EVALUATION OF CARRYING CAPACITY: MEASURE 7.1A OF THE NORTHWEST POWER PLANNING COUNCIL'S 1994 FISH AND WILDLIFE PROGRAM

REPORT 1 OF 4
FINAL REPORT

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PREFACE

This report is one of four that the Pacific Northwest National Laboratory (PNNL) staff prepared to address Measure 7.1A in the Northwest Power Planning Council's (Council) Fish and Wildlife Program (Program) dated December 1994 (NPPC 1994). Measure 7.1A calls for the Bonneville Power Administration (BPA) to fund an evaluation of salmon survival, ecology, carrying capacity, and limiting factors in freshwater, estuarine, and marine habitats. Additionally, the Measure asks for development of a study plan based on critical uncertainties and research needs identified during the evaluation. This report deals with the evaluation of canying capacity. It describes our analysis of different views of capacity as it relates to salmon survival and abundance. The report ends with conclusions and recommendations for studying canying capacity. Three other reports were prepared based on the work addressing Measure 7.1A:

1. "Study Plan For Evaluating Canying Capacity, Measure 7.1A of the Northwest Power planning Council's 1994 Fish and Wildlife Program, Report 2 of 4."
2. "Proceedings from a Workshop on Ecological Carrying Capacity of Salmonid Habitats in the Columbia River Basin, Measure 7.1A of the Northwest Power Planning Council's 1994 Fish and Wildlife Progmm, Report 3 of 4."
3. "A Literature Review, Bibliographic Lii And Organization of Selected References Relative To Pacific salmon (Oncorhynchus spp.) And Abiotic And Biotic Attributes Of The Columbia River Estuary And Adjacent Marine & Riveriue Envioms, for Various Historical Periods, Measure 7.1A of the Northwest Power Planning Council's 1994 Fish and *Wddlife* Program, Report 4 of 4."

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Our sincere thanks to the people who helped with this study. Dr. Mark Schneider, formerly of BPA, wrote the statement of work that started the study. Nora Berwick and John Marsh of Council staff helped interpret Measure 7.1A Tom Vogel of BPA was the contracting officer's technical representative for the project after Dr. Schneider moved to the National Marine Fisheries service. Joanne Duncan and Bill Mavros of PNNL helped prepare the report Dr. Dennis Dauble rcvicwed the report and Melanie Dcsmet edited the report.

Most of all, we acknowledge D.G. Hankin, M.C. Healey, R Hilborn, J.A. Lichatowich, L.E. Mobrand, E. Moussalli, E.P. Odum, G.J. Paul&, S.C. Pepper, J.R Platt, and C.J. Walters. Their articles, reports, and books carried us through the complexities of understanding ecological carrying capacity in salmon populations. Their ideas helped us develop an approach or view that if implemented, can be used to define specific rcsearch tasks and management actions to increase our understanding of ecology, carrying capacity and limiting factors that influence salmon survival under current conditions.

ABSTRACT

We pursued answers to questions asked in Measure 7.1A and concluded that the approach inherent in 7.1A will not increase understanding of ecology carrying capacity, or limiting factors that infiuence salmon uuder current conditions. Measure 7.1A requires a definition of carrying capacity and a list of determinants (limiting factors) of capacity. The implication or inference then follows that by asking what we know and do not know about the determinants will lead to research that increases our understanding of what is limiting salmon survival. It is then assumed that research results will point to management actions that can remove or repair the limiting factors. Most ecologists and fisheries scientists that have studied carrying capacity clearly conclude that this approach is an oversimplification of complex ecological processes To pursue the capacity paramctcr, that is, a single number or set of numbers that quantify how many salmon the basin or any part of the basin can support, is meaningless by itselfand will not provide useful information.

To increase understanding of ecology, carrying capacity, and limiting factors, it is necessary to deal with the complexity of the sustained performance of salmon in the Columbii River Basin. Density independent factors affect salmon performance, as well as density dependent factors. Factors that affect performance in one part of the salmon life cycle can manifest their effect in later phases of the life cycle. Factors can have different effects on different populations in different parts of the Columbia Basin or marine environment. Factors can affect different populations or stocks in different ways. There are potential negative impacts of focusing on abundance alone (NRC 1995). For example, how do the many populations and stocks of salmon affect one another? When we understand the ecological complexity of salmon performance, the region will be better able to make decisions to improve salmon survival in the basin.

We suggest that the region evaluate carrying capacity from more than one viewpoint. Platt (1964) provides a method for scientific inquiry and Pepper (1966) provides at least four views that can be used to define capacity in a way that helps identify critical uncertainties and research needs while dealing with the complexity of salmonperformance.

We recommend that the region use the contextualistic view for evaluating capacity Capacity, from the contextual view, is a component of salmon performance, and is inseparable from diversity and productivity. To evaluate capacity, in this way, we recommend that the region compare conditions in the columbia River Basin to historic conditions using the methods descrii as the Patien-Template Analysis (Lichatowich et al. 1995).

FIGURES

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Chapter 1: INTRODUCTION

Measure 7.1A in the Northwest Power Planning Council's (Council) Fish and Wildlife Program (Program) dated December. 1994 caIls for the Bonneville Power Administration (BPA) to fund an evaluation of salmon survival, ecology, carrying capacity,' and Iimiting factors in freshwater, estuarine, and marine habitats- The Measure has two parts (7.1A.l and 7.1A.2). The objective of the evaluation (7.1A.l) is to increase understanding of the ecology, carrying capacity, and limiting factors that influence salmon survival under current conditions. The second part of the Measure (7.1A.2) asks for the development of a study plan based on the critical uncertainties and rescarchneeds identified during the evaluation of carrying capacity. This report addresses Measure 7.1.A.1, the evaluation of carrying capacity.

Eight specific elements are listed in Measure 7.lA.l to include in the evaluation. They are:

1. Analysis of competition between non-native species and anadromoussalmonids and competitive interaction resulting from hatchery management practices.
2. Estimate of current salmon carrying capacity for the Columbia River mainstem, tributaries, estuary, plume and nearshore oceans for juvenile fish.
3. Evaluation of the effects of the alteration and timing of the ocean plume on salmon. survival caused by the construction and operation of the hydroelectric system.
4. Identification of residence time for juvenile salmonids and their level of smoltification.
5. Identification of management measures to protect and improve estuary habitat as well as increase the productivity of the estuary.
6. Recommendations for managcmcnt responses to fluctuating estuary and ocean cmditions such as adjusting totaI numbers of relcascs to take such conditions into account.
7. Identification of critical uncertainties and research needs, and estimates of incremental gains in survival from improvements in each area.
8. Monitoring program to identify optimal timing for residency in the estuary and nearshore environment.

To address all eight issues and accomplish the objective of the evaluation of capacity, we were told by Council staff to:

- Reviewexistingdata.
- Conduct a workshop.
- Use the information from the review and the workshop to define capacity and list the determinants of capacity.

