SIMPLE DECISION GUIDELINES FOR TERMINAL FISHERIES TARGETING ATNARKO RIVER, BRITISH COLUMBIA, CHINOOK SALMON *(Oncorhynchus tshawytscha)*

by

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ABSTRACT

Simple decision guidelines (SDG) describe the basic components of more complex decision-support tools. These components are: (1) management objectives, (2) management options, and (3) guidelines for assessing stock status and responding accordingly. In close cooperation with the local fisheries manager, I developed SDG for terminal fisheries targeting Atnarko River chinook salmon.

To describe management objectives, I developed a hierarchical summary, elicited verbal assessments of attributes reflecting these objectives, and used three simple methods for eliciting relative preferences. All three produced consistent rankings, but a newly-developed graphical weighting method best facilitated the interaction with the manager and also captured his attitude towards risk.

To identify reference points for in-season management, I built a Bayesian projection model, and fit classification trees to the manager's interpretations of the model's output. Using these reference points, I summarized in-season decision-making in two simple tables. Management actions since 2002 have been consistent with these guidelines.

Acknowledgments

Everything should be made as simple as possible, but not simpler.

Albert Einstein

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Glossary

Classification tree	Consists of a series of binary choices (e.g. yes-no, if-then), which split a set of observations into discrete categories and identify the appropriate class for a new observation. One example are the dichotomous keys used in field guides, which use a series of easily observable characteristics to identify species.
Contained hierarchy	Hierarchical structure in which higher levels consist of, and fully contain, all elements at lower levels. Examples include taxonomic nomenclature (phylum, class, order, family, genus, species) and administrative structures (country, province, regional district). Also referred to as a nested hierarchy.
Escapement	Abundance of adults on the spawning grounds, after the last interception fishery.
Food fisheries	See Food, Social, Ceremonial fisheries.
Food, Social and Ceremonial (FSC) fisheries	First Nations fisheries to satisfy dietary and cultural need. FSC fisheries are an aboriginal right established in court, and have the highest priority among harvest groups.
FOC	Fisheries and Oceans Canada, formerly Department of Fisheries and Oceans (DFO).
Harvester	Any individual catching salmon for dietary, cultural, recreational or commercial purposes. This includes First Nations individuals actively involved in fisheries.
Indifference range	Range of values for an attribute over which the respondent is indifferent, because of uncertain data and robust management response.
MD	Mean deviation.
MAD	Mean absolute deviation.
MAPE	Mean absolute percent error.
Participants in the decision-making process	This group includes all managers, analysts, and stakeholders actively and constructively contributing to fisheries management.

Stakeholders — Any individual or organization with harvest or non-harvest interests in the salmon. This group includes harvesters, environmental interest groups, academic researchers, and the general public.

Terminal area — Used by FOC staff to describe the final part of the salmon migration route from their approach to freshwater entry into freshwater and up-river to the spawning grounds.

Terminal returns — Abundance of adult chinook migrating into the Bella Coola area, estimated from escapement and local catches in the food, recreational, and commercial fisheries.

1 Introduction

1.1 Simple decision guidelines

Fisheries management systems are becoming more complex as management agencies struggle to incorporate new considerations such as more sources of uncertainty, diverse management objectives, and broader participation of harvesters and other interested groups (e.g. Cochrane 1999, Cochrane 2000, Hilborn et al. 2001). This increasing complexity overwhelms decision makers, frustrates stakeholders, and makes detailed quantitative decision-support methods infeasible for wide implementation.

Published analyses of decision-support tools for fisheries management tend to recommend quantitatively demanding frameworks, but agencies such as Fisheries and Oceans Canada (FOC) generally do not have the resources available to properly implement these complex methods for many small, locally important fisheries. Quick and easy decision-support tools have the potential to improve management of these fisheries by increasing transparency and consistency, improving communication between all participants in the decision-making process, and encouraging contingency planning.

I developed the concept of simple decision guidelines as a quick and easy addition to the decision-support toolbox available to fisheries managers. The concept of simple decision guidelines is based on two observations: (1) Most decision-support tools share the same basic elements. (2) Simulation studies of applications as diverse as choosing investment portfolios and predicting egg production of Arctic charr showed that simple rules of thumb can, in theory, perform as well as complex control rules (Gigerenzer et al. 1999). In practice, simple rules of thumb should perform much better than complex methods. They can be more robust, more easily understood and communicated, and more consistently implemented.

