheries are likely to affect FSR). This structure is more congruent with a decision analysis approach that assigns probabilities to alternatives for each life stage or forcing factor. Included in Table 1-1 are examples of some of the data available to evaluate the strength of various components on life cycle or life stage specific estimates of survival. Most of the completed and proposed Level 2 analyses appear on the first row of Table 1-1 describing changes in life cycle survival; the multivariate analyses in Chapter 4 attempt to bridge across all five forcing factors. Any retrospective aggregate hypothesis can be thought of as some combination of low, medium, or high effects on survival from the five components in one or more life history stages. The observed data on spawning and recruitment constrains the number of feasible or credible alternative aggregate hypotheses. The existence of delayed effects, the absence of historical data on life stage specific survivals, and the difficulty of finding index stocks with the appropriate contrast in component effects (to examine changes in R/S) place constraints on how much one can differentiate between alternative retrospective hypotheses.

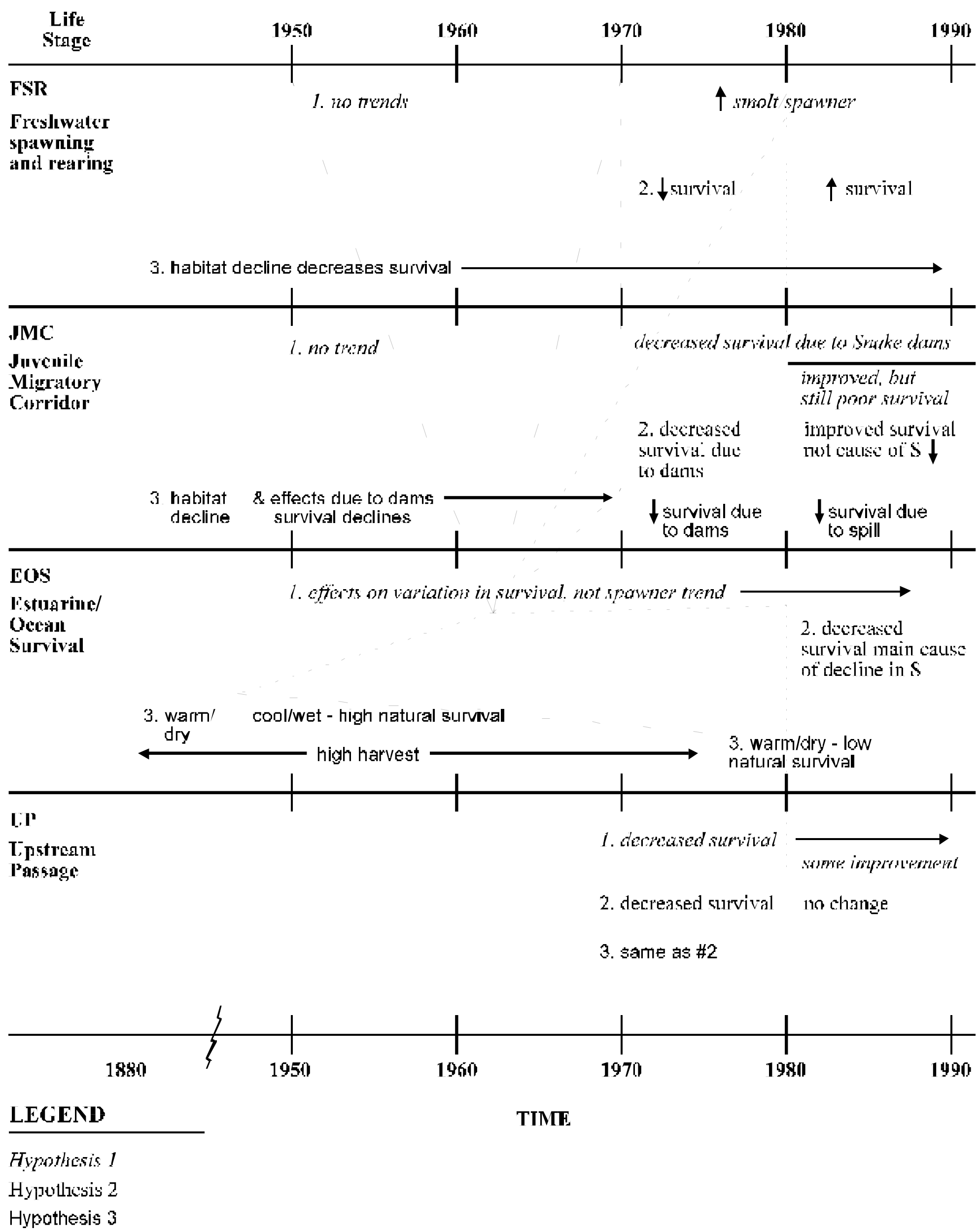

Figure 1-2: Retrospective aggregate hypotheses.

Table 1-1 Levers on historical / future survival and examples of potential data analyses to quantify effects. A "—" means that the forcing factor does not affect that life stage.

Stage	Forcing Factor					
	Hydro	Habitat	Hatcheries	Harvest	Climate	
Life Cycle Survival	L	L	L	L	L	Chapter 4 Multivariate analysis
	M	M	M	M	M	
	H	H	H	H	H	
	ln(R/S) (Ch 3) Estimated μ (Ch 5)	R/S trends with/ without habitat effects (Ch 10)	R/S trends with/ without hatchery (Ch 11)	Harvest estimates	MLE δ (Chs 5, 12)	
FSR	—	L	L	—	—	
		M	M			
		H	H			
		Chapter 9 Smolt: Spawner trends				
JMC	L	L	L	—	—	
	M	M	M			
	H	H	H			
	PIT-tag studies NMFS survival estimates (Ch 6)	PIT-tag studies NMFS survival estimates (Ch 6)				
EOS	L	L	L	L	L	
	M	M	M	M	M	
	H	H	H	H	H	
	(delayed effects)	(delayed effects)		ocean harvest estimates	CWT data	
UP	L	L	L	L		
	M	M	M	M	?	
	H	H	H	H		
	dam counts	dam counts	dam and rack counts	in-river harvest estimates		

1.4 Structure of this Report