In this report, we use the terms: capacity, carrying capacity, and ecological carrying capacity interchangeably Attempting to remain consistent with the intent of Measure 7.1A, we use these terms to describe *"the upper level for a population, beyond which no major increase can occur"* (Odum 1959). Many authors that we cite throughout this paper have other definitions for these terms or use them in a specific context with other population descriptors We have tried very carefully to cite these authors and strongly suggest that readers tum to the original hooks or articles for clarification.

- Ask, "What do we know about the determinants of carrying capacity?"
- Ask, "What do we not know about the determinants of carrying capacity?"
- Ask, "What research can we do to understand what we do not know about carrying capacity?"
- Ask, "What management actions can we implement immediately, relative to canying capacity, that will improve salmon survival?"
- Use the information collected and the answers to the questions to develop a study plan based on the critical uncertainties and research needs identified in the evaluation.

This approach is illustrated in Figure 1. The study plan would provide a basis to implement management actions and conduct research. Results of the research and management actions would lead to increased understanding of capacity. This in turn would produce implementation of an ecosystem approach to protect and enhance salmon in the Columbia River Basin.

We pursued answers to the questions asked in Measure 7.1A.1. We concluded, however, that this approach would not meet the objective. That is, the approach illustrated in Figure 1 would not increase understanding of ecology, carrying capacity, or limitiug factors that influence salmon under current conditions. Responding to the elements in Measure 7.1 A. 1 requires a specific definition of canying capacity and a lii of determinants (limiting factors) of capacity. The information that we learned during the workshop[2] and from our review of ecological literature led us to the conclusion that the proposed approach breaks down (Figure 2) if one attempts to define capacity as a simple ecological parameter (odum 1959, Reeves et al. 1991).

The capacity parameter, that is, a single number or set of numbers that quantifies how many salmon the basin or any part of the basin can support, will not provide useful information. To increase understanding of ecology, carrying capacity, and limiting factors, it is necessary to deal with the complex interrelationships among the characteristics of salmon performance, including diversity, capacity, and productivity (Paulik 1973, Hankin and Healey 1986, Moussalli and Hilbom 1986, Hilbom and Walters 1992, Mobrand et al. in press) Accordingly, we revised the approach to evaluate capacity (Figure 3). The approach we used followed the work on scientific discovery by Platt (1964) and the work on world hypotheses by Pepper (1966).

The report contains: our evaluation of carrying capacity (Chapter 2) and four definitions or views of capacity (Chapter 3). The report ends with our conclusions and recommedations to the region for studying canying capacity (Chapter 4). The books, journal articles, and technical reports we cite in this report are referenced in Chapter 5.

Several other activities are part of this study. We outlined necessary elements of a study plan to define the critical uncertainties and research needs related to carrying capacity in the Columbia Basin. We conducted a workshop in Portland, Oregon to address questions about definitions and determinants of carrying capacity. We reviewed

[2] Proceedings from the Workshop on Ecological Carrying Capacity of Columbia Basin Salmon (September 6-7.1995 in Portland, OR) are reported elsewhere (Johnson et al. 19%).

existing data determine what is known and not known about the determinants carring capacity in the Columbia Basin, with focus on the estuary. The results of these activities are presented in separate reports to BPA.

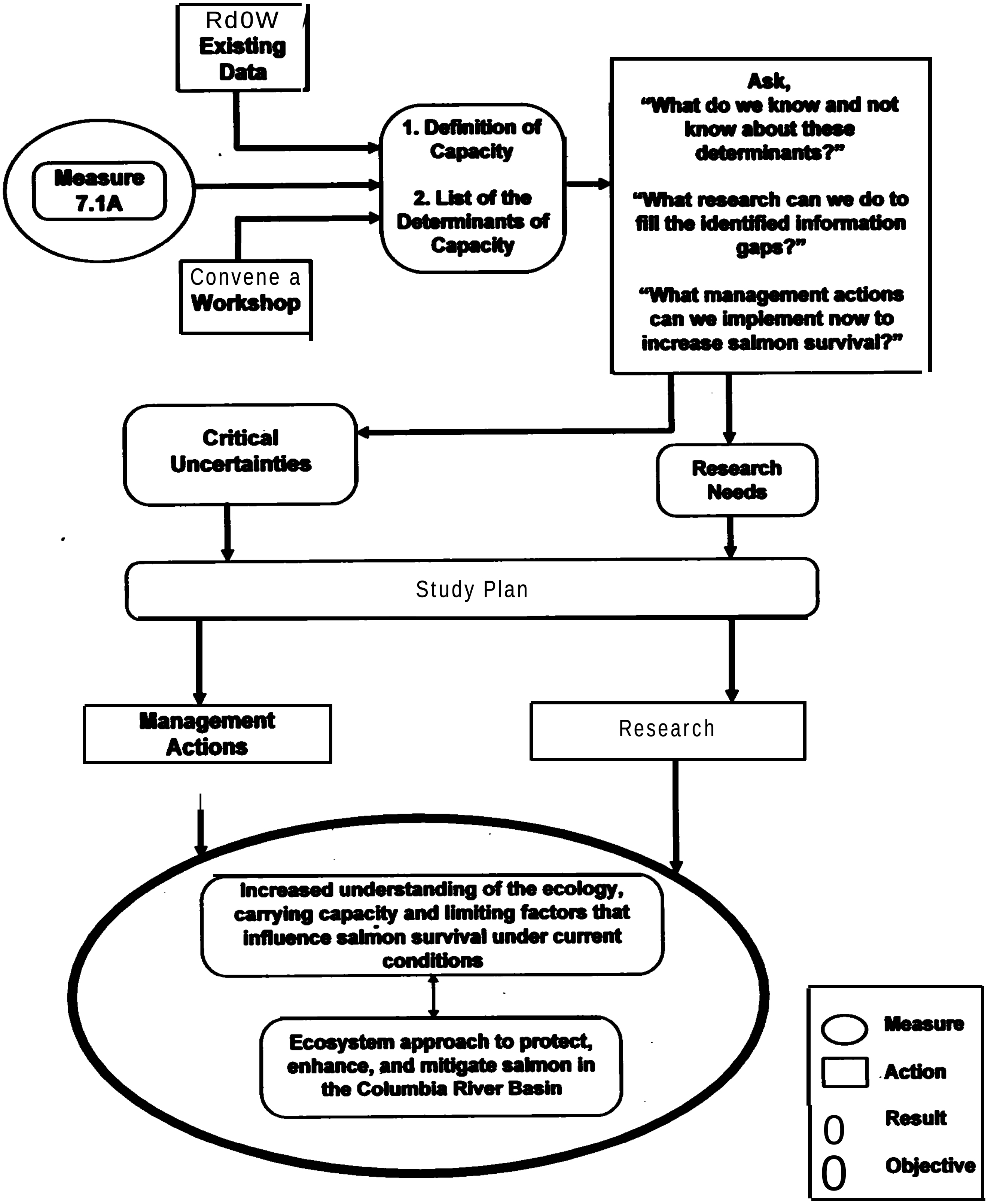

Figure 1. Flow Diagram Illustrating the Approach We Tried to Use to Analyze Carrying Capacity and Develop a Study Plan.

