APPLICATION OF DECISION ANALYSIS IN THE EVALUATION OF RECREATIONAL FISHERY MANAGEMENT PROBLEMS

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ABSTRACT

Fisheries management is a decision-making process, yet typically formal decision analysis techniques are not used in structuring problems, quantifying interactions, or arriving at a prioritized solution. Decision analysis tools are applied in the decision-making process for Alaska's recreational fisheries management as a means to reduce risk in management at the policy (Chapter 2) and field (Chapter 3) levels. In Chapter 2 the analytic hierarchy process is applied to the recreational fishery for chinook salmon (*Oncorhynchus tshawytscha*) in the Kenai River. Model structure is developed through an iterative interview process involving individuals asked to represent the perspectives of 15 different stakeholders. Individual stakeholder judgments are combined using a geometric mean, and maximax and maximin criteria. The sensitivity of the results to under-representation is explored through various models. Despite the contentious differences of perspective represented among stakeholders, the analytic hierarchy process identifies management options that enjoy broad support and limited opposition.

In Chapter 3 decision analysis is applied to the recreational spear fishery for humpback whitefish (*Coregonus pidschian*) in the Chatanika River. A modified form of catch-age analysis is used to combine information derived from creel surveys and run age composition with auxiliary information in the form of mark-recapture estimates of abundance. Four systems are used in weighting annual observations: prior beliefs regarding their reliability, by the inverses of their variances, through a combination of these two weighting schemes, and equal (no) weights. The perception-weighted model generates the most reasonable estimates of abundance, which are relatively precise and associated with small bias. Forecasts of mature exploitable abundance are calculated based on various recruitment scenarios, maturity schedules, and exploitation rates. From

these outcomes, the odds of stock abundance occurring below a threshold level are presented.

By applying decision analysis methodologies which incorporate judgments and perceptions into decision-making affecting fisheries, sensitivity to uncertain information is made explicit, components of the problem are structured, interactions among components of the problem are quantified, and options are prioritized, thus increasing the chances of finding an optimal solution.

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CHAPTER 1

INTRODUCTION

Fisheries management is a decision-making process where managers do not have complete information, and must choose among an array of risks and benefits to address a collection of often conflicting goals. Risk in fisheries management involves the probability of an undesirable event (e.g., stock abundance falling to an unacceptable level) involving some consequence or loss (e.g., diminished social or economic benefits derived from fishing) in relation to a reference point (Morrissey 1993, Cordue and Francis 1994). As society has become increasingly complex, so have the tradeoffs between risks to the resource and risks of foregone fishing opportunities. Complicating the question of risk is uncertain information, due to either a lack of information about the value of parameters (measurement uncertainty), a lack of information about which parameters adequately describe the process (descriptive uncertainty), or suspect information. Because the sources of uncertainty will never be completely removed, fisheries managers routinely make intuitive judgments (preferences) regarding varying sources of information and have personal perceptions (beliefs) about the accuracy of estimates. These judgments and perceptions are often integrated in their decision-making (see Pfund 1985).

In this dissertation methodologies were applied which make the judgments and perceptions of stakeholders[1] and decision-makers explicit in mathematical decision models. It is only by making the decision process visible can an informed constituency

[1] Stakeholders are those who have a stake in the management outcome or are responsible for oversight of the resource.

ensure a balancing[2] of those who receive the benefits and those who assume the risks. When the decision-making process is invisible and there is an imbalance of risk, there is controversy and contention. While stakeholders may not agree with a decision, if there is some assurance all the components of a problem have been considered, then impartiality of the decision-maker will be less suspect. Furthermore, by explicitly representing subjective information, techniques which have been designed to use subjective information can be applied in seeking a solution to a complex fisheries problem. There is a need to address complex problems and their associated risks in fisheries management, because the failure to do so will result in oversimplification of complex issues and misrepresentation of results (see Mackett 1985, Hilborn and Walters 1977).

By using decision analysis, complex problems in fisheries management can be structured, the interactions among components of the problem quantified, and options can be prioritized, thus increasing the possibility of finding a solution by enhancing the overall understanding of the problem. Decision analysis is a technique that is sensitive to uncertainty in decision-making because it can incorporate judgments and perceptions into mathematical processes used to describe problems and arrive at their respective solutions.

In this dissertation decision analysis tools are applied at two different levels in the decision-making process for Alaska's recreational fisheries management. In Chapter 2, multiple criteria decision analysis is applied to the recreational fishery for chinook salmon (*Oncorhychus tshawytscha*) in the Kenai River at the policy-making level. The analytic hierarchy process (Saaty 1990a) is used to identify and prioritize preferred policy options

[2] Because different managers and stakeholders have different acceptable levels of risk, the definition of balance is a constant issue. One method of setting an acceptable level of risk is to use the preferred option to an issue. The level of risk which is acceptable is implicit in the option that is most preferred (Saaty 1990a). The process of establishing an acceptable risk level involves intuitive judgment (Rowe 1988).

which seek to control such risks as overfishing, imbalanced allocation among user groups, habitat damage, and reduced quality of the recreational experience.

In Chapter 3 an assessment of humpback whitefish (*Coregonus pidschian*) stock status is combined with perceptions of data accuracy. In contrast to Chapter 2, this chapter introduces decision analysis at the field level and represents a fishery professional's view for policy change. The influence of perceptions on the risk of overfishing is evaluated in an application of catch-age analysis (after Deriso et al. 1985) to the humpback whitefish population. As is often the case in fisheries, assessment of the humpback whitefish population requires use of an incomplete data series collected under varying circumstances. While researchers had more confidence in this data set for some years than others, discarding suspect data seemed inefficient. Rather than accept suspect data as equally reliable, or entirely discount these data, Chapter 3 explores a methodology for explicitly weighting observations according to prior perceptions of reliability. By quantifying perceptions, the sensitivity of model forecasts to alternative weighting is examined.

The objective of both studies is to determine the significant variables of the management problem that affect policy changes. In Chapter 2, the significant variables are the most preferred options to important issues. In Chapter 3, the significant variables are the most desirable harvest strategies given states of the fish population.

Several themes join the two studies. The first theme introduces structure to complex fisheries management processes comprised of interlinked components. In Chapter 2, the problem of managing a recreational fishery is expressed as a hierarchy of issues and options linking biological, social, economic and political components of the problem. In Chapter 3, the problem of modeling the interaction between the recreational fishery and the fish population is expressed as a catch-age model, where such parameters as exploitation, natural mortality, and vulnerability are interlinked. To reduce uncertainty in both management processes (that is, descriptive uncertainty), important variables of the processes are identified and their functional relationships are mathematically described.

The second theme involves the assignment of specific measures of value or interaction to defined variables, thus reducing measurement uncertainty in management processes at the policy and field levels. In Chapter 2, values are assigned to issues and options in the form of numerical priorities, obtained through judgments. Judgments are used because preferred solutions to many issues could not be found through simple quantitative methods. In Chapter 3, harvest and population values are observed. However, observed data is associated with statistical error and suspected of bias, thus making this empirical data set limiting. Accordingly, perceptions are introduced into the model in an effort to more closely discriminate among the alternatives for harvest strategy.

The third theme involves the revelation of judgments and perceptions used in arriving at a decision. In Alaska, both the Board of Fisheries and fisheries managers each to a certain extent interpret the conservation needs of the resource and the social and economic needs of stakeholders, and thereby assign options by promulgating a regulation or enacting an emergency order. These options may be preferred or undesired, depending upon the perspectives of different sets of stakeholders. In making such decisions, the Board of Fisheries and fisheries managers are subject to intense questioning by the public. The questions include: What information was used in making the decision? How were priorities assigned to variables comprising the information set? What was the effect of personal values and/or beliefs of the decision-maker(s) on the decision? In general, the Board of Fisheries and fisheries managers do not directly receive benefits or incur losses as a result of their management actions. Instead, their decisions impact stakeholders. When stakeholders are not involved in the decision-making process, the imposition of risk of loss becomes involuntary. By opening the judgments and perceptions of managers to review, the validity of their decisions can be examined.

Mathematical decision models have been used extensively in the management sciences, military, and engineering disciplines. However, they have not yet been widely adopted in the natural resource management literature. In a study conducted in Finland, Hämäläinen (1992) noted the challenge which faces policy-makers in a democratic society when they attempt to consider and present options in a balanced way. Environmental policy-making was promoted when Finland's National Energy Committee communicated options to stakeholders in a clear framework (Hämäläinen 1992). Hilden et al. (1994) used decision analysis to assist the National Board of Waters and Environment in planning for reduced impacts due to flooding in Finland. He reported that use of decision analysis improved stakeholder involvement, clarified the definition of concepts, enhanced the overall understanding of the problem, and increased the possibility of finding a compromise solution. In examining policy-making in the Netherlands, Beinat and Janssen (1994) noted that decision-makers were often faced with incomplete and uncertain information, so their decisions relied not only on expert testimony, but perceptions as well. When Beinat and Janssen showed decision-makers how to establish a relationship between a quantitative measurement, a subjective preference, or a perception with importance, and thus to represent judgments as value functions, the tradeoffs between options became more explicit. These researchers noted that the decision-makers participating in the decision analysis were generally satisfied with the resulting model.

Despite the fact that decision analysis has been used successfully to display options in a framework and make tradeoffs explicit, it is a common lament in the decision theory literature that people generally tend to mistrust the outcomes of analyses based on mathematical modeling. Furthermore, mathematical representations of real systems can oversimplify the complexities, and these simplifications can have a profound effect on the "solution". In practice, many decision-makers prefer to rely on intuition (Gass 1983, Tait 1988). Because the internalization process is dependent in part upon each person's unique past experience (Gass 1983), people will process identical information differently, and arrive at differing solutions which will discount complex information. The problem, then, is to demonstrate to potential users that a solution found through decision modeling is optimal. Lack of faith in mathematical decision model outcomes can be addressed by increasing the training of decision-makers in the formulation of mathematical decision models, or alternatively, to incorporate their judgments and perceptions into the mathematical process. The ability to incorporate judgments and perceptions may make a difference in decision models being used and implemented in fisheries management. If judgments and perceptions are not included in the analysis of the problem, the solution may fail to be implemented.

CHAPTER 2

EVALUATION OF THE ANALYTIC HIERARCHY PROCESS FOR AIDING MANAGEMENT DECISIONS IN RECREATIONAL FISHERIES: A CASE STUDY OF THE CHINOOK SALMON FISHERY IN THE KENAI RIVER, ALASKA

INTRODUCTION

Although multiple criteria decision analysis has been used extensively for strategic planning, conflict resolution, and policy development in economics, engineering, and political and military science (see for example, Keeney and Raiffa 1976, Saaty 1990a, 1990b or Warfield 1990), it has only recently been applied to decision-making in the management of fisheries. Multi-attribute utility analysis was used by Hilborn and Walters (1977) to balance conflicting goals in the management of salmon fisheries in the Skeena River, Canada; by Bain (1987) to integrate various factors for planning the management of recreational fisheries for brown trout (*Salmo trutta*) in the Au Sable River, Michigan; by Walker et al. (1983) to investigate the design of salmon management policy in Oregon, and by Healey (1984) to demonstrate an analytical model for optimum yield strategies in fisheries management. Mackett (1985) employed a different approach to multiple criteria decision analysis, interpretive structural modeling, to develop a strategic plan for research and management of the fishery for north Pacific albacore (*Thunnus alalunga*).

The need for multiple criteria decision analysis arises when there are multiple objectives that are not wholly compatible with each other; and/or when there are many, conflicting options and the course of action seems unclear. Varied objectives and options may arise from a plurality of stakeholders or for a single decision maker with multiple responsibilities. The fishery management problem becomes more complex when identification of options involves addressing social and economic issues, thus necessitating public involvement in the decision-making process of governing agencies. Governing agencies are constrained in their problem-solving ability to the proposal and implementation of only those options within their authority. Further, governing agencies may face multiple objectives which are incompatible. The recreational fishery for chinook salmon in the Kenai River, Alaska, is a multiple criteria decision problem because it involves integrating quality of life issues with biological conservation and production goals, and coordinating the development of a solution among multiple governing agencies, interest groups, and private citizens.

This chapter examines one approach to multiple criteria decision analysis, the analytic hierarchy process (Saaty 1990a), as a tool for facilitating decision making in fisheries management. The analytic hierarchy process (AHP) structures decision problems into levels encompassing issues or objectives of similar importance. Structuring complex problems permits decision makers to focus on smaller sets of decisions, improving their ability to formulate accurate judgments (Brownlow and Watson 1987). Stakeholders[3] often have differing objectives. Nevertheless, they often share common concerns. The AHP builds on these areas of common interest and identifies options that are consistent with the objectives of many stakeholders. In addition to developing a framework for applying the AHP to fisheries management decisions, the sensitivity of the results to the presence of strong (conflicting) judgments, and, the effects of the under-representation of stakeholders are explored.

[3] Definitions of terms used in this study which may be unfamiliar to most fishery biologists can be found in Table 2.1.

Table 2.1. Definitions of terms used in analyzing the recreational fishery for chinook salmon in the Kenai River using the AHP.

Term	Definition
Element	A component of the decision hierarchy, either an issue or an option.
Encompassing hierarchy	A merging of individual decision hierarchies into one, which includes all issues and options.
Global priority	An approximation of the strength of stakeholders' judgments for an option adjusted to reflect the importance assigned by the stakeholder to the issues addressed by that option.
Goal	The future management of the recreational fishery for chinook salmon in the Kenai River.
Importance	A comparison between issues; e.g., "How much more important is allocation than regulation?"
Individual decision hierarchy	One stakeholder's view of the problem and its solution, organized as a hierarchy of issues and options.
Interest category	An aggregate of stakeholders who share a common primary objective or who represent the interests of select individuals.
Issue	A component of the decision hierarchy that expresses a specific portion of the entire problem.
Judgment	An expression of strength of dominance or preference of one element over another.
Level	Stratification of issues and options comprising a decision hierarchy.
Local priority	The normalized vector of judgments for one single set of comparisons.
Maximax	The most preferred solution of the most strongly favored options. This strategy seeks the maximum payoff.
Maximin	The least objectionable set of the most strongly disliked options. This strategy seeks the smallest maximum loss.
Option	A component of the decision hierarchy that seeks to address an issue; a proposed alternative or course of action to take.
Preference	A comparison between options, e.g. "How much more preferable is the status quo to revising permitting standards?"
Priorities	Derived from judgments. Setting priorities is a process of weighting and adding judgments to derive a single number to indicate the priority of each element.
Problem	All issues of the decision hierarchy. In this paper the problem is defined as the management of the recreational fishery for chinook salmon in the Kenai River.
Solution	The most preferred set of options to the problem.
Stakeholder	An individual or a representative of a constituency who have a stake in the outcome of a decision problem.

This study was conducted in 1992, so the status of the fishery and issues surrounding its management are most relevant to 1992. However, many of the issues identified in 1992 are ongoing. A central assumption of this paper is that the problem of managing the recreational fishery for chinook salmon in the Kenai River should be approached using group decision-making. Most public policy decisions are an intricate composite of different judgments made by many individuals. One might argue that while groups are beneficial in describing the problem, a single decision making entity should prescribe the solution. There are many decision problems in the public sector where the decision-maker can be viewed as an individual (Keeney and Raiffa 1976). However, when the objectives of stakeholders are mutually incompatible, each will seek to influence the choice of options. Multicriteria decision analysis facilitates decision-making when tradeoffs are required.

OVERVIEW OF THE FISHERY AND ITS COMPLEX MANAGEMENT

The Kenai River supports the largest freshwater recreational fishery for chinook salmon in Alaska. Kenai River chinook salmon are prized by recreational anglers for their large size. Little effort was directed towards this fishery until 1973, when brightly colored lures bounced along the bottom of this glacially turbid river from drifting boats was discovered to be highly successful at catching chinook salmon. Chinook salmon return to the Kenai River in two runs, early and late. The early run arrives in mid-May, and harvest peaks in mid-June. The late run arrives in early July and harvest peaks in late July.

The sport fishery is regulated by the Alaska Department of Fish and Game (ADF&G), Division of Sport Fisheries. There is a state constitutional mandate for

ADF&G to manage fisheries on a sustained yield basis. The ADF&G has the authority to issue emergency orders, which are laws made under field announcement. The ADF&G has the power to enforce laws pertaining to the capture and retention of fish and game. These enforcement powers overlap with those of several other state and federal agencies. Restrictive regulations for this popular sport fishery include limiting the area of the fishery to a 80 km area downstream from Skilak Lake (Figure 2.1). Unless modified by emergency order, the open season is January 1 through July 31, with a daily bag and possession limit of one chinook salmon 16 in (40.6 cm) or greater in length. There is a season limit of two fish. The majority of the harvest is taken using boats. After retaining a chinook salmon using a boat, an angler may not fish from a boat in the Kenai River for the remainder of that day.

Although there is no institutional structure in Alaska for prioritizing and implementing all the options to a complex fishery problem, the Board of Fisheries (Board) has the broadest policy-making authority to solve complex fishery problems. Policy for regulating and allocating fisheries resources in Alaska is determined by the Board, which was created by legislative statute. The Board is composed of seven members appointed by the Governor, subject to confirmation by a majority of the members of the Legislature. The Board must work in cooperation with industry, private interest groups, state agencies and local governments. Furthermore, the Board's decisions are subject to gubernatorial, legislative, and judicial review (see Figure 2.2). In addition to biological information and advice provided by the ADF&G, the Board accepts public testimony and considers recommendations from regional advisory committees. Regional advisory committees were created by legislative statute and are composed of persons knowledgeable about local fish resources. The advisory committee has the authority to hold public hearings and to forward policy recommendations to the Board. However, the Board is not obligated

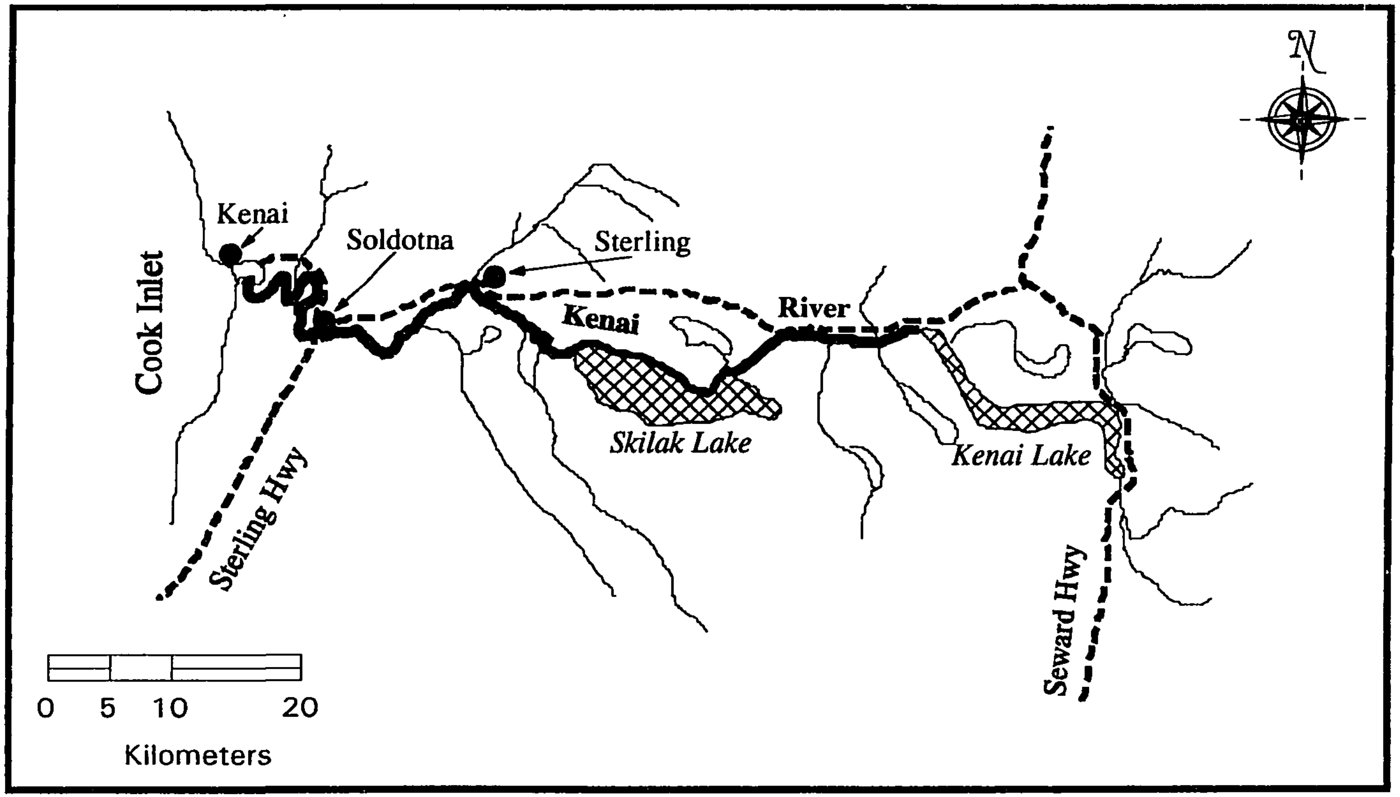

Figure 2.1. A map showing the Kenai River, Kenai Peninsula, Alaska.

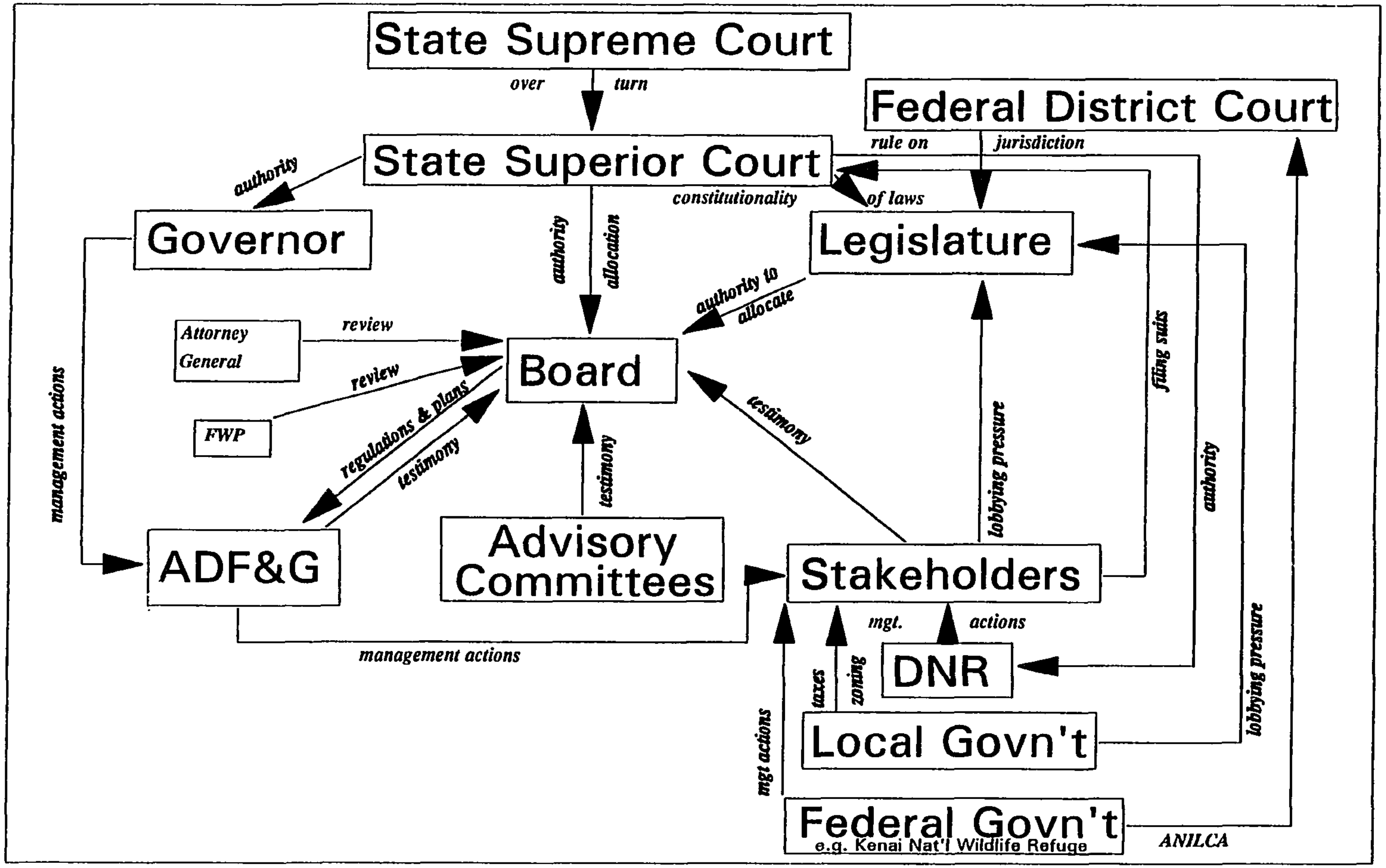

Figure 2.2. The decision-making process for addressing Alaska state fisheries management problems at the policy-making level.

to follow the recommendations of state agencies or advisory committees. Stakeholders lobby the Board in support of preferred, often conflicting alternatives. In 1988, the Board adopted a management plan which established minimum and optimum escapement goals for chinook salmon in the Kenai River and identified specific restraints on commercial, subsistence, and sport fisheries to facilitate attainment of these goals. The Board is free to change provisions of the management plan based upon new information or appeals from stakeholders. Despite the adoption of the management plan, many contentious and complex issues remain.

Commercial drift and set gill net fisheries for sockeye salmon (*O. nerka*) in upper Cook Inlet incidentally intercept late run chinook salmon. Commercial fisheries in Cook Inlet are regulated by ADF&G, Division of Commercial Fisheries Management and Development. Current Board policy prohibits commercial salmon fishing in Cook Inlet prior to July 1, thereby reserving the majority of the early run of Kenai River chinook salmon to the sport fishery. However, the incidental harvest of late run chinook salmon averaged 25% of the 1985-1991 total return, while sport fishing harvests averaged only 17% of the total return over the same time period. In testimony before the Board, anglers have argued that it is neither optimal nor equitable for the commercial bycatch to exceed the directed catches of the in-river sport fisheries. For their part, commercial fishermen have expressed concern that measures intended to reduce bycatch of chinook salmon would necessitate costly gear modifications and result in reduced catches of sockeye salmon. Although the relative benefits of recreational and commercial fisheries to local and state economies are brandished in debates regarding allocation among these two user groups, the actual marginal net benefits are not known. Moreover, even if a reallocation was pareto optimal, it would be opposed by stakeholders whose catch share is reduced.

Furthermore, there exist other stakeholders whose interests are not represented by either commercial or sportfishing benefits.

Responsibility for management of the Kenai River and lands adjacent to the Kenai River is divided among several municipal, state, and federal agencies. The Alaska Department of Natural Resources, Division of Parks, oversees the Kenai River Special Management Area (KRSMA) and state-owned uplands, which includes the majority of the area open to sport fishing for chinook salmon. Regulations promulgated by the Division of Parks can also affect the sport fishery. For example, in 1987 the Division of Parks reduced the maximum size of outboard motors used on the Kenai River to 35 horsepower, in part to reduce bank erosion caused by the wake they create. Ambiguity in the enabling legislation for KRSMA resulted in a court ruling which in 1992 limited the authority of the Division of Parks to enforce fishery and land use regulations. The Department of Public Safety, Division of Wildlife Protection, has the authority to enforce fishery regulations.

The federal government has jurisdiction over lands and waters included in the Kenai National Wildlife Refuge and the Chugach National Forest, and over activities that could impact those lands and waters. The federal government also has authority over subsistence fishing rights granted under the Alaska National Interest Lands Conservation Act (ANILCA), enacted into law in 1980. To maintain State responsibility for fish and game management, ANILCA required the State to distinguish between user groups and assign priority opportunities for subsistence uses. The State Legislature has struggled to comply with the ANILCA requirement, while at the same time trying to comply with the State's constitutional mandate of equal access. Subsistence uses of fish have been assigned a higher priority in Alaska than sport, commercial and personal uses. Heated controversy has surrounded the priority-use designation of subsistence, as Alaska native groups and local residents compete amongst themselves and with other users for a share of limited resources. In 1992 the State Legislature passed a law which gave the Board power to declare that residents of certain areas do not qualify for subsistence rights. The Kenai Peninsula was declared non-subsistence, eliminating the priority previously accorded to subsistence users. Personal use opportunities to dip net for chinook salmon in the mouth of the Kenai River and set gill nets remained, however personal use does not take priority over other uses. Questions regarding allocation of fisheries resources among user groups have been at times decided at the judicial level. For example, an Anchorage superior court ruled in favor of Native-only education fisheries for the purpose of allowing tribes the opportunity to pass on knowledge of traditional methods of fishing.

Local and municipal agencies such as the Kenai Peninsula Borough and the cities of Soldotna and Kenai also hold jurisdiction over lands adjacent to and activities that impact management of the Kenai River. For example, imposition of a bed tax might decrease the length of stay or discourage non-local anglers from visiting the area. Zoning ordinances can encourage or discourage conservation of riparian lands adjacent to the Kenai River.

Private individuals and organizations also have a stake in the management of the Kenai River. The Kenaitze Indians and other private landholders (many of whom are represented by the Kenai River Property Owner's Association) control extensive acreage affecting or affected by management of the Kenai River. The large amount of recreational activity coupled with commercial undertakings has resulted in visible degradation of some parcels adjacent to the river. Environmental groups (notably the Nature Conservancy) are concerned about degradation of this unique riparian habitat and its effects on chinook salmon survival. Within ADF&G, the Division of Habitat has the authority to enforce laws protecting the habitat of fisheries resources. The Division of Habitat reviews and issues permits to regulate commercial activities impacting fish, the river, and adjacent lands.

Although non-guided anglers account for the majority of effort (angler-days) in the Kenai River chinook salmon fishery, guided anglers account for the majority of chinook salmon caught and removed by sport fishers. In 1991 there were 288 fishing guides employed in 176 businesses registered to guide fishing trips on the Kenai River. Many of these guides belong to the Cook Inlet Professional Sportsmen's Association. Concerns about crowding and differences in success rates between guided and non-guided users have led to increased regulation of guiding activities. In 1992 the Alaska Legislature authorized the Board to develop separate regulations and allocations for residents and nonresidents, and guided and non-guided anglers. Competition between non-guided and guided anglers for the best fishing areas is contentious. Crowding has prompted concerns regarding the social carrying capacity of the Kenai River sport fishery.

METHODS

Selection of Stakeholders

The analysis began with the identification of interest categories. Interest categories are groups who share some common primary objectives or interests; management agencies and commercial fishermen are examples. The interest categories were identified through consultation with fishery managers, and from documents and newspaper articles. A broad array of interest categories representing local, state and federal government, industry, and private interests was defined. These interest categories were then divided into stakeholders. Stakeholders are individuals or sets of individuals who share many common objectives or interests. Stakeholders included individuals from agencies responsible for oversight of the river and its resources, and parties directly or indirectly affected by management decisions. See Table 2.2 for a complete listing of interest categories and stakeholders included in this analysis. While it is desirable to have many stakeholders participate in constructing the hierarchy of issues and options, analyzing the elements of the hierarchy can become unwieldy if too many are included (Saaty 1990a). Thus, it is necessary to tradeoff the benefit of completely canvassing the stakeholders against the difficulty of evaluating and interpreting a complex representation. Mackett (personal communication, National Marine Fisheries Service, Southwest Science Center, La Jolla) recommends that the maximum number of stakeholders not exceed 12 to 15. Accordingly, 15 stakeholders were defined from 10 interest categories. Several individuals were interviewed within stakeholder categories that included multiple levels of authority. For example, in the management agencies, judgments from the field as well as the policy-making levels were acquired.

Individual stakeholders in positions of authority, or otherwise reputed to be influential and/or familiar with the issues pertaining to their group's interest were contacted by telephone. The nature and purpose of the study was explained, and their participation was solicited. All those contacted agreed to participate in the study.

<u>Individual Decision Hierarchies</u>

Individuals were asked to identify issues they believed to be important to the future management of the Kenai River sport fishery for chinook salmon, and to suggest options for these issues. Each individual responded with a unique list of issues and options. The individual was prompted for suggestions of structural relationships among issues, but

Table 2.2. Stakeholders represented in multiple criteria decision models of the Kenai River recreational fishery for chinook salmon. [a]

Category of Interest Groups		Stakeholder
Commercial Fishermen	1.	Kenai Peninsula Fishermen's Association
	2.	Upper Cook Inlet Driftnetter's Association
Sport Fishing Guides	3.	Cook Inlet Professional Sportsmen's Association
Sport Anglers	4.	A sport angler
Local Agencies	5.	City of Soldotna
State Agencies	6.	Alaska Department of Public Safety (Fish & Wildlife Protection)
	7.	Alaska Department of Natural Resources (Division of Parks)
	8.	ADF&G (Sport Fisheries Division)
		ADG&G (Commercial Fisheries Management & Development)
		ADF&G (Habitat Division)
	9.	Board of Fisheries
	10.	Kenai Peninsula Fish and Game Advisory Committee
Federal Agencies	11.	U.S. Fish & Wildlife Service (Kenai National Wildlife Refuge)
Business Retailers	12.	Kenai Peninsula Sporting Goods Retailer
Property Owners	13.	Kenai River Property Owner's Association
Conservationists	14.	Nature Conservancy
Native Indians	15.	Kenaitze Indian Tribe[b]

[a] The opinions expressed by stakeholders reflect the perceptions of a small number of individuals selected from the stakeholder class and do not represent the official views of the organizations to which they belong.

[b] Questionnaire rating options not returned.

often the structure was created for their review. See Table 2.3 for a summary of the model development process.

Issues and options identified during the telephone interviews were structured into unique decision hierarchies for each stakeholder. An individual decision hierarchy is one stakeholder's view of the problem and its solution (see Table 2.1). To structure the hierarchy, issues were segregated into groups. For example, all issues concerning the riparian habitat were grouped separately from issues that were not directly related to riparian habitat. Issues within a group were stratified into different levels depending on their scope. Options formed the base of the decision hierarchy (Figure 2.3). The individual decision hierarchies were mailed to the stakeholder for review and modification. Once stakeholders had received copies of their individual decision hierarchy, a second round of telephone interviews was conducted. The interview process was continued until the stakeholders indicated that the individual decision hierarchy accurately reflected their personal perspective.

Additional options were identified from documented testimony presented before the Board and the KRSMA task force, from stakeholder interviews reported in newspaper articles, and from historic data. The options specified by stakeholders and the additional options were organized into a questionnaire. The questionnaire was composed of three parts: 1) options grouped by issue; 2) issues as a group; and, 3) preferred mechanisms for funding options. Questions regarding the desirability of options were formatted to give the stakeholder an opportunity to express either a desire for continuation of the status quo, a liberalization of restrictions, or a more conservative approach to the issue than the status quo. Opportunity was provided for respondents to write-in additional options and to assign a score to these suggestions. For each option, a scale from 1 to 9 was displayed, and stakeholders were asked to circle the number which best represented their desirability

Table 2.3. Outline of methods used to: select stakeholders; elicit issues and options; structure the decision problem; approximate strength of preference for issues and options; and, model the outcome.

1. Specification of stakeholders.
    a. Identification of interest categories.
    b. Listing of stakeholders by category.
    c. Selection of stakeholders per category.

2. Identification and structuring of issues and options. Elicitation of judgments.
    a. Interviews to elicit lists of issues and options.
    b. Structuring of models and mailing to stakeholders.
    c. Interviews to edit models and elicit judgments.
    d. Further refinement of models.
    e. Development of additional options.
    f. Development of draft questionnaire.
    g. Solicitation of comments on draft questionnaire.
    h. Finalization of questionnaire.
    i. Informing stakeholders of the questionnaire.
    j. Mailing of questionnaire to stakeholders.
    k. Interviews with stakeholders regarding the questionnaire.

3. Merging of individual models. Determination of global priorities using AHP.
    a. Merging of the individual hierarchies into one encompassing model structure.
    b. Creation of 14 replicates of encompassing model structure.
    c. Entering of each stakeholders' judgments into a model copy.
    d. Determination of global priorities using AHP.
    e. Export of 14 model copies into Lotus 1-2-3.

4. Creation of combined models in Lotus 1-2-3 (maximax, maximin, geometric mean, and subsets of state, sport, and commercial fishing interest categories).

5. Ordering of options by combined model.

6. Comparison of results.

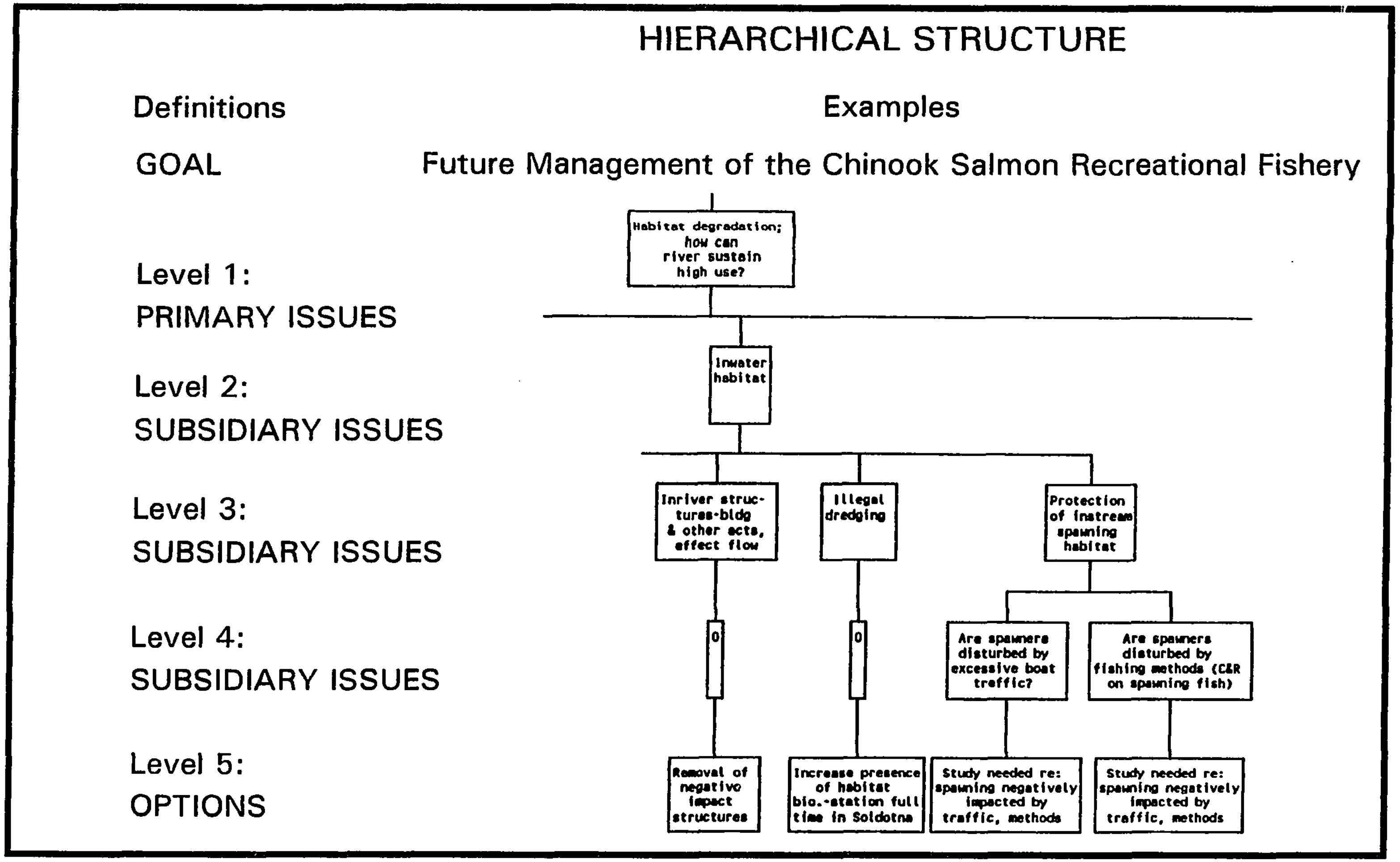

Figure 2.3. Hierarchical structure of issues and options.

of options, relative to that grouping. At the end of the questionnaire, stakeholders were asked to rate the importance of the major issues using the same scale (1 to 9).