This document presents the results of retrospective analyses planned at the first PATH workshop and carried out by the various PATH workgroups. Draft versions of these chapters have been circulated among all PATH participants. However, there has not been sufficient time for a true integration across all chapters.

Chapter 2: T*he Snake River in the Context of Broad Scale Patterns of Change in Stock Indicators: A Level 1 Pilot Analysis*

This chapter demonstrates different approaches to testing hypothesis L1.1 (Page 5-1 of Marmorek *et al*, 1995a):

> There has been a similar trend in the state indicators for anadromous salmonid species/stocks that spawn in a variety of geographical locations in the Pacific Northwest.

The management implications of the hypothesis are straight-forward: if all stocks (listed and otherwise) show the same pattern in escapement, recruitment, or other state variables, then some common forcing function (e.g. ocean conditions) would be the most likely candidate for the (joint decline). If on the other hand there are systematic differences among races, deems, or stocks, then other, more stock-specific causes are more likely to be associated with the observed historical patterns.

Trends in 12 different state indicators were investigated using two correlation analyses (Pearson product-moment and Kendall τ) and two clustering methods (Ward’s and oblique principal components) to assess the similarities between spring/summer chinook stocks. Results indicate that all stocks do not have the same trends in either abundance or survival measures. Different measures of stock status give somewhat different views of which stocks are most closely related and how close the relationships are. The Pearson correlations are consistently higher than the Kendall, and relationships based on abundance show stronger correlations than do the survival-based measures. Perhaps the most interesting outcome of the analysis is the similarity between the R/S and S_{t+4}/S correlations and clusters. In some ways this is not too surprising, in that all 16 stocks are subject to similar harvest patterns in the Lower Columbia. Nevertheless, it raises the possibility of performing a similar analysis on a much wider range of stocks for which no run reconstructions are presently available.