Simple decision guidelines include rules of thumb for each of the basic elements of more complex decision-support tools. They are more likely to be used by agency staff, and fit into organizational structures where central authorities devolve decision-making to local managers, but need to provide clear policy direction. Taking an analogy from health care, simple decision guidelines correspond to basic first-aid knowledge, which is crude and incomplete, but still more useful to a hiker in the backcountry than an intensive care unit far away. Similarly, FOC staff managing many small, local fisheries need advice regarding the minimum requirements for improvement over their current approach to decision-making, rather than continued refinements of the best possible, technically complex decision-support tool.

In the context of fisheries management, simple decision guidelines need to describe how management actions respond to the status of the resource. Using common elements of more complex decision-support tools (Section 1.4), a more precise definition of decision guidelines is: *"Predetermined actions useful for responding to estimated states of the resource to assist with achieving specific objectives, as measured by appropriate performance indicators."*

Figure 1 illustrates the four essential components captured in this definition:

- Management objectives
- Management options
- Guidelines for assessing status
- Guidelines for management responses to status assessment

Management objectives set the context for the other components, define the necessary scope and level of detail, and provide the basis for choosing performance measures. Guidelines for assessing status describe how different types of information are used to estimate the current status of the fishery relative to the objectives. Guidelines for responding to status assessment describe which of the options will most likely be chosen, given an assessed status.

The concept of simple decision guidelines can be applied to a wide range of management tools from broad policies to case-specific decision rules, such as harvest rules. In each case, considering all four components can benefit the decision process. Groups involved in drafting broad policies, for example, tend to focus on the management objectives. Even informal discussions around procedures for assessing status and responding to different contingencies can help participants foresee challenges in practical implementation. While the concept is widely applicable, the most appropriate format for simple decision guidelines is specific to each situation. For a general audience, a concise verbal description of each component may suffice.

Before moving on to discussing the potential benefits of simple decision guidelines, I need to briefly clarify the terminology I use to describe different forms of public involvement in fisheries management. In this report, I distinguish between three groups of individuals. (1) *Harvesters* catch salmon for dietary, cultural, recreational or commercial purposes; they include First Nations individuals actively involved in fisheries. (2) *Stakeholders* have harvest or non-harvest interests in the salmon, and this group includes harvesters, environmental interest groups, academic researchers, and the general public. (3) *Participants* in the decision-making process, which includes all managers, analysts, and stakeholders who actively and constructively contribute to fisheries management.

Simple decision guidelines have many potential benefits for fisheries management agencies. The process of developing simple guidelines encourages participants to make explicit value judgments and clarify their objectives, highlights sources of uncertainty, helps identify gaps in existing policies, and helps to set research priorities (e.g. Butterworth and Punt 1999, Starr et al. 1997). Even the simplest, most general decision guidelines should: (1) reduce implementation error and institutional uncertainty through more consistent and transparent decision making (e.g. Polacheck et al. 1999, Young 1998), (2) encourage communication at the interface between scientists and managers (e.g. de la Mare 1998), (3) improve compliance of harvesters and reduce in-season conflict through clear pay-offs and increased transparency of rationales for decisions (e.g. Gauthiez 2000), and (4) reduce response time in unlikely, but anticipated, scenarios. Simple decision guidelines are conducive to constructive feedback and fine-tuning over time, and help document the accumulated experience of participants. Documenting participants' input also increases their perception of fairness for the management process (Hunt and Haider 2001). Simple decision guidelines can serve to keep participants' expectations reasonable by clearly describing plausible scenarios and their expected impacts. Tempered expectations and improved understanding of the components of uncertainty should provide incentives for all participants to prepare for the inherent variability in environmental, biological, and economic aspects of the fishery system (Stephenson and Lane 1995).

For these potential benefits to be realized, all four components of decision guidelines need to be addressed at a consistent level of detail. For example, a complex, theoretically immaculate assessment of a stock's status (e.g. estimated abundance) is of little use if the underlying objectives are vague, or if it is unclear to participants how these assessments affect management actions. In many small fisheries, developing a broad, simple description of all four components could be more useful than a detailed explanation of one of the four parts.

1.2 Overview of the projects

1.2.1 Purpose and scope

I applied the general concept of simple decision guidelines in a case study and worked out simple methods for developing and communicating the four components described above.