A draft of the questionnaire was pre-tested for completeness and clarity. After incorporating comments on the draft questionnaire, Linsky's (1975) recommendations were followed to increase responses to the questionnaire. Each stakeholder was contacted by telephone to describe the questionnaire and solicit their continued willingness to cooperate with the study. Next, a cover letter accompanied the questionnaire, reiterating the purpose of the study and explaining the rating scale to be used. A self-addressed stamped envelope was included in those questionnaires mailed, and a return FAX number was sent with those questionnaires FAXed. One to two weeks after the questionnaire had been sent, non-respondents were contacted and encouraged to reply. Responses were received from 14 of the 15 stakeholders.

The questionnaire was superior to each stakeholder's individual decision hierarchy because it asked each stakeholder to judge issues and options in the context of issues and options identified by other stakeholders. In some cases, judgments of issues and options changed slightly from the individual's decision hierarchy. However, in the majority of cases, and especially for strongly felt judgments, judgments were unchanged. The responses to questionnaires were used to represent the perspectives of the stakeholder group from which the individual was selected. For two stakeholders (ADF&G and Alaska Department of Natural Resources), more than one individual was interviewed, so that interests representative of divisions within departments could be considered. Individual judgments were added and divided only by the number of individuals that included a particular issue or option in their judgments.

Scaling of Judgments and Preferences

Stakeholders were asked to make judgments about the importance of a set of issues, relative to the issue under which they were grouped in the hierarchy. Stakeholders were asked such questions as: "On a scale of 1 to 9, where 1 is extremely unimportant and 9 is extremely important, how important is bank modification, erosion, and decreasing shoreline vegetation relative to degrading shoreline rearing habitat?" The stakeholder might rate bank modification as 7, erosion as 6, and shoreline vegetation as 9. Options were similarly rated, except the 1 to 9 scale was expressed in terms of preference, instead of importance (see Table 2.4). Most stakeholders preferred judging issues and options within a group to pairwise comparisons, because pairwise comparisons are time consuming.

Because a 1 to 9 scale does not necessarily have a uniform distribution of local priorities (see Salo and Hämäläinen 1993), the distribution of the 1 to 9 scale used in this study was examined using pairwise comparisons in the graphical mode of Expert Choice (per personal communication, Ernest Forman, George Washington University, Washington D.C.), and compared with the normalized ratio distribution obtained from Saaty's (1990a) scale. The 1 to 9 scale was modified by eliminating two mid-range values (2 and 7) from the comparison test because Saaty (1990a) maintains that pairwise comparisons of more than seven elements at a time decrease consistency.

Formation of the Encompassing Hierarchy

The individual decision hierarchies identified by each stakeholder were merged to form an encompassing hierarchy. The same process used to structure issues and options in the individual decision hierarchies was used in developing the encompassing hierarchy. Primary issues formed the highest level of the encompassing hierarchy (Level 1).

Table 2.4. The scale used in judging the importance of issues and the preferences of options (after Saaty 1990[a]).

Absolute Scale[a]	Rating Intensity
1	Extremely unimportant or undesirable
2	Very strongly unimportant or undesirable
3	Strongly unimportant or undesirable
4	Moderately unimportant or undesirable
5	Neutral
6	Moderate importance or desirability
7	Strong importance or desirability
8	Very strong importance or desirability
9	Extreme importance or desirability

[a] The nine-point scale used by stakeholders was converted into a ratio scale with Expert Choice for analysis; i.e., 1 corresponds to 1/9, 2 to 1/7, 3 to 1/5, 4 to 1/3, 5 to 1, 6 to 3, 7 to 5, 8 to 7, and 9 to 9.

Subsidiary issues were represented as Levels 2 through 4. Options formed the base hierarchical level of the model, Level 5 (see Figure 2.3).

Each individual stakeholder's judgments were mapped into a copy of the encompassing hierarchy and solved for global priorities. Issues that were not identified in an individual stakeholder's hierarchy and options that they did not identify or judge were assumed to have been of little or no importance to them.

Solving for Global Priorities

Stakeholders' judgments were mapped into a ratio scale (see Table 2.4). The priority of each option relative to the objective is called the global priority. Global priorities approximate the strength of stakeholders' judgments for each option adjusted to reflect the importance assigned by the stakeholder to the issues addressed by that option. The software program Expert Choice[4] was used to derive the global priorities.

While Saaty (1990a) advocates pairwise comparison because it provides more information than a direct scaling vector, in situations involving complex problems the number of pairwise judgments needed will be enormous, time-consuming and mentally taxing.[5] Redundant comparisons of issues and options occasionally occurred, however comparisons were not pairwise in all cases and were therefore not analyzed as such. Sinuany-Stern (1988) showed a 97% correlation between direct ranking and Saaty's

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4 Forman, Ernest H., Thomas L. Saaty, Mary Ann Selly, Rozann Waldron. Expert Choice, Decision Support Software, McLean, VA, 1983. Expert Choice is a visually oriented software package based on the analytic hierarchy process theory developed by Dr. Thomas L. Saaty.

5 The number of combinations of pairwise comparisons is $C_2^n = \frac{n!}{2!(n-2)!}$, where n is the number of elements to be compared. As n becomes large, the number of pairwise comparisons becomes very large. For example, stakeholders would need to perform 4,186 pairwise comparisons to represent the 92 unique options represented in the fifth level of the encompassing hierarchy.

eigenvalue (pairwise) scoring. Thus, while there is no measure of inconsistency within individual decision hierarchies, the use of a direct scaling approach in this study is justified on the basis of practicality, and its demonstrated close correlation with pairwise scoring.

Issues are denoted C_i, while their relative rating of importance is denoted w_i. The ratio $w_i/\Sigma w$ gives an estimate of the relative judgments of issues $C_{i \ldots n}$. The local judgments are normalized to sum to one and entered into the local priority vector **w**. Global priorities on a set of issues or options of the hierarchy are the product of **w** and the set of weights assigned to the next highest level. This procedure was continued throughout the hierarchy. The total score for each option was calculated by adding the weighted proportions. Options were then ranked according to total score.

As an example, consider the comparison of three issues: BANK (bank modifications from structures and foot traffic), which is given a rating of 7 (strong importance); VEGE (shoreline vegetation), which is assigned a rating of 5 (neutral); and, EROSION (erosion of the bank), which is given a rating of 3 (strongly unimportant). The ratings are summed (7+5+3=15), and the ratios (7/15, 5/15, and 3/15) are normalized, to obtain the local priorities of 0.467, 0.333, and 0.200, respectively. The issue in the next highest level of the hierarchy is PROTECT (protection of shoreline rearing habitat), which has a weight of 0.500. The global priorities, then, of BANK, VEGE, and EROSION are 0.467 x 0.500 = 0.233, 0.167 and 0.100, respectively.

Although most survey respondents did not report pairwise comparisons, two stakeholders completed pairwise comparisons for their individual decision hierarchies. The consistency of their judgments was examined using Saaty's eigenvalue approach in the computer program Expert Choice. For pairwise comparisons, a matrix **A** is formed, composed of judgments a_{ij}. Columns in matrix **A** are normalized to yield a vector of weights or priorities w_i:

(2.1) $$w_i = \frac{1}{n}\sum_{j=1}^{n} a_{ij} w_j$$

where n is the number of rows (columns) in **A**. Saaty computes the weight in judgment error, w, as:

(2.2) $$Aw = \lambda_{max} w$$

where λ_{max} is the maximum eigenvalue of **A** (λ_{max}). From this approach, λ_{max}-n provides a measure of degree of inconsistency, CI:

(2.3) $$CI = \frac{\lambda_{max-n}}{n-1}$$

This measure is normalized by the size of the matrix and compared to a purely random matrix to obtain the consistency ratio CR. A value ≤ 0.1 is considered acceptable. For a more detailed explanation of using pairwise comparisons to obtain a consistency index see Saaty (1990b, pg.21).

Models of Stakeholders' Global Priorities

Six different models of stakeholders' global priorities were created.[6] The six models were developed to explore the extent of opposing support for options and the effect of the under representation of stakeholders. The first model considered was the geometric mean of all of the stakeholders' global priorities. The mean provides an overall

[6] The global priorities of the combined models were renormalized for each model to ensure feasibility. The renormalization was accomplished by multiplying each global priority by the inverse of the sum of the global priorities.

representation of the judgments of the group. A geometric rather than arithmetic mean was chosen because the global priorities had been derived from a ratio based scale. The geometric mean is defined as:

(2.4) $$\breve{X}^j = \sqrt[n]{\prod_{i=1}^{n} X_i^j} \ ,$$

or more conveniently,

(2.5) $$\ln\left(\breve{X}^j\right) = \frac{1}{n}\sum_{i=1}^{n} \ln\left(X_i^j\right),$$

where X_i^j is the i^{th} stakeholder's global priority on the j^{th} option.

Maximax and maximin models were created to explore the effect of strongly expressed judgments. The maximax model was based on the highest preference rating given by any individual stakeholder for each option. The maximax solution thus represents the most preferred solution of the most strongly expressed options. The maximin model was based on the lowest preference rating given by any stakeholder for each option, and thus represents the least objectionable set of the most strongly disliked options. The maximax and maximin heuristics would not be expected to result in similar sets of most preferred options. However, options favored under both the maximax and maximin models enjoy strong support and weak opposition. As an illustration of the maximax and maximin solutions, consider the following example of four options rated under the issue of CROWDS: DRAFT G (restrict guides to drift fishing only); SYSTEM (reduce the number of anglers with a permit limitation system); STATUS QUO (no change); and, REDUC (plan public access to reduce crowding).

Option	Stakeholder			Maximax Solution	Maximin Solution
	A	B	C		
DRAFT G	7	9	5	9	5
SYSTEM	2	3	3	3	3
STATUS QUO	1	3	8	8	3
REDUCE	9	6	7	9	6

This example suggests that REDUCE has as much support as DRAFT G and less opposition. SYSTEM and STATUS QUO share equal opposition, but STATUS QUO has stronger support. Dominance structure indicates that the options should be ordered: REDUCE $\succ$ DRAFT G $\succ$ STATUS QUO $\succ$ SYSTEM.

The sensitivity of results to the under representation of stakeholders was explored through models based on the geometric mean global priorities of sets of stakeholders: state agencies with direct management authority (a Board member, persons in charge of park supervision and land use planning in the Alaska Department of Natural Resources, and regional supervisors and area managers in the ADF&G); persons in positions of responsibility in organizations representing commercial fishing interests (the Upper Cook Inlet Driftnetter's Association and the Kenai Peninsula Fishermen's Association); and, sport fishing interests (a Kenai Peninsula sporting goods retailer, a person in a position of responsibility in the Cook Inlet Professional Sportsmen's Association, and an unaffiliated angler).

Funding Preferred Options

In the final part of the questionnaire mailed to individual stakeholders, a brief statement explained that measures or actions (options) needed to solve problems (issues) sometimes require funds. Preferences were solicited from stakeholders regarding possible payment vehicles for generating funds dedicated to implementing the options for the future management of the Kenai River sport fishery for chinook salmon. These questions were not intended to provide an estimate of the willingness-to-pay for options. Instead, the results indicate the degree of acceptance of various payment vehicles.

Stakeholders were presented with a range of values for each of six hypothetical funding mechanisms: a hotel/camp site head tax; a local surtax on sporting goods; a KRSMA property tax mill rate surcharge; a landing tax on chinook salmon taken in the Kenai River by guided anglers; a landing tax on chinook salmon harvested in the upper Cook Inlet commercial fishery; and, the sale of a mandatory Kenai River chinook salmon stamp. Stakeholders were asked to rate their strength of preference for the payment vehicles, and select the range of values which was most acceptable for those funding mechanisms that received an acceptable score. The scale was 1 to 9, where 1 is highly undesirable, and 9 is highly desirable.

RESULTS

Although all 15 stakeholders willingly participated in the identification of issues and options, some were hesitant about developing hierarchies, and several were reluctant to judge the importance of issues and options. Ultimately, 14 stakeholders provided judgments from which global priorities were derived. When presented with many of the issues and possible options in the form of a questionnaire, some stakeholders chose not to respond to particular questions. It was assumed that those questions answered represented strongly held opinions. Those questions left unanswered were assumed to be of little concern to the respondent.

Based on interviews with stakeholders, seven primary issues were identified:

1) regulation (e.g., actions by local, state and federal agencies which affect users of chinook salmon in the Kenai River);
2) monitoring (e.g., assessment of chinook salmon run strength, catch and bycatch);
3) allocation (e.g., distribution of fishing opportunity among users);
4) biological productivity (e.g., escapement goals relative to biological parameters, run forecasts based on biologic indicators and technology);
5) habitat degradation (e.g., compatibility of development with habitat requirements of chinook salmon in the Kenai River);
6) quality of the recreational fishery experience (e.g., social and aesthetic values); and,
7) enforcement of existing regulations (e.g., authority and ability).

In addition to these seven primary issues, the encompassing hierarchy included 31 secondary issues (Level 2), 43 tertiary issues (Level 3), 24 quaternary issues (Level 4), and 105 options for addressing the issues (Level 5; see Appendix 2.1). Because some options address multiple issues, only 92 of the 105 options were unique.

Scaling of Judgments and Preferences

The distribution of local priorities based on graphically choosing how much more important (or preferred) a given value is to another in the scale of 1 to 9 was similar to the distribution of local priorities using Saaty's normalized ratio scale (Figure 2.4). A rating of 9 versus 1 would mean that an issue or option rated as 9 is actually 100 times more important (or more preferred) than an issue or option rated as 1. Stakeholders were not able to interact with the software Expert Choice which would have allowed an examination of their individual distribution of local priorities of the 1 to 9 scale. Accordingly, it was assumed that their collective distribution of local priorities approximated mine. And, since mine was similar to the distribution of local priorities of Saaty's normalized ratio scale, this was thought to be sufficient justification for using ratio-scaled priorities. There are possible biases introduced through the ambiguity of preferences associated with mid-range values (see Figure 2.4). Poyhonen et al. (1994) point out that mid-range values of the 1 to 9 scale do not precisely represent verbal expressions corresponding to numerical counterparts. Another source of bias might have been introduced through the transference of ratings from the 1 to 9 scale to the ratio scale (e.g., 1 into 1/9; 2 into 1/7; etc.). However, the biases would entail a small deviance in the local priority, and should not affect the rank order of highly preferred options.

Preferred Options of Individual Stakeholders

If all stakeholders had identical preferences the management process would not be controversial. Unfortunately, management decisions favorable to one set of stakeholders are often detrimental to another. Management options that are most likely to be adopted without controversy are those that are highly favored by several stakeholders and are not strongly opposed by others. A simple measure of the degree to which stakeholders agree

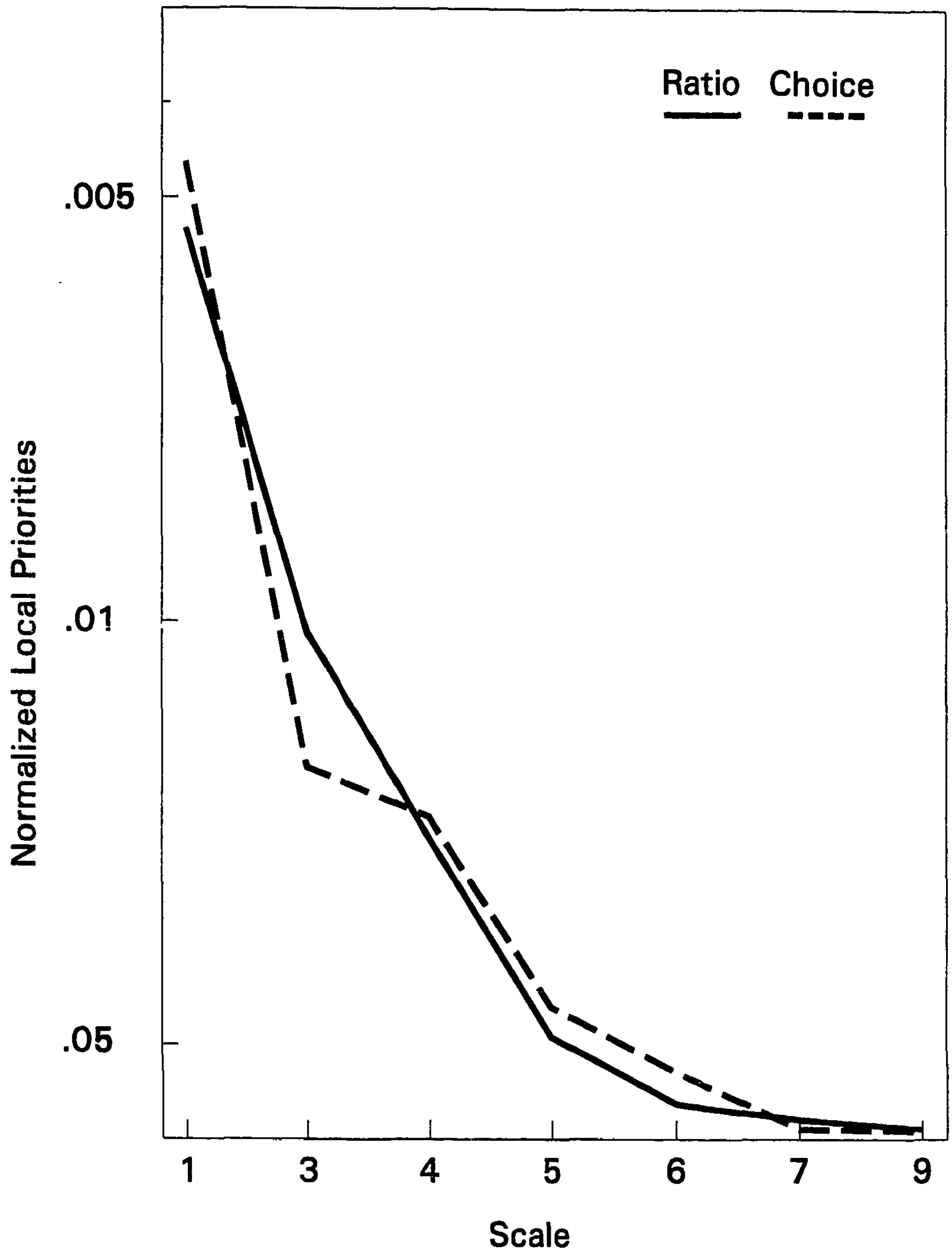

Figure 2.4. Dispersion of local priorities using a normalized ratio scale and based on choice.

on responses to issues is given by the percentage of stakeholders who assigned high global priorities to specific options.

If stakeholders agreed on the importance of every issue and the desirability of each option, the union of their 10 most preferred options would consist of 10 unique options. If there were incomplete agreement on issues, the union of the 14 stakeholders' 10 most preferred options could include as many as 92 unique options.[7] The union of the sets of 10 most preferred options identified by the 14 stakeholders included 48 different options (see Figure 2.5). Six options were selected by at least 78% of the stakeholders. These six broadly supported options were: "increase funding to Alaska Fish and Wildlife Protection for enforcement of existing regulations"; "reduce property taxes for property owners who dedicate their river frontage to conservation"; "expand public awareness of habitat requirements for chinook salmon"; "reduce filling of contiguous wetlands"; "station a Habitat Division biologist in Soldotna"; and, "clarify legislative intent regarding the enforcement authority of the Alaska Division of Parks". Four additional options were highly preferred by at least 50% of the stakeholders. All other options were highly preferred by less than half of the stakeholders. Adoption of any of the first six options would attract considerable support, whereas adoption of any of the latter options is unlikely to enjoy broad support.

The global inconsistency ratios for the two stakeholders who engaged in pairwise comparisons were 0.06, indicating a high degree of consistency in setting priorities (see Saaty 1990a). This suggests that the questions were sufficiently clear, and that the stakeholders made few mistakes in discriminating between pairs of judgments. Consistent judgments are necessary to obtaining realistic results using the AHP (Saaty 1990a).

[7] Since there are only 92 unique options in the encompassing decision hierarchy, the union of the 14 stakeholders' 10 most preferred options can include at most 92 entries.

Table 2.5 The 10 most preferred options in the geometric mean solution and their ordering by maximin, maximax, and weighted model solutions.

Rank of Options in the Mean Solution	Preferred Order by Model Solution				
	Maximin [a]	Maximax [a]	State Agencies	Commercial Fishery	Sport Fishery
1. Increase funding to Alaska Fish and Wildlife Protection for enforcement of existing regulations	10	1	1	2	1
2. Reduce property taxes for property owners who dedicate their river frontage to conservation	5	2	6	5	3
3. Appeal judicial rulings	1	0	3	0	0
4. Increase accuracy of preseason forecasts of run strength	6	3	0	1	0
5. Locate public access points to limit adverse impacts on existing subdivisions	0	4	2	8	10
6. Clarify legislative intent concerning the enforcement authority of the Alaska Division of Parks	10	8	10	0	8
7. Station a Habitat Division biologist in Soldotna	0	3	7	0	0
8. Commercial fishermen should closely observe nets for live release of chinook	0	8	0	6	4
9. Reduce filling of contiguous wetlands	0	0	5	7	7
10. Compensate property owners for the dedication of their property towards the public good	9	10	0	0	2
Number of options shared with the mean solution	6	8	7	6	7

[a] The ranks of some options were tied.

Preferred Options by Model

The problem with simply focusing on the options most frequently assigned high global priorities is that in so doing, the extent of opposition to those options is ignored. The first model considered was the geometric mean of the stakeholders' global priorities. The mean results in a solution that potentially offsets low global priorities assigned by one stakeholder with high global priorities assigned by others. The 10 options with the highest mean global priorities are listed in Table 2.5. As might be anticipated, there is considerable correspondence between the options with high mean global priorities and the options preferred by a large percentage of stakeholders (see Figure 2.5). Seven of the 10 options with the highest mean global priorities are also among the 10 most frequently preferred options in individual stakeholder models. While options with high mean global priorities enjoy strong support, they may be opposed by some stakeholders. Therefore, implementation of options with high mean global priorities will not necessarily be universally supported, and may even be vigorously opposed by one or more stakeholders.

The maximax and maximin models represent the strongest positive or negative judgments assigned to the options by individual stakeholders. Because of this focus on polar judgments, it was not expected that the maximax and maximin models would agree on the 10 most preferred options. However, those options that are preferred under both maximax and maximin criteria enjoy strong support from at least one stakeholder and are less strongly opposed by other stakeholders than other options. Therefore, adoption of options preferred under both the maximax and maximin models is likely to meet with limited opposition.

Options with high global priorities for both the maximax and maximin models included: "increase funding to Alaska Fish and Wildlife Protection for enforcement of

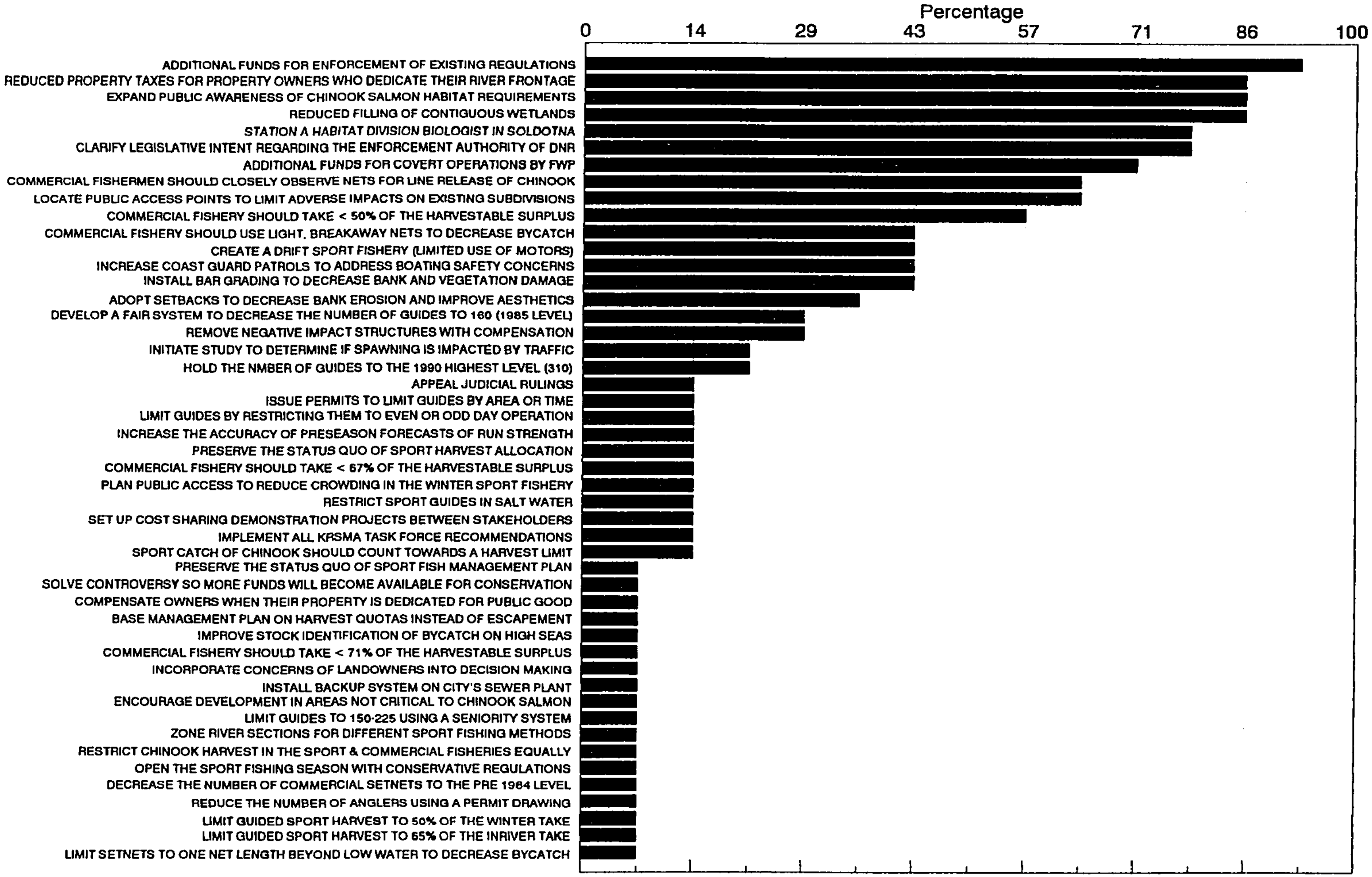

Figure 2.5. Percentage of stakeholders that had a particular option among their 10 most preferred.

existing regulations"; "reduce property taxes for property owners who dedicate their river frontage to conservation"; "increase the accuracy of preseason forecasts of run strength"; "clarify legislative intent concerning the enforcement authority of the Alaska Division of Parks"; and "compensate property owners for the dedication of their property towards the public good" (Table 2.5). While "increase funding to Alaska Fish and Wildlife Protection for enforcement of existing regulations"; "reduce property taxes for property owners who dedicate their river frontage to conservation"; and "clarify legislative intent concerning the enforcement authority of the Alaska Division of Parks" were also among options most frequently included in the individual stakeholder models, "increase the accuracy of preseason forecasts of run strength" was among the most highly preferred options in only two of the individual models, and "compensate property owners for the dedication of their property towards the public good" appeared in only one individual stakeholder's most preferred options list.

Moreover, some of the options frequently included among the 10 most preferred in the individual models were not among those assigned high global priorities by the geometric mean, maximax and maximin combined models. For example, although "expand public awareness of habitat requirements for chinook salmon" was identified as a preferred option by 86% of the stakeholders, it was not regarded as a highly desirable option by the remaining stakeholders and so, was not identified as one of the 10 most preferred options under any of these three combined models.

Preferred Options by Weighted Model

In a complex problem setting, it is not always evident who the stakeholders are. Additionally, decision-makers do not always feel compelled to empower some or all stakeholders with a say in the solution-seeking process. Nevertheless, failure to attend to major interests of some or all stakeholders could lead to opposition to the adopted options that could take the form of legislative review, legal challenge or non-compliance. While under representation is not desirable, it is a reality of some decision problems. Accordingly, it is important to find a decision analysis tool that is not highly sensitive to under representation of stakeholders. Robust options are those which would be assigned high global priorities no matter how the set of stakeholders was identified or how the judgments of the individual stakeholders are weighted in the decision process. To explore the robustness of the results, models were examined based on the geometric mean global priorities of state agencies, sport fishing interests, and commercial fishing interests.

The three "interest group" models shared four most preferred options: "increase funding to Alaska Fish and Wildlife Protection for enforcement of existing regulations"; "reduce property taxes for property owners who dedicate their river frontage to conservation"; "locate public access points to limit adverse impacts on existing subdivisions"; and, "reduce filling of contiguous wetlands". Models combining the perspectives of state agency representatives and sport fishing interests each produced seven preferred options common to the 10 most preferred options in the model based on the mean global priorities of all 14 stakeholders. Six of the 10 most preferred options for the mean of all stakeholders were also highly preferred in the model representing commercial fishing interests (Table 2.5).

Prioritizing Options for Addressing Issues

The AHP can also be used to highlight the strength of judgments for options to individual issues within the encompassing decision hierarchy. That is, rather than seeking to design a comprehensive management strategy, the AHP can be used to examine preferred options to individual issues. By comparing the global priority score for each option, the decision maker can determine the relative desirability of options and the relative importance of issues. Figure 2.6 represents the global priorities assigned to the options for 10 different issues. The priorities are drawn from the model based on the geometric mean of the global priorities of the 14 stakeholders, but could have been done for any of the combinations of stakeholders or even for individual models. The issues illustrated in Figure 2.6 are from various levels in the hierarchy.

"Preservation of the status quo" was the least preferred option to issues of long-term stewardship, shoreline habitat degradation, the number of sport fishing guides, management of the incidental catch of chinook salmon in the commercial fishery, nuisances associated with sport fishing, and enforcement of existing regulations (Figure 2.6). "Create a drift fishery" was the most preferred option addressing concerns related to overcrowding. "Encourage development in areas not critical to chinook salmon" was the most preferred solution when stakeholders were asked if streamside development adversely affected the quality of the recreational experience. "Equal allocation" and "restrict guides in salt water" were the most preferred options addressing the issue of the allocation of catches among recreational users. The most preferred option to concerns about in-river management of the sport fishery was to open the season with regulations restricting use of bait and mandating catch and release, and then once run strength was determined to be within the guideline for harvest, liberalize regulations. Preservation of the existing in-river management plan was also a highly preferred option to this issue (Figure 2.6).

Funding Preferred Options

Thirteen stakeholders responded to the question regarding possible payment vehicles for generating funds to implement options (Table 2.6). The sale of a Kenai River

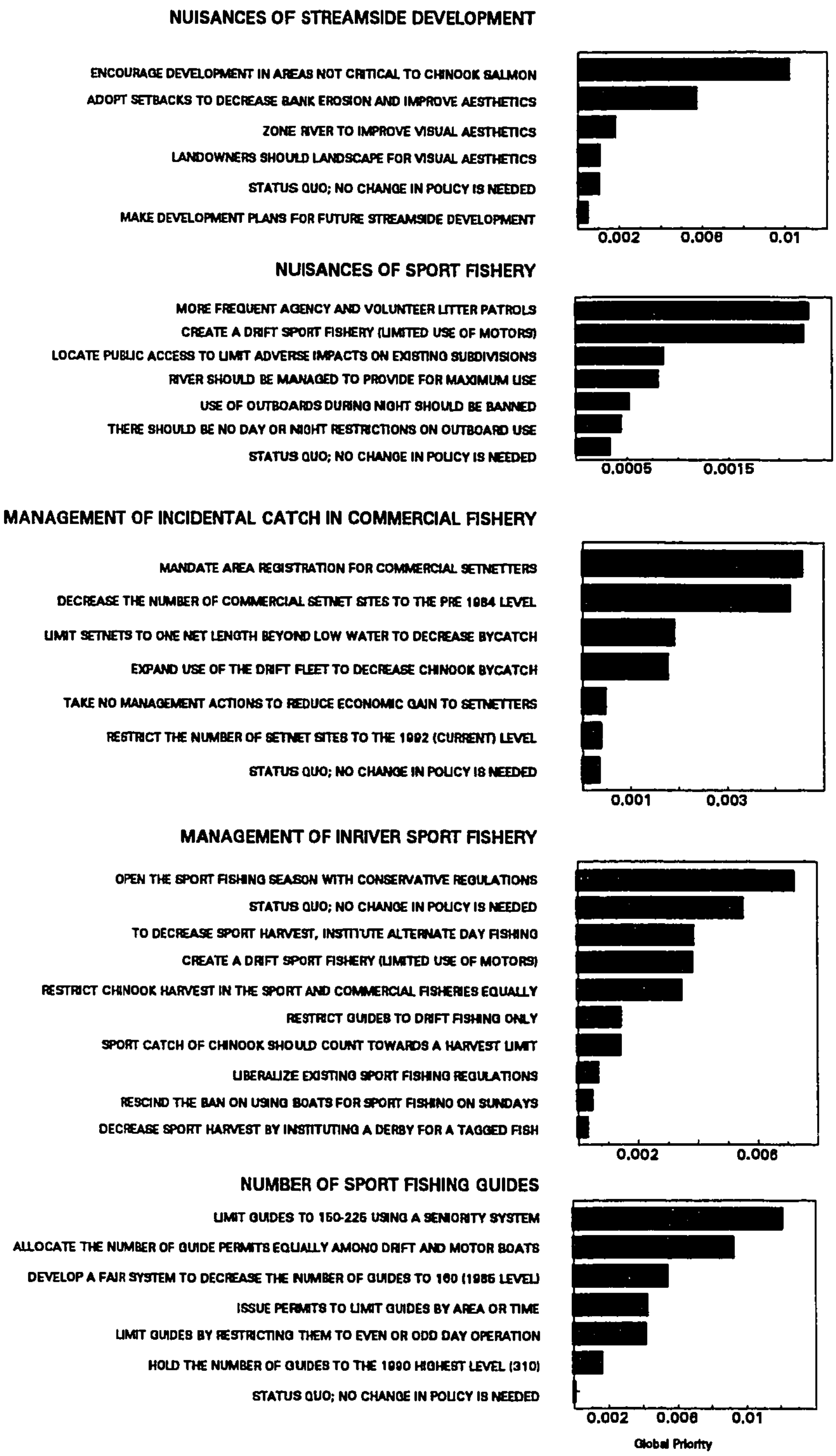

Figure 2.6. Ordering of mean options by issues. Global priorities are between 0 and 1.

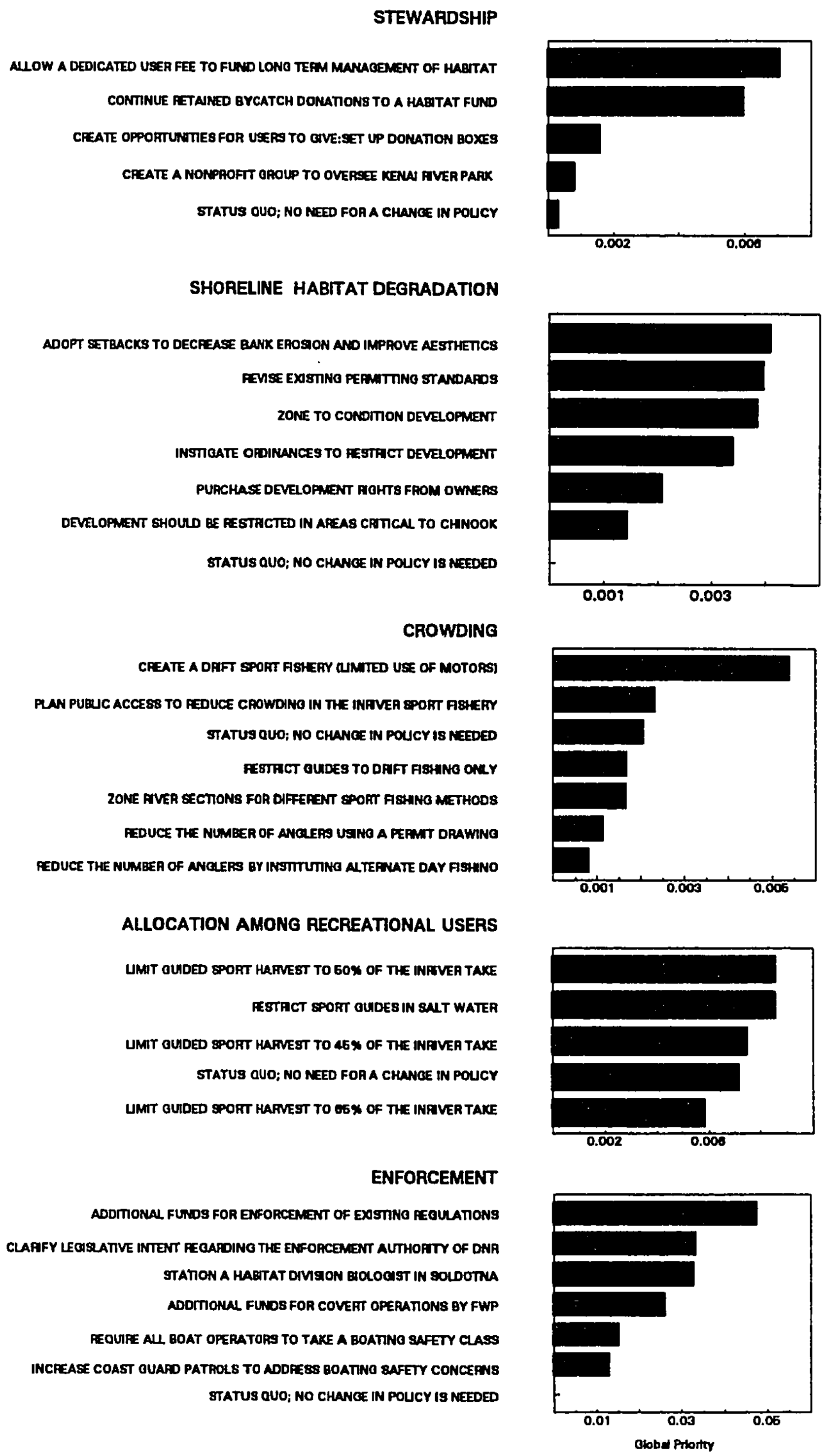

Figure 2.6. (Continued).