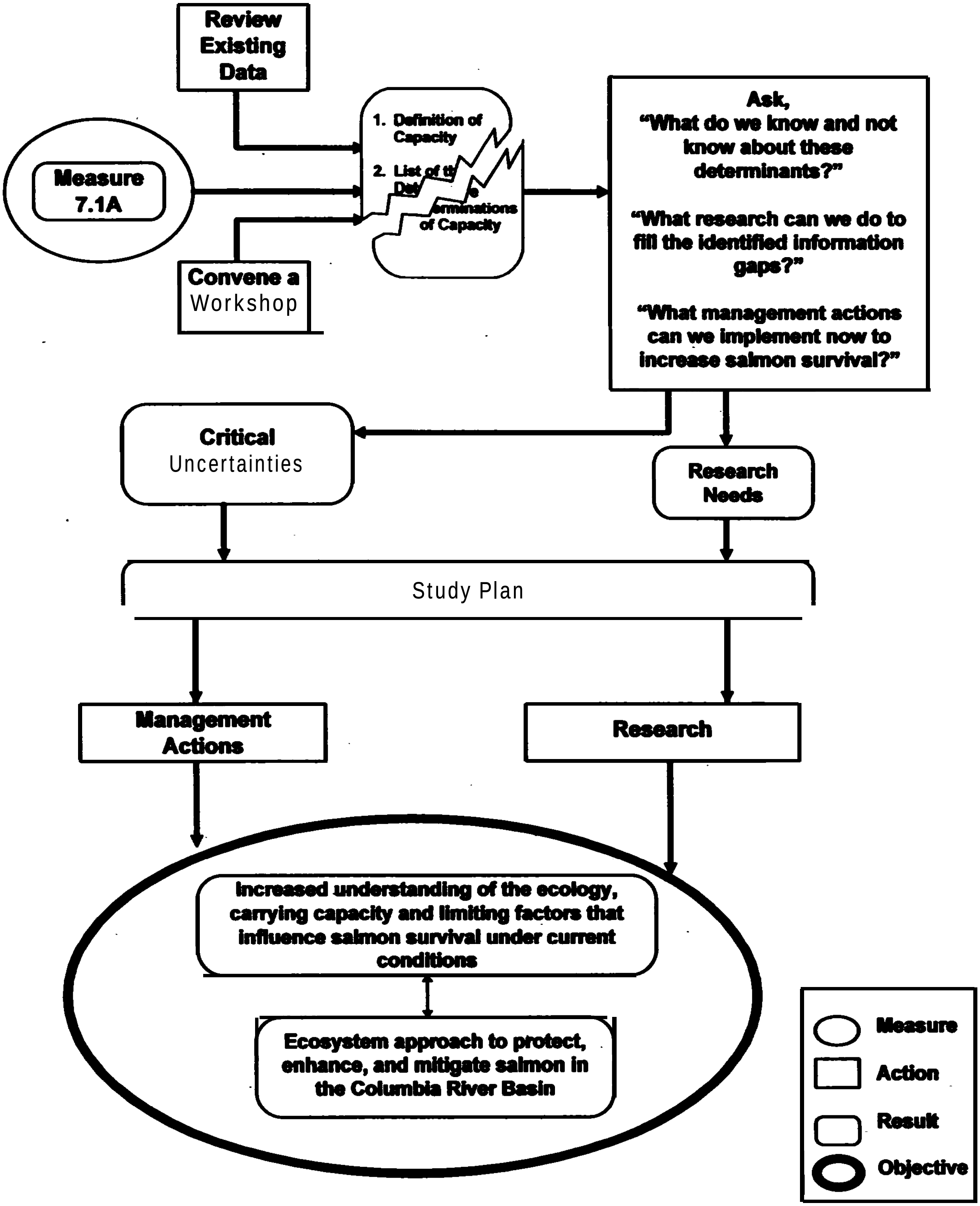

Figure 2. Flow Diagram Illustrating the Breakdown in the Approach We Tried to Use to Analyze Carrying Capacity and Develop a Study Plan.