Fisheries for Atnarko River chinook salmon (*Oncorhynchus tshawytscha*) in statistical Area 8 on the Central Coast of British Columbia, Canada, provided an ideal setting for this initial study of simple decision guidelines (Figure 2). Atnarko chinook fisheries are managed by a single local decision maker with many years of experience with this stock, and a good rapport with local stakeholders. Also, detailed records of past management actions are available. The fishery and its management are relatively simple, but illustrate the typical situation where many small, local fisheries are managed by a few staff. All of the standard challenges of salmon management are present: (1) several groups of harvesters share the resource; (2) the order of interception along the migration route does not coincide with FOC's established priority for access to the fish; (3) abundance and timing of adult returns fluctuates considerably from year to year; (4) the window of opportunity for each group of harvesters is short; (5) decisions are based on highly uncertain information; and (6) the same decision has to be made repeatedly, but with changing information (e.g. "Given the available data, how long should the fishery be open this week?").

The purpose of this project was to capture the rules of thumb used by the manager during the fishing season, and summarize them in a format that would facilitate his communication with stakeholders and preserve his acquired experience for others taking over the management of this fishery in the future. The results presented here differ from most published papers on decision support, because I show a comprehensive summary of what an experienced fisheries manager actually does, rather than what should be done. This project was conducted during the Summer of 2002 in close co-operation with the local fisheries manager, Lyle Enderud (Fisheries and Oceans Canada, Bella Coola), with an emphasis on (1) easy application of the methods in this type of setting, and (2) practical use of the results for this particular fishery.

As will be described in detail later, I worked together with the fisheries manager to develop simple summaries of management objectives, in-season management options, guidelines for assessing stock status, and guidelines for responding to estimates of stock status. In this case study, I use the term "stock status" to reflect the abundance of Atnarko chinook, and other qualitative considerations that affect the manager's choices throughout the fishing season. Using records from previous fishing seasons and extensive interviews of FOC staff, I first constructed a hierarchical summary of harvest management objectives for Atnarko chinook fisheries, defined relevant ranges of values for each attribute to measure how well an objective was being met, elicited verbal assessments of these value ranges, and tested three simple ranking methods for eliciting relative preferences for different management objectives. To develop a simple summary table of in-season assessment guidelines, I programmed a Bayesian projection model for in-season estimates of total escapement, tested the manager's use of the projection model, and analyzed his assessments using classification trees to identify cut-off points for the in-season indicator that correspond to discrete categories of stock status. In further interviews, I then elicited a set of in-season management options and established the link between individual management options and stock status (Figure 1). Finally, I summarized in-season decision making for Atnarko chinook fisheries in two simple, overall decision tables: one mapping weekly in-season data onto a discrete estimate of stock status, the second specifying management actions for each week of the targeted commercial fishery corresponding to the different estimates of stock status.

This report does not strictly follow the usual format of presenting scientific research, for two reasons: (1) Developing simple decision guidelines is an iterative process, where all parts are continually revised to arrive at a coherent whole with consistent level of detail for all components (Figure 3). The results of one step in the interaction with the fisheries manager influenced the choice of methods for the next. Therefore the sections corresponding to the four components of simple decision guidelines overlap. For example, when describing the methods used to determine values of the in-season indicator that correspond to different categories of stock status, I use some of the management objectives described in the results section. (2) The methods used here span a variety of fields with their own specialized terminology and concepts, and the easiest way of illustrating them is by referring to the actual results, rather than hypothetical examples. For example, I use a single diagram to illustrate a fundamental difference between two decision-support tools in the Introduction, to explain the concept of a contained hierarchy in the Methods, and to show a part of the Results.

In the remainder of this section, I briefly outline the methods used to develop each of the four components of simple decision guidelines for this fishery.

1.2.2 Eliciting management objectives and relative preferences

I developed a simple framework for capturing vague, and often competing, objectives in a format useful for co-operative decision making, consensus-building with stakeholders, and evaluation of fishery performance. Lack of clearly defined and measurable objectives has contributed to numerous failures of fisheries management (Cochrane 2000, Stephenson and Lane 1995, O'Boyle 1993), but at the same time little practical guidance is available to help management agencies to develop clear objectives. Fisheries managers are expected to consider a wide range of vague objectives at various spatial and temporal scales. Individual stakeholders, local and regional stakeholder groups, national policy, regional policy, and specific local concerns all bear on harvest decisions, as do short-term concerns and long-term implications. To be useful in this setting, objectives need to be described in a more comprehensive form than a simple list of performance measures, or a quantitative value function for selecting one alternative action from a finite set (Section 1.4).

Using records from previous fishing seasons and extensive interviews of FOC staff, I elicited a comprehensive list of management objectives for Atnarko chinook fisheries and structured them hierarchically to help the manager illustrate the link between high-level policy and specific, low-level operational objectives relevant to the local fishery and affected stakeholders. This is a common first step in many of the more complex decision-support methods, and the resulting hierarchy is often referred to as a value tree (e.g. Borcherding and von Winterfeldt 1988, Keeney and McDaniels 1999).