Table 2.6. Statistics on hypothetical payment vehicles for funding preferred options to the problem of the future management of the Kenai River sport fishery for chinook salmon, obtained from questionnaires sent to 15 stakeholders.

Payment Vehicle	n	Mean	SD	Range	Value Range First Choice	Value Range Second Choice
Hotel/Camp Head Tax	12	5.66	0.69	1 - 9	2.6 - 5.0%	0 - 2.5 %
Sport Fishing Goods Surtax	12	5.16	0.66	1 - 9	0.26 - 0.5%	5.1 - 7.5 %
Mill Rate on Property Tax	12	2.00	0.41	1 - 6	0 - 0.25 mil	0.25 - .50 mil
Landing Tax on Guides	12	3.58	0.55	1 - 9	$0 - 0.50	$0.51 - 1.00
						$1.51 - 2.00
Landing Tax on Commercial Fishery	12	4.66	0.62	1 - 9	$0 - 0.50	$1.51 - 2.00
Sale of a Kenai River Stamp	13	8.00	0.78	4 - 9	$0 - 5.00	$6.00 - 10.00

stamp, to be affixed to the back of a fishing license, received a higher mean score (8.00, sd = 0.78) than any other funding mechanism. A surcharge on property tax received the lowest mean score (2.00, sd = 0.41). Of five possible ranges ($0-$5, $6-$10,$11-$15, $16-$20, and other) the most often chosen range of values (the mode) for the sale of a Kenai River stamp was $5.00 or less, although the majority of stakeholders said they would be willing to pay more (Table 2.6).

Discussion

Group Decision-Making

In the public policy setting, complex or risky decisions are seldom handled by a single individual, because a governmental agency has limitations in its prerogatives for action. In Alaska, the Board is a group decision-making body wherein biological, social, economic, and legal issues comprising complex fisheries allocation or management problems are considered. While the institutional arrangement may dictate group interaction among stakeholders of varying disciplines and objectives, people participating in group decision-making are rarely trained for it.

The problem of managing the recreational fishery for chinook salmon in the Kenai River from a group decision-making perspective was chosen for several reasons. The first is the general premise in the decision sciences literature that group decision-making in a structured setting can provide a superior solution compared with a unitary decision-maker (Coughlan and Armour 1992). Undoubtedly, some situations can arise where, without warning, an instantaneous decision is required before a group can be assembled, and a sole decision-maker must make "tough choices". But, these odd occurrences may actually be rare. As complex problems develop, conflict and controversy emerge, and the assemblage of elaborately interrelated elements of the problem begin to require more consultations with technical experts, colleagues in other areas within the agency, decision-makers in other agencies, the news media, and representatives of industry and interest groups.

A second reason for approaching this problem from a group decision-making perspective is that participation of fishermen and other stakeholders in selected applications of fisheries management may lead to improved management, and reduced controversy (Lane 1989). Hilborn and Walters (1977) recommend that stakeholders' preferences be an integral component of resource management. Third, those participating in the decision-making process will have a stake in the outcome, and thus implementation of the prescribed solution may be facilitated. And fourth, government is not a single-voiced entity. Within the departments governing the Kenai River, there is disagreement due to multiple and often conflicting objectives. Agencies can be particularly intransigent about their mission and authority. Disagreement among unitary decision-makers representing departments, or heads of divisions within departments, can not only slow down the decision-making process, but cause credibility problems with the public. Structured group decision-making techniques, such as the AHP, would assist governing branches in arriving at a consensus position which they could present before the Board.

Group consensus provides greater validity to conclusions (Saaty 1990a). However, Roper-Lowe and Sharp (1990) suggest that it can be very difficult to get decision-makers to the same meeting; and, there is the danger that in an unstructured group setting, individuals will go along with the loudest or most opinionated person's view. For these reasons, Roper-Lowe and Sharp collected data for application of the AHP by interview, similar to the approach employed in this study. While inconsistency in judgments can be higher with a survey as compared to a group setting (Forman et al. 1994), Borcherding's (1994) research has shown that people are more consistent on important issues, and that inconsistency arises on issues that are of less importance to them.

Stakeholders and Their Combinations

A significant aspect of describing a complex problem is to ask who has a stake in the management regime. Several different approaches have been used to decide which constituencies to take into account, and how to combine them. Hilborn and Walters (1977) identified stakeholders in the Skeena River salmon fishery by asking: Who are affected by management and who have similar desires? These authors prepared what they termed an "exhaustive" list of interest or pressure groups. Healey (1984) maintains that realistic bounds need to be placed on the stakeholder list; however, the stakeholder list should include those whose views are likely to influence final fishery management decisions. To identify stakeholders, Healey (1984) asked: Which groups are likely to be affected by management of the New England herring fishery? His criteria for combining stakeholders included gear type, product dichotomies (onshore versus offshore processors), and geographic proximity (regional versus outside the region). In Keeney's (1977) analysis of the Skeena River salmon fishery, stakeholders were identified by their involvement in the fishery. Keeney's criteria for grouping stakeholders included primacy of involvement in the fishery, gear type, geographic region, and his belief that given members of a group would react similarly to any potential policies.

The approach used in this study to identify interest categories and stakeholders was similar to those approaches reported in Hilborn and Walters (1977), Healey (1984), and Keeney (1977). The definition of stakeholders was more refined than "government, sport or commercial users", yet less detailed than "nonresident fly-fishers". The problem was bounded by limiting the stakeholder list to a maximum of 15. While clearly other stakeholders could have been included in this study, it is not likely that more stakeholders would have resulted in the elicitation of additional crucial issues and options. This belief is based on the observation that as the last few of the 15 stakeholders were interviewed, issues and options became redundant. Stakeholders not represented in this study, by interest category (in capitals), include: nonresident anglers, offshore sport trollers, organized sport fishing associations (SPORT ANGLERS); hotel/motel operators, the Chamber of Commerce (BUSINESS RETAILERS); the Coast Guard (FEDERAL AGENCIES); the city of Kenai (LOCAL AGENCIES); and, state legislators (STATE AGENCIES).

The grouping of individual stakeholder judgments in this study as a geometric mean is the correct form of aggregation of individual judgments (Aczel and Saaty 1983; Weiss and Rao 1987; Roper-Lowe and Sharp 1990) for purposes of group decision-making. Usually, group priority setting involves debate. When debate is eliminated and individual opinion taken by questionnaire (as was done in this study), final priority values are derived from the geometric mean of the judgments. The geometric mean is also used to resolve a lack of consensus after debate. The mean opinion provides an overall representation of the judgments of the group. It is not meant to replace dissent and group debate. Dissent and debate are valuable processes in group decision-making because alternative viewpoints and options are explored. But, dissent and debate must accomplish something - they must lead to cooperation and consensus if the problem being considered is to be eventually resolved. An argument against the mean is that it can mask the true views of stakeholders if there are wide countervailing differences of option, for example 0 and 100. In this case the mean, 50, would be unacceptable to either stakeholder. Therefore, it is also important to examine extreme views using such strategies as maximax and maximin.

Maximax and maximin are strategies used for obtaining solutions to game theory problems (see Hillier and Lieberman 1990). The maximax strategy seeks the maximum payoff no matter what the possible loss. The maximin strategy seeks to find the maximum loss for each action and to choose that action which has the smallest maximum loss. Unlike the maximax, the maximin is an extremely conservative strategy. Maximax and maximin strategies have been used in this study to represent the conflict within the problem of managing the recreational fishery for chinook salmon on the Kenai River. It is particularly noteworthy that there was considerable agreement between the maximax and maximin solutions.

Robustness of the solution to extreme judgments (such as represented by the maximax and maximin models) can be a useful criterion in discriminating among choices (Rosenhead and Wiedemann 1979). In this study there were several options which were common to the list of 10 most preferred options for the maximax and maximin models. For purposes of group decision-making, these robust options provide a base from which to proceed to constructive compromise through arbitration. The maximax and maximin models are also convenient methods for simplifying a multicriteria problem. Stewart (1981) used the maximax and maximin as a means of displaying a multicriteria problem involving fewer dimensions.

In combining individual judgments, an assumption of "interpersonal comparisons of preferences" (see Keeney and Raiffa 1976) is made. That is, as individual judgments were combined, their scales of preference were interlinked, and it is assumed that the scale used to assign preference was applied consistently among the individuals. In this study, the verbal meaning of the numerical scale used to assign preference was explained to those stakeholders interviewed; it is assumed that the 1 to 9 scale was similarly understood and applied among the stakeholders.

The choice of whom to represent each stakeholder was in some cases straightforward (such as the manager of the recreational fishery) and in some cases arbitrary (i.e., the individual sport angler). That is, not all individuals interviewed officially represented a given class of stakeholders (such as the Board, the advisory committee member, the individual sport angler). Nevertheless, many of these people were in a position to influence final decisions regarding the management of the fishery. The fact that some judgments were from individuals who were arbitrarily chosen to represent a given stakeholder implies that priorities derived under various combinations of judgments may change depending upon who was interviewed. To address this concern, the priorities derived from weighted models of stakeholders were examined.

Weighted Models of Stakeholders

In developing the mean, maximax, and maximin models equal voice was assigned to each stakeholder. That is, the judgments of a stakeholder representing 100 people were given the same weight as the judgments of a stakeholder representing, say, 10 people. Similarly, the judgments of a powerful stakeholder (such as a member of the Board or a state enforcement agency) were given equal weight as the judgments of a private citizen. In reality, do stakeholders share equal voice? Should they have equal voice? If weights are to be applied, what criteria should be used to specify the weights?

There is a general lack in the decision analysis literature regarding discussions of differential weighting of judgments among individuals engaged in a group decision setting. Frequently, authors encourage debate to arrive at a consensus (Coughlan and Armour 1992; Saaty 1990a), or recommend the negotiation of compromise (Healey 1984), assuming equal weight among participants. In contrast, Lindblom and Woodhouse (1993) acknowledge that not only is equality among groups of citizens not a political reality, but that most people do not care greatly to have equal control over policy-making, preferring instead to leave decision-making in the hands of those who are educated and competent in their disciplines (i.e., decisions on medical care to the medical profession, etc.). While equality is not a generally accepted axiom, effects of inequality on problem solving can be substantial. Lindblom and Woodhouse (1993) caution that inequality in the policy-making process interferes with the ability to solve social problems. They state, "If government functionaries are to focus their attention on important social problems, the broader policy-making process needs to help them see and conceptualize those problems". For example, if poor, less educated people participate to a lesser degree in describing the problem and voicing their priorities for solutions, the social problem may not be adequately defined nor proportionately weighted as to importance, thus perpetuating inaction and continuance of the problem.

Group decision heuristics can be implicitly weighted through the selection of stakeholder representatives. In this study, weights were explicitly displayed. Further, weighted models were developed from their constituent parts to examine how sensitive the priorities were to under representation of stakeholders. Evaluation of model outcome is important to the credibility of the decision analysis process and to the acceptance of model output. So, weighting in this study was used as a method of testing for sensitivity of model results, rather than an attempt to derive a solution based on differential weightings according to stakeholder authority, political clout, the number of people represented, revenue generated, or other criteria. On the one hand, it would be difficult for a decision analyst to demonstrate to potential users and critics that a solution based on the geometric mean is politically realistic. On the other hand, it would be far more difficult to gain acceptance of a solution from the majority of stakeholders if the decision analyst differentially weighted stakeholder judgments according to his or her own criteria; motives behind the criteria would be questioned. Only if the stakeholders themselves agreed to a differential weighting scheme would a weighted solution have credibility within the public policy environment. In facilitating a group decision-making session with a team of scientists from the National Aeronautics and Space Administration, Forman (1994) noted that the group elected one member who was thought to have more insight into the particular problem, so his judgments were given more weight than the other members' judgments.

Priorities derived from state agencies, commercial fishers and sport fishing advocates are interesting in their own right. These three models shared high priority options addressing the general issues of "enforcement" and "monitoring" (see Table 2.5). Only state agencies were interested in appealing judicial rulings. This is because of the balance of power struggles between the three branches of government; court interpretation of laws can greatly affect how state agencies conduct business. Only commercial fishing interests identified accuracy of pre-season forecasting of run strength as a top priority option. Their concern is directly related to the minimum escapement goal for chinook salmon, which drives the eastside Cook Inlet setnet commercial fishery for sockeye salmon. Commercial fishery openings for any given space-time period occur prior to the inriver recreational fishery on that portion of the run subjected to commercial fishing. Assessment of chinook salmon run strength is accomplished inriver, due to the mixing of stocks at sea. Thus, decisions regarding management of the commercial fishery must take place in advance of the best information on run strength. If run strength of chinook salmon is underestimated, and closures of the sockeye salmon fishery are implemented to decrease the bycatch of chinook salmon, then commercial fishermen have needlessly foregone income. Thus, it is in their economic interest that run strength is accurately assessed. In contrast, while accurate assessment of run strength is important to state agencies, it is not an issue. This is because staff in state agencies are reasonably confident they are adequately assessing run strength as much as is technologically and fiscally possible. Only sport fishing interests identified a high priority option which addresses issues related to private regulation. This is because the solution to issues such as "public good versus private rights" and "development versus conservation" affects many aspects of sport fishing: access, conservation of rearing habitat for salmon smolt, etc.

Structuring of a Hierarchy

In public policy one aim of decision analysis is to present large quantities of technical information in a concise and understandable way - a hierarchical structure is useful for clarifying a complex problem. Saaty (1990a) provides brief guidance on how to structure a hierarchy. Brownlow and Watson (1987) maintain that structuring of a complex problem is an art, which relies on the decision analyst's intuition and experience. There is no way to ensure that the problem is adequately structured (Thomas and Samson 1986), yet the structure can have significant effect on analysis (Brownlow and Watson 1987). If the problem is structured differently, this may affect perceptions of the problem, possibly leading to the recommendation of a different course of action.

In this study, Levels 1 - 3 of the hierarchy were often organizational headings and tools used to group closely related issues. Each issue in the hierarchy was unique, however there were several replicate options. Saaty (1987) states that replicate options may depreciate the value of the original and its rank order. But, in this study it was those options which appeared repeatedly that occurred among the most preferred ordering. This occurred in part because the weights of each were additive, but primarily because of high weights on the issues these options addressed.

Rank reversal with the addition or deletion of options has been examined for relative measurement by various authors (Saaty 1987, Schoner and Wedley 1989, Holder 1990). Forman (1990) argues that rank reversals in multicriteria problems are legitimate and even desirable. Additions and deletions of options represent an evolving solution to a problem that may be responsive to certain changes over time. In this study, stakeholders were given the opportunity to write in options on the questionnaire, primarily to more fully account for the set of available options. Only one of the 14 stakeholders responding to the questionnaire had a priority associated with their "write in". Because others did not list this option, it is improbable that the rank order of the most preferred options would change with additional iterations.

Scaling of Judgments and Preferences

Human choice behavior, including the use of verbal scales (such as poor to good, worst to best, or unimportant to important) in comparing objects, is affected by many biases (Hogarth cited in Poyhonen et al. 1994). For example, the order in which issues or alternatives are presented, the presentation of the problem, and the context all can have an effect on prioritization. Poyhonen et al. (1994) are fairly critical of verbal expressions for fixed numerical values, stating that verbalization can lead to biased estimates of weights. They suggest that one solution is to carry out preference solicitation without using words. Another solution is to carefully clarify the exact meaning of the numerical values in the verbal scale. Lund and Palmer (1986) found that while a verbal scale can introduce confusion on quantitatively-measured objects, it can assist in eliciting preference statements about qualitatively-measured items. In this study, a combination of verbal and numerical scales was available to the stakeholder. The extreme points of the 1 to 9 scale were defined verbally (extremely unimportant and extremely important), however the stakeholder made his or her choice on a numerical scale. No tests for consistency in perceived meaning of either scale was conducted, however the combination of verbal and numerical scales should have increased the chances of: 1) eliciting a preference statement in the first place, and 2) obtaining a somewhat accurate assessment of preference.

In their examination of the scale used in the AHP, Salo and Hämäläinen (1993) suggest that the proper procedure to follow is to ask the decision-maker to make pairwise ratio statements about positive value differences in regards to a reference point. Under this scenario, the AHP constitutes a variant of multiattribute value measurement. However, pairwise ratio statements are not feasible for large problems - they would be too time consuming. Additionally, it was thought that the ratio scale itself would be unfamiliar to stakeholders, who are used to conducting prioritizations in their daily lives on an integer scale. To have insisted on a ratio scale might have introduced greater inaccuracies into study results, than obtained through the transference of ratings made on a 1 to 9 scale into a ratio scale.

Issues Raised and Feasibility of Options

The issues raised in this study reflect primarily the regional concerns of people regarding their economic and social well being, and governmental agencies regarding their ability to fulfill their missions. These concerns arise from competition among users for a limited supply of chinook salmon, and the perpetual struggle of governmental agencies to operate on a limited budget.

For some issues, few or no options were proposed. For example, few options were suggested under the primary issue of Biological Productivity. This phenomenon reflects the real world, where, for some issues, there is no apparent course of action to take. That is, there are some issues such as: "Are escapement goals appropriate?", with no easy answers. Additionally, the lack of options suggested for some issues could indicate a lack of familiarity which most stakeholders have with issues of a highly technical nature. Some of the issues raised by stakeholders (e.g., "The Board does not consider economics in allocations") may in fact be based on false impressions, lack of communication, or the difficulty of reviewing the current decision-making process. The status quo, or "do nothing" option, was not mentioned by those interviewed in this study as a possible solution to all issues; perhaps this was because to do nothing was not a viable option to selected issues.

Choosing the best option has been addressed by analysts from widely differing disciplines in various ways. Approaches for choosing the best set of options include: how options cluster or deviate on the basis of related criteria (Stewart 1981); a probability distribution which displays the perceived risk of various options (Thomas and Samson 1986); viewing options in terms of a time-stream of indicator variables as opposed to a single criterion (Thomas and Samson 1986); favoring options which are sensitive to events so that a stable and robust set of options are chosen (Arbel and Tong 1982, Rosenhead and Wiedemann 1979); and, maximax and maximin solutions (White 1984). Another possible rule for selecting a set of options is to choose those options that are easiest to implement, that is pick options that do not require radical departures from the status quo. Or, options can be chosen based on their cost. White (1984) argues that an optimal solution which is static and inflexible should be rejected in favor of options which allow for preference evolution. In this study, options were chosen based on judgments according to preference intensity.

The most preferred options will only be adopted if they are feasible. Fishery managers may be constrained in their adoption of preferred options by legal, enforcement, biological feasibility, cost, or time frame considerations. Risk of failure is an important constraint, however consideration of risk should be reflected in the priority weights (see Saaty 1990b). Hilborn and Walters (1977) point out that decision-makers may have to choose lower ranked options when constraints eliminate more preferred options.

The emphasis placed by stakeholders in this study on political, social, and economic concerns which are not commonly within the domain of fishery managers was striking. The implementation of some of the preferred management responses suggested by the models would require an unusual level of cooperation between fishery managers, a collection of local, state, and federal agencies, and the public. While Lindblom and Woodhouse (1993) favor a comprehensive approach to decision-making, they pessimistically predict that public agencies will continue to employ an incremental approach to problem solving. Their rational for this gloomy prediction is that most agencies do not have the latitude to implement all of the preferred options, and the level of cooperation required among agencies to ensure implementation of the ideal solution is not normally realized. It is true that most agencies, such as ADF&G, do not have the authority to implement many of the preferred options such as determined from this study. However, other entities, such as the Board, or the North Pacific Fisheries Management Council, do have expanded authority to address comprehensive solutions.

The feasibility of implementing options is not only constrained by existing institutional arrangements, but by legal precedence as well. Management of natural resources takes place in a context of legal rights. This means that even one discordant voice can dictate the options if that voice is supported by law.

The ultimate test of the solution is to examine how reasonable it is. The 10 most preferred options in the mean solution reflect testimony presented before the Board. All highly preferred options in the models have been previously proposed by various stakeholders - no new or unusual options appeared in the lists of "10 most preferred" options. The difference between the usual process of public hearings versus the AHP is that options were clearly identified, related to specific issues in a structured framework, and prioritized according to preference intensity. In prioritizing options, stakeholders implicitly made tradeoffs.

Insights Revealed by the AHP

This study revealed a belief by the stakeholders interviewed in a solution which combines governmental intervention with initiatives of the private citizen. The implementation of such preferred options as stationing a Habitat Division biologist in Soldotna, limiting guides using a seniority system, and mandating area registration for commercial setnetters would clearly call for more governmental intervention. Private citizens and nonprofit groups are part of the solution as well, by the implementation of such options as continuing retained bycatch donations to a habitat fund, closely observing nets for live release of chinook salmon, and expanding public awareness of chinook salmon habitat requirements. Nearly 66% of the banks of the Kenai River from Skilak Lake to the mouth of the river is private. Decisions made by private property owners will make a big difference regarding habitat and access issues.

There is a prevailing attitude that the Kenai River should be considered as a multiple use corridor. Stewardship of this corridor is paramount, as revealed in the many options suggested to limit use and conserve fish habitat. Preference for social and economic options for addressing such issues as habitat degradation is evidenced by strong support for property tax incentives and public education programs. There is an opportunity for governing agencies to encourage the entrepreneurial spirit exhibited by such private groups as the Kenai Peninsula Fishermen's Association's project HabPro, and the Kenai River Sportfishing Association's "Kenai Eagle" award. Reducing property taxes for property owners who dedicate their river frontage to conservation, adopting setbacks, and compensating property owners for the dedication of their property towards the public good are three such options which would build upon the momentum of these two private groups.

The existing sport fish management plan ranks among the highly preferred options under the issue of managing the inriver sport fishery. However, preservation of the status quo ranked last in regards to management of the incidental catch of chinook salmon in the commercial fishery. This contrast in levels of approval in regards to agency policy towards these two issues points out where resources should be expended. The preferred option to increase funding for enforcement of existing regulations indicates a belief that there are many lawbreakers at large.

Advantages of the AHP

According to Schoner and Wedley (1989), the AHP's principal application is for judgmental problems in which subjective criteria play a dominant role. With the AHP there is no need to estimate a utility function since it deals with stated preferences at each step. However, other decision methodologies (such as multiattribute utility theory) rely on utility functions in choosing options (Corner and Kirkwood 1991, Korhonen and Soismaa 1981). Other advantages of the AHP over the traditional decision making processes include: 1) the facilitation of simultaneous consideration of multiple criteria; 2) suggestion of possible resolutions that would not occur to individual stakeholders; 3) promotion of useful discussion by requiring that stakeholders formally represent their understanding of the problem's structure; 4) communication of the relative importance of issues and relative desirability of options between stakeholders; 5) ability to review the reasoning behind a decision; and, 6) ease of updating as new information becomes available.

A particular strength of AHP is the facility with which conflicting objectives of multiple stakeholders are incorporated. In the public sphere different interest groups approach issues from very different perspectives which often leads to conflict. Conflicting opinion is one feature which makes problems in the public sphere difficult to deal with. The identification of robust options among varying interest categories can assist the policy-maker in reducing conflict. These results indicate that even in complex problems, there may be options that are preferred irrespective of how the judgments of the individual stakeholders are weighted. The robustness of these options demonstrates a large degree of commonality among stakeholders that may not otherwise be apparent. Identification of options with no concordance assists policy makers to focus on areas of potential conflict. The greatest debate would probably occur over those options which were extremely preferred by some stakeholders and strongly disliked by others.

Where managers choose to implement controversial options, the AHP can be used to provide an indication of the extent and relative intensity of opposition to the option. The maximax and maximin models are particularly helpful in identifying the intensity of controversy associated with various options. In this application of the AHP, it was found that many of the most preferred options are common to the maximax and maximin models. The most strongly preferred options can only agree with the least objectionable set of the most strongly disliked options when there is little disagreement among the stakeholders over the global priorities assigned to the option. These robust options typically arose when the Levels 1 and 2 issues that they addressed were assigned high global priorities and when implementation of one option addressed several different issues.

Because the identification of stakeholders to involve in the decision process and the weight to be given to the different stakeholder's judgments are problematic, options that are robust with respect to the exclusion of stakeholders should be selected when possible. Alternatively, decision-makers could work to reduce opposition through disseminating information explaining the need for adopting controversial measures. Although it had been anticipated that state agencies, sport fishing interests and commercial fishing interests, would disagree on the importance of issues and desirability of options, there was nearly universal agreement. That is, the options identified as highly preferred were robust with respect to the exclusion of stakeholders in this case.

Difficulties in Using the AHP

One difficulty encountered in applying the AHP to the management of Kenai River chinook salmon was the reluctance of stakeholders to provide judgments for some issues and options, and their reluctance to engage in exhaustive pairwise comparisons of the issues and options. Reluctance on the part of stakeholders to provide judgments on some issues and options has also been reported by Brownlow and Watson (1987). This reluctance may have occurred because people were ambivalent about issues outside of their area of focus, had doubts about their own expertise or knowledge regarding some issues or options, were indecisive, or because they were worried about the consequences of taking a stance on a particular issue or option. When the problem is large and complex and requires numerous judgments, Weiss and Rao (1987) indicate that it may be desirable to use multiple decision makers, each focused on a group of issues. Most of the stakeholders who participated in this study did not wish to engage in pairwise comparisons because it is time consuming and was less familiar than judgments of importance among a group of issues or options. If pairwise comparisons are available, the degree of inconsistency in judgments can be assessed. Because the reliability of policy recommendations based on decision models is commonly questioned by stakeholders, a measure of low inconsistency might contribute markedly to the acceptance of model-based policy recommendations (Gass 1983).

Because stakeholders recognize that they will be benefited or adversely impacted by different management options, respondents might attempt to manipulate model outcomes through strategic responses or expressing strong preferences. This might result in a suboptimal solution. Indefinite, inexact, and non-responses are not uncommon to decision problems. The decision analyst can address this possibility by testing for inconsistent responses, and requesting re-evaluation of judgments from the stakeholder. In addition, sensitivity of the preferred solution to weighting of stakeholders' responses can be explored, as was done in this paper.

Funding Preferred Options

In seeking to implement an optimal solution, information about the distribution and magnitude of expected costs to benefits must be considered by the decision-maker. For example, implementing the option to increase enforcement of existing regulations would require either a re-distribution of enforcement effort or additional enforcement effort. The latter course of action would cost more money than is presently spent on enforcement. However, questions remain regarding how much more enforcement is needed and in what form it is needed to satisfy stakeholders' desire for increased enforcement. Beyond some point the marginal cost of implementing an option rises sharply and outweighs the benefit. This study was not intended to provide an estimation of costs to implement a preferred solution. However, if costs of implementing options had been available, they could have been incorporated into the hierarchy prior to elicitation of judgments.

Instead, statistics were gathered on hypothetical payment vehicles for funding preferred options. The idea behind a preferred payment vehicle is that its acceptance, implementation and longevity will be superior to one not so preferred. The sale of a Kenai River stamp was by far the most preferred payment vehicle - a "user pays" funding mechanism. Purchase of a stamp for the privileges of recreating at a particular site is required in such states as Colorado and California. Proceeds from stamp sales go towards funding the management of resources at these sites, installation and maintenance of public facilities, etc. While every stakeholder highly preferred the sale of a Kenai River stamp, a dedicated user fee is against Alaska's state constitution. There is no regulatory mechanism presently in place in Alaska that would allow the proceeds from the sale of Kenai River stamp to be dedicated towards funding options in the Kenai River corridor. However, stamp sales would make imminent sense as a means for users to fund options to site-specific issues.

In 1993, the state of Alaska imposed the cost of a $10 chinook salmon stamp on anglers targeting chinook salmon. While the revenue generated from the sale of the stamp is not fishery-specific, the intent was to provide a source of funds for statewide research and management of chinook salmon. It is unknown if revenues generated from the sale of the statewide stamp are directed towards implementing preferred options which address high priority fishery issues.

Conclusion

In conclusion, the AHP can be a valuable decision-making tool for addressing divergent interests. It can serve as a learning tool, permitting decision-makers to explore the effect of varying the judgments assigned to the issues and options. Structuring the hierarchy forces decision-makers to think through the problem in a formal, exhaustive, and systematic manner. The AHP helps identify options likely to enjoy broad support and those that are likely to meet with strong opposition. In addition, the AHP encourages people to explicitly state their judgments. People's judgments should be an integral component of fisheries management.

Fisheries management can have many dimensions, depending upon the complexity of the problem. For example, a successful management tool for achieving the escapement goal on the Kenai River has been the imposition of catch and release regulations. However, because of the interrelationships among elements of the problem, catch and release regulations can influence issues such as perception of the quality of the fishery, revenue to guides, local businesses and local governments, etc. Decision analysis, and in particular the AHP, promotes awareness of interrelationships and their relative importance to help the fishery manager make not only successful choices but good choices.

Although there is no guarantee that use of a multiple criteria decision analysis technique, such as the AHP, would ultimately reverse the decline of a fish stock or prevent loss in regional quality of life, decision-makers could have more confidence that the probability of these undesirable scenarios occurring has been minimized and the best possible effort has been made.

Two options were identified as among the most preferred in all six models. The robust support for "increase funding to Alaska Fish and Wildlife Protection for enforcement of existing regulations", and "reduce property taxes for property owners who dedicate their river frontage to conservation" suggests that implementation of these options would be considered desirable by most stakeholders and would face limited opposition from the remainder.

CHAPTER 3

INFLUENCE OF PERCEPTIONS OF DATA ACCURACY AND INVERSE VARIANCE WEIGHTING ON THE ESTIMATION OF HUMPBACK WHITEFISH ABUNDANCE USING CATCH-AGE ANALYSIS WITH AUXILIARY INFORMATION

INTRODUCTION

Much has been written about analytical tools which are used to estimate stock abundance, population dynamic rates, and fishing mortality (Beverton and Holt 1993, Ricker 1975, Gulland 1977, 1983, Deriso et al., 1985, Methot 1989, Hilborn and Walters 1992). By describing mathematical relationships between population dynamic parameters and harvest, models can reduce uncertainty in how harvest influences abundance, and thus in setting harvest limits. Uncertainty in the stock dynamics increases the risk of overfishing. Because the sources of uncertainty will never be completely removed, fisheries managers routinely make personal judgments about the accuracy of annual estimates, or the reliability of a given source of information, and often integrate these perceptions of accuracy in their decision-making affecting fisheries. Perceptions of data accuracy are particularly important in situations where there is little current information at hand, yet fisheries managers must make a decision on the basis of best available information.

While there is no question that perceptions play a role in decision-making (Luce and Suppes 1965, Wehrung et al. 1978, Tait 1988, Badinelli and Baker 1990) and that the importance of perceptions to fisheries management decisions has been identified (Brewer

1979, Pearse and Walters 1992), little research has been conducted to quantify the influence of perceptions on a given solution to a fisheries problem. Martin (1979) incorporated subjective probability estimates into a framework to estimate the optimum numbers of units of gear in salmon drift gillnet fisheries and to evaluate the economic feasibility of processing pollock in southeast Alaska. Geiger and Koenings (1991) incorporated subjective information about spawner-recruit parameters based on perceptions of smolt characteristics and lake system limitations into a Bayesian framework to evaluate escapement goals for sockeye salmon.

The purpose of this study was to incorporate measurements of subjective perceptions of data accuracy and prior information of data precision to reduce uncertainty in the estimation of fish population parameters. The goal was to reduce risk in sustained yield management of recreational fisheries illustrated with the case of humpback whitefish in the Chatanika River. A measure of risk in the threshold harvest policy for humpback whitefish was computed by simulating population abundance at exploitation rates specified in the management plan. An analytical tool was chosen which is familiar to fisheries biologists: catch-age analysis with auxiliary information and weighting of observations. This analytical tool was used to model the interaction of the humpback whitefish population in the Chatanika River, Alaska, with the recreational spear fishery.

Funk et al. (1992) developed a form of the catch-age analysis approach of Deriso et al. (1985) and implemented the method using a spreadsheet. This model was modified to combine information derived from creel surveys and run age composition, along with auxiliary information in the form of population estimates. The model was fitted to the data using a non-linear least squares technique. Auxiliary information was used to stabilize parameter estimates (after Deriso et al. 1985). This age-structured model provides estimates of abundance for humpback whitefish, age vulnerability, and exploitation rate.

The model developed to describe the humpback whitefish population differs from that developed by Funk et al. (1992) in several important ways. First, Funk et al. assumed observed harvest is measured without error; that is, all error is in the age composition. In contrast, in the humpback whitefish situation, total harvest is not observed but estimated from a creel survey. Consequently, the error between estimated harvest from a creel survey and estimated harvest from an exploitation fraction is incorporated into the humpback whitefish model. That is, the calculation of estimated harvest in the humpback whitefish model assumes that vulnerability and exploitation are separable along the lines of Deriso et al. (1985).

Second, while Funk et al. used aerial survey biomass estimates, the humpback whitefish model uses population abundance estimates derived from mark-recapture experiments. With the use of bootstrap techniques, three potential error structures were examined.

The third difference between the two models is that Funk et al. used the inverse sine function to transform age composition proportions. In the humpback whitefish model, the log likelihood of the multinomial distribution of age proportions (obtained from mark-recapture sampling) was used (after Methot 1989), to reflect the sampling strategy.

Four systems for weighting annual observations were examined: equal (hereafter referred to as the base model); the inverse variance of estimates; subjective perceptions of accuracy; and, a combination of perception and inverse variance weights (hereafter referred to as the combined model). By weighting deviations of observed and estimated parameters it is possible to modify their influence according to prior expectations on their reliability. Weighting according to the inverse variance of estimates is commonly employed in weighted regression analysis (Steel and Torrie 1960) and in abundance estimation (following Paloheimo cited in Seber 1982). Weighting according to perceived accuracy of the data is tantamount to explicitly expressing the "gut feeling" and incorporating it into model estimation. Weighting according to perceptions is not commonly found in abundance estimation procedures, however it is employed in decision analysis. In Srinivasan and Shocker (1973), eight methods of assigning weights are reviewed, including expert judgment.

The formal procedure for using prior information to aid in the selection of an action is Bayes' criterion (Hillier and Lieberman 1990). Updated information (fit of estimated values to observations and trends in residuals) along with prior knowledge is called the posterior distribution. In this study, weights from prior information (hereafter denoted as θ) were assigned to annual observations and remained fixed. However, scaling of the data types was progressive in that values of the scaling factor (λ) were reassessed as updated information became available as the solution was sought. Thus, the selection of λ to scale data types was accomplished following Bayes' decision procedures. Other applications of Bayes' theorem to fisheries can be found in Fried and Hilborn (1988) and Charles (1988).

This study is the first to examine the influence of subjective perceptions of data accuracy and prior information of variance on the performance of a catch-age model applied to a recreational fish species. Resulting model performance was judged on the basis of: small coefficients of variation, minimal bias, reasonableness of estimates (within the range of historical values and likely given prior harvest and cohort abundances), rank order of mean squared errors (MSE's), and risk level (in terms of conservative versus optimistic scenarios). Changes in the management policy for humpback whitefish are suggested based on forecasts of mature exploitable abundance for varying exploitation, recruitment, and maturity scenarios using the age-structured models.

Accurate forecasts of abundance are needed to predict the effects of substantial alterations in regulations on the population, or the effects of population declines (e.g., through recruitment failures) on harvest opportunity (Hilborn and Walters 1992). Additionally, accurate forecasts are needed when there is uncertain assessment of stock size in-season. In regards to sustained yield management of humpback whitefish in the Chatanika River, there is a question whether a representative portion of the population is sampled using mark-recapture methods.

MANAGEMENT AND RESEARCH PROBLEMS OF THE WHITEFISH SPEAR FISHERY

Review of Whitefish Research

Assessment of whitefish (*Coregonis spp.*) has primarily focused on those populations in North America exploited in commercial fisheries. Most of these studies are on lake whitefish (*C. clupeaformis*) and lake herring (*C. artedii*) commercially exploited by gill, pound or trap nets near the Hudson and James bays (Morin et al. 1982, Kemp et al. 1989, Lambert and Dodson 1990), Great Slave Lake (Healey 1975) and other Northwest Territories waters (Reist and Bond 1988), and the Great Lakes, especially Lake Michigan (Walter and Hoagman 1975, Ebener and Copes 1985, Scheerer and Taylor 1985, Taylor et al. 1987, Jensen 1976, Patriarche 1977). There are far fewer references to assessment of whitefish recreational fisheries. Evans and Waring (1987) studied the population dynamics of lake whitefish and lake herring in Ontario's Lake Simcoe winter sport fishery.

History of the Fishery

Alaskan whitefish are harvested in limited commercial fisheries, and in more substantial subsistence and recreational fisheries. The largest recreational fishery for whitefish occurs in the Chatanika River in the Tanana River drainage near Fairbanks (Figure 3.1). The fishery targets a large spawning run and accounted for over 75% of Alaska's whitefish sport harvest in 1987 (Mills 1988). Fishermen wade into the shallows to spear whitefish upon their arrival on the spawning grounds in September. Effort peaks when spawning is completed in the upper river and spawners return downriver. Although most of the run is composed of least cisco (*C. sardinella*), conservation concerns for the less abundant humpback whitefish have driven management decisions for the fishery. High harvests in the mid-1980's combined with successive year class failures have reduced populations of both species.

The Chatanika River spear fishery developed slowly. The estimated harvest from 1972 to 1977 averaged about 2,000 whitefish. The average harvest rose to about 5,000 whitefish in the period from 1978 to 1985, which made it one of the fastest growing recreational fisheries in the Tanana River drainage. The estimated harvest from the Chatanika River in 1987 was 25,000 whitefish (Mills 1988). Of these, 4,577 were humpback whitefish (Table 3.1).