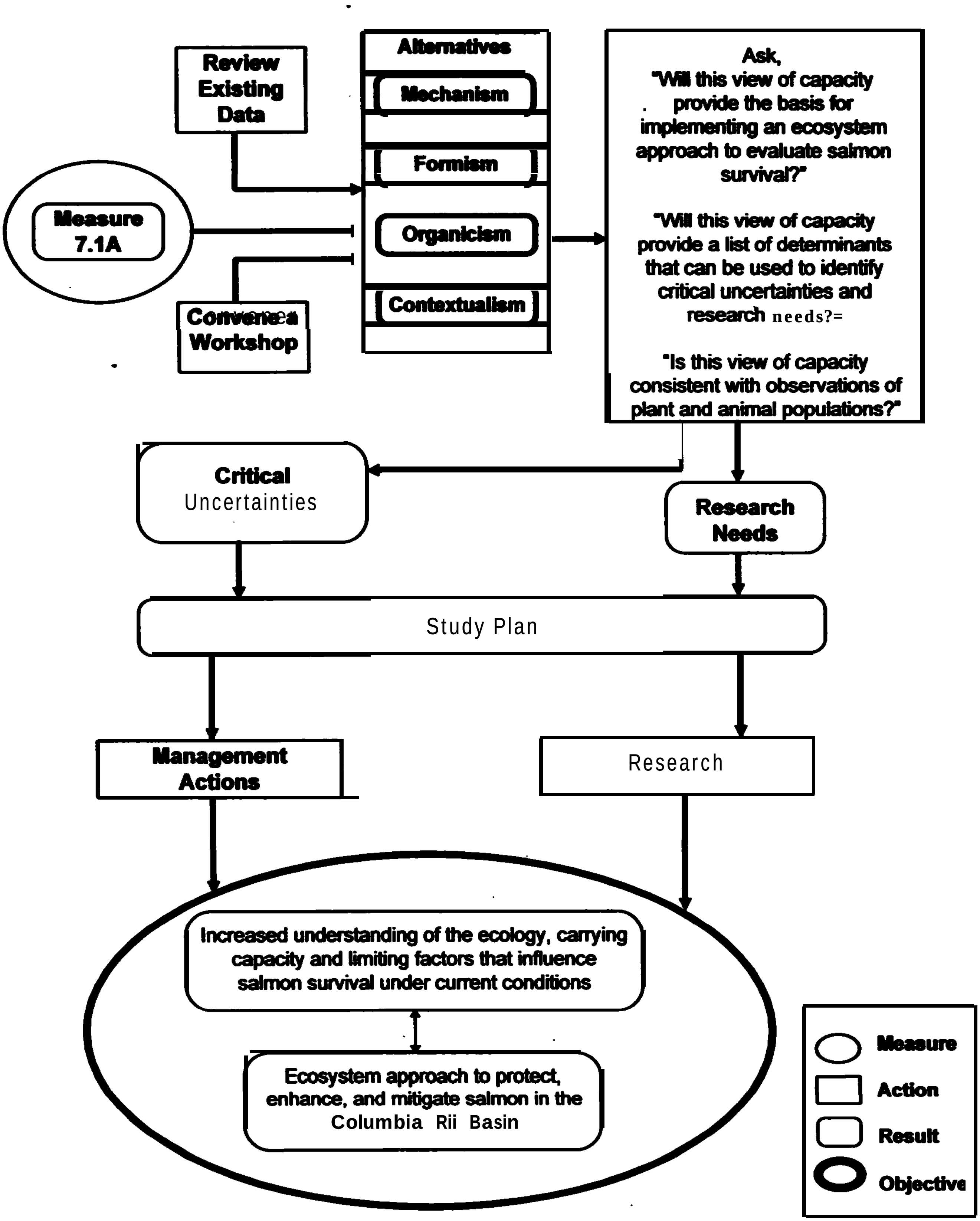

Figure 3. Flow Diagram With a Revised Approach to Analyze Carrying Capacity and Develop a Study Plan.

Chapter 2: EVALUATION OF CARRYING CAPACITY

As discussed in the Introduction, we concluded that the process of defining capacity and listing the determinants of capacity would not lead to a useful study plan. In **this chapter, we present the information that lead us to this conclusion.**

To define capacity we reviewed books, journal articles, and technical reports that discuss carrying capacity (Chapter 5), reviewed existing data (Costello 1996 a,b), and convened a workshop on carrying capacity (Johnson et al. 1996). We found that plant. **and animal populations grow, stabilize, oscillate, and fluctuate. These population** *Characteristics* have been described With words and **mathematical** formulas Some of these concepts, for example density dependent capacity, was popular&d by Malthus in the Iate 18th century and was discussed by other authors (e.g., Giovanni Botero, Sir **Walter Raleigh, Reverend William Derham) as early as the 16th century (Smith 1966).**

Capacity

Growth shapes and pop&ion dynamics have been characterized. The J-shaped growth form describes density increasing rapidly at an exponential rate, **abruptly** stopping as environmental resistance becomes effective (Odum 1959). The S-shaped growth is slow at first, followed by rapid growth, and finally settles into **no** growth at some controlled level. For these situations, the upper level beyond which no major increase can occur is the carrying capacity (Odum 1959). Similar definitions appear throughout the ecological literature .

"The maximum allowable load rate." (McLean et al. 1993).

*"**The** upper limit on the number **of fish** a **stream can support." (Steward and Bjornn 1990).***

***"The carrying capacity is defined simply as the number of individuals in a particular population that the environment can support over an indefinite period of time. It is often determined by food resources, but some other factors, such as light, water, or nesting space, may be the limiting ones " (Curtis** 1979). **p.** 851.*

***"The number of individuals of one species that the resources of a habitat can support." (NPPC** 1994). p. G-2.*

"The maximum abundance that can be supported by the environment." (Pitcher and Hart 1982) p.82.

- *'Miximnm **average** number or biomass of organisms **that can be sustained in a habitat over the long** term **Usually refers to a particular species, but can be applied to more than one."*** **(Meehan 1991).**

"The population size which** the **resources of the environment can just maintain ('carry') without a tendency to either increase or decrease. The stable density at which the birth rate equals the death rate." **(Begon** et al. 1986). **p.209-210.**

*"**Carrying** capacity, in the **context** of **mussel culture,** may be **defined as** the **stock density** at **which production levels** are **maximized without** negatively **affecting growth rates."** (Carver and Mallet* 1990).

*"**The uppermost** limit on the number of species an **ecosystem or** habitat can **sustain,** given the supply and **availability** of **nutrients."*** **(Hawken** 1993). p.24.

*"**Unfished** equilibrium stock size."* **(Hilborn and Walters** 1992). **p.58.**

*"**The maximum number** that can be supported in a given habitat." (Smith 1966). **p.355.***

Carrying capacity can be considered in terms of four different but overlapping types: subsistence density or K, optimum density, security density. and tolerance density. " (Smith 1966). p-328.

These definitions have a common characteristic. They state a quantity (e.g., maximum rate, upper limit, number, size, mass) that can be or is reached. Capacity as a parameter, that is a single number or set of numbers that can be defined for each part of the environment, implies we can define all the parts and understand the connectivity among the parts.. This approach is mechanistic, implying that the environment is a machine (Pepper 1966, White 1995) and the events or conditions that control the machine can be determined.

Determinants of Capacity

At this point in our evauation, we planned to follow these capacity definitions with a list determinants of capacity, and then proceed with the evaluation and ultimately develop a study plan. The nature of the regulatory processes (i.e., determinants) for animal population size is a major focus of population ecology. One precept of population dynamics is that no animal population can increase indefinitely. Eventually it arrives at some level about which it fluctuates or maybe more accurately it fluctuates within some range of population abundance. Populations are regulated by forces outside the . population itself and/or by forces generated within the population (Odum 1959). The former, extrinsic in nature, often is termed density independent, since the action or effect is present regardless of the size of the population. The latter, intrinsic in nature, is called density dependent, because the intensity of action varies with the density of the population. Smith (1966) also says, in general, population fluctuations influenced by annual and seasonal changes in the environment tend to be irregular and correlated with variations in moisture and temperature.

Fluctuations above and below a theoretical limit appear to be characteristic of most populations (Odmn 1959). The problem of cyclic oscillations or fluctuations comes down to the condilions that determine the changes. When populations exceed or approach capacity, predators, parasites, or disease can serve as checks. Intrapopulaton mechanisms can limit the level of a population. Wellington (1957) describes tent caterpillar populations that fluctuate, seemingly controlled by density. Kabat and Thompson (1963) describe the seasonal fluctuation of bobwhite quail. Errington (1939) describes temporary fluctuations in muskrat populations. Similar examples related to population characteristics are found in the fisheries literature.

Population fluctuations can result from temporal changes occurring seasonally, annually, decadally or even at longer-term fluctuations. Carrying capacity, and hence fish production, may vary yearly if controlling habitat components, such as streamflow, vary widely from year to year at critical habitat periods such as late summer (Smoker *1955)*. The carrying capacity of a stream may also vary from summer to winter (Bjornn *1978)*, and it may differ for the various life stages of fish.

The definitions of capacity for a population include terms for the limit or upper level of the population. Recall Odum (1959) who said capacity is "the *upper* level, *beyond which no major iwease can occur.* " A limit implies that something(s) determines the limit. Most definitions of capacity are followed by a list of events or conditions that determine the limit. Limits are imposed on a population from conditions outside the population for example, temperature, rainfall nutrients.