Where possible, I then defined measurable attributes for the operational objectives using available data, and elicited a combination of indifference ranges and verbal assessments for each range. Indifference ranges describe a set of values for an indicator over which the respondent is indifferent, because of uncertain data and robust management response. For example, based on the current management approach and limited precision of escapement estimates for Atnarko chinook, the manager was indifferent to fluctuations in estimated escapement over the range of 9,000 to 16,000 (see results in Sec. 3.1). This approach captures more information than simply asking respondents whether different performance measures should be minimized or maximized, and may even serve as a reasonable approximation to a univariate utility curve (e.g. Wallsten et al. 1999). In aggregate, these verbal assessments define the target state of the fisheries system and the indifference ranges can also be used to reduce biases in further elicitation tasks.

Finally, I tested three simple ranking methods for eliciting relative preferences for different management objectives: (1) simple ranking of a list, (2) modified swing-weighting tasks, and (3) a newly developed computer-based graphical ranking task based on adjusting the relative vertical location of boxes representing the different objectives. I checked for consistency across methods and compared their feasibility in this type of setting.

1.2.3 Identifying options for in-season management

In many fisheries management situations, a clear and concise description of available management options for a specific decision should improve interaction among participants in the decision-making process. For example, options not considered by the original decision makers could be identified (e.g. closure of a certain area for fishing), or some of the options could be eliminated due to considerations not incorporated in the original decision. All options need to be clearly documented, even the ones that are rejected, so that they stay rejected. Describing options seems like a very basic requirement, but in practice often only the final decisions are recorded. When the options under consideration are not properly documented, problems arise in more complex fisheries management systems, where several technical, management, and stakeholder groups are supposed to reach decisions together over several months of pre-season planning. In-season management options for Atnarko chinook could be summarized quite simply, once the timing and process for the different management decisions were mapped out (see Section 1.3.3).

1.2.4 Guidelines for in-season assessment of stock status

Using the in-season management of terminal Atnarko chinook fisheries as an example, I illustrate an approach for developing simple summaries of complex assessment models and subjective interpretations of model output.

Salmon management in British Columbia often relies on information collected while the fisheries are occurring, due to the large uncertainty associated with pre-season projections of abundance, effort, and fishing success. For example, fisheries for Fraser River sockeye are adjusted weekly based on data collected from on-going commercial fisheries, specifically-designed test-fisheries, sampling of scales and DNA, hydro acoustic estimates, and counting fences (FOC 2003). Harvesters increasingly collect these data at their own expense, but perceive the resulting assessment and decision-making processes as a "black box". Similarly, the traditional division of responsibilities between scientific staff and fisheries managers creates situations where each group tries to guess the other's intentions. Analysts may try to guess which decisions will be triggered by their scientific assessments, and fisheries managers question which considerations influenced the assessments. This is particularly prevalent with precautionary adjustments to run size forecasts and allowable catches. Managers may wonder whether the forecast was already hedged towards the low end, and analysts may feel that all their forecasts are indirectly inflated by the managers before catch targets are determined. Sætersdal (1980) and Hammer and Zimmermann (2004) present evidence of this discrepancy.

Simple summaries of in-season status assessments are necessary to improve communication among all participants in the decision-making process, reduce mistrust, and enhance the consistency of decisions. All participants need to understand how in-season information is assessed and incorporated into specific decisions.

For Atnarko chinook fisheries, the fisheries manager assesses the expected end-of-season escapement each week during the fishing season, based on available in-season information, and plans fisheries accordingly for the following weeks. As described in detail below, I fit simple linear regressions to the weekly cumulative catch data in the Nuxalk food fishery after reviewing available in-season data for quantitative links to total spawning escapement, and combined the resulting weekly estimates into a single projection of total end-of-season escapement using Bayesian updating. The Bayesian method provides an attractive framework for integrating new information with the current projection of total escapement (e.g. Fried and Hilborn 1988). I evaluated the performance of the projection model through cross-validation, using the observed time series of in-season data.

In addition to providing this projection model, I presented the fisheries manager with observed and simulated sets of in-season data, elicited his assessments of stock status based on the model output, and fit classification trees to the responses. The resulting classification trees capture both the characteristics of the quantitative projection model and the subjective judgments of the fisheries manager. Classification and Regression Tree (C&RT) analysis can be used to construct a simple tree of binary choices to describe a user's assessment of the model output. C&RT models are widely applied in machine learning and medical decision making, because they provide an attractive non-parametric way to reduce a large body of expert knowledge into a simple aid to decision-making by identifying the minimum information required for a classification (e.g. Breiman et al. 1984, Gigerenzer et al. 1999, Venables and Ripley 1999). For example, Breiman et al. (1984) developed a tree for identifying high-risk cases among heart-attack patients entering emergency care, based on up to three yes-no questions, and the observed values of three variables. This simple classification tree outperforms a multiple regression model composed of 19 variables. In fisheries management, similar simplifications in descriptions of stock status assessment and harvest decisions would be very useful for improving consistency and communication.