There was no bag limit for whitefish from the inception of the fishery through 1987. A 15-fish bag and possession limit for all whitefish was imposed in 1988 because of high exploitation rates on least cisco and humpback whitefish (Merritt et al. 1990). The estimated harvest of whitefish in the Chatanika River in 1988 was about 8,000, which was considerably less than harvests prior to the imposition of regulatory restrictions. However, in 1989 the harvest rebounded to about 15,500 whitefish, including 3,835

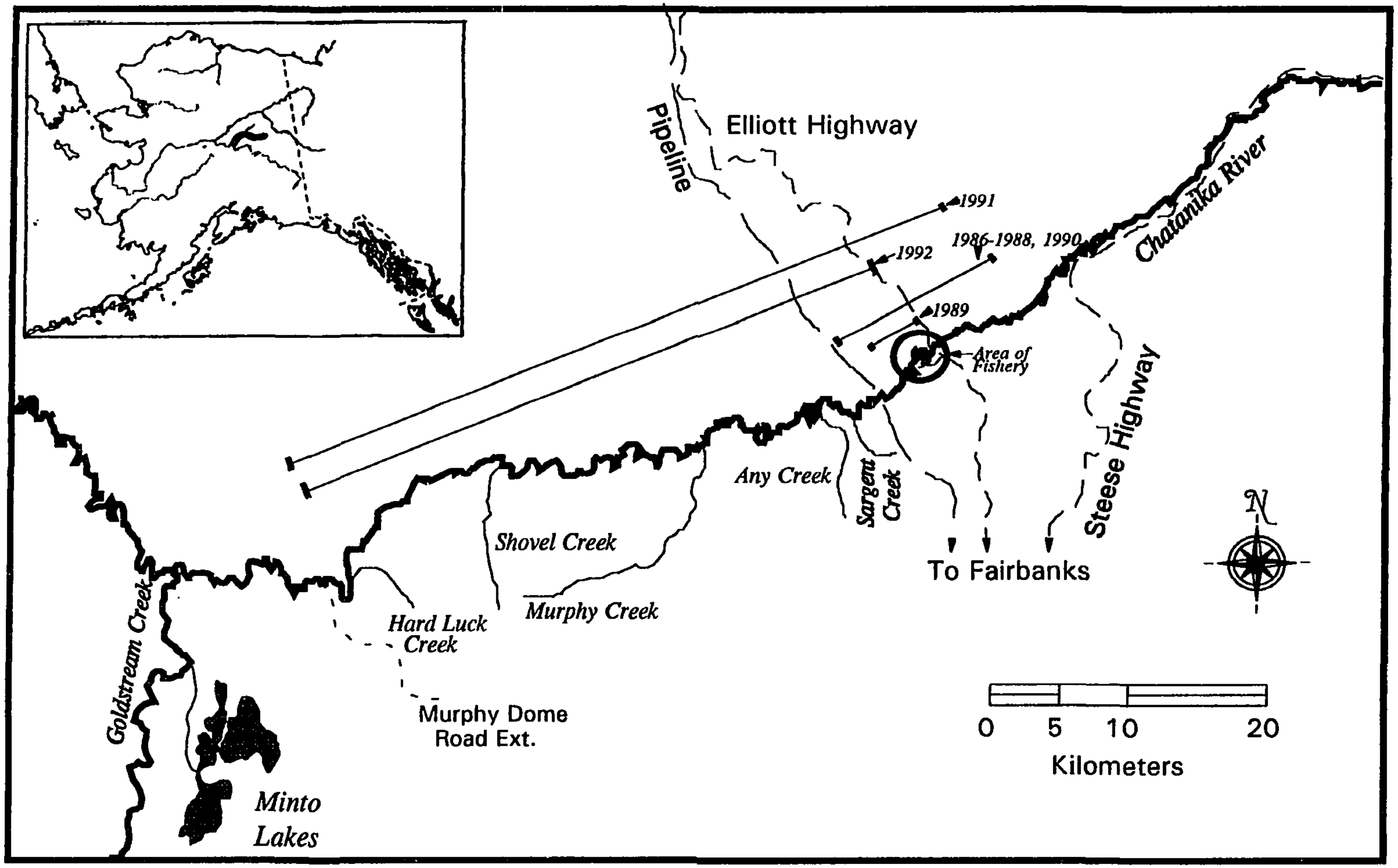

Figure 3.1. Location of the recreational spear fishery and portions of the Chatanika River surveyed for abundance of humpback whitefish and least cisco, by year.

Table 3.1. Estimated total angler effort, HPUE, and harvest of humpback whitefish in the Chatanika River obtained from on-site creel surveys, 1972-1992.

Year	Date	Angler Effort (Hrs)	(SE) [a]	Harvest	(SE) [a]	HPUE [b]
1972	10/10- 10/16	302	---	197	---	0.65
1973	09/01-10/07	1,356	---	542	---	0.40
1974	09/01-10/04	1,054	---	464	---	0.44
1975[c]	-	---	---	---	---	---
1976	09/01-10/12	300	---	387	---	1.29
1977	09/01-10/16	416	---	484	---	1.16
1978	09/09-10/21	968	---	3,211	---	3.32
1979	09/12-10/12	919	---	319	---	0.35
1980	09/05-10/22	1,026	---	493	---	0.48
1981[c]	-	---	---	---	---	---
1982[c]	-	---	---	---	---	---
1983	09/30-10/16	223[e]	---	73[e]	---	0.33
1984	09/11-10/11	2,548	---	921	---	0.36
1985	09/15-10/14	2,012	168	867	---	0.43
1986	09/14-10/14	3,309	114	2,528	914	0.76
1987	09/11-10/18	3,849	279	4,577	926	1.19
1988	09/09-10/16	3,974	196	3,571	293	0.89
1989	09/12-10/14	5,950	600	3,835	491	0.64
1990[d]	09/14-10/10	4,894	111	957	34	0.20
1991	Closed	0	---	0	---	---
1992	09/18-09/26	1,239	16	392	9	0.32

[a] No standard errors of the estimate are available until the mid 1980's.
[b] Creel survey harvest estimate divided by angler effort.
[c] No creel survey was conducted.
[d] Closed by Emergency Order.
[e] Minimun estimate.

humpback whitefish (Table 3.1). Anglers responded to the bag limit restrictions by increasing the number of trips taken.

In 1990, low estimates of abundance for humpback whitefish in mark-recapture experiments and low catch rates in the harvest were observed. Year class failures of age 4 and 5 humpback whitefish had been observed in 1989 (Timmons 1990) and were thought to contribute to the low numbers of fish seen in 1990. When the estimated exploitation rate of humpback whitefish in the harvest climbed above 15%, fishery managers decided to close the spear fishery by Emergency Order in early October of 1990. The fishery remained closed by Emergency Order for the entire 1991 season. In 1992, a limited fishery was allowed to proceed under area and season closures.

In late 1992, the Chatanika River sport fishery management plan was developed to direct management of the multi-species sport fishery according to specific objectives, including the objective that harvests of whitefish be sustainable. To achieve sustained yield in the recreational spear fishery for whitefish, management follows a threshold harvest policy. A threshold harvest policy is a balance between a fixed escapement policy and a constant harvest rate policy (Quinn et al. 1990; Zheng et al. 1993a.) When abundance falls below a fixed level, the population is protected by various management strategies, including a no-harvest policy. At higher abundances, harvest can proceed at varying rates. Threshold harvest policies are in effect for Pacific herring (*Clupea pallasi*) in Alaska (Zheng et al. 1993b) and have been examined through simulation studies for Eastern Bering Sea pollock (*Theragra chalcogramma*) (Quinn et al. 1990) and sablefish (*Anoplopoma fimbria*) in the Gulf of Alaska (Sigler and Fujioka 1993). The threshold abundance level for humpback whitefish in the Chatanika River has been tentatively set at 10,000 fish (referred to in the management plan as "spawners"). When the estimated population abundance is 10,000 to 15,000 spawners, the allowable maximum harvest rate is 10%; at 15,000 to 20,000 estimated spawners, harvest will be held to the "mid-range" of between 10% and 15% . When estimated spawner abundance exceeds 20,000 fish, harvest will be allowed to approach the 15% exploitation limit. The determination of these exploitation ranges is not well documented.

History of Stock Assessment

Sampling problems associated with whitefish in the Chatanika River are common to other studies of coregonids, due to their complex life history and migrations. One important question relative to sustained yield management of whitefish in the Chatanika River is whether a representative portion of the population is being sampled. Kemp et al. (1989) discovered that the scale of coregonid population dynamics in Hudson Bay may be underestimated by spatially and temporally limited sampling. In the fall, juveniles and non-reproductive adults remained in estuaries, whereas reproductive fish moved upstream. Whitefish species appear to segregate by age group and reproductive condition, which is complicated by skip-spawning (Reist and Bond 1988, Lambert and Dodson 1990).

Beginning in 1972, visual counts from boats and the Schnabel (1938) mark-recapture method were used to periodically estimate the abundance of humpback whitefish in the area of the spear fishery (Kepler 1973; Table 3.2). Beginning in 1986, abundance was annually estimated with the modified Petersen mark-recapture method (Seber 1982) using pulsed DC electrofishing (see Hallberg and Holmes 1987; Hallberg 1988, 1989; Timmons 1990, 1991; Fleming 1993 for detailed descriptions on how data were collected). Whitefish were tagged prior to the spear fishery, and creel sampling of spear fishermen served as the recapture event from 1986 through 1990. Because the recapture event was treated as being randomly drawn, the Chapman modification of the Petersen single-mark method (Seber 1982) was used.

Table 3.2. Historical abundance estimates of humpback whitefish by area of the Chatanika River sampled and year, 1972-1992.

Year	Tagging Dates	River Kilometer a	Abundance	SE
1972	09/06 - 09/12	0 to + 12	4,300	---
1972	09/06 - 09/12	0 to - 16	2,400	---
1972[b]	Total		6,700	
1973	08/27 - 09/10	0 to + 19	5,000	---
1973	08/27 - 09/10	0 to - 16	2,000	---
1973[b]	Total		7,000	
1974	08/13 - 08/17	0 to + 19	2,800	---
1974	08/13 - 08/17	0 to - 16	1,700	---
1974[c]	Total		4,500	
1977[c]	08/24	0 to - 16	2,500	---
1984[d]	NA	- 2	---	---
1986[d]	08/04 - 09/25	+15 to - 16	14,906[g]	3,172
1986[ef]	09/26 - 10/11	-4	15,646	---
1987[d]	08/10 - 09/23	+15 to - 15	28,165[g]	3,434
1987[ef]	09/19 - 10/17	- 4	30,310	---
1988[d]	08/17 - 09/21	+15 to - 15	41,211[g]	5,155
1989[d]	08/16 - 09/27	0 to -5	17,322[g]	1,655
1991[d]	07/11 - 09/14	+15 to -109	15,313[g]	2,078
1992[d]	08/17 - 08/28	0 to -109	20,180[g]	1,663

[a] Abundance estimate is germane to the area from the Elliot Highway Bridge to a given distance above (+) the bridge or to a given distance below (-) the bridge, except for tower counts, which is the number of fish which passed a specific point.

[b] Combination of visual counts from a boat and Schnabel (1938) estimates of abundance.

[c] Visual counts from a boat.

[d] Petersen estimates of abundance.

[e] Visual counts from a tower.

[f] Species composition of the population estimated from samples taken during mark-recapture experiments.

[g] For fish greater than 359 mm fork length.

In 1991 and 1992 electrofishing was used to capture fish for both the mark-recapture events. The Bailey modification of the Petersen method (Seber 1982) was used because the recapture event was no longer treated as a simple random sample, but rather systematic (see Seber 1982). Fish were observed not to mix completely, but remained in the approximate location of their initial capture.

From 1986 through 1988 the population estimate was for fish occurring from approximately 15 km upstream to 15 km downstream (30 km total) of the Elliot Highway Bridge. Because the spear fishery primarily occurred from the Elliot Highway Bridge downstream to the Olnes Pond Campground (5 km), the 1986-1989 abundance estimates relied on the assumption that whitefish tagged upstream and downstream of the fishery would migrate through the fishery. In 1989 the population estimate was relevant to only the area of the spear fishery (the Elliot Highway Bridge to approximately 5 km downstream). In 1990 the area sampled included 15 km upstream and 19 km downstream of the Elliot Highway Bridge, however no population abundance estimate was generated because the assumption of a closed population could not be met. In 1991, the area sampled was from about 15 km upstream to 109 km downstream of the Elliot Highway Bridge. Thus 1991 was the first year for which an "entire" river estimate was generated. In 1992 the area sampled was the same as in 1991, except that low water prevented sampling the area 15 km upstream of the Elliot Highway Bridge. Estimates limited to the vicinity of the fishery may not be representative of the population (Figure 3.1). More recent estimates are believed to be less biased because they were obtained by sampling a larger portion of the population downriver from the fishery.

The relationship between spawners and recruits is not clear for humpback whitefish in the Chatanika River because maturity at age information is incomplete. Alt (1979) noted in a sample of 199 spawning fish that the dominant age groups were 7 and 8;

the youngest mature female in the sample was age 5. While Clark and Bernard (1992) estimated fecundity at length for humpback whitefish in the Chatanika River, maturity at age cannot be inferred because of the high degree of overlap in length among age groups. Because it is likely that mature fish are the ones subject to a recreational fishery which occurs on the spawning grounds, the management plan has defined these fish as spawners. Nevertheless, precise age at maturity information is lacking. Additionally, the number of years for which abundance at age is available is few. For these reasons, parameter estimates were defined by catch-age models which avoided using a spawner-recruit relationship.

History of Creel Surveys

Creel surveys from 1986 to 1990 (Clark and Ridder 1987; Baker 1988, 1989; Merritt et al. 1990; Hallberg and Bingham 1991) were both multi-stage roving and access-location designs (Guthrie et al. 1991), with a general sampling level of 50%. Because the fishery was closed in 1991, there was no survey. Sampling in 1992 was a complete census except for missed vehicles (Hallberg and Bingham 1993). From 1986 to 1989, days within time periods represented the first sampling stage, and angler interviews were the second sampling stage. In 1990, days within time strata represented the first sampling stage, vehicles were the second-stage units and anglers interviewed within vehicles were the third stage units. In 1992 anglers interviewed within vehicles represented first-stage sampling units. The only area surveyed in 1986 was what is now known as the Whitefish Campground, because the fishery was mainly confined to this area (Figure 3.2). The 1987 creel survey was expanded to include the "ditch" (now called Olnes Pond). Areas surveyed in 1988 and 1989 were expanded to three (the Whitefish and Olnes Pond campgrounds and the Steese Highway) in response to an expanding fishery. In 1990 and

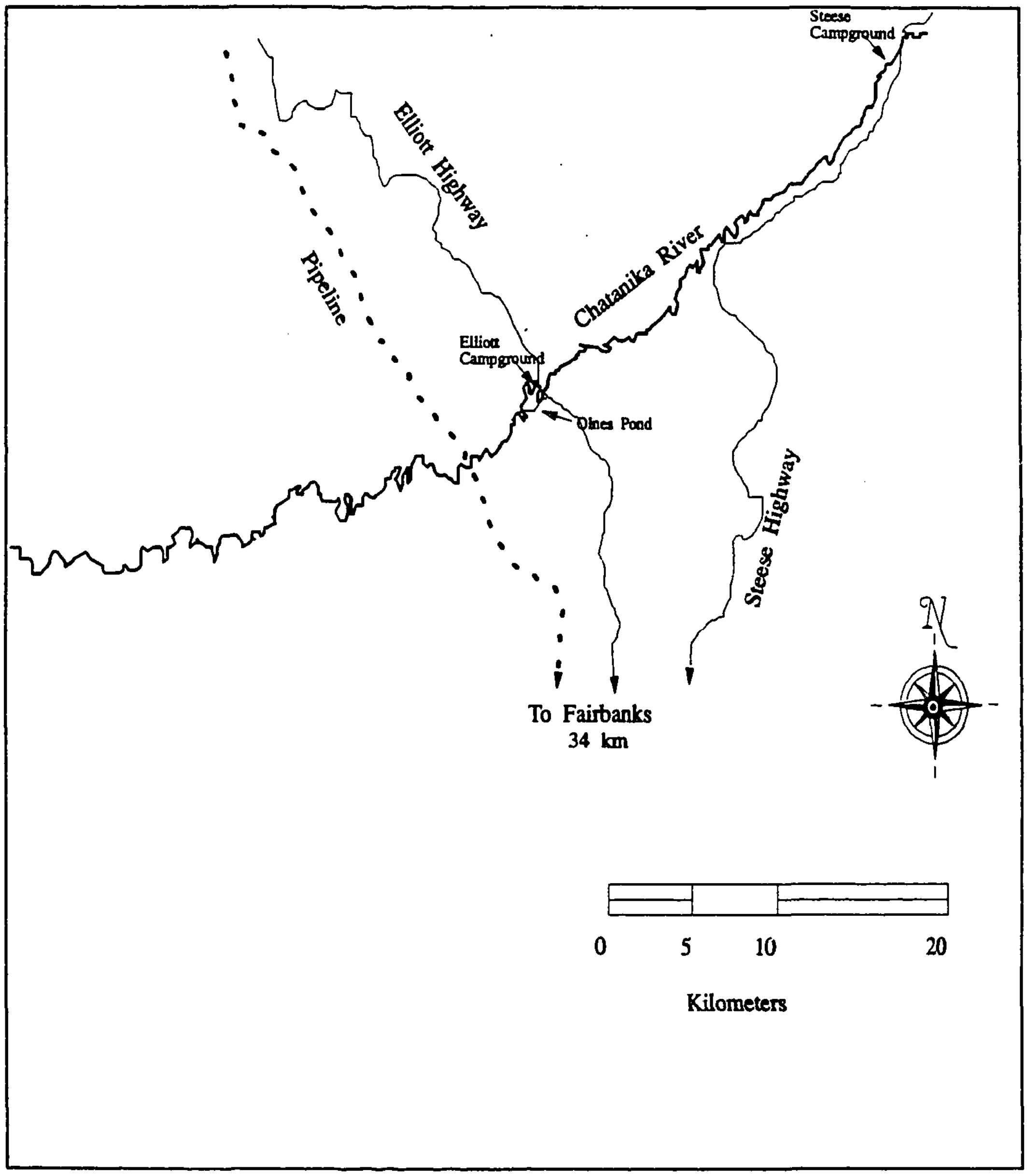

Figure 3.2. Location of Chatanika River whitefish spear fishery, Tanana River drainage, Alaska.

1992, the Steese area was dropped because of low angler effort. Most fishing was thought to occur between 2000 to 0200 hours so the fishing day was defined as this six hour period.

METHODS

Notation

Notation used to define abundance and harvest at age, instantaneous natural mortality, vulnerability, selection of initial values for catch-age analysis, population dynamic models, and statistical models follows. A caret (^) is used to denote parameter estimates from data (such as observed age composition, harvest from creel surveys, or abundance from mark-recapture experiments) and parameter estimates from catch-age models are left unadorned. Let:

n	=	number of fish sampled for age composition,
n_a	=	number of fish of age a in the sample,
$\hat{p}_a$	=	estimated proportion of age a fish in the sample,
$\hat{H}_y$	=	observed harvest from the creel survey in year y,
$\hat{N}_{mark,y}$	=	observed exploitable abundance from the mark-recapture experiment in year y,
L_a	=	length at age a,
$s(a)$	=	an age-specific vulnerability function,
α	=	age of 50% vulnerability to gear,
β	=	a steepness parameter in the vulnerability function,
K	=	von Bertalanffy growth coefficient,
L_∞	=	asymptotic length of humpback whitefish,
t_o	=	theoretical age at length zero,

t_{mb} = 0.38 of the maximum observed age,

S = proportion of the cohort surviving from the end of the fishery in year y to the beginning of the fishery in year y+1, assumed constant,

$e_{i,y}$ = a vector of estimation errors for model i or j in year y,

r = correlation between the sums and differences of the estimation errors,

T = number of years,

$N_{a,y}$ = estimated number of fish in the cohort at age a just before the fishery in year y in the catch-age model,

$H_{a,y}$ = estimated harvest of fish of age a in year y in the fishery from the catch-age model,

$s(a)N_{a,y}$ = estimated exploitable abundance at age a in year y,

EN_y = total estimated exploitable abundance in year y for all ages,

EN_s = total estimated exploitable abundance of mature (spawning) fish,

θ = vector of Bayesian prior weights of influence given to annual objective function components,

λ = scalar used to scale the objective function to be similar, and

μ = exploitation fraction.

Catch-age Analysis

The catch-age analysis used methods similar to Deriso et al. (1985, 1989). The development of the prototype of the model used here is given in Funk et al. (1992) and Rowell et al. (1993), which undertook catch-age analyses on stocks of herring in Alaska. Three observed data sources were used in this analysis[7] : harvest at age estimates (1986 - 1992), ages 3 through 10+; estimates of abundance from mark-recapture experiments

[7] Air temperature and discharge data were inspected for inclusion into the model as an auxiliary data source, however were dismissed from further consideration for two reasons. First, air temperature and discharge are not measured on-site, so the extrapolation of data from other sites (Fairbanks and the Chena River, respectively) introduced a great deal of variability. Second, no correlation was found between: abundance of age 4 fish and mean discharge in May following their natal year (as was suggested in Timmons 1991); or, harvest and discharge or air temperature during the fishery.

(1986 - 1992 except 1990); and observed age frequencies in the mark-recapture sample (1986 - 1992), ages 3 through 10+. The total number of parameters estimated by the model were: 14 initial cohort abundances (all ages in the first year and age 3 in all years); two gear vulnerability parameters, α and β; and, seven exploitation fractions (ages combined, 1986 to 1992). The natural annual survival rate of humpback whitefish was fixed. The Microsoft Excel spreadsheet Solver was used to estimate values for the parameters which minimized the combination of weighted sums of squares for mark-recapture and harvest estimates, and the negative of the age composition likelihood, as explained below. This approach was developed to reflect the multinomial sampling of the data, and to incorporate error in mark-recapture and harvest estimates directly. The appropriateness of the multinomial error structure for age composition samples by Methot (1989) is described by Fournier and Archibald (1982). An alternate approach is to use a lognormal error structure (Deriso et al. 1985).

Abundance and Harvest at Age:

Age composition was estimated from the fishery in 1986 and 1987; however, because estimates did not significantly differ from those calculated from samples taken during mark-recapture experiments, the fishery was not sampled for ages after 1987. Age composition proportions for harvest during 1988 - 1992 are assumed the same as those from mark-recapture experiments. Age samples of size n were considered as randomly drawn from a multinomial distribution. The estimated proportion at age a in year y is then:

(3.1) $\hat{p}_{a,y} = n_{a,y} / n_y$.

An unbiased estimate of the variance for each proportion was calculated according to Snedecor and Cochran (1980):

(3.2) $V[\hat{p}_{a,y}] = \hat{p}_{a,y}(1 - \hat{p}_{a,y}) / (n - 1).$

Harvest at age from 1986 through 1992 was estimated by multiplying the estimated proportion by age class from mark-recapture experiments (Table 3.3) and the estimated harvest from creel surveys (Table 3.4):

(3.3) $\hat{H}_{a,y} = \hat{H}_y \hat{p}_{a,y}.$

Vulnerability:

Because the same age distributions were used for estimates of age composition in the harvest and mark-recapture experiment, common vulnerability parameters were selected for both spearfishing and electrofishing gears. Following Funk et al. (1992), parameters in the function chosen to describe the relationship between gear vulnerability and age were α and β, represented in the logistic form:

(3.4) $$s(a) = \frac{1}{1 + e^{\beta(a-\alpha)}}.$$

While the average of age classes seemingly fully vulnerable to electrofishing during mark-recapture experiments conducted from 1986-92 is age 5 (Figure 3.3), vulnerability was not constrained in the models. The consequences of not fixing vulnerability were more reasonable estimates of harvest.

Table 3.3. Estimated proportion of humpback whitefish by age class and sample sizes (n) from mark-recapture experiments in the Chatanika River, 1986-1992.

	Age								
Year	n	3	4	5	6	7	8	9	10+
1986	73	0	.205	.356	.164	.151	.096	.027	0
1987	686	.028	.290	.357	.201	.079	.026	.015	.004
1988	546	.005	.156	.421	.284	.099	.026	.009	0
1989	982	0	.013	.215	.441	.202	.086	.023	.020
1990	991	.010	.050	.257	.330	.221	.083	.023	.025
1991	342	.029	.038	.058	.149	.251	.208	.129	.137
1992	641	.011	.064	.056	.075	.184	.229	.176	.204

Table 3.4. Harvest at age[a] (standard errors are in parentheses)[b] for humpback whitefish, Chatanika River, 1986-1992, estimated from on-site creel surveys and age composition from mark-recapture experiments in Table 3.6.

		Age							
Year	Total	3	4	5	6	7	8	9	10 +
1986	2,528 (914)	0 (0)	556 (142)	1,113 (129)	354 (155)	202(155)	202 (155)	76 (167)	25 (167)
1987	4,577 (926)	128 (27)	1,327 (78)	1,634 (82)	920 (69)	362 (46)	119 (27)	69 (23)	18 (14)
1988	3,571 (293)	20 (12)	556 (89)	1,504 (203)	1,014 (144)	353 (63)	92 (27)	33 (15)	0 (0)
1989	3,835 (491)	0 (0)	38 (19)	805 (38)	1,689 (38)	767 (38)	345 (19)	77 (19)	114 (32)
1990	957 (34)	8 (4)	48 (10)	263 (19)	348 (21)	198 (17)	71 (11)	15 (6)	6 (4)
1991	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	(0)
1992	392[c] (9)	4 (3)	25 (4)	22 (4)	29 (27)	72 (4)	90 (8)	69 (4)	80 (7)

[a] The estimated harvest in age group a in the total harvest was calculated as:

$$\hat{H}_{a,y} = \hat{H}_y \hat{p}_{a,y} .$$

[b] The variance for $\hat{H}_{a,y}$ is the sum of the exact variance of a product from Goodman (1960):

$$V[\hat{H}_{a,y}] = \sum_y (V[\hat{p}_{a,y}]\hat{H}_y^2 + V[\hat{H}_y]\hat{p}_{a,y}^2 - V[\hat{p}_{a,y}]V[\hat{H}_y]) .$$

[a] Abundance by age does not sum to total because of some age 2 fish in the sample.

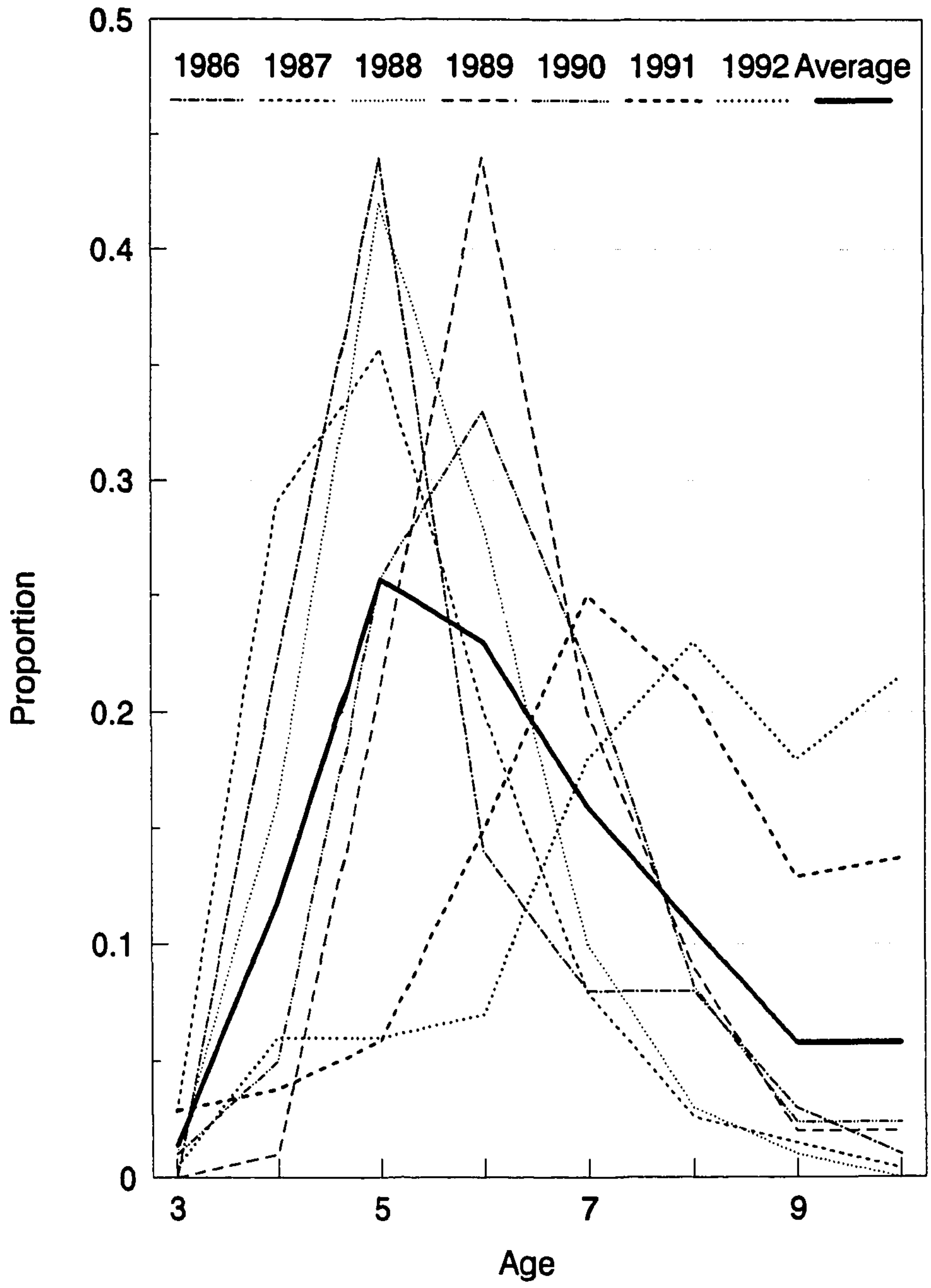

Figure 3.3. The proportion at age of humpback whitefish in the mark-recapture sample by year, and the average for the years 1986-1992.

Instantaneous Natural Mortality:

The von Bertalanffy growth model (von Bertalanffy 1938) was used in the estimation of the following life history parameters: K, L_∞, and t_o. Estimates of these parameters were obtained using a modified Marquardt non-linear least squares procedure contained in a FORTRAN program. The equation used was:

$$(3.5) \quad L_a = L_\infty(1 - e^{-K(a-t_0)}).$$

Although on occasion a few age 14 and age 15 humpback whitefish were observed, the oldest age consistently present in samples was age 13, which was used as the maximum age of humpback whitefish for purposes of estimating instantaneous natural mortality. Alverson and Carney (1975) reasoned that because the time at which cohort biomass is maximized is a function of growth and mortality, natural mortality could be estimated by:

$$(3.6) \quad M = \frac{3K}{e^{t_{mb}K} - 1}.$$

Equation (3.6) was used with results from the von Bertalanffy models for years in which individual age data were available (1989-1992).[8] The average of the years 1990-1992 was used as the estimate of natural mortality for all ages. Natural mortality was converted to annual survival fraction (S) using:

$$(3.7) \quad S = e^{-M}.$$

[8] In 1989 insufficient numbers of large fish were captured to give consistent estimates of parameters for the von Bertalanffy model, so this year was excluded from the estimate of average natural mortality.

The annual survival fraction describes survival between annual recreational fishing seasons which occur over a relatively short time interval. The term, S, includes all sources of mortality other than the fall recreational spear fishery.

Subsistence harvest of whitefish by the village of Minto undoubtedly includes humpback whitefish which spawn in the Chatanika River. The only accurate estimate of subsistence harvest of whitefish (all coregonid species) was small (6,477 fish in 1984; Andrews 1988), and was taken from a large geographic area (which probably included other whitefish stocks; Figure 3.4). For these reasons, subsistence harvest of Chatanika River whitefish stocks is deemed to be small and is subsumed into M.

Equation (3.5) was used with three values of K (0.05, 0.10, 0.20), obtained from fitting von Bertalanffy models for the years 1990-92 (Table 3.5). The average of these (0.46) was used as the estimate of instantaneous natural mortality rate for all ages in later analysis. Natural mortality was converted to 65% annual survival. The Alverson-Carney method produced a reasonable estimate, comparable to others generated for coregonids (see Healey 1975).

Error Structure:

One of the key developments of this paper is the use of empirical distributions to select the error structure for the model. The rationale for the age composition error structure was previously described based on sampling considerations. The choice of error structure for the auxiliary information is described here. To obtain an idea of the underlying distributions for annual mark-recapture estimates, bootstrap procedures were used. Data for the years 1986 - 1992 (excluding 1990) were randomly drawn with replacement from a uniform distribution between 0 and 1 using a FORTRAN program.

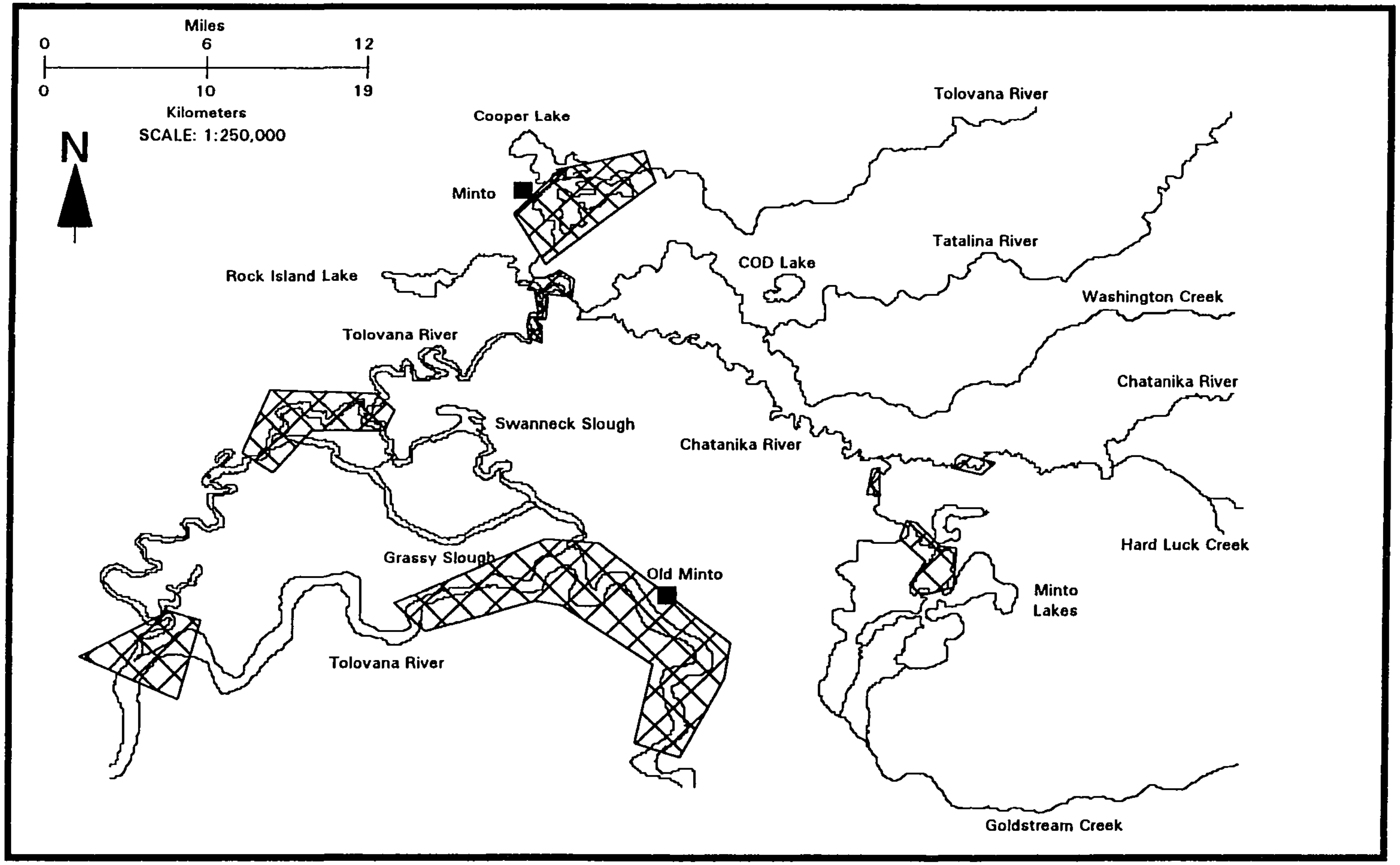

Figure 3.4. Locations (hatched areas) of reported subsistence harvest of coregonid species by Minto villagers in 1984 (from Andrews 1988).

Table 3.5. Estimates of life history parameters and instantaneous natural mortality for humpback whitefish in the Chatanika River.

	von Bertalanffy Model			Alverson-Carney Estimates of M	
Year	K	t_o	L_∞ (mm)	for K equal to	M
1990	.10	-10.36	515	.10	0.47
1991	.19	-3.20	499	.20	0.36
1992	.05	-13.00	657	.05	0.54
Average					0.46

The generation of population estimates from each set of bootstrapped capture histories was repeated 1,000 times (Efron 1982). Because repeated mark-recapture histories can be defined by proportions (Buckland and Garthwaite 1991), the random draw from a uniform is transformed to a draw from a multinomial distribution. Visual inspection of the resulting distributions indicated that the mark-recapture experiments during the years 1986, 1988, and 1991 produced skewed distributions. Skewness in 1986 was due in part to low numbers of recaptures. Transformation of the mark-recapture estimates was thus warranted, and the inverse of N_{mark}, as per Seber (1982) was selected (see Table 3.6 for total mark-recapture estimates of abundance).[9] It is assumed that the transformed mark-recapture estimates are approximately normally distributed (see Figure 3.5).

Variation in harvest at age estimates from creel surveys (Table 3.4) is less than variation in abundance at age estimates (Table 3.6). Thus, relatively less error is introduced from harvest estimates compared with error from the auxiliary and age composition data sources. For this reason, little penalty was incurred by assuming that creel harvest estimates are normally distributed. This differs from other catch-age analyses (Doubleday 1976, Deriso et al. 1985) which assumed logarithms of harvest age compositions to be normally distributed.