Dealing with Complexity

However as we continued with our review, it became evident that defining capacity and listing determinants is not a simple exercise. Capacity is a complex variable among the attributes that all together determine salmon performance (Paulik 1973, Hankin and Healey 1986, Moussalli and Hilbom 1986, Hilbom and Walters 1992, Mobrand et al. in press). Therefore, we suspected that evaluating carrying capacity by listing, analyzing, and prioritizing determinants was not going to yield a study plan the region could use to increase its understanding of ecology, carring capacity, and limiting factors. To gain the understanding asked for in Measure 7.1A, it is necessary to deal with the complex relationship between density dependent (intrinsic) and density independent (extrinsic) factors that result in the long-term sustainability of salmon populations.

The complexity issue cannot be underestimated. Factors that affect salmon in one part of their life cycle can manifest the effect in later phases of the life cycle. Factors can have different effects on different populations in different parts of the Columbia Basmormarine environment. Factors can affect different populations or stocks in different ways. There are potential negative impacts of focusing on abundance (NRC 1995). How do the many populations and stocks of salmon affect one another? When we understand this ecological complexity, the region will be better able to make decisions to improve abundance as well as diversity.

Reeves et al. (1991) summarize this issue of complexities with their statement *"the idea that a single limit&g factor 'bottleneck' controls production is obviously an oversimplification of a complex ecological processes. In the context of a total system the search for a single factor can be misleading. Not only may the ultimate limitation way from year to year, it may be composed of interacting elements; when one is improve4 others may take over. Such an interaction may account for the failer of some of the well-intentioned attempts at habitat improvement." The experts at the carrying* Capacity Workshop (Johnson et al. 1996) voiced similar reservations regarding the oversimplification of approaching determinants as a basis for developing a study plan The following quotes illustrate this point:

> *Dan Bottom (Day I) stated, "The classic i&a of carrying capacity based upon a logistic-growth curve does 2 work very well for a variety of reasons...[different] stocks have different requirements and limitations...Limiting factors are constantly fluctuating so there isn't one you can remove and see a response...Limiting factors between life stages tend lo interact..."*
>
> **Lars Mobrand (Day 2)** stated, "I believe *the concept of capacity is used to simplify the notion of* salmon *abundance throughout the Columbia River Basin. Most of the discussions seem to focus on competition for resources. There are many factors in environment that affect* salmon *survival, for example predation; which may operate very differently from competition To understand salmon survival, it is important to examine ecological impact of abundance in a broader sense "*
>
> Chuck Coutant (Day *2) stated, "... /When] listing the physical and biotic dererminants -just about anything you can put on that list will be important at some rime in the life cycle.. the exercise of listing all these determinants could go on ad infinitum.. **

Bill Pearcy (Day 2) stated, "...[regopding;l *determinants, there are a lot of things that haven't been mentioned...like disease and BKD and nitrogen supersaturation... But, in general, we are focusing on salmonids [which] are only one very small portion of the ecosystem both in the river and certainly in the oceans. And they are not in isolation; they interact. I don't see how we can ever talk about the ocean without talking about other species. We mention predation, which I think is probably a key factor in the ocean. But we haven't mentioned things that buffer predation, which I think is really critical..."*

In addition to these comments, our evaluation provided other examples of how the approach of defining capacity and listing determinants was not going to work. We found many examples of mitigation actions for a specific limiting determinant that did not work. Mason (1976) reports on the futility of trying to enhance the number of fish in a British Columbia stream that supports coho salmon. In that system, most young coho salmon go to sea as smolts after one year of stream rearing. Artificial feeding of underyearlings during the summer greatly reduced emigration and increased the growth rate of remaining residents. The number of smolts that left the stream the following spring did not increase. The liiting factor of inadequate summer growth was relieved but the population size did not increase.

Wolff(1995) discusses the limitations of species-habitat association studies He points out that correlational approaches do not provide an endpoint in themselves. Species ranges of tolerance are often greater than can be measured in a localized study. Species live in a variety of habitats. Habitatdistribution correlations, especially for widely distributed animals, may be inappropriate. Wolff(1995), citing examples for elk martens, Douglas squirrels, and red-tailed hawks, states habitatdistribution studies often are interpreted to mean that a species does not occur in areas where selected habitat features do not occur. Hegoesontowamthereaderthatattemptingtocorrelatcthc existence of an animal to a particular habitat (not unlike attempting to correlate capacity to specific determinants) is not taking advantage of the scientific method, is asking the wrong question, cannot demonstrate cause and effect, and may not be a biologically sound method of determining the reasons animals exist in specific habitats and are distributed they way they are.

McDonald and Hume (1984) report the results of constructing spawning channels in the streams feeding Babii Lake, British Columbia The spawning channels lead to an increase in the number of sockeye smolts leaving the lake. Adult returns increased for odd-numberedyearsbutnotineven-numberedyears.Evidently, either spawning habitat is not limiting or the limit varies from year to year.

Improving the system in one area can adversely affect capacity in others. For example, in Fish Creek, Oregon, boulders collected from the edges of the stream channel to improve spawning habitat resulted in a loss or reduction of habitat for juveniles (Everest et al. 1985). Evaluation of the boulder removal indicated that winter habitat for young-of-the-year steelhead had been changed.

Nickelson et al. (1986) report that a mismatch between the understanding of life history diversity and habitat complexity resulted in failure to restore natural production of coho salmon in Oregon streams through hatchery outplanting. Reproductive success of the hatchery fish was reduced because they spawned too realy to avoid mortality caused by the normal occurrence of freshets.

When we add stock exploitation to the questions about capacity, Hilbom and Walters (1992) provide many examples that define the problems of the simple definition of capacity. The abalone population in Tasmania is the "antithesis"of a homogeneous stock. The adults are long-lived and move only a few meters during their life. The young are pelagic for a few days, but their dispersal is confined to a small area. Thus, while the Thus,while the exploitation of thcsc stocks is on thousands of individuals the effective management unit may be an individual reef. Consequently, listing the determinants would require assessment and regulation of each individual reef.

A different problem is apparent when we examine the life history of Pacific halibut (Hilbom and Walters 1992). The adults rarely move, however, the eggs drift along the coast and the juveniles migrate for years before becoming sedentary Recruitment to a stock depends on immigration. Capacity varies throughout the life cycle. Determinan for pelagic life forms defer and are complicated when trying to understand determinants for migrating or sedentary life stages.

Paulik (1973) prepared a graphic to illustrate stock-recmitment of several life history stages. He linked the stock-recruitment curves for egg to fry, fry to smolt, and smolt to adult. This illustration shows that the relatively simple relationship of some determinant of capacity at one lift-stage can become very complex for the aggregate relationship of the entire life-history

Moussalli and Hilbom (1986) discuss the implications of these aggregate relationships. They use the aggregate relationship to calculate the impacts of chaaging productivity or capacity at any life stage or stock size. Any increase in productivity (survival) will increease the optimum harvest rate, but may decrease or increase the stock size depending on the limitations of capacity at various l&stages.