1.2.5 Simple decision guidelines for in-season management of Atnarko chinook fisheries

During a final set of interviews with the FOC manager, we summarized all the elements of in-season decision making for Atnarko chinook fisheries in two simple decision tables, one mapping weekly in-season data onto a discrete status estimate, the second specifying management actions corresponding to the estimated stock status for each week of the directed, commercial chinook fishery in the Bella Coola Gillnet Area.

1.3 Case study background

I developed the concept of simple decision guidelines using the example of chinook fisheries in the Bella Coola/ Atnarko watershed in central B.C. It is therefore appropriate to provide some further background about these fisheries.

1.3.1 Management of Pacific salmon fisheries

FOC manages Canada's Pacific salmon fisheries under the dual mandate of conserving marine resources and managing their exploitation for the benefit of Canadians. Fisheries for Pacific salmon occur at sea and in freshwater, and generally target adults on their return migration to freshwater spawning grounds at the end of their life cycle. Due to the remarkable homing abilities of salmon, most return to their native stream or lake, and are managed as distinct populations based on their origin and migration timing, resulting in distinct annual fishing seasons. This migration pattern provides only short windows of opportunity for each group of harvesters in the different areas. Accordingly, salmon management follows an annual cycle of extensive pre-season planning, hectic in-season management during the migration, and sometimes acrimonious post-season review (e.g. FOC 2003). Consultation with stakeholders mainly occurs during the planning and review stages, while rapid in-season assessment and decision making falls to individual fisheries managers in small fisheries, or to larger panels for more complex systems, such as the Fraser River sockeye fisheries. Transparent and consistent in-season management therefore would benefit from clear and simple decision guidelines that are developed and reviewed prior to the fishing season. Stakeholders and fisheries managers need to agree pre-season on appropriate actions that will be taken under different circumstances.

A large body of policy documents and legal decisions establishes the overriding priority of long-term sustainability, and the priority of First Nations' food, social, and ceremonial (FSC) requirements over all other harvest interests (e.g. VanderZwaag 1992, Anonymous 2003, FOC 2001a, FOC 2003, FOC 2004). The relative priority of recreational and commercial fisheries differs by species. *An Allocation Policy for Pacific Salmon* (FOC 1999) identifies four distinct categories of chinook salmon use, which are in order of priority: (1) conservation, (2) FSC fisheries, (3) recreational fisheries, and (4) commercial fisheries.

Workable, widely accepted definitions of conservation requirements and these priorities of access to fish do not exist and acceptable trade-offs have not been specified. For example, marine commercial fisheries generally proceed if it is considered likely that up-river food fisheries later in the season will have adequate harvest opportunities. If run-size projections are revised downward during the season, and if commercial harvests have already exceeded the revised exploitation targets, food fisheries may be curtailed despite their clearly stated priority. This is a source of inconsistency and conflict in many fisheries, because local fisheries managers are required to find their own workable interpretations of these policies through consultation with local stakeholder representatives. Often the resulting agreements are not documented, which creates continuity problems as FOC staff and stakeholder representatives move between positions. An alternative approach, simple decision guidelines as defined in Section 1.1, would encourage participants in the decision-making process to specify management objectives and document management actions, which helps to retain the expertise even when individuals move on.

1.3.2 Chinook salmon in the Bella Coola / Atnarko watershed

Adult chinook salmon spawning in the Bella Coola /Atnarko watershed return mostly at age 4 and 5 years (each about 45% of the run), with some age 6. Most of the spawning occurs in the Atnarko River, the headwaters of the Bella Coola River (Figure 2). Snootli Creek hatchery began enhancing Atnarko chinook in 1981 due to extremely low spawning escapement (Figure 4 and Figure 5). Escapements show a steady increase since the low returns in the early 1980s. Catches were low for all harvester groups in the mid-1980s, when returns were below target escapement. As escapements once again approached target levels in the 1990s, catches increased accordingly. The stock recovered to target abundance during the 1990s, but enhancement continues. Atnarko chinook fisheries are actively managed in the terminal area, which is loosely defined by local FOC staff to include the marine approach and freshwater parts of the migration. Based on multi-year trends in performance measures and in-season information, harvests are regulated to achieve or exceed the target escapement of 25,000 fish.