An assumption of the weighted least squares regression model is that errors are uncorrelated (Abraham and Ledolter 1983). Harvest and abundance residuals were examined for significant linear trends on year using a t-test at the 95% confidence level:

$$(3.8) \qquad t = \frac{r\sqrt{T-2}}{\sqrt{1-r^2}} .$$

9 Seber (1982) notes that the inverse of a mark-recapture abundance estimate has an approximate normal distribution.

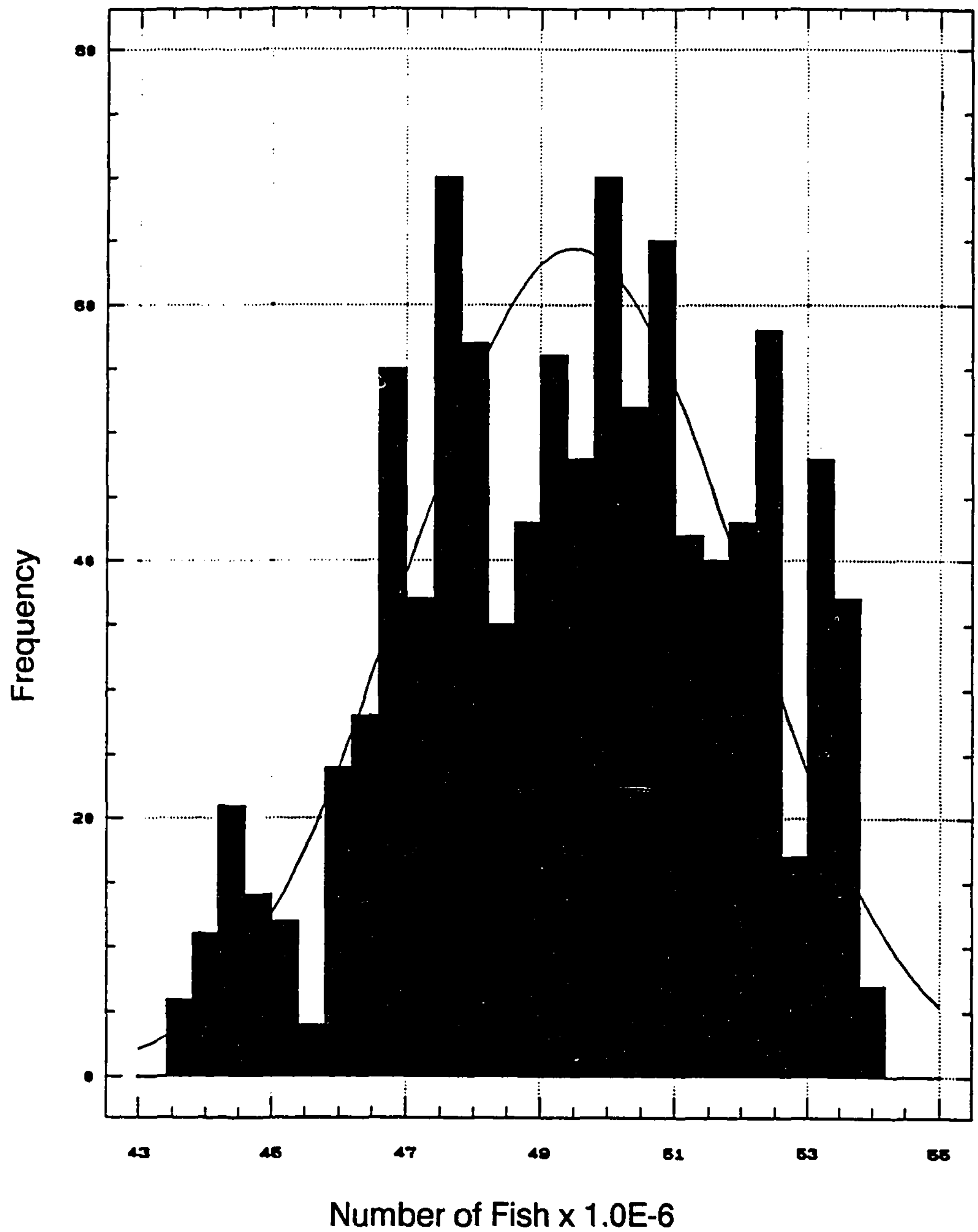

Figure 3.5. Representative example of a bootstrapped inverse abundance estimate for humpback whitefish from a mark-recapture experiment in 1992, compared with a normal distribution.

Table 3.6. Abundance at age[a] (standard errors are in parentheses)[b] for humpback whitefish, Chatanika River, 1986-1992, as estimated from mark-recapture experiments.

		Age							
Year	Total	3	4	5	6	7	8	9	10 +
1986	14,906 (3,172)	64 (64)	3,213 (789)	6,552 (1,473)	2,120 (562)	1,221 (369)	1,221 (369)	386 (173)	129 (93)
1987	28,165 (3,434)	780 (199)	8,170 (1,107)	10,059 (1,329)	5,666 (813)	2,217 (395)	739 (193)	411 (137)	123 (72)
1988	41,211 (5,155)	226 (133)	6,416 (1,023)	17,360 (2,337)	11,699 (1,663)	4,076 (730)	1,057 (307)	377 (173)	0 (0)
1989	17,322 (1,655)	0 (0)	229 (63)	3,722 (226)	7,638 (273)	3,493 (221)	1,482 (154)	406 (83)	353 (78)
1990[c]									
1991	15,313 (2,078)	443 (138)	581 (153)	902 (199)	2,280 (291)	3,856 (368)	3,183 (337)	1,974 (276)	2,094 (297)
1992	20,180 (1,633)	220 (81)	1,287 (202)	1,130 (202)	1,506 (202)	3,703 (202)	4,613 (404)	3,548 (202)	4,111 (314)

[a] The estimated abundance in age group a in the population was calculated as:

$$\hat{N}_{a,y} = \hat{N}_y \hat{p}_{a,y} .$$

[b] The variance for $\hat{N}_{a,y}$ is the sum of the exact variance of a product from Goodman (1960):

$$V[\hat{N}_{a,y}] = \sum_{y} (V[\hat{p}_{a,y}]\hat{N}_y^2 + V[\hat{N}_y]\hat{p}_{a,y}^2 - V[\hat{p}_{a,y}]V[\hat{N}_y]) .$$

[c] Abundance was not estimated because the assumption of a closed population could not be met.

The Durbin-Watson statistic was used to test for first order serial correlation in harvest and abundance residuals (Abraham and Ledolter 1983):

$$(3.9) \qquad DW = \frac{\sum_{y=2}^{T} (e_y - e_{y-1})^2}{\sum_{y=1}^{T} e_y^2} .$$

Population Dynamic Models

Catch-age models fit catches estimated by equations describing natural and fishing mortality to a time series of observed catches at age. Because the Chatanika River whitefish fishery occurs over a short time span, harvest of whitefish is considered to occur instantaneously, and closely following, the generation of abundance estimates. A discrete equation was used to model abundance of one cohort to the next year:

$$(3.10) \qquad N_{a+1,y+1} = S(N_{a,y} - H_{a,y}).$$

The model begins to track fish at age 3, which although not fully recruited to the fishery or to the mark-recapture experiment, begin to show in significant numbers on the spawning grounds and in electrofishing samples. Because bias in aging increases with age, fish of age 10 and older were pooled into a single 10+ group (Deriso et al. 1989). Fournier and Archibald (1982) recommend pooling older age classes for catch-age analysis. So, the abundance for the 10+ group was:

$$(3.11) \qquad N_{10+,y+1} = S[(N_{9,y} - H_{9,y}) + (N_{10+,y} - H_{10+,y})].$$

The catch-age model contains parameters for the abundance of age 3 fish recruiting each year, and also the abundance of all age groups during the first year. From these initial cohort values, the catch-age model estimates the abundance, $N_{a,y}$, of a cohort at subsequent times from Equations (3.10) and (3.11).

Although there is no information on age at maturity of humpback whitefish in the Chatanika River, ages 3 and 4 fish are probably not fully mature, and may not all migrate to the spawning grounds where they are exposed to the fishery. The exploitable population at each age, $EN_{a,y}$, composed of the number of fish from each cohort that migrate to the spawning grounds and are potentially vulnerable to the fishery, is given by:

$$(3.12) \quad EN_{a,y} = s(a)N_{a,y}.$$

The age composition of the harvest is proportional to the exploitable population because of the selectivity adjustment. Thus, the estimated age composition, $p_{a,y}$, of the harvest or the exploitable population from the catch-age model for each year y was:

$$(3.13) \quad p_{a,y} = \frac{s(a)N_{a,y}}{\sum_a s(a)N_{a,y}} = \frac{EN_{a,y}}{EN_y},$$

where

$$(3.14) \quad EN_y = \sum_a s(a)N_{a,y} = \sum_a EN_{a,y}$$

is the total exploitable abundance in year y.

Estimated harvest was modeled as a function of the exploitation fraction multiplied by the estimated exploitable abundance at age a for each year y:

$$(3.15) \quad H_{a,y} = \mu_y s(a)\, N_{a,y} = \mu_y EN_{a,y}$$

which assumes that exploitation and vulnerability are separable.

Statistical Models

A given sum of squares component (SSQ) represents estimation error and can be written:

$$(3.16) \quad SSQ = \lambda \sum_{x} \theta_x SSQ_x$$

where λ is an overall weight, θ_x is a data-specific weight, SSQ_X is a data-specific squared deviation of observed and estimated values, and x refers to the data (such as year, age, or some combination). In this study, the weightings were specified for each year.

The θ's represent the weight of influence given to an individual SSQ component and were used to weight each SSQ in four ways: equal weights (the base model), an inverse variance scheme, a combination of inverse variance and perception weights (the combined model), and perceptions in accuracy of the data. To weight by the variation in data, the inverse of the variance of an annual estimate was computed, and then normalized (Table 3.7). The extremes in variance for harvest are due to different magnitudes of harvest between years (a small harvest usually is associated with a smaller variance than a large harvest); and, increasing efficiency in creel survey design over time. The combined model was obtained by multiplying the inverse variance and perception weights together for each annual observation and then normalizing the result (Table 3.7).

To weight by perception, the fishery manager was asked to assign subjective priors to the credibility of annual abundance, harvest and age composition estimates for 1986 through 1992, using a scale from 1 (unbiased estimate) to 0 (do not believe the estimate is remotely close to reality; Table 3.7). Judgments regarding credibility of abundance and

Table 3.7. Weights of influence (θ) assigned to each annual SSQ component (harvest, mark-recapture abundance, and age composition estimates) for the inverse variance, perception, and combined models used in estimating abundance of humpback whitefish in the Chatanika River.

Year	Harvest	Abundance	Age Composition
Inverse Variance Model:			
1986	0.000089	0.271	0.018
1987	0.000089	0.230	0.516
1988	0.000940	0.101	0.367
1989	0.000330	1.000	1.000
1990	0.070000	0	0.009
1991	0	0.633	0.214
1992	1.000000	0.989	0.450
Perception Model [a]:			
1986	0.6	0.7	0.6
1987	0.7	0.7	0.6
1988	0.8	0.7	0.6
1989	0.6	0.2	0.6
1990	0.9	-	0.6
1991	-	0.8	1.0
1992	0.9	0.8	1.0
Combined Model:			
1986	0.000059	0.240	0.018
1987	0.000069	0.204	0.516
1988	0.000836	0.089	0.367
1989	0.000220	0.253	1.000
1990	0.070000	0	0.009
1991	0	0.640	0.357
1992	1.000000	1.000	0.750

[a] Weights are on a scale of 1.0 (exact estimate) to 0 (do not believe the estimate is remotely close to reality).

harvest estimates were primarily influenced by the manager's observations and impressions of experimental design and sampling strategy for a particular year. For example, the manager down-weighted the abundance estimate for 1989 because he did not trust the mark-recapture experiment, which was conducted in a relatively small area (5 km). Repeated passes with the electrofishing boat occurred over the same group of fish, some of which were observed to exit the study area. Based on these field observations, the manager had little confidence in the estimate. As another example, harvest estimates from creel surveys prior to 1990 were down-weighted by the manager because of creel survey design and area covered by roving clerks. To a lesser extent, judgments of credibility in abundance and harvest estimates were influenced by the manager's knowledge of variation about the estimates. Weights assigned to age composition estimates reflect more confidence in detecting annuli in older fish for 1991 and 1992, compared to earlier years. This is because a more experienced reader interpreted scale ages from annuli in 1991 and 1992, and more experience is assumed to result in greater accuracy.

Because the inverse transformation was used in an attempt to normalize abundance data, residuals from the three data sources were not in the same order of magnitude; residuals from abundance were on the order of 1×10^{-9} to 1×10^{-10}, while those of harvest were on the order of 0.01 to 100. These differences required that scaling coefficients be used (λ) to bring the SSQ from these data sources closer in magnitude for use in the non-linear minimization procedure (Rowell et al. 1993, F. Funk personal communication, ADF&G, Juneau). To scale heterogeneous SSQ's, Solver was run repeatedly to solve for preliminary values. The λ was initially set by my beliefs of confidence in each data set: the age composition was weighted as 1.0; slightly more confidence was given to harvest estimates (λ=10); and, slightly less confidence was given to mark-recapture estimates (λ= 10^{-1}). The λ was changed at incremental orders of magnitude (e.g., 10, 10^2, 10^3, 10^{-1},

10^{-2}, 10^{-3}, etc.) for one data set at a time. After each iteration, the scaled SSQs were compared for similar orders of magnitude. If the scaled SSQs were somewhat close in magnitude, the model was further examined to determine whether there were trends in residuals, similar magnitudes in the predicted and observed errors, and whether exploitable abundance was reasonable and stable for a range of λ's. Thus, the performance of the model determined the ultimate set of λ's, or the confidence emphasis of the three data sets (see Table 3.8). It was assumed that the model with the least risk of failure is the one producing the most stable error structure and giving the most reasonable estimates. Sensitivity of exploitable abundance to varying λ was examined.

The objective function component used for comparing differences between observed and estimated exploitable (from Equation 3.14) abundance was the residual sum of squares criterion:

$$(3.17) \qquad SSQ_{mark} = \lambda_{mark} \sum_{y}[\theta_{mark,y}\{\hat{N}^{-1}_{mark,y} - (EN_y^{-1})\}^2].$$

The sum of squares which compared differences between observed and estimated harvest (from Equation 3.15) was computed as:

$$(3.18) \qquad SSQ_{harvest} = \lambda_{harvest} \sum_{y}[\theta_{harvest,y}\{\hat{H}_y - \sum_{a} H_{a,y}\}^2].$$

The negative of the log likelihood[10] component for the multinomial age distribution (from Equation 3.13) was calculated as an objective, O_{age}:

$$(3.19) \qquad O_{age} = -\lambda_a \sum_{y}[\theta_{a,y} \sum_{a}(n_a \ln p_{a,y})].$$

[10] A likelihood function is an expression that describes the joint probability distributions of the observed sample data (age composition) and any given number of states (θ; Wonnacott and Wonnacott 1990).

Table 3.8. Scalars (λ) used to scale the objective function components, and mean squared errors (MSE's) of the three data sets (harvest, mark-recapture abundance and age composition estimates) for the base, inverse variance, perception and combined models.

	Base	Inverse Variance	Perception	Combined
Lambda (λ)				
Harvest	$1x10^{-6}$	$1x10^{-4}$	$1x10^{-6}$	$1x10^{-4}$
Abundance	$1x10^{10}$	$1x10^{9}$	$1x10^{9}$	$1x10^{9}$
Age Composition	$1x10^{-2}$	$1x10^{-2}$	$1x10^{-2}$	$1x10^{-2}$
MSEs				
Harvest	0.00613	0.00061	0.00009	0.00046
Abundance	0.789	0.118	0.100	0.086
Age Composition	1.296	0.538	0.885	0.618

Selection of Initial Values

While estimated values were independent of the initial values chosen (that is, Solver adjusted whatever initial values were provided to achieve virtually identical results), the number of iterations were affected by initial values. The greater the number of iterations, the longer the computing time. Thus, the choice of initial values was intended to reduce the number of iterations required by Solver (Appendix 3.1). The set of initial cohort values was obtained through iterative examinations of Excel spreadsheet output. Initial cohort sizes derived from the computer program CAGEAN (Deriso et al. 1985, 1989) resulted in such a long computing time, that they were discarded in favor of best guesses.

The initial vulnerability parameter, α, was chosen to be 3.5 because it appeared from Figure 3.3 that the age of 50% vulnerability to the gear was between ages 3 and 4. To achieve a vulnerability curve that would conform to an α between 3 and 4, the initial vulnerability parameter β was selected to be 7. These initial vulnerability values were slightly modified by Solver in successive iterations (see Appendix 3.1).

Initial exploitation values were computed by dividing estimated harvest from the creel surveys by the estimated abundance from the mark-recapture experiment for a given year:

(3.22) $\mu_y = H_y / N_{mark,y}$.

Objective Function

The objective was to minimize total estimation error (O_{total}). Total estimation error was computed by adding each of the components:

(3.23) $O_{total} = SSQ_{mark} + SSQ_{harvest} + O_{age}$.

The value of the objective function is a measure of how well the model fits observed data. A smaller objective function signifies a better fit. Megrey (1989) cautions against using the objective function as a sole criterion in judging model validity because a low objective function value can occur with absurd parameter estimates. In this study, the value of O_{total} was not used for comparisons among models because when the weights were changed in each particular model's objective function, the objective was changed.

Calculating Standard Errors and Bias Using the Bootstrap

To compute standard errors for parameter estimates, a parametric bootstrap procedure was used, where age composition was sampled with replacement (see Efron 1982). In the Excel spreadsheet, a table of observed cumulative proportions summed across age was created for each age and year, ($\Sigma \hat{p}_a$) such as:

Year	Age 3	4	5	6	7	8	9	10+
1986	0.000	0.205	0.561	0.725	0.876	0.972	0.999	1.000

A uniform random variable was generated between 0 and 1 for each observation in the table. This procedure essentially resampled the observed age composition with the same observed sample sizes (Σn_a) to generate an analogous estimated age composition. The simulated proportions at age for each year were a new multinomial data set with the same sample size, which was then used by Solver for estimating new parameters and residuals. The new parameters and residuals were stored, and the procedure was repeated 100 times for each of the four models, given the λ's and θ's from the models. A Macro was used to perform the 100 iterations (see Appendix 3.2).

The standard deviation of the bootstrapped data was used to represent the standard error of the parameter estimate. The coefficients of variation about parameter estimates were calculated by dividing the standard deviation of the bootstrap by the parameter. Bias was examined by computing the difference between the bootstrapped mean and parameter estimates. The distributions of bootstrapped parameters were plotted and visually examined for normality. Because not all parameter estimates among the four catch-age models resembled normal distributions, the 2.5 and 97.5 percentiles were selected to represent the distributions.

Forecasting and Evaluation of Exploitation Rates

Forecasting is used to predict future events given prior occurrences and assumptions about what is likely to happen (Abraham and Ledolter 1983). Because the future is uncertain, forecasts involve some risk. Forecasting is used in this paper to evaluate various harvest strategies given uncertain recruitment and maturity. The purpose of forecasting was to evaluate exploitation rates specified in the management plan given various states of the population in order to select that strategy most likely to sustain yield.

The future age distributions of abundance were modeled for varying recruitment scenarios, exploitation rates, and maturity schedules. Forecast summaries included total exploitable abundance (abundance weighted by age-specific vulnerability) and total mature abundance (abundance weighted by maturity) because exploitable abundance is the observable population for management which is measured in mark-recapture experiments (the auxiliary information used in catch-age analysis), and mature abundance is specified in the management plan. Thus, the mature portion of the exploitable population is the critical parameter of interest. For each scenario, two "extreme" forecasts were made to approximate the amount of forecast variability. The two extremes of population abundance for each age N_a were obtained from the 97.5 and 2.5 percentiles of predicted N_a.

Two recruitment scenarios within a model were examined: average recruitment, and likely recruitment. The average was based on recruitment using the perception model during 1986 - 1992 (see Table 3.9). Likely recruitment was based on past observations. From 1986 - 1992, one to two "good" recruitments were estimated in the mark-recapture data (see Table 3.6). Knowledge based on these past observations was used to predict that one good year of recruitment would occur out of five. Accordingly, the highest recruitment using the perception model and its two extremes (see Table 3.9) were inserted into the forecast for 1993, followed by four years of poor (1992) recruitment. (Recruitment in 1992 was considered "poor" and analogous to recruitment failures). Consecutive poor recruits for a number of years have been observed in the humpback whitefish population, and are not uncommon in other populations (e.g. herring in Zheng et al. 1993b).

Exploitation rate as described in Equation (3.15) was examined at 0, 0.10, and 0.15, because these are the average rates of acceptable harvest at given ranges of spawner abundances, as currently specified in the fishery management plan. To obtain approximate average 0.10 and 0.15 exploitation rates (total catch divided by total abundance) at the end of the forecast period, iterations of varying full-recruitment exploitation rates were conducted. Resulting estimates of H_a were then inserted in Equation (3.10) to forecast abundances of a cohort, N_{a+1}. Starting with exploitable abundances in 1992 population abundances were forecasted five years to 1997.

Table 3.9. Parameter estimates and standard errors from the catch-age models.

Vulnerability

	α	se	β	se
Base Model	4.56	0.05	2.78	0.09
Inverse Variance	5.40	0.31	1.48	0.21
Perception	4.85	0.11	2.01	0.20
Combined	5.19	0.07	1.68	0.22

Initial Cohorts (thousands of fish)

Base Model:

	Age															
	3	se	4	se	5	se	6	se	7	se	8	se	9	se	10+	se
$N_{3\text{-}10+,86}$	41.31	1.66	25.91	2.48	7.96	0.31	2.56	0.21	1.18	0.05	0.56	0.04	0.16	0.01	0.01	<0.01
$N_{3,87}$	19.14	0.94														
$N_{3,88}$	12.73	0.87														
$N_{3,89}$	6.88	0.38														
$N_{3,90}$	8.58	0.37														
$N_{3,91}$	47.81	1.66														
$N_{3,92}$	83.88	3.72														

Inverse Variance Model:

	Age															
	3	se	4	se	5	se	6	se	7	se	8	se	9	se	10+	se
$N_{3\text{-}10+,86}$	61.27	3.86	29.36	2.42	10.87	1.06	3.45	0.80	1.99	0.40	0.57	0.09	0.22	0.06	0.01	<0.01
$N_{3,87}$	35.90	6.39														
$N_{3,88}$	12.96	3.70														
$N_{3,89}$	6.59	1.17														
$N_{3,90}$	10.53	0.97														
$N_{3,91}$	25.34	3.91														
$N_{3,92}$	14.06	1.56														

continued

Table 3.9. (page 2 of 4)

Perception Model:	Age															
	3	se	4	se	5	se	6	se	7	se	8	se	9	se	10+	se
$N_{3\text{-}10+,86}$	53.99	2.49	29.69	1.80	10.76	1.03	3.37	0.20	1.55	0.16	0.58	0.04	0.20	0.01	0.01	<0.01
$N_{3,87}$	34.47	2.04														
$N_{3,88}$	17.95	1.02														
$N_{3,89}$	6.08	0.77														
$N_{3,90}$	4.68	0.34														
$N_{3,91}$	13.87	0.88														
$N_{3,92}$	9.43	0.69														

Combined Model:	Age															
	3	se	4	se	5	se	6	se	7	se	8	se	9	se	10+	se
$N_{3\text{-}10+,86}$	66.27	13.75	33.43	2.10	11.74	2.61	3.49	1.06	1.95	0.75	0.50	0.05	0.18	0.03	0.01	0
$N_{3,87}$	38.20	11.05														
$N_{3,88}$	14.55	6.62														
$N_{3,89}$	5.97	0.99														
$N_{3,90}$	6.90	1.01														
$N_{3,91}$	18.09	6.38														
$N_{3,92}$	10.14	0.26														

Exploitation (%)

Year	Base	se	Inverse Variance	se	Perception	se	Combined	se
1986	15.7	0.8	20.4	1.8	14.4	0.8	14.6	3.5
1987	18.7	0.8	24.4	2.3	17.5	1.0	16.6	4.9
1988	13.2	0.4	14.7	1.6	11.2	0.8	11.4	3.3
1989	15.4	0.7	13.7	2.6	12.1	1.1	11.6	0.8
1990	4.5	0.1	4.3	0.4	3.7	0.4	3.6	0.8
1991	0	0	0	0	0	0	0	0
1992	2.1	0.2	2.5	0.1	2.5	0.3	2.4	0.1

continued

Table 3.9. (page 3 of 4)

Exploitable Abundance (thousands of fish)

Base Model:

	Age															
Year	3	se	4	se	5	se	6	se	7	se	8	se	9	se	10+	se
1986	0.53	0.11	4.50	0.54	6.15	0.29	2.52	0.20	1.18	0.05	0.56	0.04	0.16	0.01	<0.01	<0.01
1987	0.25	0.05	4.66	0.61	12.65	1.18	4.47	0.17	1.41	0.10	0.65	0.03	0.31	0.02	0.09	<0.01
1988	0.16	0.03	2.16	0.27	13.02	0.65	8.95	1.22	2.41	0.09	0.75	0.06	0.34	0.02	0.16	0.01
1989	0.09	0.02	1.44	0.18	6.09	0.38	9.66	0.39	5.15	0.52	1.36	0.05	0.42	0.03	0.19	0.01
1990	0.11	0.02	0.78	0.09	4.04	0.25	4.43	0.23	5.42	0.24	2.84	0.29	0.75	0.02	0.23	0.02
1991	0.62	0.12	0.97	0.12	2.22	0.14	3.22	0.23	2.80	0.14	3.37	0.15	1.76	0.25	0.47	0.01
1992	1.08	0.21	5.40	0.62	2.80	0.13	1.84	0.10	2.13	0.15	1.82	0.16	2.19	0.09	1.14	0.12

Inverse Variance Model:

	Age															
Year	3	se	4	se	5	se	6	se	7	se	8	se	9	se	10+	se
1986	1.73	0.36	3.31	0.58	3.88	0.79	2.44	0.42	1.82	0.42	0.56	0.09	0.21	0.06	<0.01	<0.01
1987	1.02	0.36	4.47	0.78	6.66	0.99	4.64	0.75	1.75	0.31	1.03	0.19	0.29	0.04	0.11	0.03
1988	0.37	0.18	2.62	0.51	8.94	1.74	7.84	0.91	3.22	0.29	0.95	0.20	0.52	0.09	0.15	0.02
1989	0.19	0.08	0.95	0.24	5.29	1.01	10.92	1.90	5.89	0.43	1.94	0.16	0.54	0.12	0.29	0.04
1990	0.30	0.09	0.48	0.11	1.92	0.35	6.49	1.16	8.27	0.99	3.59	0.32	1.11	0.09	0.30	0.06
1991	0.72	0.20	0.77	0.15	0.99	0.19	2.43	0.42	5.28	0.85	5.53	0.45	2.27	0.26	0.69	0.06
1992	0.40	0.14	1.86	0.41	1.59	0.32	1.27	0.22	2.04	0.40	3.67	0.64	3.66	0.24	1.48	0.16

Perception Model:

	Age															
Year	3	se	4	se	5	se	6	se	7	se	8	se	9	se	10+	se
1986	1.28	0.41	4.55	1.08	6.18	0.66	3.07	0.14	1.53	0.16	0.58	0.04	0.20	0.01	<0.01	<0.01
1987	0.82	0.30	5.37	0.98	10.85	0.86	5.83	0.58	1.88	0.11	0.86	0.09	0.32	0.02	0.11	0.01
1988	0.43	0.16	3.42	0.75	12.72	0.92	10.04	0.84	3.46	0.33	1.02	0.06	0.46	0.05	0.17	0.01
1989	0.14	0.05	1.79	0.40	8.19	0.71	12.24	0.60	6.35	0.43	2.02	0.19	0.59	0.04	0.27	0.03
1990	0.11	0.04	0.61	0.13	4.27	0.55	7.84	0.43	7.68	0.40	3.68	0.28	1.16	0.10	0.34	0.02
1991	0.33	0.11	0.47	0.09	1.47	0.28	4.30	0.31	5.35	0.34	4.86	0.26	2.31	0.24	0.72	0.06
1992	0.22	0.08	1.38	0.28	1.14	0.15	1.51	0.23	3.03	0.18	3.51	0.23	3.17	0.17	1.50	0.12

continued

Table 3.9. (page 4 of 4).

Combined Model:									Age							
Year	3	se	4	se	5	se	6	se	7	se	8	se	9	se	10+	se
1986	1.64	0.25	4.01	0.60	4.96	1.00	2.78	1.02	1.86	0.76	0.50	0.05	0.18	0.03	0.01	0
1987	0.95	0.16	5.14	0.49	9.01	0.90	5.71	1.44	1.92	0.52	1.08	0.35	0.28	0.02	0.10	0.02
1988	0.36	0.06	2.96	0.39	11.54	2.21	10.28	1.07	3.86	0.57	1.09	0.16	0.59	0.12	0.15	0.01
1989	0.15	0.03	1.13	0.20	6.69	1.85	13.48	3.21	7.28	0.16	2.32	0.24	0.63	0.06	0.34	0.05
1990	0.17	0.04	0.46	0.06	2.55	1.11	7.81	2.76	9.53	1.92	4.37	0.10	1.35	0.13	0.36	0.03
1991	0.45	0.07	0.54	0.12	1.06	0.17	3.08	1.70	5.91	1.90	6.21	1.25	2.76	0.21	0.84	0.09
1992	0.25	0.05	1.41	0.16	1.23	0.20	1.30	0.28	2.40	1.19	3.99	1.22	4.07	0.80	1.80	0.04

Forecasts for average and likely recruitment (and their extremes) were examined under two assumptions about maturity: 1) fish are assumed to be fully mature at ages 3+; and 2) fish are assumed to be fully mature at ages 5+. Maturity is uncertain, so these two maturity schedules were chosen based on the rationale that all the fish that migrated are mature (3 - 10+), or alternatively maturity is knife-edged at age 5. The youngest mature humpback whitefish sampled by Alt (1979) in the Chatanika River was age 5.

For purposes of comparing conservative (optimistic) outcomes, average recruitment and its two extremes were examined for each model at zero exploitation and maturity occuring at ages 3+.

A per-recruit analysis based on an age-structured approach can be used to estimate sustained yield when information such as the spawner-recruit relationship is lacking (see Quinn and Szarzi 1993). By assuming that spawning abundance is stock abundance, and following the assumption of logistic population growth, the highest annual production is at 50% of spawning abundance at μ = 0 (an age-structured modification of the Schaefer model; see Hilborn and Walters 1992, pp. 82 and 302; and Der Hovanisian 1994). To determine the exploitation rate which would reduce the abundance of the unfished, exploitable population of mature fish by 50%, a simple per-recruit analysis was performed. Given the age-specific vulnerability function, the number of fish at age a+1 was abundance after exploitation multiplied by natural survival, or:

$$(3.24) \qquad N_{a+1} = (N_a - H)S$$

where H is harvest, obtained by:

$$(3.25) \qquad H = s(a)\mu N_a .$$

Spawning abundance (N_s) for varying μ was then:

$$(3.26) \quad N_s = \sum_{a=s}^{10+} N_a .$$

To examine the outcome for a given recruitment scenario, exploitable mature abundance of fish maturing at ages 3+ is

$$(3.27) \quad EN_{s,3+} = \sum_{a=3}^{10+} s(a)N_a ,$$

while abundance of fish maturing at ages 5+ is

$$(3.28) \quad EN_{s,5+} = \sum_{a=5}^{10+} s(a)N_a .$$

By varying μ in a spreadsheet the spawning abundance corresponding to 50% of spawning abundance at $\mu = 0$ was found.

Rationale for Choosing the Best Model

Model performance was judged on the basis of the following criteria: small coefficients of variation, minimal bias, reasonableness of estimates (within the range of historical values and likely given prior harvest and cohort abundances), and rank order of mean squared errors (MSE's). To rank models based on the magnitude of MSE's, Lehmann's (1959) asymptotic test for equality of mean squared errors was applied (after Criddle and Havenner 1991). The mean squared errors of the models will be equal only if the estimated correlation between the sums and differences of the errors is not significantly different from zero. This estimated correlation is:

$$(3.29) \quad r = \frac{\sum_{y=1}^{T} (e_{iy} + e_{jy})(e_{iy} - e_{jy})}{\sqrt{\sum_{y=1}^{T} (e_{iy} + e_{jy})^2 \sum_{y=1}^{T} (e_{iy} - e_{jy})^2}}.$$

The hypothesis that the correlation is equal to 0 was tested with a t-test at the 95% confidence level using Equation (3.8).

In addition to these criteria, risk levels (in terms of conservative versus optimistic predictions) associated with each model were considered.

RESULTS

Vulnerability Function Coefficients

The estimate of the α vulnerability parameter was higher than the initial value after minimization of the objective function in all four models. Estimates ranged from 4.561 in the base model to 5.398 in the inverse variance model (Table 3.9), suggesting that age of 50% vulnerability to gear is slightly greater than that age initially proposed (3.813). Age-specific gear vulnerability curves show decreasing vulnerability to gear for the inverse variance, perception and combined models, as compared to the base model (Figure 3.6).

In the inverse variance model, estimated α and β values produced slightly different gear vulnerabilities at age 3 (2.8%) and age 4 fish (11.3%) compared with the base model

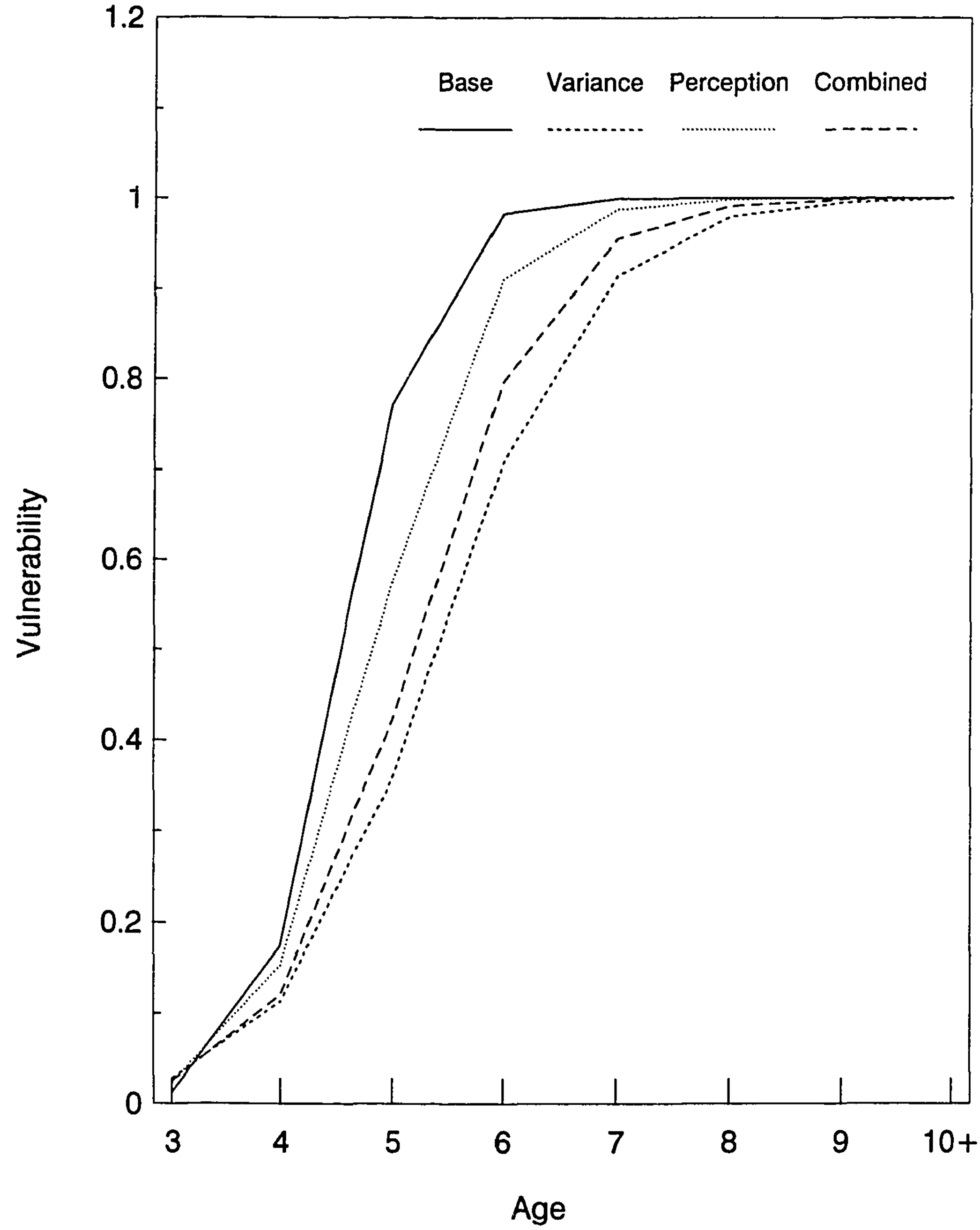

Figure 3.6. Gear vulnerability function values at age for the base, perception, inverse variance, and combined models.

(1.3% and 17.4% for ages 3 and 4, respectively; Figure 3.6). Similarly, in the perception model, estimated values of α and β resulted in slight changes in vulnerability at age 3 (2.4%) and age 4 (15.3%), compared to the base model. In the combined model, gear vulnerabilities were in-between those found in the inverse variance and perception models: 2.5% at age 3 and 12.0% at age 4. Standard errors for α and β values were less in the base model compared to standard errors in the other models (Table 3.9).

Estimated Abundance

Estimated total annual exploitable abundance for all catch-age models showed increasing trends similar to those estimated in mark-recapture experiments from 1986 to 1988 (Figure 3.7); however, mean estimates from the catch-age models were more conservative than mean estimates from mark-recapture experiments during this time interval. Total annual exploitable abundance estimated by catch-age models was similar between 1988 and 1989. In contrast, a large decline in exploitable abundance was estimated in the mark-recapture experiment between 1988 and 1989. In 1990 and 1991 total exploitable abundance estimated by catch-age models declined, similar to the trend estimated in the mark-recapture experiment; however, the differentially-weighted models (inverse variance, perception and combined) estimated a less precipitous decline in total exploitable abundance than estimated in mark-recapture experiments or in the base model. All catch-age models estimated less exploitable abundance in 1992 than estimated in the mark-recapture experiment (Figure 3.7), although this is not significantly less considering the variability in the mark-recapture estimate.