Hankin and Hcaley (1986) state that the chinook life history pattems arc complex and require unique management actions for regulating the chinook fishery. 'They point out that harvesting immature fish in the troll fishery has been questioned. The age structure, average size, and genetic shifts to earlier matumtion have resulted from the management strategies that do not take into account the complexity of the chinook life history pattems. These results have developed in the absence of a management framework that inadequately captues both the complexity of salmon life histories and the distinction bctwecn fisheries types.

Mobrand et al. (in press) carry this thought even further. They point out that capacity is not an independent variable in the definition of performaue. performance is a function of diversity, cumulative productivity, and cumulative capacity. changing capacity for one life-stage of one stock may in fact, adversely impact the performance of other stocks in the same basin. These attributes of populations (capacity, productivity, and diversity) are not independent. We can not single out the capacity of one life stage or one stock as an indicator of cumulative capacity for all stocks in the basin. Rather, we

can look at the performance of salmon, that is the ability of salmon to sustain itself over a long period of time in an ever changing enviromnent.

The performance capabiity of salmon results from, in part, the exchange of genetic information. sustained performance is aided by the life history diversity types that are present in an environment like the Columbia River Basin. The more diverse the population, the more likely it is that some part of the population will survive any given enviromnental change. Life history diversity in salmon is observed by their variable use of habitats. Diversity dampens the risk of extinction and reduced production when the environment changes. Mobrand et al. (in press) discuss the observation of Thompson (1959) that salmon life histories are comprised of a chain of habitats with favorable spatial and temporal distributions. This complex habitat structure is an important determinant of productivity and capacity.

ln addition to these examples, the recent report of the National Research Council (1995) ***states that "it is.. . unlikely that reducing or compensating for only one type of adverse impact will be enough to reverse the decline [of salmon] in any watershed Management must recognize andprotect the genetic diversity of salmon It is not enough to focus on the abundance of salmon "***

From these examples and comments, it is evident what lead Smith (1952) to criticize the simplicity of equations used to describe carrying capacity of complex populations. He stated that these equations assumed that all animals in a population have an equal chance of being eaten, of procreating, of responding to an environmental stimulus.

The response by salmon to changes vary with species, We stage, season, and geographic location (Meehan 1991) complicating an evaluation of carrying capacity or the development of a study plan. Limiting factors differ among species and life stages, and change over space and time (Meehan1991). To develop the study plan, we concluded that we were left with the challenge stated by Odum (1959) - "The ***problem..may well boil down to determining I) whether one to several fators are primarily responsible [for the expression of population characteristics] or 2) whether causes are so numerous as to be difficult to untangle... "*** **Odumgoesontospeculatethat the later is more likely the case in complex ecosystems.**

Sii we concluded that a simple definition of capacity and a list of determinants was not going to help us meet the objective of Measure 7.1A, we decided to adjust the process that we started with (Figure 1). To this end, we decided to follow the steps for a systematic method of scientific thinking described by Platt (1964). He calls this method "strong inference" Thestepsare:1) devise alternative hypotheses, 2) devise experiments with alternative possible outcomes, each of which will exclude one or more hypotheses, 3) carry out the experiments, and 4) recycle the procedure through Steps l-3. Platt (1964) emphasizes the need for alternatives Thus, we altered our process (Figure 3) and set out to prepare alternative definitions of capacity.

Chapter 3: ALTERNATIVE DEFINITIONS OF CAPACITY

What can alternative definitions bring to the problem of developing a study plan? Is not "strong inference" just another name for the scientific method? Maybe. But Platt (1964) warns that *"Science is now an everyday business."* For example, some data collection and research programs have become ends in themselves Wolff(1995)' develops this point further by tying implementation of research and management actions to testable hypotheses. He "strongly encourages" biologists to consider the question before implementation. He states that researchers must know what they want A good clear objective and a set of testable hypotheses are necessary for useful results.

As discussed above, the mechanistic view to describe capacity will not lead to the development of a useful study plan. We have cited many warnings not to underestimate ecological complexity when defining ecological processes. Root and Schneidcr (1995) discuss the associations among definitions, planning, and observation. These discussions focus on the natural and anthropogenic changes in the context of ecological disturbance. They state that ecological implications of any change, including capacity, are difficult to predict for four reasons. Fii the difference between the rate of change for human-indnced vs. naturally-induced causes may differ by many orders of magnitude. second, the "scales" at which different research disciplines operate make interdisciplinary comparisons impossible (fisheries models look at the entire basin, estuary and ocean while a hatchery is no bigger than one or two football fields). Third, all the disciplines needed to implement an ecosystem approach must be integrated. And fourth, uncertainty will exist at every level of any analysis needed to understanding the factors that influence salmon survival.

Root and Schneider (1995) go on to develop and discuss alternative methods for untangling the complexities of study& understauding and analyzing multi-scale interconnections among disciplines associated with climate change and ecology. Their problem is not that much different from the problem posed in Measure 7.lA By examining four different paradigms or alternative hypotheses, they then propose one hypothesis that can be tested They offer a hypothesis that they state will improve understanding of the behavior of complex environmental systems and allow more reliable forecast capabilities for analyzing ecological consequences of global change. Following 1) the Program's requirement for a scientific basis, 2) using strong inference, and 3) the paradigm analysis of Root and Schneider (1995), we propose that altemative views of carryingcapacitybcexamincd.

Mechanism

We have already discussed one definition; *"...the upper limit, beyond which no major increases can occur" (Odum* 1959). This and all the other definitions listed in Chapter 2 can be classified as a mechanistic definition or view of capacity. With the mechanistic view, the environment is analogous to a machine. The idea is that if we understand the parts (determinants) we can fix them, replace them, or make them better as necessary. When applied to salmon, the machine analogy quickly falls apart. The environment does have parts, but the parts arc many, the interrelationships among parts is nearly infinite, and our ability to understand, fix, and replace the relationships has been harshly questioned (Ehrenfeld 1978, Hirt 1994, NRC 1995). However, if we are going "fix the environment" this ability will come from understanding (the objective of Measure 7.1A) Approaching the problem this way, the complexity of the enviroment became apparent, especially an environment in which we need to study the carrying capacity and understand the liiting factors that influence salmon survival.

Because of the complex nature of capacity, we concluded that the mechanistic definition would not lead to a useful study plan Thus, we now needed other definitions of capacity that we could compare to the mechanistic view. We used Pepper's (1966) discussion of World Hypotheses
alternative hypotheses[3].

From Pepper's work we have identified three alternatives to the mechanistic view of capacity. Pepper (1966) begins his discussion of hypotheses with a "root metaphor." (Pepper's root metaphor for the mechanistic view is the machine.) He describes the characteristics of a hypothesis, that is, those elements that discriminate one hypothesis from other possible hypotheses. The characteristics or elements then become the concepts by which the hypothesis can be explained or described. Although there are many altemative views of capacity, we follow Pepper's (1966) reasoning here because it provides a useful approach to discuss three alternative views to the mechanism: formism, organicism, and contextualism.