In the terminal area, data are collected for the stock and each harvester group. Escapement estimates are derived from carcass surveys, drift net surveys, and adults collected in weirs to provide brood stock for the Snootli Creek hatchery. Commercial catch information is collected from aerial gear counts, sales slips, and dockside monitoring. An observer records all day-time drifts and catches in the Nuxalk FSC fishery, and regularly visits fishing holes, lodges, and campsites for representative catch and effort data from the recreational fishery. These data are extrapolated to total catch and effort for each sector based on the observer's experience.

Very little information is available about interceptions in Alaska and along the North coast of British Columbia, so these catches are considered part of the highly variable and uncertain ocean mortality. However, this may change over the next few years because in 2002 the Pacific Salmon Commission designated the Atnarko as a key stream under the Canada-US Pacific Salmon Treaty, providing for increased data collection and assessment.

1.3.3 Harvester groups in the Bella Coola area

Three groups of harvesters fish for Pacific salmon in British Columbia. Commercial fisheries, licensed to sell their catch, generally occur in marine or estuarine areas, are vessel-based, and use gill nets, seine nets, or troll gear. Commercial fisheries have traditionally concentrated on these so-called off-shore and approach areas, because the price/kg of their catch decreases as salmon undergo the physiological changes necessary for transition into freshwater, up-stream migration, and spawning at the end of their life cycle. Recreational fisheries and traditional First Nations fisheries mostly take place near-shore and in-river. This established geographic pattern of exploitation is undergoing changes as commercial harvesters are under pressure to harvest closer to spawning rivers in order to fish more selectively and reduce incidental catches.

Harvesters from all three sectors target chinook in the Bella Coola area (Figure 2). Each group is managed individually based on their different objectives, harvest methods, and effort dynamics. The Nuxalk band harvests salmon in-river near the mouth of the Bella Coola River using drift nets from small row boats. Recreational anglers have access to several fishing spots further up-river, but also fish from drifting boats. Commercial harvesters fish for Atnarko chinook with gill nets further seaward in the inlet. Chinook migrate through the fishing areas for all three harvester groups within a week. The chinook fishery is only one of the local harvest opportunities (Table 1).

The general management approach to the local chinook fishery is cautious, with a conscious trade-off between stable access and catches, both yearly and long-term. Essentially, some of the projected harvestable surplus is allocated to buffer against variable returns, so that drastic in-season changes are generally not required in response to revised estimates of returns. All three groups of harvesters in the Bella Coola area have repeatedly expressed a strong preference for stable access, making this approach feasible given current levels of abundance. There is no demand for an explicit definition of catch sharing, but rather the understanding that each sector has a fair and stable pattern of opportunity, while actual catches are naturally expected to fluctuate considerably. This approach is much less confrontational than the specific allocations of catch that have been developed for other fisheries, where they cause extensive problems when confronted with the inherent variability and uncertainty of fisheries resources (e.g. a fixed percentage of total allowable catch assigned to each group of harvesters). Concurrent openings for the three harvester groups and weekly reviews provide additional safeguards against scenarios where any particular group is disproportionately affected by revised estimates of abundance. Under these conditions, the local agency staff felt that any attempts to develop formal sharing arrangements may actually be detrimental to the currently stable situation. However, catch sharing would likely become a much more controversial issue at low abundances, when all three harvester groups would have to be restricted in some form.

The remainder of this section provides a brief overview of each fishery, harvesters' preferences, and the current management approach.

The Nuxalk FSC fishery

Harvesters in the Nuxalk FSC fishery drift about 6.5 km down the lower Bella Coola River while rapidly adjusting the net by hand. They catch chinook for immediate consumption early in the season (June/July), and preserve chinook caught later on for the winter. Nuxalk FSC fishing effort, measured as the number of drifts, peaks in June and July (Weeks 22 to 30), targeting chinook and sockeye. When large number of pinks swamp the river in August (weeks 31 to 34), the drift netting essentially stops. Effort picks up again in September, targeting coho, but catch-per-unit-effort is much higher, and total effort levels are relatively low. The Ulkatcho band also harvests a limited number of chinook in the Atnarko River.

Harvesters in the Nuxalk Food, Social and Ceremonial Fishery want to have adequate and reliable access to all targeted salmon species, with minimal changes to established harvest patterns. Current food fisheries, like traditional fisheries, are controlled by local dietary demand, and fall far below the negotiated communal quota of ten thousand chinook (Table 1). If the illegal sale of food fish becomes an issue, and direct local demand fails to regulate effort, external effort restrictions may be necessary. However, traditional values and social repercussions among the Nuxalk discourage the sale of fish caught in the food fishery and illegal sales are currently not a concern.