Chapter 3 *Contrasts in Stock Recruitment Patterns of Snake and Columbia River Spring/Summer Chinook Populations*

This paper examines evidence related to three hypotheses: 1) whether productivity declined more and became more variable for stocks most affected by hydropower (Snake and upper Columbia rivers) than for similar stocks below fewer dams (lower Columbia River); 2) whether survival rates declined more and became more variable for stocks most affected by hydropower than for similar stocks below fewer dams; and 3) whether the interior Columbia River stocks have been in long-term decline, or the decline corresponded with completion of the hydropower system. Spawner (S) and recruit (R) data were developed for seven Snake River, three upper Columbia River and six lower Columbia River (above Bonneville Dam) spring and summer chinook stocks, and for an aggregate run of wild spring chinook (from above Bonneville Dam), which included all spring chinook index stocks. Hypothesis (1) was addressed by comparing Ricker production parameters and fits for the index stocks between time periods and region, and by analysis of covariance (ANCOVA) for effect of time period. Hypothesis (2) was addressed by comparing survival rate indices, ln[(observed R/S)/(predicted (R/S)], from fitted Ricker functions between regions and time period, using analysis of variance and multiple comparison procedures. Hypothesis (3) was addressed by ANCOVA tests for effect of time period for five decades of spawner recruit data for the aggregate upriver run, and by examination of plots of residuals (survival rate indices). Temporal patterns of productivity and survival from lower river index stocks indicate recent declines that might be attributed to poorer oceanic or environmental conditions. However, the spatial and temporal comparisons indicate that upriver stocks have fared much worse. Empirical evidence best supported the hypotheses that the productivity and survival rate of spring and summer chinook stocks that were most affected by hydropower development (Snake and upper Columbia regions) declined more and became more variable over time than those of the lower river stocks. Evidence from the aggregate run best supported the hypothesis that productivity and survival rate declines over the last 50 years were quite abrupt and corresponded with construction and completion of the hydropower system.

Chapter 4: *Stressors Correlated with Patterns of Change in Stock Indicators: An Analysis of Level 2 Hypotheses*

This chapter provides a pilot demonstration of different approaches to testing the following hypothesis:

> *Trends in spawner to recruit survival are related to stressors during the xxx stage, where xxx can be freshwater spawning and rearing, juvenile migration, estuary and ocean residence, upstream passage, or prespawning survival.*

The management implications of this set of analyses are that management should focus on those stressors and life-history stages most strongly related to trends in stock indicators. However, management inferences are constrained by uncertainties in the cause-effect links between stressors and life-history stages, and the fact that multiple regression analyses only indicate association, not causality.

The above hypothesis is tested for 16 Columbia River spring chinook stocks, all spawning above Bonneville Dam. Data on environmental conditions in both freshwater (e.g. spawning/rearing area flows, drought index) and marine (e.g. index of upwelling strength off the mouth of the Columbia, index of strength of the North Pacific Index (NPI)) habitats are used to represent possible sources of stress at different life stages. Multiple regression is used to analyse the relationships between these environmental data and stock indicators related to spawner-recruit survival. For a given stock, the number of regression models in which an individual environmental variable is significant provides a measure of the strength of the relationship between spawner-recruit survival and the environmental factor.

Although results should be interpreted cautiously, some patterns were evident. Increased spawning escapement had a negative effect on survival for most stocks, consistent with a Ricker stock-recruit relationship. The findings for dams and migration are flows are very strong: in almost all cases, Mid-Columbia and Grand Ronde / Snake River spring chinook stocks, which should be affected by in-river migration conditions, show significant effects. However, 8% of the models for Lower Columbia stocks showed an unexpected negative relationship with flow, and no significant flow effects were found for the Snake River summer chinook. Migration corridor dams have relatively little effect on the John Day, and strong negative effects on all three up-river aggregates. The effects of climatological factors such as the drought index, minimum precipitation index, and snowpack depth were more ambivalent, implying that additional indices of the condition of spawning and rearing habitat should be tested.

Stocks differed substantially in their responses to the NPI and the upwelling index, suggesting that more work should be done on their ocean distributions and ocean survival. The fact that increases in the May upwelling index cause decreases in survival for the John Day and lower river stocks is contrary to previous work with coho, suggesting that upwelling in a different month or a different location would have been a better indicator. Time series data on anthropogenic alteration to spawning and rearing habitat (e.g. grazing, logging, irrigation, etc.) was lacking but is necessary for assessing the effects of recent land use practices on fish survival.