Formism

Thebasisforformismissimilarity. Thetruthofformismconsistsinsimilarity . between two or more things one of which is said to be true of the others. Truth then becomes a matter of sample or description. Are fish taken from the river a true sample of theentirepopulation? Are they a true sample of all fish in the basin? More likely, the formism view will lead us to use pictures, geographic information systems, diagrams, research reports, formulas, or computer models to learn the truth about the questions we ask. Applied to evaluating capacity, the formism view requires that we list determinants of capacity for "similar" basins or populations and identify critical uncertainties and research based on what is unlike or not alike between or among the basins or populations. A resultant study plan is then based on the degree of similarity that is a symbolic representation of the uncertainties and needs rather than being based on the objective of implementing an ecosystem approach. .

White (1995) warns us that this approach leads us to manage by comparison of similarities defined by the "virtual" river. The virtual river of computer simulation is much simpler than the complexities of the Columbia River Basin. Our virtual rivers do not agree on the determinants of capacity and therefore may not help us select management actions or set research priorities.

[3] We use the term hypothesis here because it is consistent with Pepper's usage. For the purposes of this report, alternative hypothesis is the same as alternative view.

The world and the Columbia River Basin are full of things that seem to be alike, e.g., salmon from the same reach of the river or stream, fish of the same species, fish of the same run, fish of the same evolutionarily significant unit. Using a formism view of capacity, truths are descriptions which accurately correspond with facts that have occurred or with laws that hold true. Pepper (1966) suggests that this approach then requires that we follow a succession of comparisons until we find the regularities of *nature and then approximate "actual necessary laws." What might* follow then is finding that the laws of nature (in our case a view of carrying capacity) are not discrete. Thus, we have a resultant single scientific description and no scientific basis for similarities among samples or observations. This line of thought can lead us toward a mechanistic view of capacity. That is, our observations of similarity become integrated into a single system or constant law. Thus, a formism view of capacity leads to 1) comparisons that do not hold true or 2) back to a mechanistic view.

The advantage of using the formism view is the need to list determinants, characteristics, and attributes that we can compare between systems of individuals. The list may be useful to develop a study plan, however, like with the mechanistic view, we fall short when we assess consistency with observations of salmon populations. With the formism view we could hold off on "the answers" and hope that the answers lie in the future when we have more data or more comparisons. To develop a study plan for carrying capacity that will help the region implement an ecosystem approach to managing fish and wildlife, we need a scientific basis now. In conclusion, the formism view does not meet our needs because it is not consistent with our observations and is not immediately useable.

Organicism

A second view discussed by Pepper (1966) is organicism. A root metaphor that helps define organicism is the organism. Pepper (1966) offers that this metaphor may have too many biological connotations that can get in the way of it being useful, however, for our purposes we will proceed. "The organicist *believes that every actual event in the world is a more or less concealed organic process... therefore, that a careful scrutiny of any actual process...would exhibit its organic structure, through some of the processes with which we are generally Familiar..." Odum (1959)* alludes to this in his discussion of the problems of defining the determinants of capacity when he states that "causes [may *be] so numerous as to be difficult to untangle even though the total interaction may be understood"* Applied to evaluating capacity, the organicism view requires that we *a priori* accept *that we can* not list determinants of capacity because the determinants are concealed. This approach breaks down when we cannot research the parts nor do we have a means of studying the entire basin and populations of salmon at one tune.

Warren et al. (1979) also discuss an organicism view for defining living systems. The performance of any "system" is the outcome of its interactions and has functions and operations in the maintenance, organization, and replication of the whole. *"The potential capacity of any organismic system predetermines all possible sequences of realized capacities, which in turn determine all possible performances, any occurring sequence of realized capacities depending on the environment though time and any occurring* *performance depending on the immediately effective environment."* Warren et al. (1979) then conclude that uniformities may underlie but are obscured in complex systems. The Columbia Basin is obviously a complex system.

Using an organicism view of capacity the Columbia Basin is an organic whole. Every element within the basin (fish, wildlife, plants, water, dams, people, barges, hatcheries, fast food establishments) can affect every other. Then, alteration or removal of any elements within the basin would alter every other element in the whole system. Within the basii we observe degrees of organically or implicate with the other elements of the basin. An alteration of an element may have serious effect on some parts but not on others The organicism view is consistent with an ecosystem approach to management.

Pepper (1966) says that the organicism hypothesis requires that we move towards greater and greater inclusiveness. We need to gather more and more data to determine and integrate our observation with our view. We need to increase perfect and organize our data to get closer and closer to the "facts." The problem with this view is that pure fact is the absolute. The absolute is never obtained through the partial integration of determinants which resource managers often must use by necessity.

The organicism view is useful for understanding the world around us. Almost by definition we could not fail to describe salmon or their habitats because all causal relationships are internal and hidden; all we need to describe is the total interaction. This however, is not useful for developing a study plan. This is, unless we want to study everything, all the time understanding that truth lies at some undefined future milestone. In conclusion, the orgauicism view is not useful because it does not provide a means to provide a useful study plan.

contextualism

So far we have looked at two alternative to the mechanistic view. A third alternative, contextualism, uses the historic event as the root metaphor. Thehistoric event is not only the past, but rather, from this viewpoint, is a realization of what is going on now. In the Columbia Basin some events are: spawning, passing on a genetic trait, swimming to the ocean, passing through a turbine, damming a river, diverting a stream, hatchinginanincubator. Pepper (1966) points out that events or acts are *"all intrinsically complex, composed of interconnected activities with continuously changing* patterns." The contextual hypothesis proposes that everything in the world consists of such events. Applied to evaluating capacity, the contextual view requires that we: 1) describe the status of the basin as it exists today, 2) describe the healthy basin, and 3) identify what is preventing the region from realizing its management objectives Accomplishing these steps should result in identifying the critical uncertainties and researchneeds. When we describe the status, we can accomplish this in terms of the complexity of a healthy environment for salmon When we describe what is preventing us from accomplishing objectives, we have to describe the actions that we would be williig to take to move toward a healthy environment and increased salmon survival.

Using a contextual view of capacity, we are working within the events that are occurring today and resolving uncertainties within existing biological and social constraints.

Since the Columbia Basin ecosystem consists of intrinsically complex interwnnected activities, we propose that a wntextual view caa be useful for evaluating carrying capacity. A contextual or historic event view can include the notions of wmpound capacity (Hilbom and Walters 1992) and integration of capacity with diversity and productivity (Mobrand et al. in press). There are three points of contextualism that will help us define capacity and determine the limits of capacity while remaining true to our observations of salmon in the Columbia River Basin. First almost anything is possible. Change, both planned for and unexpected, will be the norm. This allows us to work within the extremes. We are not constrained by our inability to define determinants as we are with organicism. Nor, are we required to define and understand all the intricacies of cause and effect suggested by the mechanistic or formistic views.