Management of the Nuxalk FSC fishery

Management of the FSC fishery is based on agreements negotiated between FOC and the elected Band Council through the Aboriginal Fisheries Strategy. Through a communal license, all band members have the right to fish for FSC purposes during open times, but FOC has the authority to unilaterally change fishing regulations in-season to reduce the impact of FSC fisheries. In the emerging legal situation, this may constitute an infringement on aboriginal rights and would probably have to be defended in court later on. In general, any changes to the FSC regulations are a major decision made between seasons in consultation with Nuxalk representatives. However, if in-season information unexpectedly indicates very poor returns, FOC and Band Council could probably agree on an appropriate response. Also, catch-per-unit-effort in the FSC fishery declines rapidly as returns decrease, increased effort can't compensate, and catches decrease accordingly. Currently the FSC fishery is open 4 days per week all year, but fisheries only occur when salmon are in the river. The 3-day weekly closure is intended to let a portion of each run segment pass undisturbed and is well enforced socially within the community (Lyle Enderud, FOC Bella Coola, pers. comm.). Chinook catches in the Nuxalk fishery early in the season are generally intended for immediate consumption, so that changes to the duration of the fisheries opening would simply redistribute effort without reducing the overall catch. At very low run sizes, this fishery could be curtailed once all other fisheries are closed.

The recreational fishery in the Bella Coola/Atnarko watershed

Recreational harvesters, mostly locals or regulars, frequent fishing holes along the Bella Coola and Atnarko Rivers. As the season progresses, they target first chinook, then pink salmon, and finally coho. Recreational effort, measured in angler days, shows 3 distinct peak times, closely corresponding to the run timing for chinook in June/July (weeks 20 to 30), pink salmon in August (weeks 31 to 34), and coho in September.

Harvesters in the in-river recreational fisheries in the Bella Coola/Atnarko system are a diverse group, and their motivation differs by target species. Beginners, families out camping, and other recreational users generally target pink and chum salmon, which are very abundant and relatively easy to catch. Chinook salmon are much larger, less abundant, and of higher quality. They attract more serious anglers looking for a challenge, and many of these sport fishers are regulars who come for a fishing holiday to the same fishing hole every year around the same time. Accordingly, overall fishing success is less important for chinook anglers in this area than quality of the fishing experience, individual success, and reliable openings.

Management of the recreational fishery in the Bella Coola/Atnarko watershed

Management of the recreational chinook fishery in the Bella Coola / Atnarko watershed is complicated by the diversity of anglers and their loose organization. Fisheries managers have the legal authority to open and close the sport fishery in-season on short notice. However, the *Allocation Policy* (FOC 1999) provides sport anglers priority for predictable and stable access to chinook, ahead of the access priority for commercial fisheries, once conservation and First Nation's needs have been met. In practice, recreational fishing regulations are decided annually through pre-season consultations on a regional level. In the past, local in-season decisions led to earlier closures when in-season projections of escapements were very low. This resulted in a severe backlash from recreational stakeholder organizations and had little effect on escapement, because catches declined rapidly at low run sizes anyway. Substantial changes to sport fishing regulations and openings would preferably happen between seasons, based on multi-year trends. While FOC always has the legal option of a rapid in-season response to unexpected conservation concerns, the due process for these changes includes consultation with local and regional advisory boards. Simple decision guidelines, developed ahead of time and covering a range of possible scenarios, have the potential to speed up the response in these situations, and reduce any backlashes that are often triggered by lack of communication.

Current management measures for the recreational fishery include (1) non-retention of chinook salmon after about July 15th on the Atnarko, and a complete closure on smaller tributaries, to protect spawning chinook salmon, (2) year-round closure of the Upper Atnarko to protect spawning habitat, (3) bait ban until May 15 to reduce by-catch of steelhead, and (4) mandatory single barbless hooks to reduce catch-release mortality. During the open season, there are no weekly closures, but catch and possession limits exist. Province-wide catch limits for chinook currently are: 1 per day, 2 in possession, 10 per year. Regardless of actual catches this is considered "full limits" under the *Allocation Policy,* intended to satisfy sport fishing priority requirements so that commercial openings are possible. FOC managers could change these limits locally, but in practice they would adjust effort and harvests through area and gear restrictions. At very low run-sizes this fishery could be curtailed once the commercial fishery is closed.