Chapter 5: *Retrospective Analysis of Passage Mortality of Spring Chinook of the Columbia River*

There have been decades of debates about passage mortality in the Columbia River. We empirically estimated instantaneous in-river passage mortality (*m*) and its associated probability distribution, using spawning and recruitment data for seven Snake River and six lower Columbia River spring chinook populations. Our empirical estimates of μ showed low bias, and were generally close to (and between) those produced by the two more mechanistic models CRiSP and FLUSH, though significantly higher than one version of CRiSP. A total of 37 models were applied to the data, incorporating different assumptions about spawning measurement error, transport survival, intrinsic productivity, methods of estimating *m*, and 'year effects' which accommodate common factors affecting the survival of all stocks. The 12 'top' models estimates of *m* ranged from 0.55-1.90 (mean of 1.09); two of these models simply made *m* proportional to Water Transit Time (WTT). These estimates of μ imply that in-river passage from Lower Granite to John Day dam reduces recruitment by 42-85% (mean of 66%). The year effect shifts from generally positive effects on 1952-68 brood years to generally negative effects on 1970-89 broods. Year effects were not correlated with WTT, *m*, the North Pacific Index (NPI) or an Upwelling Index, but were inversely correlated with Bristol Bay (Alaska) sockeye survival anomalies. We discuss the improvements required to apply these models to prospective analyses.

Chapter 6: *A Decision Tree for the Columbia River Hydrosystem, and A Proposed Approach To Synthesizing Evidence Relevant to these Decisions*

This chapter summarizes evidence relating to the effectiveness of different hydro management strategies in meeting an in-river survival goal for juvenile Snake River spring/summer Chinook stocks. Until this survival goal is established by PATH, the Hydro Work Group proposed using a range of in-river survival rates of 50-70% as an interim goal. This range is based on estimates from the 1960's when only 4 dams were in place and Snake River stocks were strong and stable. The Work Group created a decision tree to identify possible management strategies for achieving this survival goal. Evidence is summarized for the two major questions in the decision tree:

1. Can the current operation of the hydroelectric system compensate for the effects of human-induced habitat modification on survival of juvenile Snake River Spring/Summer Chinook salmon using transportation, current passage measures, or a combination of these two methods?

2. If current operations are unable to compensate, can the hydro system be modified either through adjustments to current passage measures or through structural changes to allow compensation?

1. The Work Group concluded that the survival of transported fish to the point of release is approximately 96-98% and thus exceeds the in-river survival goal. Evidence regarding the magnitude of delayed mortality effects due to transportation is conflicting, and more information is needed about the relative smolt-to-adult survival rates of transported fish, and the susceptibility of transported fish to predation, disease, and impaired saltwater adaptation following release. Opportunities for increasing transportation survival by improving collection and release facilities are unknown and limited because direct transportation survival rates are already high. This issue will need to be addressed if delayed transportation mortality is significant. Opportunities for increasing collection rates by improving collecting systems (e.g. extended-length screens or surface collectors) are limited but uncertain because the effectiveness of proposed improvements and the feasibility of implementing them are largely unknown. More research is needed on the effectiveness of proposed designs in improving collection efficiency.

Current survival of in-river migrants is estimated to be 40-50%, with unknown delayed mortality. Therefore, current passage measures(those that improve survival past dams and through reservoirs) are unable to achieve the in-river survival rate goal. Based on this conclusion, the Work Group concluded that a combination of transportation and passage measures was also unlikely to achieve the survival goal.

2. Devices to improve dam passage survival are currently being designed or installed, but these devices do not appear to produce large enough improvements in the survival of juveniles to achieve the interim goal for in-river survival. A predator control program is in place to improve reservoir survival, and is not likely to be expanded. Further information is needed about the effects of these and other passage measures on in-river survival, as well as on the delayed effects of in-river passage measures on mortality.