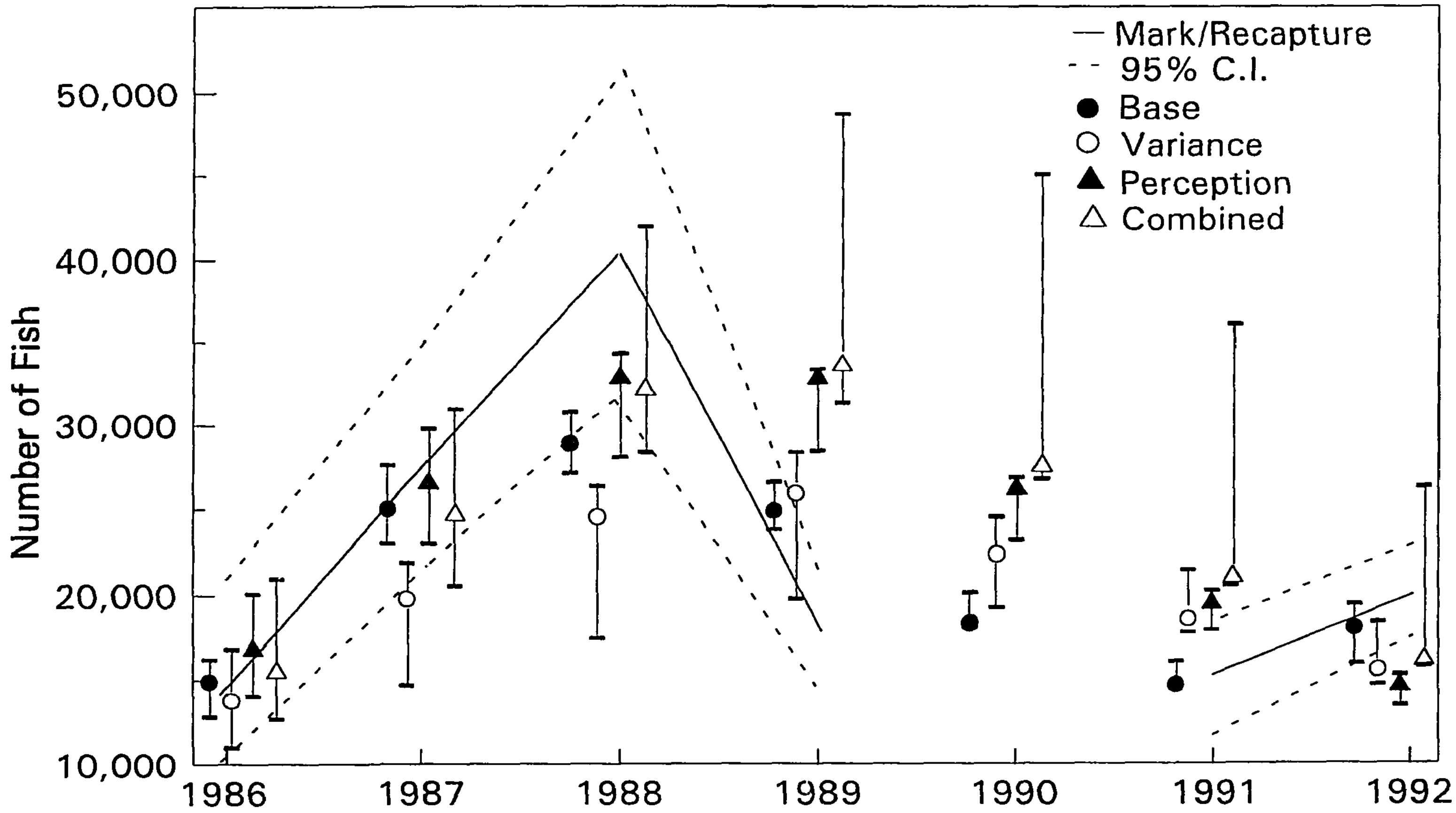

Figure 3.7. Total exploitable abundance of humpback whitefish estimated from catch-age models by year, compared with mark-recapture estimates. The 2.5 and 97.5 percentiles of bootstrapped model estimates are shown as dashes.

Total exploitable abundance as a percentage of pre-fishery abundance ranged from 12.9% to 19.6% in 1986 (Figure 3.8). This percentage rapidly increased until 1990, at which time total exploitable abundance as a percentage of pre-fishery abundance ranged as high as 68.2%. As pre-fishery abundance became increasingly comprised of exploitable fish, total pre-fishery abundance was declining (Table 3.9). Two strong year classes appeared in 1987 and 1988 as 5 year olds. These two year classes could be tracked in successive years until age 10+ (see Table 3.9). Diminished numbers of age 5 cohorts beginning in 1989 through 1992 contributed to the reduction in total pre-fishery population abundance. All catch-age models showed similar trends until the two most recent years - 1991 and 1992. As expected, the combined model produced results in between the inverse variance and perception models. In the base model, estimated pre-fishery abundance had recovered in 1991 and 1992 due to an influx of younger-aged fish. As seen in Figure 3.8, total exploitable abundance as a percentage of pre-fishery abundance declined to 14.4% by 1992 in the base model. The estimates of the inverse variance, perception and combined models are much more conservative. Total exploitable abundance as a percentage of pre-fishery abundance was still quite high (46.5%) in 1992 according to the perception model, and total pre-fishery abundance was quite low (33,333 fish; Table 3.9). Thus, while the base model produced the most optimistic outlook for 1991 and 1992, in contrast parameters generated using the perception model painted a bleak picture for pre-fishery abundance in 1991 and 1992 (see Figure 3.9). The smallest coefficients of variation for total exploitable and pre-fishery abundances were generated using the base and perception models (Table 3.10).

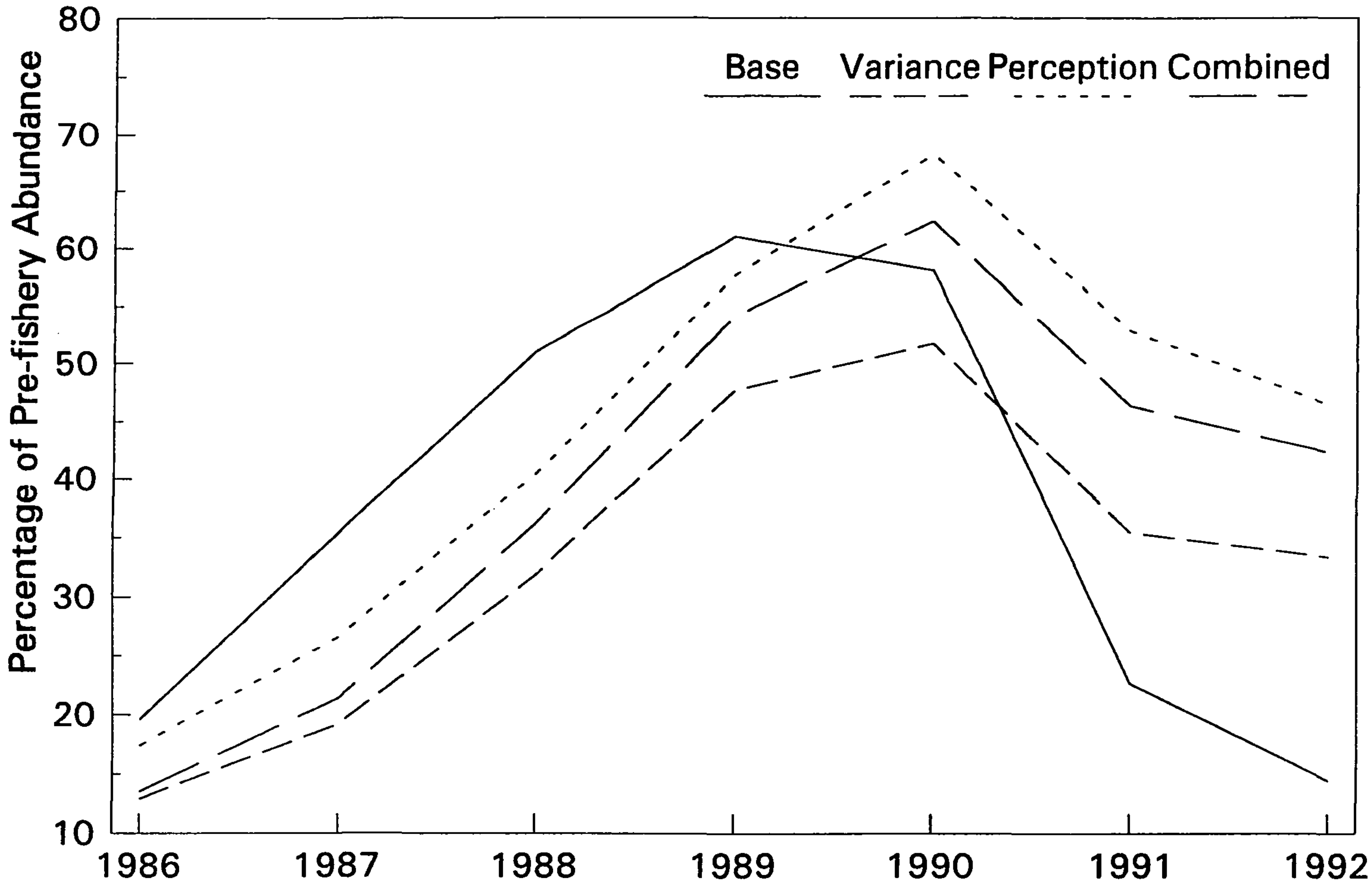

Figure 3.8. Total exploitable abundance of humpback whitefish as a percentage of total pre-fishery abundance estimated from catch-age models by year.

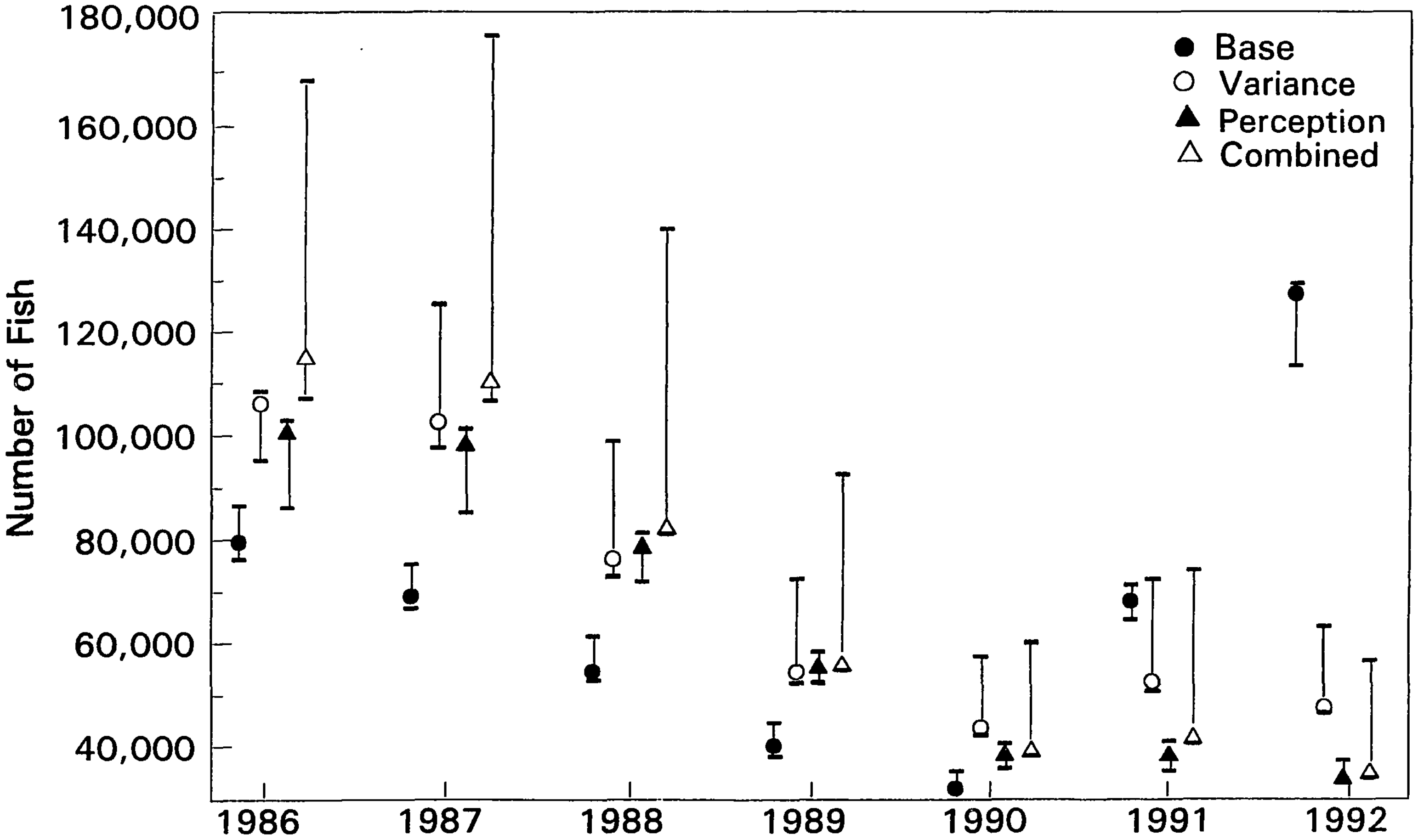

Figure 3.9. Total pre-fishery abundance of humpback whitefish estimated from catch-age models by year. The 2.5 and 97.5 percentiles of bootstrapped model estimates are shown as dashes.

Table 3.10. Coefficients of variation for total exploitable and pre-fishery abundance estimates of humpback whitefish in the Chatanika River, 1986-1992, as generated using four differentially-weighted catch-age models and from mark-recapture experiments.

Total Exploitable Abundance:

Year	Base	Inverse Variance	Perception	Combined	Mark-Recapture
1986	5.0	11.2	8.7	13.8	21.3
1987	4.6	9.7	6.7	11.0	12.2
1988	3.2	9.9	4.5	12.1	12.5
1989	2.6	9.6	3.6	16.3	9.6
1990	2.9	7.8	3.1	21.1	-
1991	2.2	6.1	2.5	22.9	13.6
1992	4.0	6.4	2.6	19.7	8.2
Average	3.5	8.7	4.5	16.7	12.9

Total Pre-fishery Abundance:

Year	Base	Inverse Variance	Perception	Combined	Mark-Recapture[a]
1986	2.9	2.7	4.1	17.0	
1987	2.9	6.7	4.4	20.4	
1988	3.4	9.9	3.4	23.8	
1989	2.9	11.1	3.3	22.1	
1990	2.5	10.2	3.4	16.9	
1991	2.7	11.1	4.0	24.5	
1992	3.1	9.9	4.1	18.5	
Average	2.9	8.8	3.8	20.5	

[a] No estimates of pre-fishery abundance are available with the mark-recapture method.

Estimated Exploitation

In 1986, catch-age models estimated average exploitation at about 15%, except for the inverse variance model, which estimated about 20% average exploitation (Figure 3.10). A slight increase in average exploitation was estimated in 1987, with the inverse variance model estimating a higher rate, at about 25%. Similar to the trend observed in the creel survey, average exploitation declined somewhat in 1988. While the average exploitation observed in the creel survey in 1989 and 1990 was around 20%, the catch-age models estimated declines in exploitation, to below 5% in 1990. Estimated average exploitation in 1992 was very similar to that observed in the creel survey (see Figure 3.10). The catch-age models suggest that the creel survey slightly underestimated exploitation in 1987 and 1988, and greatly overestimated exploitation in 1989 and 1990. The discrepancies between average exploitation rates observed in the creel survey and those estimated by the catch-age models are due largely to exploitable abundance estimates. For example, the overestimation of average exploitation by the creel survey in 1989 and 1990 was due in large part to the underestimation of exploitable abundance during those years (see Figure 3.7). Average exploitation rates estimated by the base and perception models were generally more precise than exploitation rates estimated by the inverse variance and combined models (see Figure 3.10; Table 3.9).

Sensitivity of Exploitable Abundance to Scaling

The order of magnitude of λ for scaling SSQ_{mark} and $SSQ_{harvest}$ was examined for its effect on estimates of exploitable abundance. Nine scenarios of various combinations of λ were modeled (Table 3.11). The λ for O_{age} was held constant at 0.01 for all scenarios. Weights of influence (θ) assigned to annual SSQ components were set equal to

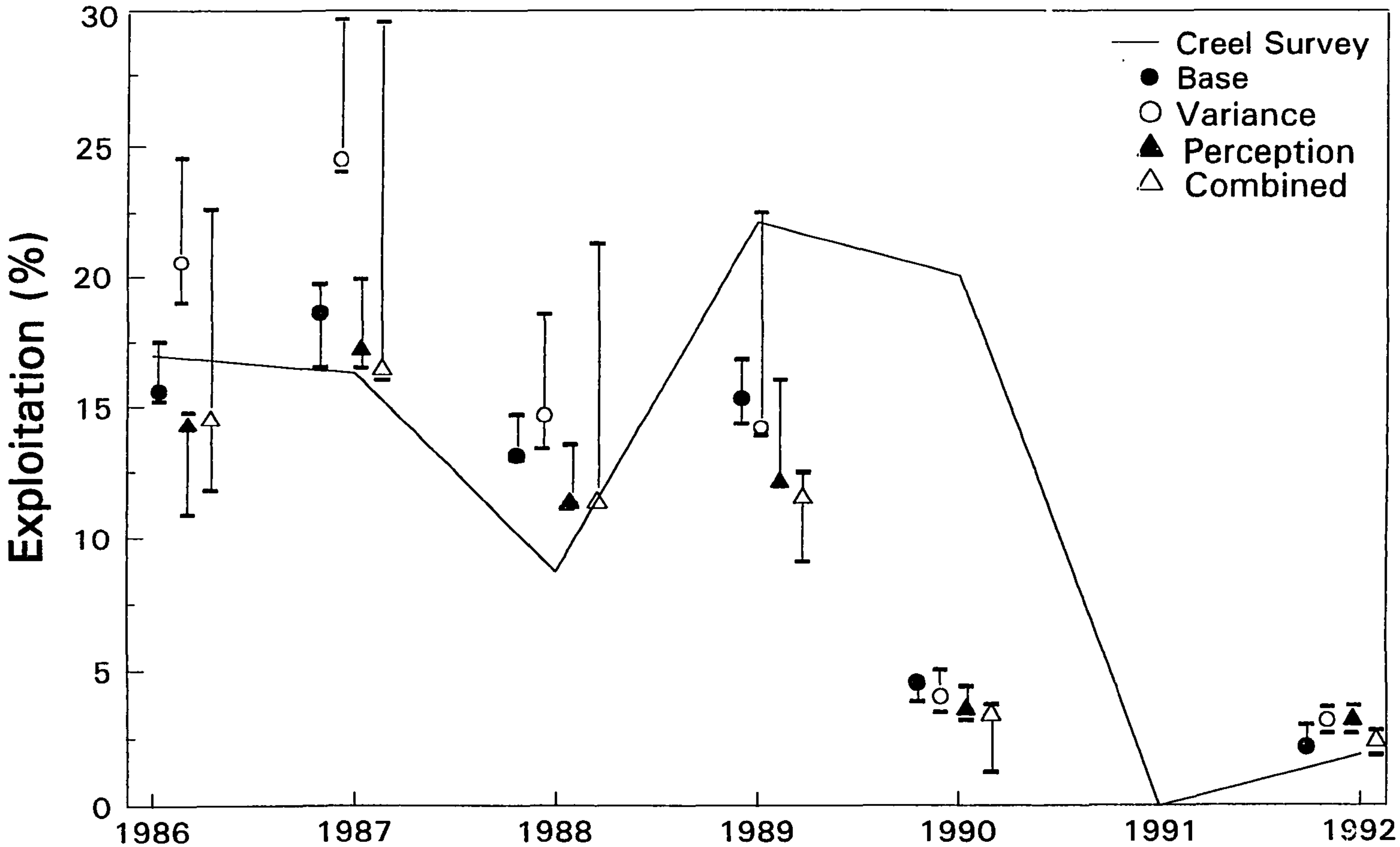

Figure 3.10. Average exploitation of humpback whitefish in the sport fishery estimated from catch-age models by year, compared with creel survey estimates. The 2.5 and 97.5 percentiles of bootstrapped model estimates are shown as dashes.

Table 3.11. The average percent deviation of predicted exploitable abundance for catch-age models with various combinations of λ from mark-recapture estimates of abundance and harvest information.[a]

Lambda values for Data Sources		
Mark-Recapture (λ_{mark})	Harvest ($\lambda_{harvest}$)	Average Percent Deviation
1.0E+11	1.0E-03	-2.2
1.0E+11	1.0E-04	-0.5
1.0E+10	1.0E-06	-1.0
1.0E+ 09	1.0E-07	12.9
1.0E+ 09	1.0E-03	72.5
1.0E+ 09	1.0E-05	72.5
1.0E+ 09	1.0E-04	73.3
1.0E+ 08	1.0E-05	111.6
1.0E+ 08	1.0E-06	111.7
1.0E+ 07	1.0E-07	109.3

[a] The annual SSQ weighting component θ was set equal to 1 for all data sources. The λ value for the age composition data source was held constant at 0.01 in all scenarios.

1.0. The resulting abundances were compared to estimates of abundance from mark-recapture experiments, which are a convenient benchmark for comparison purposes. When SSQ_{mark} was scaled high, the average deviation of exploitable abundance from mark-recapture estimates of abundance was small (from -0.5% to -2.2%; Table 3.10). However, when SSQ_{mark} was scaled lower, the average deviation of exploitable abundance from mark-recapture estimates of abundance increased markedly (Table 3.11). Thus, as the influence of mark-recapture information is diminished in the catch-age model, estimates of exploitable abundance increasingly depart from observed estimates. This departure has a consistent pattern of high abundance in 1986 ranging to low abundance by 1992 (Figure 3.11).

Residual Analysis

Likelihood components from run age composition were visually examined by year and age and showed no consistent pattern (Figures 3.12 and 3.13). Residuals from all four models were examined for trends with respect to year for exploitable abundance (Figure 3.14), and harvest (Figure 3.15). Using a t-test, a significant linear trend was detected in the perception model at the 95% confidence level (Table 3.12). However, as there were only seven years of data, it is likely that additional observations would alter these preliminary findings regarding trend. Because this time series of data is short, trend in residuals is not a serious consideration in judging model suitability.

The perception model yielded significant serially correlated errors among harvest residuals (Table 3.12). Positive serial correlation indicates that adjacent residuals in time are similar. Kennedy (1985) lists several reasons for serial correlation in ordinary least squares models, and included among these are: shocks (disturbances) that persist over more than one time period, an incorrectly specified model, and psychological conditioning

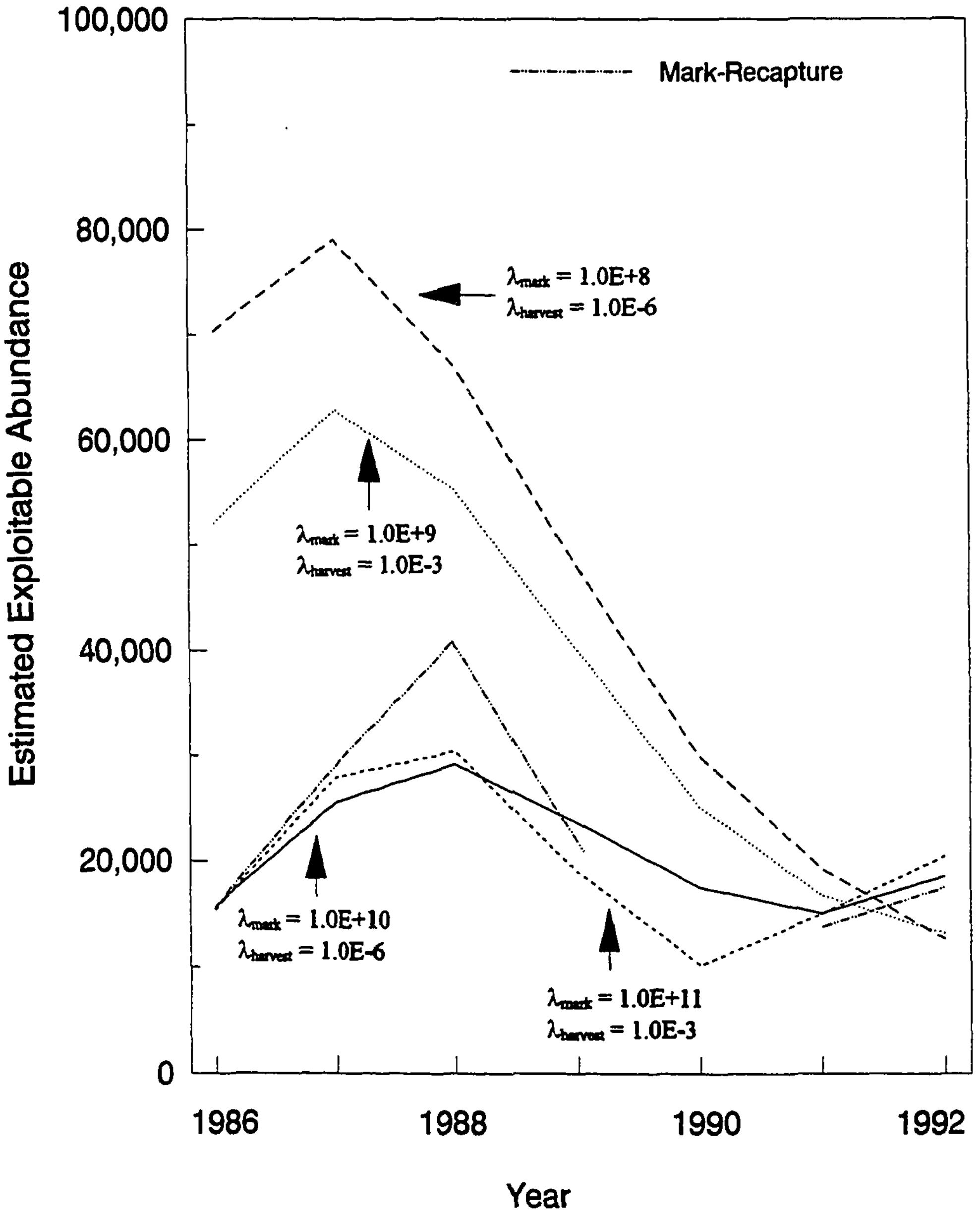

Figure 3.11. Representative examples of estimated exploitable abundance by year for models in which lambda was varied for abundance and harvest data sources.

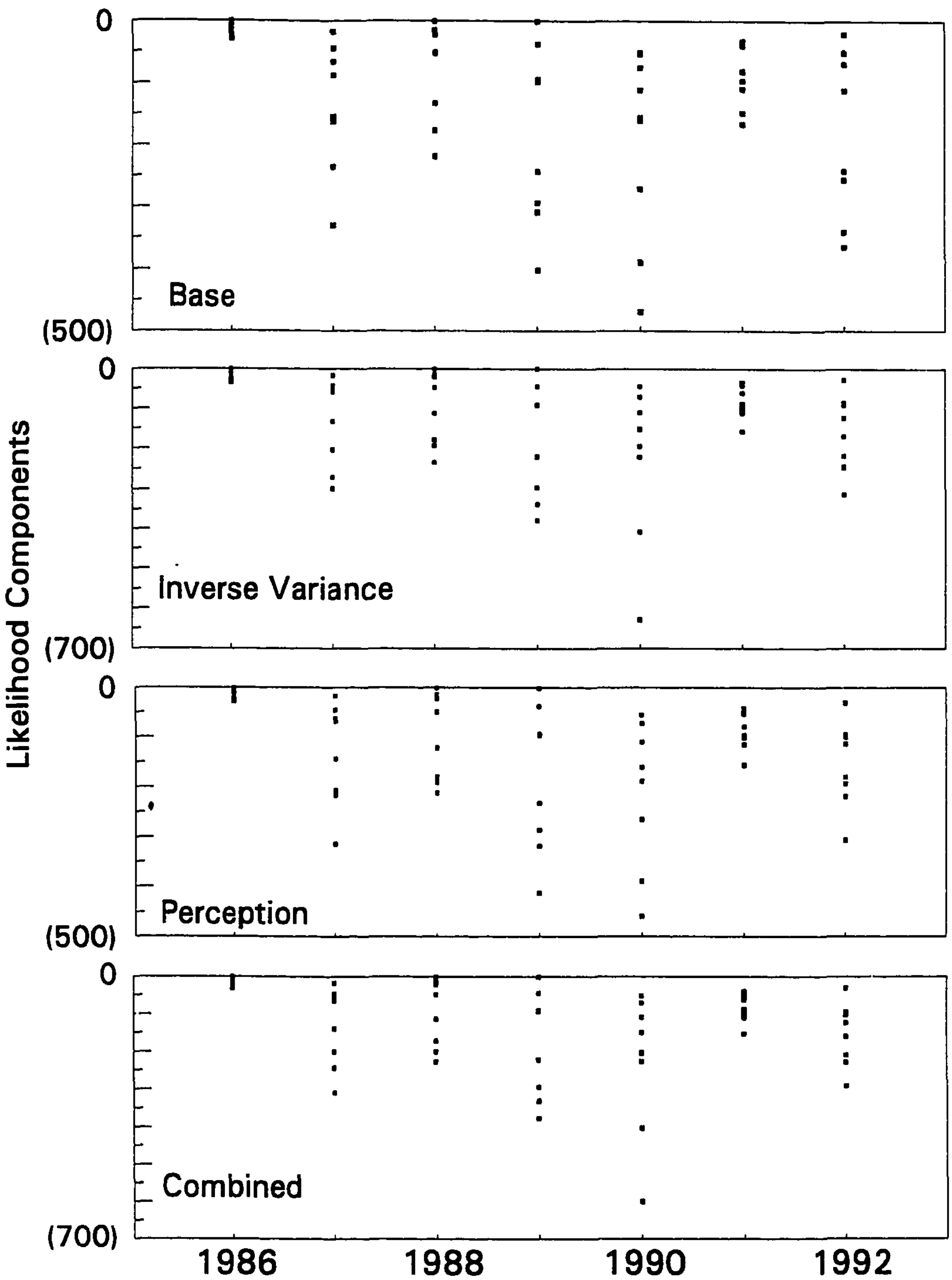

Figure 3.12. Likelihood components of age composition estimated from catch-age models by year.

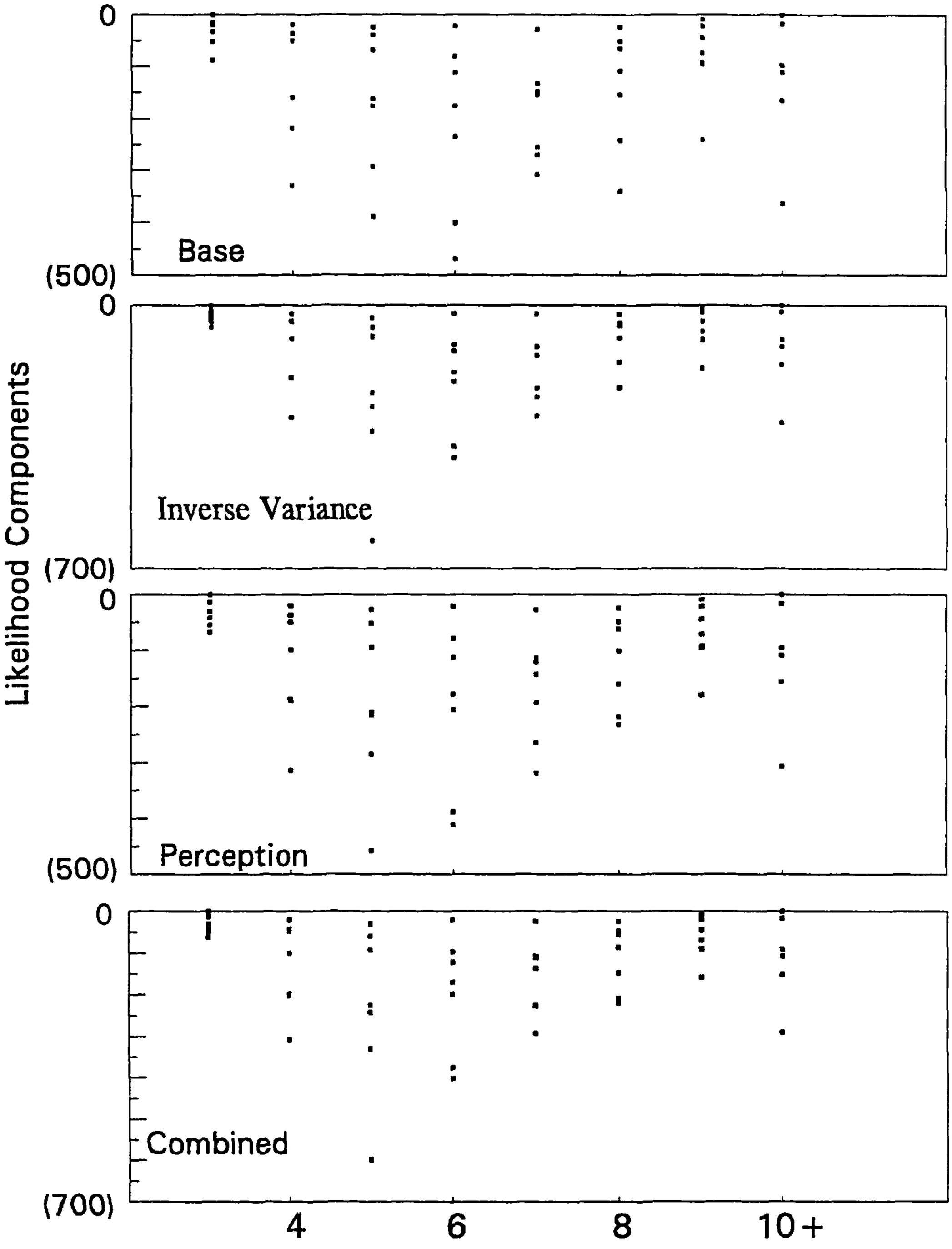

Figure 3.13. Likelihood components of age composition estimated from catch-age models by age.

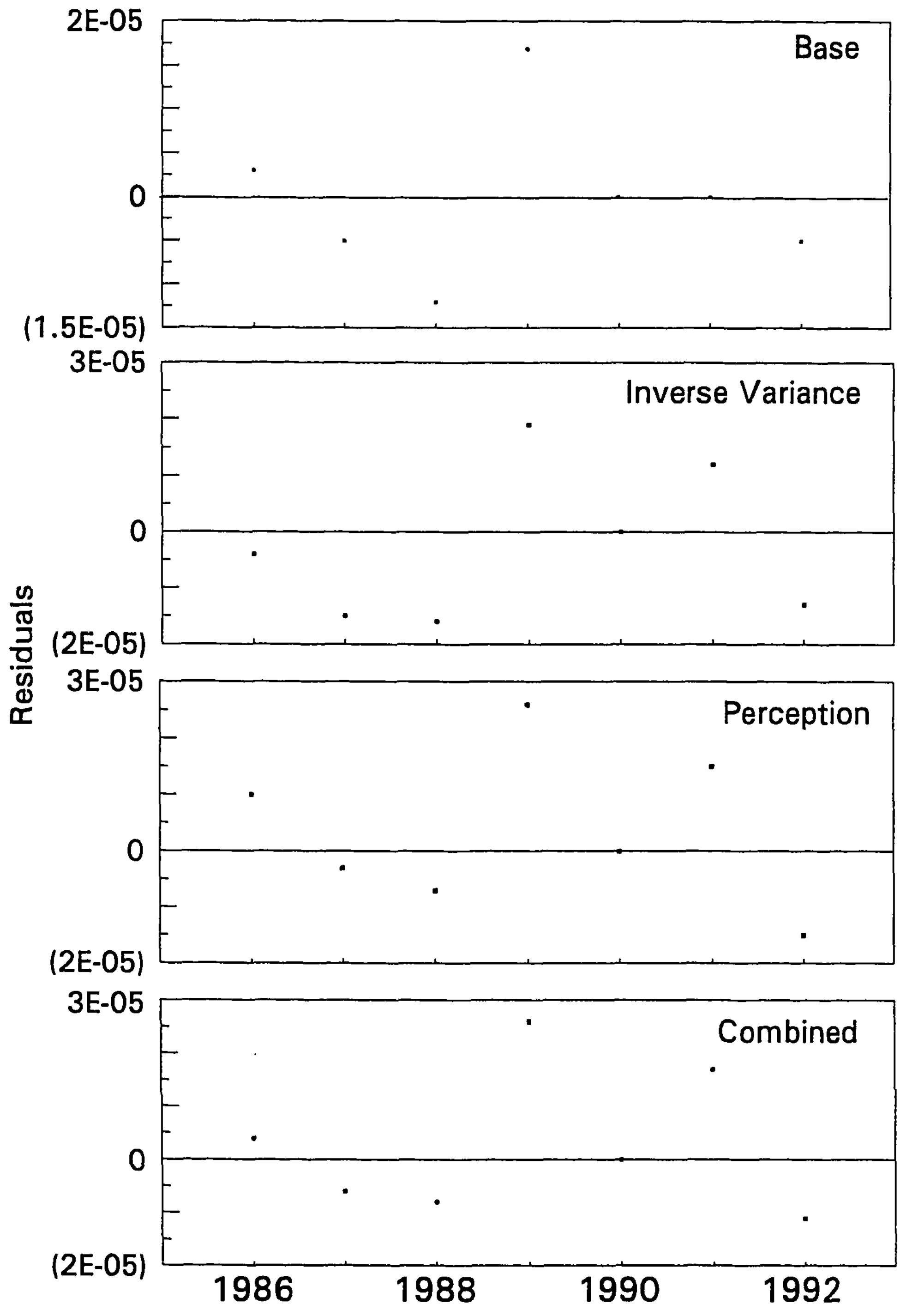

Figure 3.14. Residuals of total exploitable abundance estimated from catch-age models by year.