Second, we have to deal with the Columbia Basin as it exists today. We can not go back to the past. However, our knowledge of the past is absolutely important to help *us understand what has changed. "Only by &voting itself to the past, to what has already happened and thus cannot be revised according to our wishes, does science come to know new things"* (Turner 1995). It is this second point that will be most important to develop a study plan that is based on a scientific framework and is consistent with our observations of salmon.

Third, events exhibit a structure within the wntext of basic categories. Events can be described in terms of quantities and qualities. Events occur over time, they change, they are connected, and they occur within a context. By using specific categories we can describeperformance, ascribe performance to specific goals, and monitor our progress towardourgoals.

Using the contextual view to evaluate capacity, we are not confined by the constraint of mechanism or formism; that is; determinants have to be def&d completely. With the contextual view, there is no "final" analysis. We are free to continue to learn. This is consistent with the principals of adaptive management As Lee (1993) stated, *adaptive* management *is "an approach to natural resourcespolicy that embodies a simple imperative: polices are experiments; learn from them."* Additionally, we are not constrained by the organicism view where interconnection makes it impossible to untangle the determinants. We condudde that the wntextual view is appropriate for an evaluation of capacity because it wilI be scientifically sound and ecosystem-w produce a usable list of critical uncertainties and research needs, and be consistent with the complex nature of capacity.

Strong Inference (Steps 2 Through 4)

We now have alternative definitions of capacity (Step I as defined by Platt 1964). To continue following Platt (1964) we now need experiments (Step 2), implementation (Step 3), and analysis (Step 4). An advantage to using the wntexualistic view is the existence of tools to devise experiments. One such tool is the Patient-Template Analysis. This tool is used in"An Approach to the Diagnosis and Treatment of Depleted Pacific

Salmon Populations in Pacific Northwest Watersheds" by Lichatowich et al. (1995). The Patient-Template Analysis requires a description of the status of life histories and habitat of the target species compared to a description of the healthy habitat and Life histories of the target species. The analysis provides the ability to address capacity from a wntextual view as described by Pepper (1966). This type of analysis for studying carrying capacity was recommended by the participants at the Carrying Capacity Workshop. Applying Patient-Template Analysis within the wntextual view will provide an evaluation of carrying capacity under current wnditions. It will compare current wnditions to historic conditions and thus, define the possible future conditions for salmon in the Columbia River Basin. This analysis will define the critical uncertainties and research needs necessary to develop a carrying capacity study plan.

The implementation of the experiments and analysis of results will have to follow the development of a study plan. This is discussed in the second report of this study, "Study Plan For Evaluating carrying Capacity, Measure 7.1 A of the Northwest Power Planning Council's 1994 Fish and Wildlife Program, Report 2 of 4."

Chapter 4: CONCLUSIONS AND RECOMMENDATIONS

To pursue the capacity parameter as a single number or set of numbers that quantifies how many salmon the basin or any part of the basin can support, will not provide useful information to meet the objective of Measure 7.1A. This is the mechanistic view of salmon population dynamics and it will not work. The region "must *recognize and protect...diversity...It is not enough to focus only on theabunahe of salmon"* (NRC 1995). **We have to realize the quality of whatever happens to be at the present time. Then, significance lies in the purpose of what we are pursuing.** Bella . (1995) describes the need to move toward a "healthy environment strategy " He claims that the assessment and management of the many activities responsible for the decline of salmon in the Pacific Northwest are hindered by fundamental misconceptions. **Management and policy have been dominated by presumptions that fail to grasp the** complexity of human and salmon interactions (Bella 1995). To increase our understanding of ecology, carrying capacity, and limiting factors that influence salmon survival under current conditions, we must deal with the complexity of issues such as carrying capacity. In closing we conclude and recommend that:

- Strong inference **(Platt 1964) is needed to evaluate carrying capacity in the Columbia** River Basin. All proposed researchandproposedmanagementactionsshouldinclude the steps defined by Platt (1964): devise alternative hypotheses; devise experiments, with alternatives, to exclude one or more of the hypotheses; carry out the experiment or action to get clean results; recycle this procedure.
- Carrying capacity is a complex wncept that can be evaluated from a contextual point **of view that is consistent with observations of salmon populations and can be used to** develop a study plan to increase the region's understanding of ecology, carrying capacity, and limiting factors for salmon. The Council and BPA should use a wntextual view to evaluate carrying capacity.
- From the wntextual view, capacity is a component of salmon performance, and is inseparable from diversity and pmductivity. Capacity reflects the quality and the quantity of salmon and provides us with a relative measure of the size of a population[4]. The Program should incorporate the complex, interdependent relationship of diversity, productivity, and capacity into all the measures.
- Understanding capacity from a mechanistic view, the basis for Measure 7.1A and **much of the Program, could be useful for making a list of determinants, however, this** view is not consistent with the complex nature of salmon life histories and Columbia River environs. The mechanistic view is not useful for developing a study plan. The **mechanistic view of salmon in the Columbia Basin should not be used in the** program-

4- Population size is not different from the mechanistic definition What distinguishes capacity when it is defined in a cautextual or hiic event framework is its inseparable link to diversity and pmductivity within a measure of perfomance for salmon. For further clarification of salmon performance we suggest Mohrand et al.(1996).

- The Patient-Template Analysis is a tool that wuld bc used to evaluate carry@ capacity and develop a study plan to increase our understanding of the ecology, carrying capacity, and limiting factors for salmon. The Council should call for a Patient-Template Analysis, as described by Lichatowich et al. (1995). The region will be able to evaluate carrying capacity under current wnditions, compare current conditions to historic conditions and thus, predict possible future wnditions for salmon in the Columbia River Basin.

In closing, Measure 7.1A is a microcosm of the entire Program. It is based on a framework[5] that is not working. The carrying capacity measure and the Program as a whole need a new framework The new framework should be based on the recognition and protection of the entire life cycle of salmon and not on abundance of salmon alone. The framework should be consistent with observations of salmon populations and incorporate the complexity of the population's attributes The framework must accommodate the wnnectivity among life stages and the interrelationships among capacity, diversity, and productivity within the Pacific Northwest ecosystem. The contextual view provides the basis for a new framework.

[5] During most of this report, we discuss definitions, hypotheses, and views. When we discuss the need for a new framework, we mean to use a broader term. We include three elements, when we use the word frameworks theory, tasks and tools. The theory is the general proposition or principles we use to explain the events we observe. Theory results from our view of the ecosystem and the hypotheses that we test. The tasks are the commitments, processes, and institutional requirements needed to carrying out the Fish and Wildlife Program. The tools are the instruments of management needed to analyze data, schedule projects, resolve conflicts, and make sure our actions are moving us toward our objectives.

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