   Primary options for structural changes include spillway crest and natural river drawdowns at up to 4 Snake River projects and John Day reservoir. Based on previous analyses, the Work Group concluded that the potential for increased dam passage mortality caused by drawing down Snake River projects to spillway crest would probably exceed any potential improvements in reservoir survival. The Work Group could not reach consensus on the effects of spillway crest drawdowns at John Day on Snake River stocks. There was general agreement, however, that natural river drawdowns at Snake River projects would increase in-river survival of smolts to 57-72% and would thus achieve the survival goal. Natural drawdown is also expected to substantially increase survival of adults during upstream passage. However, more research is needed on the potential adverse effects of dam breaching on survival rates.

Chapters 7 an 8:

These chapters formerly held material now integrated into Chapter 6. We have maintained the previous chapter numbers to minimize confusion.

Chapter 9: E*valuation of Survival Trends in the Freshwater Spawning and Rearing Life Stage for Snake River Spring/Summer Chinook*

This paper examines evidence for, and tests whether, a net decrease in survival in freshwater spawning and rearing (FSR) life stage has occurred since completion of the hydropower system that could explain the decline in adult recruitment and productivity of Snake River spring/summer chinook. Numbers of wild spring/summer chinook spawners and smolts were indexed at the uppermost dam from available data sets for the following brood years: 1962-1973, 1962-1982, and 1990-1993. Regression models showed a significant density-dependence between ln(smolts/spawner) and spawner, when a wide range of spawning escapements was examined. Estimates of ln(smolts/spawner) vs. spawner were generally consistent among the data sets, and recent estimates were well within the bounds of the historic estimates. While numbers of spawners declined significantly since completion of the hydropower system, productivity as measured by smolts/spawner and ln(smolts/spawner) increased, consistent with density dependent production functions. Based on a means test of the residuals, the index of FSR survival showed no significant decline since completion of the hydropower system for four combinations of spawner and juvenile indices. Analysis of covariance of the same data sets indicated a significant decline in FSR survival for one of the four combinations. But when drought years were dropped from the analysis, the index of FSR survival again showed no significant decline. In essence, this evaluation does not rule out small decreases in FSR survival in recent years, but provides no empirical support for a hypothesis that spawner-to-smolt survival was the primary life stage responsible for the decline of Snake River spring/summer chinook. This analysis, however, does not address whether there was a significant decline in FSR survival prior to the completion of the hydrosystem.

Chapter 10: *A Decision Tree for Structured Syntheses of Evidence Concerning Changes in Spawning and Rearing Habitat*

The purpose of this chapter is to synthesize information relating to the effects of quantity and quality of freshwater habitat on the survival of juvenile spring/summer chinook salmon in the Snake River Basin. Several sources of information were used:

1. Empirical evidence was used to evaluate a series of retrospective hypotheses about the relationship between freshwater habitat degradation and trends in abundance of Columbia River chinook stocks, and about the relative effect of freshwater habitat quality and quantity on different freshwater life stages (e.g. spawning/early rearing, downstream rearing, and overwintering) and on different abundances of spawners. Not all of these hypotheses were able to be tested because of limitations in the availability and resolution of data.

2. Additional information was obtained from a classification of habitat into high, medium, and low quality based on the relative impact of development on the river. Assessments of the effect of habitat quality on chinook stocks were made by comparing habitat quality in regions where chinook stocks were considered strong, depressed, or absent.

3. Results of two analyses of recruitment were used to document the effects of freshwater habitat on stock abundance and persistence. One of these analyses is presented in Chapter 4. In the other analysis, simulation modelling using the Stochastic Life Cycle Model (SLCM) was used to evaluate the relative contribution of quality of spawning habitat, quantity of rearing habitat, and mainstem smolt passage survival on the persistence of the population and the average number of female spawners.

4. PIT-tag data for stocks originating from streams with different habitat quality classifications, and at different distances from the point of detection, were used to illustrate the effects of freshwater habitat quality on juvenile survival.

5. Finally, the results of several case studies of changes in salmon productivity due to changes in spawning and rearing habitat are reviewed.

Data from these sources suggests that the quality of freshwater habitat can be an important factor in the abundance and resiliency of chinook stocks. However, it is difficult to generalize the results because the data are limited and the effects of habitat quality depend on local conditions.