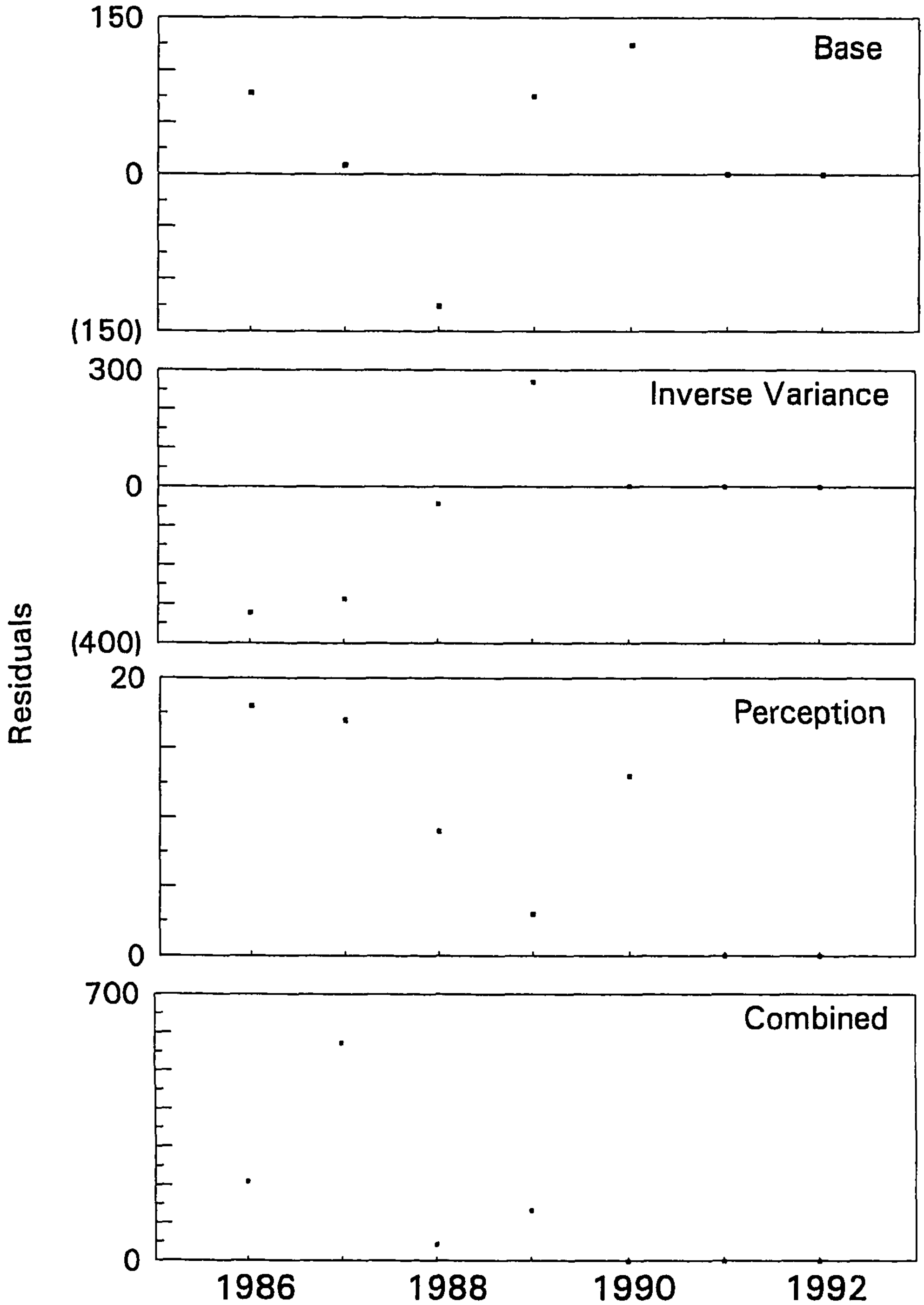

Figure 3.15. Residuals of harvest estimated from catch-age models by year.

Table 3.12. Test statistics for harvest and abundance residuals versus year by catch-age model.

Statistic	Base	Inverse Variance	Perception	Combined
Harvest:				
r	-0.002	0.611	-0.839	-0.673
$t_{0.05, df=5}$	-0.004	1.727	-3.452*	-2.032
DW[a]	1.885	0.884	0.424 *(positive)*	1.120
Abundance:				
r	-0.017	0.242	-0.176	0.051
$t_{0.05, df=5}$	-0.038	0.557	-0.399	0.113
DW	2.577	2.115	2.395	2.503

* Significant at the 95% confidence level.

[a] With seven observations, DW statistic < 0.700 indicates significant (5%) positive serial correlation; DW statistic < 3.300 indicates significant negative serial correlation.

in which past actions have an influence on current actions. Of these possible explanations, it seems likely that the manager would have favored harvests which do not differ markedly from previous years. The consequences of positive first-order serial correlation are that variances of the forecast errors are larger than they would be if the model were corrected for first order serial correlation. Additionally, the standard errors on the coefficients are underestimated. Because the focus was on the performance of the forecast, and not the significance of the estimated coefficients, correcting for serial correlation in the perception model would have made it even more preferred. Thus, attempting to correct for serial correlation in the perception model was not worth the computational cost. Perhaps higher weight (λ) on the harvest SSQ would correct for the trend in harvest residuals observed in the perception model.

Estimated Bias

Based on the difference between estimated and bootstrapped parameters, minimal estimated bias in total annual exploitable abundance, total annual pre-fishery abundance, exploitation, and initial cohorts was detected in the base and perception models. Greater estimated bias was found between estimated parameters and the average of bootstrapped parameters in the combined and inverse variance models (Figures 3.16 - 3.19). In some years for these models, extreme estimates occurred in some replications. Greater estimated bias in the combined and inverse variance models may be due to insufficient weight (λ) of the auxiliary data source on model parameters.

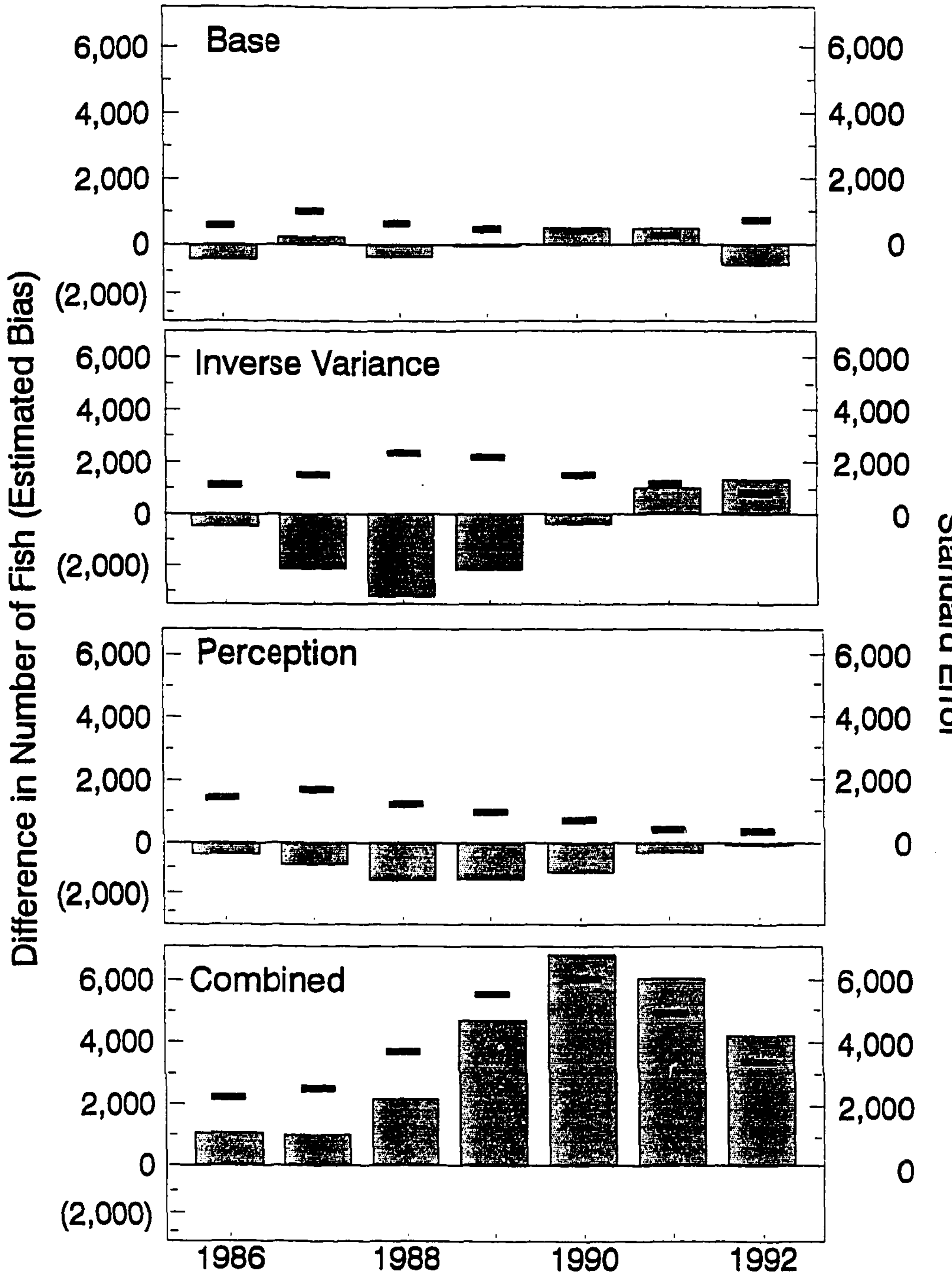

Figure 3.16. Difference of bootstrapped mean from estimated total exploitable abundance, and standard errors (dashes) by year.

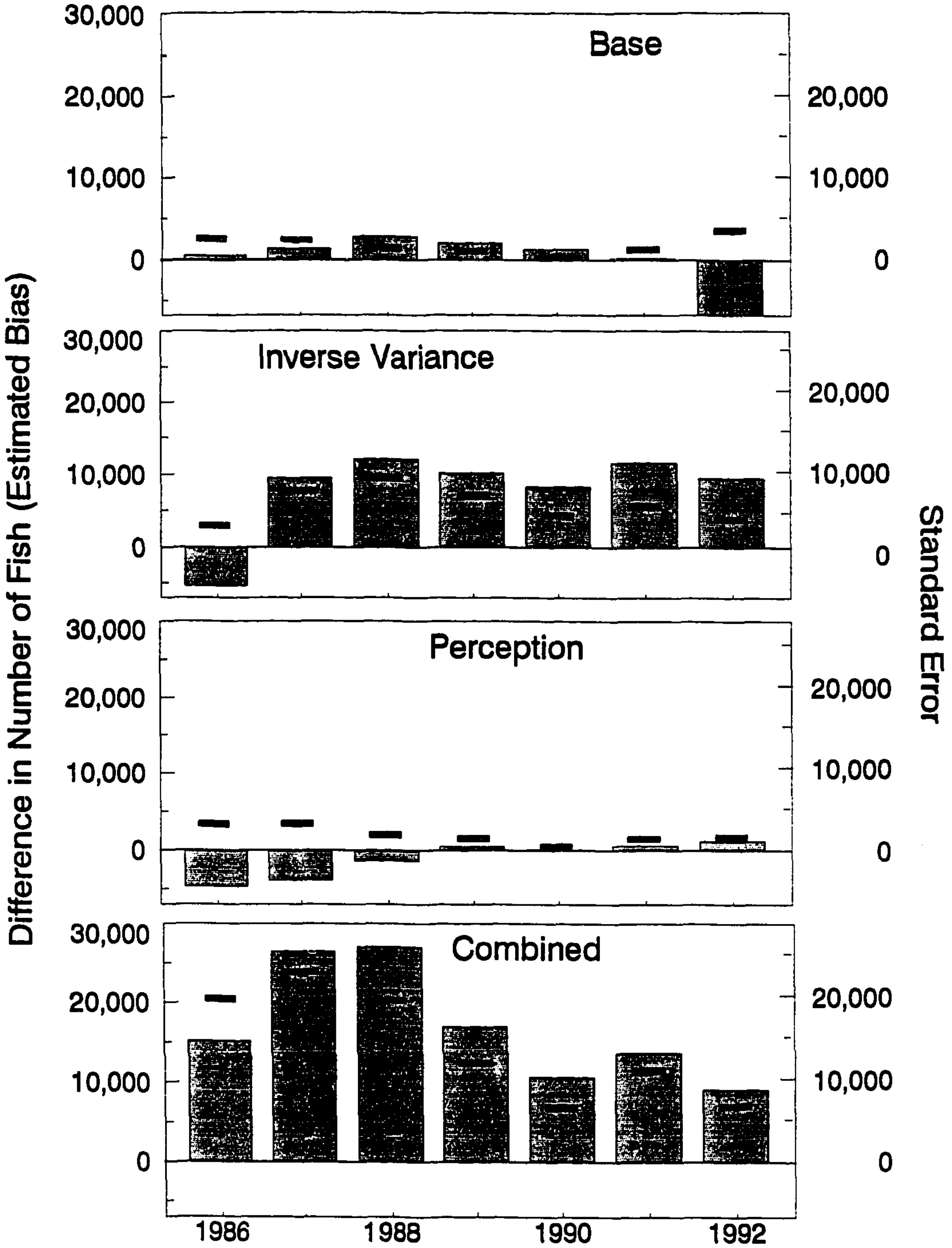

Figure 3.17. Difference of bootstrapped mean from estimated total pre-fishery abundance, and standard errors (dashes) by year.

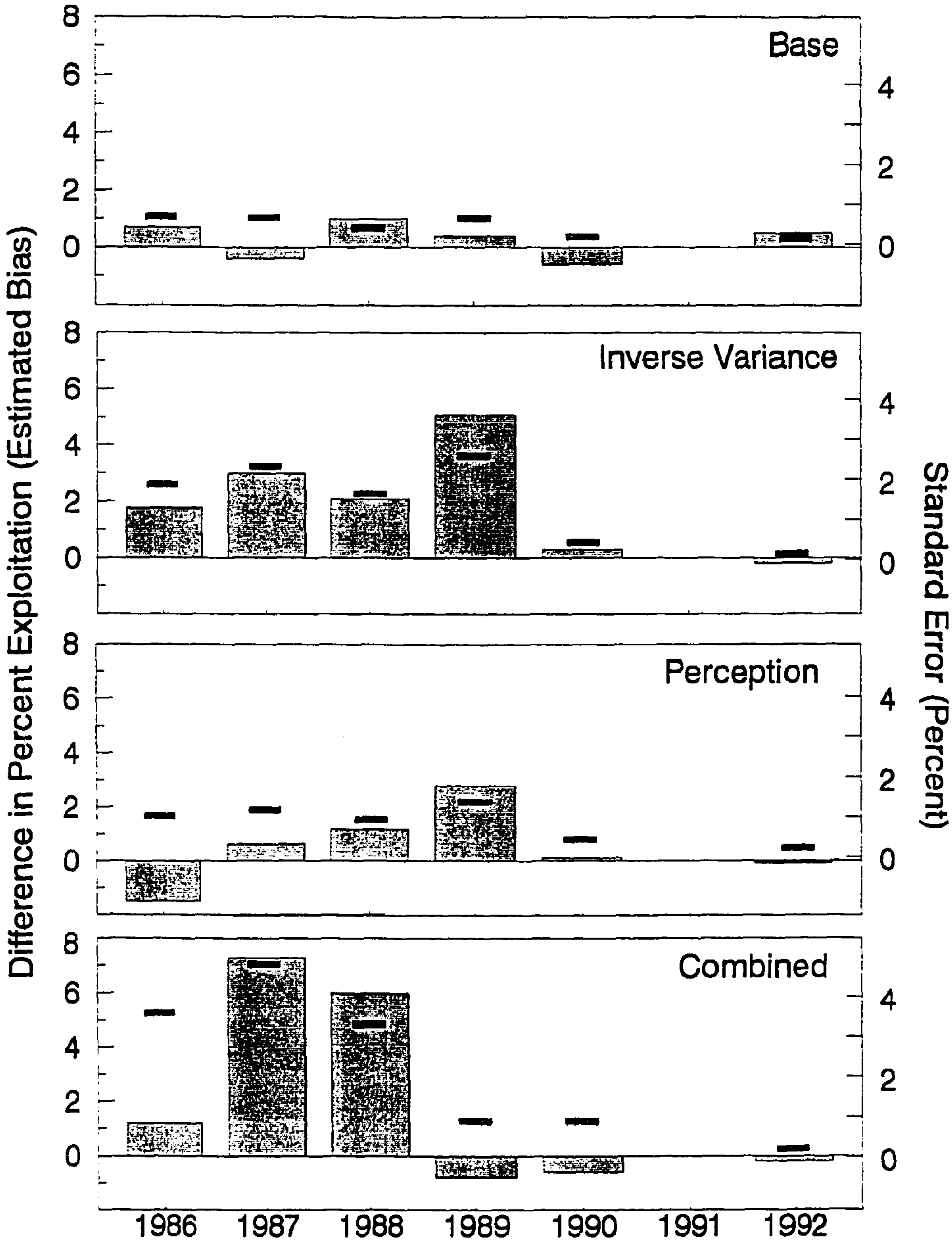

Figure 3.18. Difference of bootstrapped mean from estimated percent exploitation, and standard errors (dashes) by year.

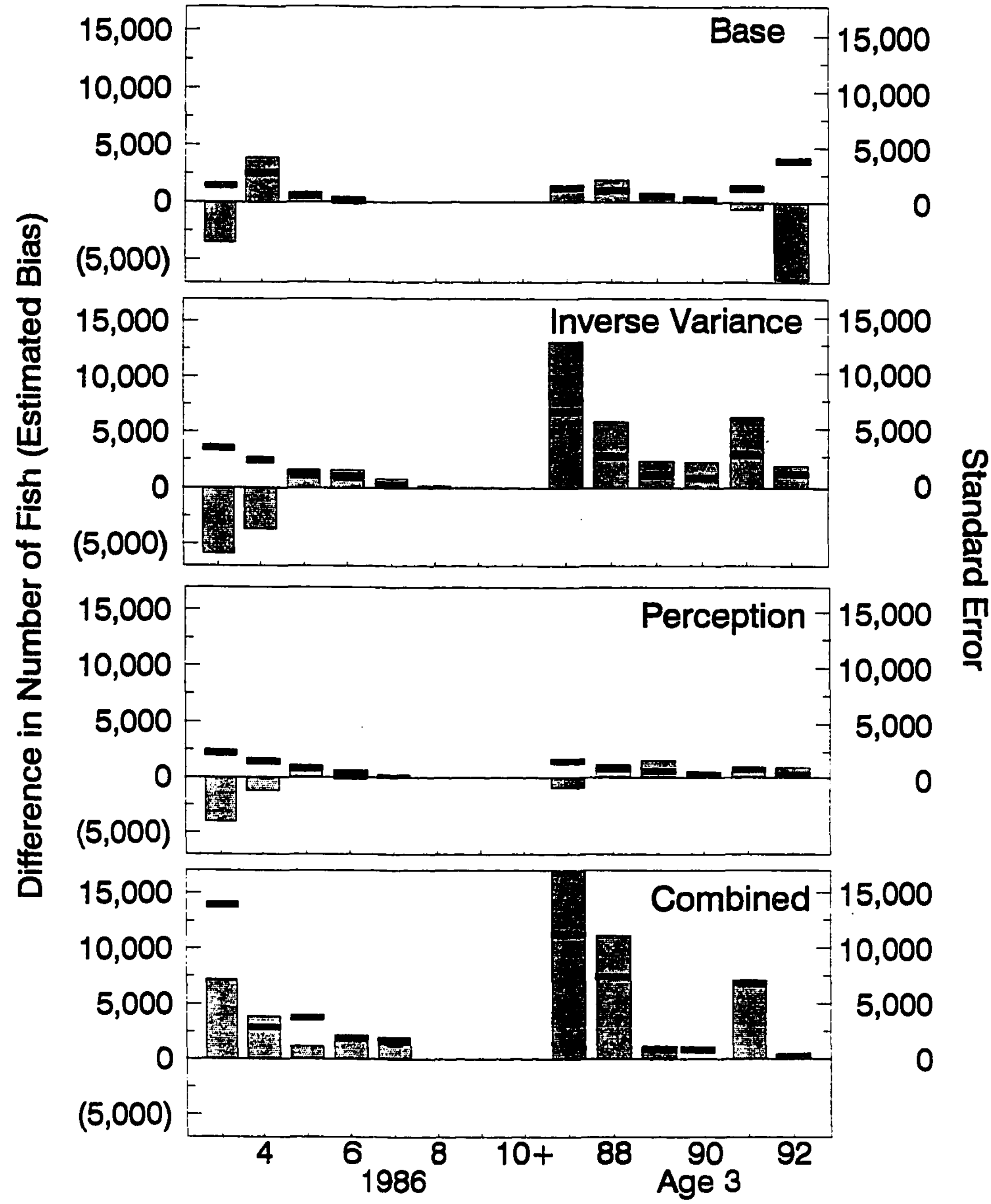

Figure 3.19. Difference of bootstrapped mean from estimated initial cohorts, and standard errors (dashes) by year and age.

Forecasting and Evaluation of Exploitation Rates

Average and Likely Recruitment Scenarios:

Using fully mature fish at ages 3+, average recruitment and its two extremes from the perception model at zero exploitation resulted in a decline in exploitable abundance with the 2.5 percentile, however for the mean and 97.5 percentile exploitable abundance increased over the forecast period (Figure 3.20). At constant average exploitation rates of 0.10 and 0.15 exploitable abundance declined to lower levels then leveled off with the 2.5 percentile, initially declined then increased to a stable level with the mean, and increased then began to level off with the 97.5 percentile (Figure 3.20).

The width of the 2.5 and 97.5 percentiles is an indication of uncertainty given the model (uncertainty of the model is unknown). With a narrow distribution there will be greater confidence in the expected long run forecast. The width between the 2.5 and 97.5 percentiles markedly increased over time, demonstrating greater uncertainty by 1997.

Using fully mature fish at ages 5+, average recruitment and its two extremes from the perception model produced initial declines in mature exploitable abundance at the 2.5 percentile, mean, and 97.5 percentile with exploitation (Figure 3.21). By 1994, exploitable abundance began to increase for the mean and 97.5 percentile. At the 2.5 percentile, a downward trend was observed, however it leveled off by 1997. Again, the width between the 2.5 and 97.5 percentiles is quite large by 1997.

These results suggest that if fish are fully mature at ages 3+, constant average recruitment can maintain exploitable abundance at the mean and 97.5 percentile at approximately 10,000 or 25,000 fish, respectively, with a constant average exploitation rate of 0.15. If fish are fully mature at ages 5+, constant average recruitment can maintain exploitable abundance at the mean and 97.5 percentile at approximately 8,000 to 20,000 fish, respectively, with a constant average exploitation rate of 0.15. Thus, depending on

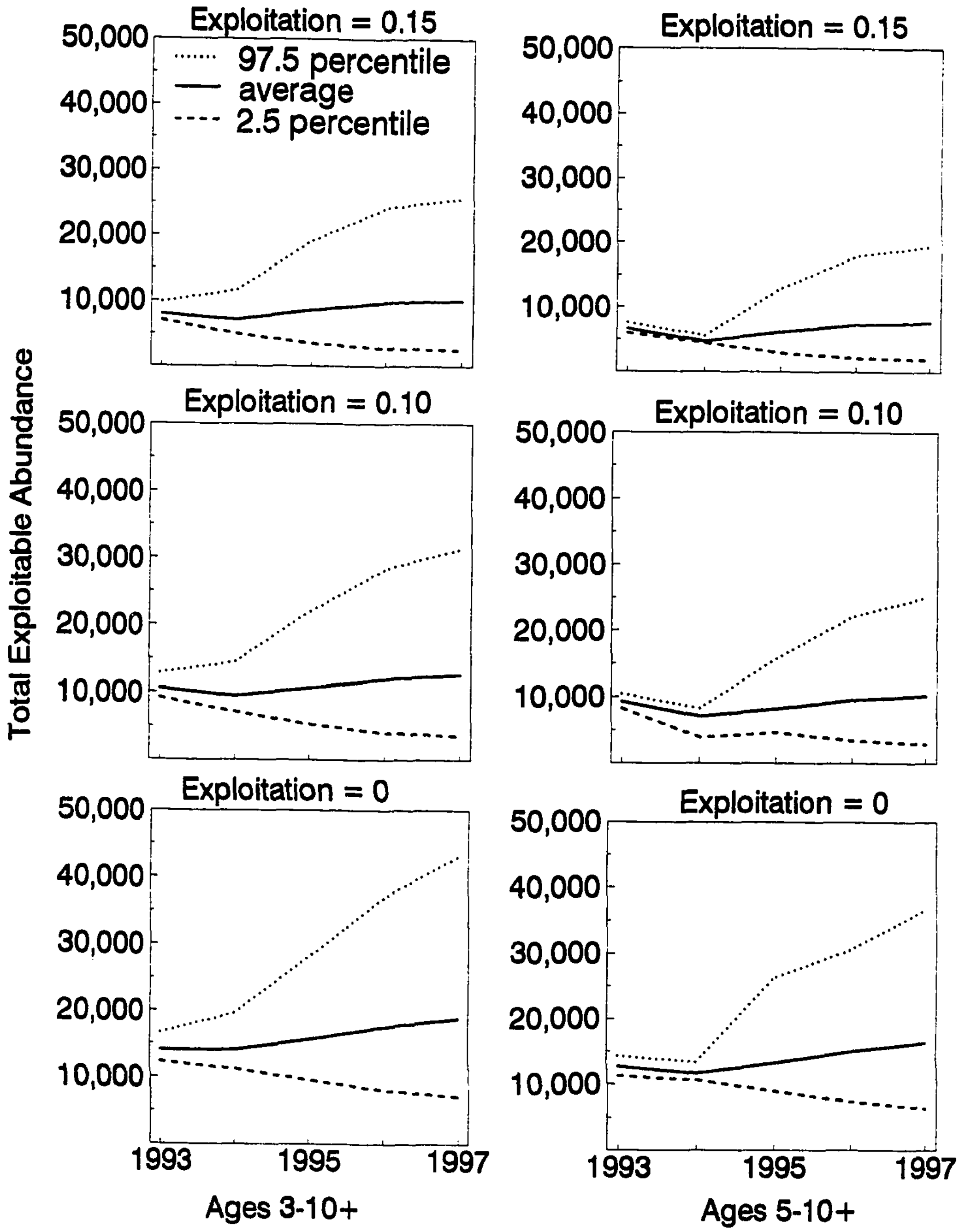

Figure 3.20. Forecasted total exploitable abundance for two maturity schedules (ages 3+ and 5+) and three exploitation rates (0, 0.10, and 0.15) for the average recruitment scenario.

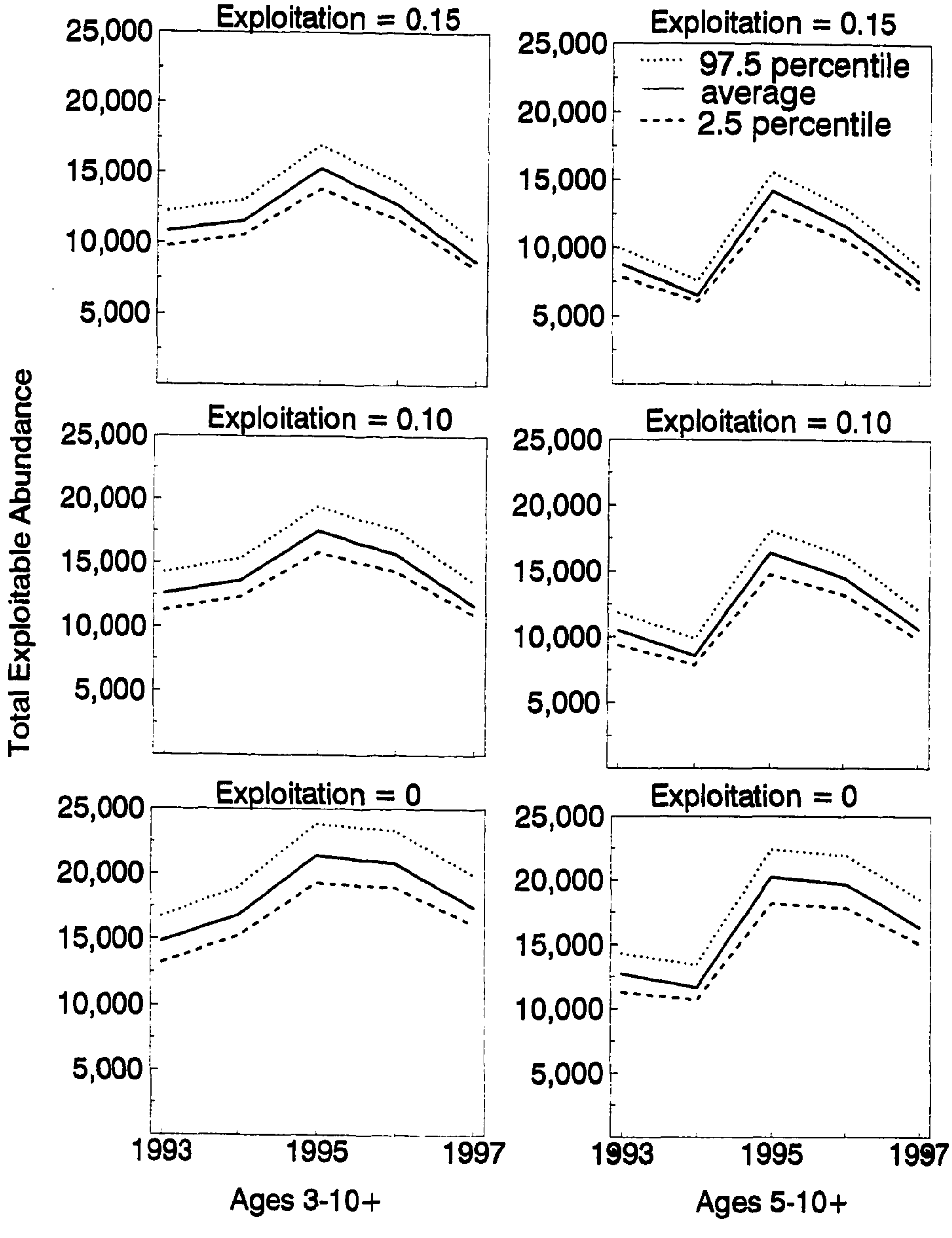

Figure 3.21. Forecasted total exploitable abundance for two maturity schedules (ages 3+ and 5+) and three exploitation rates (0, 0.10, and 0.15) for the likely recruitment scenario.

the age at maturity, different population levels may be maintained for given constant recruitment and exploitation rates.

The likely recruitment scenario was then examined. With full maturity occurring at ages 3+, a peak in exploitable abundance was observed in 1995 (two years following the "good" recruitment year), with the population declining thereafter (Figure 3.21). At an average exploitation rate of 0.15, the population remained above the 10,000 spawner threshold the first four of the five years. With full maturity occurring at ages 5+, the population initially declined, experienced a peak in 1995, then again declined (Figure 3.21). At an average exploitation rate of 0.15, the population remained above the 10,000 spawner threshold in only two (1995 and 1996) of the five years. The width between the 2.5 and 97.5 percentiles by 1997 is narrow for both maturity schedules.

Thus, if recruitment occurs at a frequency of one good year out of five, and maturity occurs at ages 3+, the population can be maintained above 10,000 spawners with more fishing than if maturity occurs at ages 5+.

Comparison of Models Using Forecasting:

Using constant average recruitment at zero exploitation from each model, and assuming maturity occurs at ages 3+, total exploitable abundance by 1997 is most optimistic with the base model, and most conservative with the perception model, as shown below:

	Base	Inverse Variance	Combined	Perception
97.5 percentile	81,990	48,414	46,688	43,053
mean	40,964	21,769	18,888	18,868
2.5 percentile	18,093	9,413	7,897	7,028

Per-recruit Analysis:

Threshold harvest policies are not only sensitive to accurate population abundance estimates, but a spawner-recruit relationship as well (Quinn et al. 1990). Because this relationship is at present uncertain for humpback whitefish in the Chatanika River, some assumptions were made in order to approach a spawner-recruit analysis.

Age-specific vulnerability for humpback whitefish is not a consequence of gear selectivity (larger fish being more susceptible to sampling with electrofishing) because no size selection was detected between events in the mark-recapture experiments. Rather, age-specific vulnerability is due to age-specific presence of humpback whitefish in the sampling area. Thus, the exploitable population based on age-specific vulnerability is essentially the observable population, and management strategies can be defined in terms of the exploitable population. Because the humpback whitefish are observed and exploited on their spawning grounds, the mature portion of the exploitable population is the critical parameter of interest. While this may be the first application to use this component for defining management strategies, it is conceptually a reasonable population component to use, as explained below.

For an unfished population (exploitation rate of 0), age 3 recruitment of 1,000 fish, a natural survival rate of 0.65, and full maturity at ages 3+, then total (mature) abundance is 2,766 fish, and exploitable (mature exploitable) abundance is 1,032 fish (Table 3.13). With a full selectivity exploitation rate of 0.68, total (mature) abundance becomes 2,206 fish, and the exploitable (mature exploitable) portion becomes 516 fish, which is 50% of the mature exploitable population (1,032 fish) just prior to fishing.

For an unfished population and full maturity at ages 5+, total abundance is 2,766 fish, mature abundance is 1,116 fish, exploitable abundance is 1,032 fish, and mature

Table 3.13. Total, mature, exploitable, and mature exploitable components of the population by age for maturity at ages 3+ and ages 5+.

Age	3	4	5	6	7	8	9	10+	Sum
Vulnerability	0.024	0.153	0.575	0.910	0.987	0.990	1.000	1.000	
Total N for all Fish (μ=0)	1,000	650	423	275	179	116	75	49	2,766
Mature at Ages 3+ (μ=0):									
Mature N	1,000	650	423	275	179	116	75	49	2,766
Exploitable N	24	100	243	250	176	115	75	49	1,032
Mature Exploitable N	24	100	243	250	176	115	75	49	1,032
Mature at Ages 3+ (μ=0.68):									
Total N	1,000	639	372	148	37	8	2	0	2,206
Mature N	1,000	639	372	148	37	8	2	0	2,206
Exploitable N	24	98	214	134	36	8	2	0	516
Mature Exploitable N	24	98	214	134	36	8	2	0	516
Mature at Ages 5+ (μ=0):									
Mature N	0	0	423	275	179	116	75	49	1,116
Exploitable N	24	100	243	250	176	115	75	49	1,032
Mature Exploitable N	0	0	243	250	176	115	75	49	908
Mature at Ages 5+ (μ=0.54):									
Total N	1,000	642	382	171	56	17	5	2	2,274
Mature N	0	0	382	171	56	17	5	2	633
Exploitable N	24	98	220	156	55	17	5	2	576
Mature Exploitable N	0	0	220	156	55	17	5	2	454

exploitable abundance is 908 fish (Table 3.13). With a full selectivity exploitation rate of 0.54, the mature exploitable portion becomes 454 fish, which is 50% of the mature exploitable population (908 fish) just prior to fishing.

The full selectivity exploitation rates which reduce the mature, exploitable population to 50% of that just prior to fishing correspond to the average exploitation rate (catch divided by abundance) of about 0.15 mentioned in the management plan (see below).

	Age at Full Maturity	
	3+	5+
Full selectivity exploitation rate	0.68	0.54
Average exploitation rate	0.16	0.14
% of unfished total abundance	79.75	82.21
% of unfished mature abundance	79.75	56.69
% of unfished exploitable abundance	50.03	55.84
% of unfished mature exploitable abundance	50.03	49.98

Thus, an average exploitation rate of 0.15 approximates maximum annual production.

One reason for using the mature exploitable population instead of just the mature population is that the results are more reasonable. If all fish mature at ages 3+, then it is not possible to reduce the mature population to 50% even with infinite fishing effort, because vulnerability is so low at young ages. However, it is possible to reduce the mature exploitable population to 50% of the unfished, and since the exploitable population is observable, results using a component of the exploitable population should be more robust to measurement and model errors than those based on the unobservable total population.

Comparison of Models

The base and perception models generated reasonable parameters in the sense that they had the smallest coefficients of variation and the least bias of the four catch-age models examined in this study. The θ weighting schemes used in the combined and inverse variance models do not appear to provide parameter estimates with acceptable levels of precision and bias. (To some extent, further exploration of the λ weighting scheme might somewhat improve performance of the combined and inverse variance models.) Of the two models, then, that provide acceptable levels of precision and bias, the perception weighting scheme offers risk-averse managers a conservative stock assessment model for humpback whitefish in the Chatanika River.

Mean squared errors in the harvest data source differed significantly at the 95% confidence level among four of the six possible combinations (Table 3.14). The catch-age models were ordered on the basis of statistically significant differences in harvest MSE's as follows: Base $\succ$ Inverse Variance $\succ$ Combined $\succ$ Perception.

Harvest MSE's in the perception model are significantly smaller at the 95% confidence level than those of the other three models. Mean squared errors in the abundance data source did not differ significantly at the 95% confidence level among the models. Thus, no model was preferred over another in regards to mean squared errors in the abundance data source.

Table 3.14. Correlations[a] among catch-age models that are significantly different from zero at the 95% confidence level[b], based on Lehmann's test for equality of mean squared errors in harvest and abundance data sources (see Table 3.8 for MSE's).

	Base	Inverse Variance	Perception
Harvest:			
Inverse Varaiance	0.717		
	(2.30)		
Perception	0.965*	0.966*	
	(8.23)	*(24.93)*	
Combined	0.807*	0.250	0.998*
	(3.06)	*(0.58)*	*(35.30)*
Abundance:			
Inverse Variance	0.644		
	(1.68)		
Perception	0.650	0.077	
	(1.71)	*(0.16)*	
Combined	0.633	0.027	0.144
	(1.64)	*(0.05)*	*(0.29)*

[a] Only sub-diagonal entries of the correlation matrix are shown.
[b] t values with 2 df are determined by Equation 3.8 and are in italics.
* Significant at the 95% confidence level.

DISCUSSION

Review of Modeling

The catch-age analysis used in this study consisted of various objective functions to be minimized; constraints associated with the problem; sources of historical harvest and age information; auxiliary information in the form of mark-recapture estimates of abundance; and, weights attached to each source of information as well as to annual SSQ and O components. The objective was to minimize the sum of identified error components (for all practical purposes, this is total estimation error). Minimization of total estimation error involved minimizing SSQ_{mark}, $SSQ_{harvest}$, and the negative of the log likelihood component for age composition, O_{age}. Minimizing SSQ components involved reducing the sum of squared differences between observed and estimated abundance and harvest data. Minimizing the negative of the log likelihood function is equivalent to maximizing a likelihood function (Megrey 1989). Weights associated with each source of information (λ) reflected assessments of the relative importance of the sources. Weights attached to annual SSQ components (θ) represented uncertainty about the precision and/or accuracy of the data. The minimization procedure was begun by introducing guesses and/or estimates of each parameter into the model. A non-linear least squares algorithm was used in the search for parameter estimates. Searches for a solution occurred in an iterative fashion. At each iteration, parameters were estimated simultaneously by the linking of data from successive cohorts. By making use of prior information and updated model estimates the search for the "best" solution is analogous to Bayesian estimation. The resulting solutions were compared on the basis of residual patterns, realistic error structure, reasonableness of estimates and the spread in magnitude of scaled and weighted SSQ sources. While similar orders of magnitude were not achieved for SSQ_{mark}, $SSQ_{harvest}$, and O_{age}, because of model performance demands (i.e., reasonable error structure and estimates), nevertheless the minimization algorithm converged to a solution in all cases, indicating that a deviation of up to five orders of magnitude in scaled and weighted SSQ would still produce an acceptable solution. Standard errors were calculated by the bootstrap technique (Efron 1982) by resampling the estimated age composition with a multinomial distribution. By not resampling harvest and abundance data sources, total variance was underestimated. However, bootstrapped standard errors calculated from the age composition represent a major portion of total variance because the age composition data was associated with the greatest mean squared error (Table 3.8).

Effects of Weighting Schemes on Model Results

In the perception model greater weight on annual SSQ components was associated with more confidence in estimates. Sufficient weight was placed on early cohorts to generate parameters with little bias and acceptable precision, similar to the base model. However, the perception model estimated less pre-fishery abundance than the base model. Specifically, the highest weights of influence in the perception model were placed on the two years (1991 and 1992) in which ages 3-5 fish comprised the smallest proportion of the population since 1986 (0.13 for both years). This resulted in considerably lower pre-fishery abundances in the perception model than in the base model. Overall, the perception model generated the most conservative scenario of the four models in terms of pre-fishery abundance. Although the θ's used to weight annual SSQ components in the inverse variance model were based on precision, it was those weights based on perception of data accuracy that resulted in more precise estimates than in the inverse variance model.

In the inverse variance model, greater weight on annual SSQ components was placed on estimates with the smallest amount of measurement error (high precision). There was a tendency to place more weight on the later years in which fish abundance was lower. This contributed to lower estimates of age-3 and total pre-fishery abundance in 1991 and 1992, compared with the base model. In addition, lower weights on mark-recapture estimates in 1986-1988 resulted in a discounting of the years having the greatest information on cohorts. With lower weight on the auxiliary data source, more weight was placed by default on the age data source, which is associated with the largest error (largest SSQ). Accordingly, more variability was introduced and the inverse variance model generated parameters with greater bias and less precision than the base and perception models. Specifically, in the inverse variance model, in two of three years high weights were placed on instances in which ages 3-5 fish comprised a small proportion of the population. For example, in 1992 a high weight was associated with a low (0.13) proportion of ages 3-5 fish. This resulted in lower pre-fishery abundance in the variance model than in the base model. In 1992, total exploitable abundance of fish ages 3-5 in the inverse variance model was 3,842 fish, whereas in the base model ages 3-5 fish totaled 6,298. Using the inverse variance model, there was half the fish available to the fishery of ages 3-5 than with the base model for 1992. Overall, the inverse variance model generated a more dire scenario than that generated by the base model - less fish abundance and greater exploitation.

The θ's used to weight annual SSQ components in the combined model were a combination of weights used in the inverse variance and perception models. As such, estimates from the combined model should have been in-between those of the inverse variance and perception models. Overall, total exploitable abundance from the combined model was greater than that estimated by the base model, and in-between those estimates of the inverse variance and perception models. For the years 1989 - 1991, however, the total exploitable abundances estimated by the combined model were the greatest among the four models. Concurrently, exploitation rates estimated by the combined model were the smallest among the four models for 1989 - 1990. Surprisingly, from 1986 - 1989 annual pre-fishery abundances from the combined model were higher than those estimated by the other models, resulting in the greatest mean total pre-fishery abundance. The answer to these unexpected results may lie in part in the θ's used to weight the annual SSQ components in the age composition data source. During 1987 - 1989 (when fish abundances estimated in the mark-recapture experiments were high), the mean proportion of ages 3 - 5 fish in the observed population was 0.53. High weights were applied to these years in the combined model (mean $\theta = 0.63$). In contrast, low weights (mean $\theta = 0.28$) were applied to the remaining years whose mean proportion of ages 3- 5 fish in the observed population was 0.28. High weights applied to years in which the majority of the population was comprised of young fish probably contributed to the high pre-fishery abundances from 1986-1989 in the combined model. Overall, the combined model provided the least precise and most biased estimates among the four models. In both the inverse variance and combined models, more stable parameter estimates would likely be achieved if the weight (λ) of the mark-recapture auxiliary data source was increased. Additional sources of auxiliary information (if they were available) could also be used to stabilize parameters (Methot 1989, Deriso et al. 1985).

In the base model, all SSQ components were given equal weight. This method of weighting has often been used in catch-age analysis (Funk et al. 1992, Funk and Sandone 1990, Zheng et al. 1993a, Rowell et al. 1993). While equal weights resulted in parameters with little bias and acceptable precision, the age 3 pre-fishery abundance estimates in 1991 and 1992 seem unreasonable because they are so high: 47,812 and 83,875 fish, respectively. These estimates are up to three to nine times greater, respectively, than estimates for age 3 1991 and 1992 pre-fishery abundances among the other three models.

The inverse variance, combined and base weighting schemes can be discarded from further catch-age applications pertaining to humpback whitefish in the Chatanika River based on the following arguments. First, the inverse variance and combined models had the highest coefficients of variation and bias among the four models examined. Second, the base model generated unreasonably large age 3 recruitments in 1991 and 1992. Furthermore, the base model had the broadest distribution of percentiles on pre-fishery abundance, which would increase the uncertainty of stock assessment.

Therefore, the most risk-averse strategy to avoid overfishing humpback whitefish in the Chatanika River is to use the perception model because it has acceptable precision, minimal estimated bias, and conservative stock scenarios. Decisions based on perceptions of data accuracy are always present to some extent in empirical analyses. This study has made these perceptions explicit, and quantified their influence on a given model solution. There are limited alternatives to the manager. Discarding data from flawed studies is inefficient, and argues that there is no signal in the data - only noise. Alternatively, accepting suspect data as equal to reliable data dilutes the influence of the "good" observations.

Risk and Management

If the optimal weights were known, there would be a single optimal solution to the catch-age model for each objective function. Because the optimal weights are not known, a series of solutions can be generated using different relative weights. The decision-maker must choose the solution that best accords with his or her preference as reflected in the weights. In this study, the solution was evaluated on the basis of minimal error and bias, reasonable estimates, and rank order of significant differences in MSE's. Risk associated with model estimates was also examined.

An important management question is: what harvest policy should be followed considering the risks of overfishing versus foregone harvest opportunity? The acceptable level of risk depends on many factors, including consequences (e.g., to what level is a population is expected to decline); the value of the consequence (marginal value of foregone benefits); and, the probability of occurrence (Hilborn and Walters 1992). Because different fishery managers have different attitudes towards risk and marginal benefits, behavior in response to risk is expected to differ among managers, thus introducing shifts in harvest policy over time.[11] The choice in harvest policy affects the yield derived from the fishery and the risk of overfishing. A threshold harvest policy, such as that used to manage humpback whitefish in the Chatanika River, is more likely to protect a population, minimize risk of a fishery collapse, and enhance long-term productivity (Zheng et al. 1993b). A risk averse strategy could be expected to reduce the marginal benefits of the fishery in favor of stock conservation.

Uncertainty in information is critical to the examination of risk associated with a harvest policy. In fisheries management there are many uncertainties (e.g., true population abundance) so there are a multitude of possible risks (see Smith 1993). Because the future population is most affected by recruitment under uncertainty, extreme variability in age 3 recruitment was examined for its effects on exploitable abundance forecasts. In addition, exploitation rates and maturity schedules were varied. Exploitation is one of the few parameters which is subject to control by managers. (Often, however, managers exert less control over recreational users than commercial users). Variability in recruitment and

[11] Fishery managers do not typically have symmetric loss functions - they are more averse to overharvest than to underharvest.

exploitation have been simulated by Zheng et al. (1993a), Sigler and Fujioka (1993) and Clark (1993) in evaluating fishery management strategies.

Consecutive years of poor age 3 recruitment with several years of exploitation greater than 15% produced a collapse of the sport fishery for humpback whitefish in the Chatanika River. Decreased recruitment could result from environmental factors or a decline in spawning stock below the level of maximum recruitment (Schweigert 1993). While consecutive poor recruits is not uncommon, consecutive strong year classes are not likely. Thus, the only possibility of prosecuting a recreational fishery for humpback whitefish under the current management policy is if periodic strong year classes occur. As Figure 3.21 suggests, however, only consecutive year classes in greater abundance than have been observed in the past will sustain this fishery over the long run. Without consecutive strong year classes, the humpback whitefish recreational fishery will be subject to periodic closures.

The results of this study suggest changes in how the management policy for humpback whitefish may be approached. Presently, the management plan for the Chatanika River suggests threshold levels in terms of spawner abundance. (Because the age at maturity has not been determined with certainty, those fish subject to harvest should be termed the exploitable population, not the spawning population, however they are probably somewhat similar in abundance). Annual estimates of exploitable abundance are obtained through mark-recapture experiments. However, successful application of a threshold strategy requires some method of evaluating threshold levels and exploitation rates on fish abundance and harvest. One method of evaluating a threshold strategy is by modeling the stock's dynamic relationship with harvest through time, as in catch-age analysis. Prior to this study, the interaction of the humpback whitefish population with the sport fishery had not been modeled. While the management plan specifies the number of spawners as a threshold, this study has shown that the proportion of spawners may increase over time, thus masking declines in pre-fishery abundance. It is recommended that the management plan be changed to specify a threshold level of mature exploitable abundance. This change would necessitate updated estimation of pre-fishery abundance through catch-age analysis. Threshold harvest policies are not only sensitive to accurate population abundance estimates, but a spawner-recruit relationship as well (Quinn et al. 1990). Because this relationship is at present uncertain for humpback whitefish in the Chatanika River, it is also recommended that age at maturity be obtained.

One method of setting the threshold level is equal to 25% of the exploitable abundance at $\mu=0$ and under stable population conditions (T. Quinn II, personal communication, University of Alaska Juneau). Using the perception model, the average exploitable abundance at $\mu=0$ under constant average age 3 recruitment based on initial abundances in 1992 projected to 1997 is approximately 19,000 for fish mature at age 3+ and 16,000 for fish mature at age 5+. The threshold would then be 25% of 19,000 to 16,000 fish or 4,000 to 5,000. The present threshold of 10,000 fish is considerably more conservative, but is based in part on higher historical abundances from mark-recapture experiments (as high as 41,211 fish estimated in 1988; 25% of 41,211 is approximately 10,000). A high threshold will conserve the stock at the expense of fishing opportunity. Lost recreational fishing opportunity can result in social and economic losses. While fishing is more efficient when abundances are high, it is possible the angler would favor fishing more often over a less frequent opportunity to harvest more. There is a risk of overfishing if the threshold is set below the optimal level.

Because the sources of uncertainty will never be completely removed, fisheries managers routinely integrate perceptions about the reliability of information in their decision-making affecting fisheries. By not incorporating these perceptions into the solution-seeking process, the analysis may fail to be implemented. In situations where information is uncertain, and there is an individual or group familiar with the assessment program through its entirety, perception-weighted models, such as the one developed in this study, may offer advantages over other weighting schemes.

While the perception model is deemed "best" for the Chatanika River, this does not invalidate the potential usefulness of the inverse variance, combined or base weighting schemes for other fisheries. Different weighting schemes should be attempted and compared. By examining a variety of models a greater understanding of the factors that affect the dynamics of a population may be attained. Further research into the influence of perceptions on solutions to fisheries problems should be conducted. It may be that by incorporating perceptions of data accuracy, aversion to overharvest may be captured and incorporated into the solution, thus promoting conservative management.

A conservative strategy has been previously applied to the management of the humpback whitefish sport fishery in the Chatanika River. Due to uncertainty in prior population assessments and appropriateness of management objectives, exploitation during the 1992 fishing season was held at approximately 3%, despite the fact that the management plan would have allowed up to a 15% exploitation rate. Application of a perception-weighted catch-age analysis method to assessment of the humpback whitefish population should reduce uncertainty in historical population status.

One weakness of catch-age analysis is that current population abundance estimates will vary substantially as more data becomes available, however early estimates converge to stable values (Pope 1972). In a retrospective analysis of Pacific halibut (*Hippoglossus stenolepis*) Parma (1993) found consistent over or underestimation of abundance for a series of consecutive years, due in part to increasing trends in catchability and/or vulnerability. Thus, the strength of catch-age analysis may not be so much in providing current information for management, but rather as a tool for incorporating weights, such as perceptions, into a structured framework in order to quantify the risks to the population associated with various harvest strategies and population states.

Applicability to Recreational Fishery Problems

Information needs to manage recreational fisheries are varied and include population dynamics, characteristics of the harvest (e.g, relative catch per effort), and sociopolitical and socioeconomic aspects (Sigler and Sigler 1990). Specific information required to assess stock status includes abundance, recruitment, age composition, natural mortality, and exploitation. Inland fish stocks are at risk from such diverse challenges as loss of aquatic habitat by construction of power, navigation and flood control structures, pollution, and effects of introduced species. Further complicating management are multiple objectives. It is not acceptable to merely consider harvest in determining yield, because there is also value in sustaining and improving quality of the recreational experience as perceived by the angler. Because information needed by the fisheries manager will always be incomplete, uncertainty is an important component of the management problem. Uncertainty contributes to risk in decision-making.

To deal with this myriad of information, risks, options, and uncertainties, the fisheries manager needs to integrate the components comprising the problem into a structure, in order to adequately define the problem and to propose solutions. Hilborn et al. (1993) attempt to show how stock assessment and decision-making can be coordinated to address risk and uncertainty in fisheries management. They suggest that research staff provide decision-making staff with a decision table of alternative population states given various constraints and actions. The shortcoming of this approach is that the perceptions of the decision-makers regarding reliability of data sources and their intuition about future events are absent from these "what if" scenarios.

This paper has demonstrated an alternative approach to integrating diverse sources of information by applying a methodology which provides structure to a stock assessment problem. Various parameters pertaining to humpback whitefish stock dynamics were estimated using catch-age models. Abundance was forecasted in an effort to evaluate the current management policy. The model was sensitive to uncertainty by allowing perceptions of reliability in the information at hand to become integrated into the solution. Because the catch-age model developed in this study conforms to the error structure of data collected for sport fish assessment, it is possible that the model can have wide application in recreational fisheries problems.

CHAPTER 4

CONCLUSION

Fishery managers often face complex fishery problems involving integrating quality of life issues with biological conservation and production goals. The development of a solution to a complex fishery problem may require coordination among multiple governing agencies, interest groups, and private citizens who may have objectives which are incompatible with each other. Uncertain information complicates the balancing of risks to the resource and risks of foregone fishing opportunities.

Smith et al. (1993) relate a great deal of interest by fishery managers in quantifying and incorporating sources of uncertainty into the decision-making process. Despite the interest expressed by some managers in using such tools as decision analysis to address complex fishery problems, people generally tend to mistrust mathematical representations of real systems, and prefer instead to rely on intuition (Gass 1983, Tait 1988).

One resolution to this dilemma is the approach suggested in this dissertation. By applying methods which incorporate judgments and perceptions into decision-making, sensitivity to uncertain information is made explicit, components of the problem are structured, interactions among components of the problem are quantified, and options are prioritized.

Decision analysis was applied to the decision-making process in the management of Alaskan recreational fisheries to reduce risk at the policy (Chapter 2) and field (Chapter 3) levels. Risk in fisheries management involves the probability that fish abundance will fall below some acceptable level, and result in social and economic losses from foregone fishing opportunities. These probabilities are rarely known, so managers must make decisions under uncertainty in which risk is unknown. Many different approaches have been developed by various disciplines to measure this risk. In statistical decision theory (see Keeney and Raiffa 1976) a subjective probability is developed from expected values or utilities of outcomes. Psychologists (see Rowe 1988) have developed approaches that involve the probability of loss through a combination of subjective evaluation of probability prorated against utility of results. Saaty (1990a) uses numerical priorities derived from subjective judgments to arrive at preferred resolutions to contentious issues. Hilborn et al. (1993) discuss how stock assessment and decision-making can be coordinated to address risk in fisheries management. Walters and Punt (1994) advocate accompanying estimates of stock status with Bayesian odds of sustainability as a way to convey the long-term risks associated with a range of harvests. In Cordue and Francis (1994), risk associated with management strategy is examined further by evaluating the accuracy of various risk estimators.

In this dissertation, the concept of risk was associated with several themes. The first theme introduced structure to fisheries management processes comprised of interlinked components. By describing and structuring problems, descriptive uncertainty in management was revealed. Identifying important components of problems and their functional relationships is called "risk identification" (see Rowe 1988). The second theme involved the assignment of specific measures of value or interaction to defined variables, thus clarifying measurement uncertainty in management processes. Values were obtained through judgments and perceptions of reliability of observed data. Clarification of measurement uncertainty through intuition, revelation or extrapolation is called "risk estimation" (Rowe 1988). The third theme involved the revelation of judgments and perceptions used in arriving at a decision. By formalizing the decision-making or estimation process, further insight about the process was gained.

Chapter 2 was the first application of the analytic hierarchy process (AHP; Saaty 1990a) to facilitate decision-making in management of a recreational fishery. The objective of the study was to determine the most preferred options to resolve important issues relating to management of the recreational fishery for chinook salmon in the Kenai River. Model structure was developed through iterative interviews of individuals representing the perspectives of 15 different stakeholders. Their judgments were combined using a geometric mean, and the maximax and maximin criteria. Sensitivity of results to under representation of stakeholders was explored through models based on the mean preferences of state agencies, commercial fishing organizations, and sport fishing interests. Two options identified as among the most preferred in all six models are to: "increase funding to Alaska Fish and Wildlife Protection for enforcement of existing regulations"; and, to "reduce property taxes for property owners who dedicate their river frontage to conservation". Implementation of these options would be considered desirable by most stakeholders and would face limited opposition from the remainder.

In this study, stakeholders believed some issues could be resolved through better governmental regulation and action by private citizens. Implementation of such preferred options as to "station a Habitat Division biologist in Soldotna" and to "mandate area registration for commercial setnetters" are clearly the acts of government. Yet preferred options such as to "closely observe nets for live release of chinook salmon" and to "expand public awareness of chinook salmon habitat requirements" are actions of the citizen.

Advantages of using AHP include simultaneous consideration of multiple and sometimes conflicting agendas of stakeholders. By structuring problems, options were identified that might not have occurred to individual stakeholders through the traditional approaches to policy-making. Options extremely preferred by some and strongly disliked by others were identified through AHP. Opening judgments to review explicitly reveals the reasoning behind decisions. Although there is no guarantee that use of decision analysis would ultimately reverse the decline of a fish stock or prevent loss in regional quality of life, decision-makers could have more confidence that a rigorous effort has been made to define and attain management goals.

A significant challenge in describing complex problems and prioritizing solutions with AHP is choosing who to interview. Stakeholders should be those who have a stake in the management outcome and those responsible for oversight of the resource. Crucial issues and options should be elicited from those interviewed. While it is desirable that many stakeholders participate in the AHP, analysis can become unwieldy without realistic bounds on the number of stakeholders. However, when stakeholders are excluded from the decision-making process, the solution may be challenged by those disenfranchised by the process. This is not likely a problem in the analysis of the recreational fishery for chinook salmon in the Kenai River because a broad array of stakeholders were interviewed. While interviews of more stakeholders may have identified additional issues and options, it is unlikely that crucial elements of the problem were missed. Secondly, the AHP was shown to produce a robust solution in response to different weighting schemes on the judgments.

Chapter 3 was the first study to examine the influence of subjective perceptions of data accuracy on the performance of a catch-age model applied to a recreational fishery. Perception-based weighting has not explicitly been used to estimate abundance. However, managers frequently make subjective evaluations of data reliability in the development and interpretation of stock assessments. The objective of the study was to improve the estimation of abundance and to determine the consequences of several harvest strategies on the humpback whitefish population in the Chatanika River. Because the catch-age model developed in this study conforms to the error structure of data collected for sport fish assessment, the model can have wide application in sport fisheries problems.

The model weighted by perceptions of data accuracy generated the most reasonable estimates of abundance, which were relatively precise and associated with small bias. This model produced the most conservative scenario of the four models examined in terms of abundance. The other schemes produced either relatively high coefficients of variation and estimated bias associated with estimates of model parameters, or unreasonably large age 3 recruitments in 1991 and 1992. I recommend that other weighting schemes be discarded from further catch-age analysis pertaining to humpback whitefish in the Chatanika River.

Consecutive years of poor age 3 recruitment with several years of exploitation greater than 15% produced a collapse of the recreational spear fishery for humpback whitefish in the Chatanika River. Forecasts from this study show that a variety of outcomes could result from the current management policy for humpback whitefish. While catch-age analysis provides a useful framework for determining abundance estimates and relationships between abundance and harvest, further understanding of the population and clarification of the management plan are needed. The lack of maturity information precludes understanding of the reproductive capacity of the population. The management plan specifies a threshold level of spawners which cannot be precisely determined. I recommend that such maturity information be obtained and that careful consideration of the definition of the spawning population be undertaken. The use of the mature exploitable population appeared to give reasonable estimates of desired harvest rate.

An advantage to incorporating perceptions of data reliability into the analysis includes the explicit disclosure of uncertainty in the data series. Weighting information according to perceptions of reliability is more efficient than entirely discounting suspect data or entirely accepting it. Forecasts using estimates from a perception-weighted model may have the advantage of being more acceptable, and thus more likely to be used. It is probable that an individual or group familiar with the assessment program through its entirety would offer more accurate weights based on perceptions than those less acquainted with the program. In situations where information is uncertain and decision-makers are not thoroughly familiar with the data series, weighting according to perceptions may not provide the best set of estimates. Another possible disadvantage is that people will process identical information differently. The internalization process is dependent upon each person's unique past experience. Thus, individuals participating in assessing and managing the same resource may arrive at differing weights of reliability. However, good models would be robust with respect to weights over a range of perceived values.

In Chapter 3, forecasts of mature exploitable abundance were generated based on various recruitment scenarios, maturity schedules and exploitation rates. From these outcomes, the possibilities of stock abundance being below (or above) a risk reference (threshold) level were presented five years into the future. Assessment of risk was beyond the scope of this study due to insufficient information about the recruitment process. Such an assessment would include stochastic elements and provide managers with the odds of particular events occurring. However, without the assignment of a value to the consequence (e.g., unacceptable versus sufficient stock abundance), the appropriate behavior to the risk (e.g., some action to control risk such as a fishery closure, or to minimize loss such as a fishery opening) can never be certain.

By incorporating judgments and perceptions into mathematical models to facilitate decision-making in management of Alaskan recreational fisheries, priorities of stakeholders were clearly stated and sensitivity to uncertain information was made explicit. This dissertation suggests that by formalizing priorities and uncertainty in decision-making, the possibility of finding an acceptable solution to a complex fisheries management problem may be improved.

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APPENDIX 2.1

Issues and options relevant to the future management of the Kenai River sport fishery for chinook salmon, 1992, structured as a hierarchy under seven primary issues.

Appendix 2.1.1. Issues and options (in italics) relevant to the future management of the Kenai River sport fishery for chinook salmon, 1992 structured as a hierarchy, under the primary issue of REGULATION.

REGULATION
- Different interpretations of the law in different courts.
  - *Appeal judicial rulings.*
- ADF&G fisheries management.
  - Commercial fishery management.
    - *Mandate area registration for commercial setnetters.*
    - *Decrease the number of commercial setnet sites to the pre 1984 level.*
    - *Expand use of the drift fleet to decrease chinook bycatch.*
    - *Take no management actions tto reduce economic gain to setnetters.*
    - *Limit setnets to one net length beyond low water to decrease bycatch.*
    - *Restrict the number of setnet sites to the 1992 (current) level.*
    - *Preserve the status quo.*
  - Sport fishery management.
    - More conservative management.
      - *To decrease harvest, have a derby for a specially-tagged fish.*
      - *To reduce harvest, institute alternate day fishing.*
      - *Sport catch of chinook should count towards a harvest limit.*
      - *Create a drift fishery (limited use of motors).*
      - *Restrict guides to drift fishing.*
      - *Open the sport fishing season with conservative regulations.*
      - *Restrict chinook harvest in the sport and commercial fisheries equally.*
    - As is or more liberal management.
      - *Preserve the status quo of sport fish management plan.*
      - *Regulations should allow more chinook catch in sport fishery.*
      - *Ban on boats on certain days should be lifted.*
- Local government.
  - Zoning: habitat protection versus development.
    - Insufficient support from local govn't for zoning for conservation.
      - *Reduce property tax for owners who dedicate river frontage to conservation.*
    - There is a conflict between local govn't & Habitat Div. re: development philosophy.
- Private property rights.
  - Anglers destroy property
    - *Locate public access points to limit adverse impacts on existing subdivisions.*
  - Public good takes precedence over private rights.
    - *Compensate owners when their property is dedicated for the public good.*

-Continued-

Appendix 2.1.1. (page 2 of 2).

Conflicting jurisdictions and missions among agencies.
Federal land management in upper river vs. DNR re: mining, timber, wilderness use.
Pressure feds to properly manage land and resources.
Disagreements re: inriver and wetlands permitting and regulation (Feds vs. DNR).
DNR lacks jurisdiction on lands not state owned.

Appendix 2.1.2. Issues and options (in italics) to the future management of the Kenai River sport fishery for chinook salmon, structured as a hierarchy, under the primary issue of MONITOR

MONITOR.
- Unreported harvest.
  - *Additional funds for enforcement of existing regulations.*
- Bycatch of chinook salmon in the commerical fisheries.
  - In the Gulf and on the high seas.
    - Stocks cannot be adequately identified as to origin.
      - *Improve stock identification of bycatch on the high seas.*
    - Hugh bycatch results in setnet and gillnet closures, and sport restrictions.
      - *UN treaty with Pacific nations would ban fishing outside 200 mi.*
    - Actions by the North Pacific Management Council.
      - *Use "hot spot" authority to close trawl fishery if bycatch is too high.*
      - *Use vessel incentive program - close fishery if bycatch too high.*
      - *Delay starting dates for Gulf fisheries to decrease bycatch.*
  - In the Cook Inlet setnet fishery (late run of chinook salmon only).
    - Setnetters don't want to catch chinook salmon.
      - *Commercial fishery should use light, breakaway nets to decrease bycatch.*
      - *Commercial fishermen should closely observe nets for live release of chinook.*
- Recreational trolling at sea.
  - There is an unknown directed effort (unknown demand shift).
  - There is an unknown stock composition of harvest for early & late runs.

Appendix 2.1.3. Issues and options (in italics) to the future management of the Kenai River sport fishery for chinook salmon, 1992 structured as a hierarchy, under the primary issue of ALLOCATE.

ALLOCATE.

- Sport fishery.
  - House Bill 505 allocates between resident/nonresident; guided/nonguided.
    - Limits on guides are difficult for them because they sell trips.
    - Guided versus nonguided take.
      - *Preserve the status quo of sport harvest allocation.*
      - *Limit guided sport harvest to 50% of the inriver take.*
      - *Limit guided sport harvest to 65% of the inriver take.*
      - *Limit guided sport harvest to 45% of the inriver take.*
      - *Restrict sport guides operating in salt water.*
- Commercial fishery.
  - Commerical fishery has unfair views (prior rights) and political advantages over other users.
    - Has been allocated more than their fair share - they harvest 97% of salmon.
      - *Commerical fishery should take <50% harvestable surplus.*
      - *Commercial fishery should take < 67% harvestable surplus.*
      - *Commercial fishery should take < 71% harvestable surplus.*
    - Commercial fishery value is decreasing due to mariculture.Subsistence.
  - Subsistence use in the Kenai River is opposed by the majority of the people.
  - Native people have their culture and tradition to preserve.
- Board of Fisheries appointment, representation, process.
  - The BOF is unequally weighted regarding representation of user groups.
      - *Have a publically-elected Board of Fisheries.*
  - There is a problem with the system - how members are appointed, vote & conduct business.
  - The BOF does not consider economics in their allocations.
  - The existing allocation plan is based on escapement
      - *Base management plan on harvest quotas instead of escapement.*
- Conflicts among users and its impacts.
  - Conflict between sport and commercial users is disruptive to the local community.
  - There is a stigma of volitility and controversy associated with the Kenai River.
    - Funding for projects is difficult to obtain because sources are aware of conflicts.
      - *Solve controversy so more funds will become available for conservation.*
- Allocation as it affects the economic base for local governments.
  - Should revenue from sockeye fishery be sacrificed for more revenue generated by sport fishing?
  - Reduction in commercial fishery would affect city because 88% of setnetters are residents.
  - Need both commercial and sport fisheries for survival of city (multiple use).

Appendix 2.1.4. Issues and options (in italics) to the future management of the Kenai River sport fishery for chinook salmon, 1992 structured as a hierarchy, under the primary issue of BIOLOGICAL CONSIDERATIONS.

BIOLOGICAL CONSIDERATIONS.

- Timing and spawning distributions of the two runs are uncertain.
- Carrying capacity of the Kenai River system is unknown.
  - Are escapement goals appropriate? Less than 1,000 chinook difference from goal will close fisheries.
- Run enumeration/projection inaccuracies could unnecessarily close fisheries or cause low escapement.
  - No validation of sonar - it's reliability is doubted.
  - Sonar does not count age 1.2 chinook as their size overlaps with sockeyes (undercounts).
  - Inseason forecast is sometimes inaccurate, due to run timing (this happened in 1990).
    - *Increase the accuracy of preseason forecasts of run strength.*

Appendix 2.1.5. Issues and options (in italics) to the future management of the Kenai River sport fishery for chinook salmon, 1992 structured as a hierarchy, under the primary issue of HABITAT DEGRADATION.

HABITAT DEGRADATION
- Protection of shoreline rearing habitat.
  - Bank modifications - structures and foot traffic.
    - *Purchase development rights so owners won't destroy habitat.*
    - *Development should be restricted only in critical areas.*
    - *Instigate zoning ordinances to restrict development.*
    - *Revise permitting standards.*
    - *Zoning to condition development presents inverse condemnation.*
    - *Adopt setbacks to decrease bank erosion and improve aesthetics.*
  - Erosion.
    - Fire management policy.
      - *Provide city with grant to stop erosion with re-vegetation.*
      - *City and Soil Conservation Service mapped erosion potential - usemaps.*
    - Boat traffic (hull shape, outboard size, number of people in boat, etc.)
      - *Provide city with grant to stop erosion with re-vegetation.*
      - *City and Soil Conservation Service mapped erosion potential - usemaps.*
    - Logging.
      - *Provide city with grant to stop erosion with re-vegetation.*
      - *City and Soil Conservation Service mapped erosion potential - use maps.*
    - Bank armor and stabilization procedures.
      - *Provide city with grant to stop erosion with re-vegetation.*
      - *City and Soil Conservation Service mapped erosion potential - use maps.*
  - Shoreline vegetation.
    - Shore anglers cut cover and trample vegetation.
      - *Install bargrading and boardwalks to decrease bank and vegetation damage.*
      - *Reduce bank angling. Close some areas; provide boardwalks in open areas.*
- Protection of inwater habitat.
  - Water quality.
    - Boat discharges.
    - Runoff from salt stored by Department of Transportation.
    - City wastewater treatment accidents (chlorine leaks into the Kenai River).
      - *Install backup system on city sewer plant to prevent further leaks.*
    - Contamination of the river by residents and runoff.
    - Untreated sewage (human waste).

-Continued-

Appendix 2.1.5. (page 2 of 2).

Inriver structures - building and other activities affect flow.

Remove negative impact structures with compensation..

Protection of instream spawning habitat.

Are spawners disturbed by excessive boat traffic?

Initiate a study to determine if spawning is impacted by traffic.

Habitat issues related to landowners.

Landowners lack knowledge re: rearing habitat requirements.

Expand public awareness of chinook salmon habitat requirements.

Incorporate concerns of landowners into decision-making.

Offsite habitat concerns.

Reduce filling of contiguous wetlands.

Policy concerns - there is no policy to protect riparian zone.

Public agencies should set better examples; they contribute to habitat degradation problem.

Set up cost sharing demonstration projects between stakeholders.

Department of Natural Resources does not understand the need for stewardship of habitat.

Change the constitution to allow a dedicated user fee to go to theKenai River.

Create opportunities for users to give - set up donation boxes.

Create a nonprofit group with 5013C (to replace Kenai River advisory board).

Preserve the status quo.

Retained bycatch is donated to habitat fund.

Kenai River task force recommendations were never fully implemented.

Implement task force recommendations.

Table 2.1.6. Issues and options (in italics) to the future management of the Kenai River sport fishery for chinook salmon, 1992 structured as a hierarchy, under the primary issue of QUALITY OF THE RECREATIONAL FISHERY EXPERIENCE.

QUALITY OF THE RECREATIONAL FISHERY EXPERIENCE

Social carrying capacity.

There are too many guides; nonguided anglers are displaced.

Limit guides by restricting them to even or odd day operation.
Preserve the status quo.
Develop a fair system to decrease the number of guides to 160 (1985level).
Hold the number of guides to 310 (1990 level).
Issue permits to limit guides by area or time.
Limit guides to 150-225 using a seniority system.
Issue drift and motorized guide permits on a 50:50 basis.

The sport fishery is too crowded-crowds bring changes in resource use, and increase danger involved with sport fishing.

To reduce harvest, institute alternate day fishing.
Create a drift fishery (limited use of motors).
Restrict guides to drift fishing.
Preserve the status quo.
Plan public access to reduce crowding in the inriver sport fishery.
Reduce the number of anglers with a permit limitation system.
Zone river sections for different sport fishing methods.

Aesthetics.

Nuisances (noise and visual) associated with the sport fishery.

No day or time restrictions on outboards.
Create a drift fishery (limited use of motors)
Locate public access points to limit adverse impacts on existing subdivisions.
Preserve the status quo.
Prohibit the use of outboards during night.
River should be managed to provide for maximum use.
More frequent agency and volunteer litter patrols.

Inriver structures and shore development detract from the visual aesthetics of the fishing experience.

Encourage development in areas not critical to chinook salmon.
Adopt setbacks to decrease bank erosion and improve aesthetics.
Preserve the status quo.
Landscape for visual aesthetics.
For future streamside development, make development plans.
Zone for visual aesthetics.

The degree of enjoyment is related to catch and harvest rates.

The recreational experience is affected by the management options chosen.

Appendix 2.1.7. Issues and options (in italics) to the future management of the Kenai River sport fishery for chinook salmon, 1992 structured as a hierarchy, under the primary issue of ENFORCEMENT.

ENFORCEMENT

There is uncertain authority and responsibility among differing agencies.

Clarify legislative intent regarding the enforcement authority of Division of Parks.

While habitat enforcement is critical, it is underfunded and inadequate.

Station a Habitat Division biologist in Soldotna.

Private boat owners are untrained and use unsafe boating practices.

Increase Coast Guard patrols to address boating safety concerns.

Require all boaters to take a boating safety class.

Division of Parks and Recreation is understaffed for enforcement.

Additional funds for enforcement of existing regulations.

The Division of Fish and Wildlife Protection is understaffed for river patrols.

Additional funds for enforcement of existing regulations.

Illegal guiding is a problem.

Route additional funds to Fish and Wildlife Protection for covert operations.

Appendix 3.1. Initial parameter values selected for the non-linear least squares Excel model.

Vulnerability

α	β
3.813	7.455

Cohort Sizes (thousands of fish)

	Age							
	3	4	5	6	7	8	9	10+
$N_{3\text{-}10+,86}$	13.0	9.0	5.0	1.7	0.5	0.5	1.0	0.5
$N_{3,87}$	17.7							
$N_{3,88}$	27.8							
$N_{3,89}$	1.7							
$N_{3,90}$	7.5							
$N_{3,91}$	6.4							
$N_{3,92}$	8.0							

Exploitation (%)

Year	μ
1986	17.0
1987	16.3
1988	8.7
1989	22.1
1990	20.0
1991	0.0
1992	1.9

Appendix 3.2 Macro used to perform bootstraps of parameter estimates in an Excel (5.0c) spreadsheet application of catch-age analysis.

```
' copytdata Macro
' Macro recorded 8/26/94 by Sport Fish - Region 3
'
'
Sub copydata()
    Sheets("simulated ages").Select
    '  ActiveCell.Offset(-4, 0).Range("A1").Select
    ActiveSheet.Next.Select
    Range("a1").Select
    '  move to next data location
    ActiveCell.Offset(0, 1).Range("A1").Select
    Selection.End(xlDown).Select
    ActiveCell.Offset(1, -1).Range("A1").Select
    ' start copy of data
    ActiveCell.FormulaR1C1 = "Iteration"
    ActiveCell.Offset(0, 1).Range("A1").Select
    ActiveSheet.Previous.Select
    Application.Goto Reference:="C1:C10"
    ' range a39..j45
    Application.Goto Reference:="R39C1:R45C10"
    Selection.Copy
    ActiveSheet.Next.Select
    Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, _
        SkipBlanks:=False, Transpose:=False
    Selection.End(xlToRight).Select
    ActiveCell.Offset(0, 1).Range("A1").Select
    ActiveSheet.Previous.Select
    ' range n39..v45
    Application.Goto Reference:="R39C14:R45C22"
    Application.CutCopyMode = False
    Selection.Copy
    ActiveSheet.Next.Select
    Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, _
        SkipBlanks:=False, Transpose:=False
    Selection.End(xlToRight).Select
    ActiveCell.Offset(0, 1).Range("A1").Select
    ActiveSheet.Previous.Select
    Application.Goto Reference:="R99C1:R105C10"
    Application.CutCopyMode = False
    Selection.Copy
    ActiveSheet.Next.Select
    Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, _
        SkipBlanks:=False, Transpose:=False
    Selection.End(xlToRight).Select
    ActiveCell.Offset(0, 1).Range("A1").Select
    ActiveSheet.Previous.Select
    Application.Goto Reference:="R112C7:R112C8"
    Application.CutCopyMode = False
    Selection.Copy
    ActiveSheet.Next.Select
    ActiveSheet.Paste
    Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, _
        SkipBlanks:=False, Transpose:=False
    ActiveCell.Offset(0, -29).Range("A1").Select
    ActiveSheet.Previous.Select
End Sub
```

continued

Appendix 3.2. page 2 of 2.

```
Sub solve_1()
    Calc
    Sheets("simulated ages").Select
    Application.ExecuteExcel4Macro String:= _
        "[SOLVER.XLA]SOLVER!SOLVER.OK(!R82C4,2,0,(!R110C14:!R116C14,!R110C15:!R110C2
1,!R124C19:!R124C20,!R110C22:!R116C22))"
    Application.ExecuteExcel4Macro String:= _
        "[SOLVER.XLA]SOLVER!SOLVER.SOLVE(True)"
    Application.ExecuteExcel4Macro String:= _
        "[SOLVER.XLA]SOLVER!SOLVER.ok()"
    Application.Run Macro:="Quinn2.xls!CopyData"
    ActiveWorkbook.Save
End Sub

Sub Calc()
    Sheets("simulated ages").Select
    Application.Calculate
    Application.Wait (Now() + 0.00017)
End Sub
'
' Run it many times
'
Sub Run_Solve()
    For i = 1 To 100
        Application.Run Macro:="Quinn2.xls!Solve_1"
    Next i
End Sub
```