Chapter 11: *Hypotheses Regarding Hatchery Impacts*

This chapter is composed of three sections. Section 1 contains a list of management actions and hypotheses about the effects of hatchery fish on wild populations. These questions and hypotheses are classified into two categories related to future opportunities for experimental design: 1) questions about within-stock consequences of rearing part or all of the fish under hatchery conditions; and 2) questions about between stock consequences of competition, straying of hatchery fish, transmission of diseases. For some hypotheses in Section 1, evidence supporting or refuting the hypothesis is presented.

In Section 2, hypothesis tests are used to evaluate differences in the variance and mean of overall survival rates (measured as Recruits/Spawner or Ln(R/S)) between hatchery fish and wild fish. Data for these tests were obtained from two stocks, Warm Springs and Imnaha, which have been supplemented with hatchery-reared fish. The variance in survival rate (Ln(R/S)) for hatchery fish was greater ($P<.05$) than that of wild fish for the Warm Springs stocks. The same was true for Imnaha stocks, although the difference was not quite significant ($p=0.054$). Differences in mean survival rates were tested using both a parametric and non-parametric test. Mean survival rates were significantly greater for wild fish than for hatchery fish for Warm Spring stocks using both tests. However, no significant differences in mean survival rates were observed for Imnaha stocks. Though these analyses imply that hatchery fish may not survive as well as wild fish, generalizations based on these results are limited by the short time-series of the data and the small number of hatchery programs that could be tested. Alternative methods and extensions to this analysis that address some of these limitations are suggested.

Section 3 presents an example of an analytical approach to testing hypotheses about the impacts hatchery fish have had on naturally spawning stocks. The approach uses multiple regression to evaluate the relationship between Ln(R/S) of wild stocks and several variables that reflect the degree of hatchery influence on Warm Springs and Imnaha stocks. The results for Warm Springs suggest that the number of hatchery fish released, in combination with the wild spawning escapement, makes a significant contribution to variability in survival rate of wild fish ($R^2=.66$). Results for the Imnaha stocks were obscured by collinearity between the independent variables, confounding with the increase in number of dams traversed by Imnaha stocks over time, and possible autocorrelation in the time series data. The section discusses several potential improvements and extensions to this approach.

Chapter 12: *Influence of Climate on Fish - Review*

This chapter presents a brief review of the influence of climate on fish populations. Evidence suggests that the year-class strength of fish populations is related to climatic/ocean fluctuations. Interactions between populations of fish in the North Pacific and climate have complex latitudinal patterns and appear to involve decadal-scale changes in atmospheric, wind, and current patterns. In general, two major climate regimes have been identified; one associated with cool and wet climate in the Pacific Northwest and another associated with warm and dry Pacific Northwest weather (this is the regime we are presently experiencing). The most recent shift in this regime occurred in 1977. The warm/dry regime is characterized by weaker year-classes of fish stocks on the west coast of the lower United States and strong year classes of fish stocks in northern British Columbia and Alaska. For example, Alaskan catches of Pacific salmon have increased since 1977 while Washington/Oregon/California catches have decreased. Possible mechanisms include changes in the abundance of plankton in coastal upwelling zones due to shifts in ocean currents. Within seasons, climate factors related to the timing of the spring winds also have been shown to affect survival.

Chapter 13: *Hypotheses Regarding Harvest Impacts*

Chapter 13 was incomplete when these summaries were compiled.

1.5 References for Chapter 1 of Retrospective Report

Marmorek, D.R. and I. Parnell (eds). 1995a. Plan for Analyzing and Testing Hypotheses (PATH): Information package for Workshop 1 - Design of retrospective analyses to test key hypotheses of importance to management decisions on endangered and threatened Columbia River salmon stocks. Prepared by ESSA Technologies Ltd., Vancouver, B.C. with contributions from ANCOOR (Analytical Coordination Working Group) and Dr. R. Deriso, 88 pp. and appendices.

Marmorek, D.R., I. Parnell, L. Barnthouse and D.R. Bouillon. 1995b. Plan for Analyzing and Testing Hypotheses. Results of a Workshop to Design Retrospective Analyses. Prepared by ESSA Technologies Ltd., Vancouver, B.C. for Bonneville Power Administration, Portland, 71 pp. and appendices.