The commercial gill net fishery in the Bella Coola area

Commercial harvesters with Area C gill net licenses can fish in the Bella Coola Gill Net Area, but only a small part of the fleet actually participates in the openings, and in recent years only 30 to 80 of about 800 eligible vessels joined the chinook fishery in June. Effort levels are low, because the fishing area is far away from the more lucrative fishing grounds, catches are low, special nets are required, and openings are stretched out over a long period. Commercial gill net effort, measured in boat days, shows two peaks, first in June/July targeting chinook with relatively small catches, and then in August harvesting pink and chum salmon in much larger quantities. In recent years, peak effort targeting chinook averaged about 40 boats.

Actual catches may not be as important in this commercial fishery as in others, but predictable openings have a much higher priority than in other commercial fisheries. The chum salmon fishery in July provides the main source of income for local gill netters and some go to Prince Rupert to target Skeena River sockeye in June, while others stay in Bella Coola for the chinook fishery. Most of the gill netters harvesting Atnarko chinook in June are locals or regulars using this opportunity almost as a "way-of-life" fishery. A small number of additional boats may participate if the North Coast fisheries close early, and they have time to fill before the Johnstone Strait fisheries open further south (Figure 2).

Management of the commercial gill net fishery in the Bella Coola area

Openings for the commercial fishery in the Bella Coola Gillnet Area are determined during the season, but the general regulatory approach (gear restrictions and area boundaries) is developed pre-season with the Central Coast Advisory Board. Closed areas and gear restrictions are determined based on long-term trends in abundance, incidental catches, and fishery performance. During the fishing season, local FOC managers open and close the commercial fishery, based on some generally accepted guidelines and in-season information from the food fishery and previous commercial openings. Generally, the gill netters target chinook salmon throughout June and switch to directed chum salmon fisheries with smaller mesh nets in July, with possibly substantial chinook catches during the early part of July. A 1-day assessment fishery during the first week of June is planned if escapement in recent years indicates that commercial fishing opportunities are likely. For the remainder of June, weekly fishery openings can range from 1 to 3 days. Four-day openings delay the delivery of the catch and reduce its value, and, as in the food fishery, there is a 3-day weekly minimum closure. Commercial openings tend to be scheduled early in the week, so that processing plants don't have to work on weekends.

Commercial harvesters clearly prefer a stable pattern of openings. Fisheries managers generally attempt to spread out chinook openings over the full four weeks, and to announce the full duration of each opening during the previous week, rather than deciding on extensions on a daily basis. However, daily hails are used to monitor the fishery. Similarly, harvesters here prefer shorter, but weekly, openings to a single longer opening.

Seine boats used to fish Fisher/ Fitzhugh Sound for chinook further out on the coast, intercepting some from the Atnarko. However, seine boats are not currently harvesting Atnarko chinook in terminal fisheries, because chinook non-retention for seines was implemented in 1999 due to concerns for West Coast Vancouver Island, Rivers Inlet, and other chinook stocks passing through that area.

Even though chinook fisheries in the Bella Coola area represent a relatively small fisheries system, the background information in this section shows the many practical challenges faced by local FOC staff. The next section reviews some of the tools recommended in the fisheries literature to assist them with making decisions, and concludes by showing that the concept of simple decision guidelines, introduced earlier in this report, combines the common elements of these tools.

1.4 Review of decision support in fisheries management

Simple decision guidelines hold promise for dealing more effectively than other decision-support tools with some of the management challenges in these fisheries. The concept of simple decision guidelines is flexible, and draws on the common aspects of many decision-support tools already described in the fisheries literature. The following sections provide a brief review of these tools, identifying strengths and limitations, and concluding with a synthesis of common elements.

1.4.1 Types of decision-support tools

Decision-support tools can be categorized based on the emphasis they place on different aspects of the decision process. Multi-attribute utility analysis, the analytic hierarchy process, and choice modeling focus on eliciting preferences for different outcomes from decision makers. Formal decision analysis is a quantitative tool that helps to choose one of several options in the presence of uncertainty. Control rules and management procedures prescribe management responses to changing states of the resource. Reference points have been used as either management objectives, trigger points for management actions, or indicators of resource status. Control rules, management procedures, and reference points can be developed using preference elicitation techniques and decision analysis. Each is discussed in more detail below.

Many more decision-support tools could be described here, but I have limited this overview to tools with peer-reviewed applications in fisheries management. Also, some of the tools discussed here fall into very different categories (e.g. utility theory and control rules). However, in my experience they are frequently misrepresented in fisheries management discussions, and their intended uses are often misunderstood. The overview below describes their similarities and fundamental differences.

1.4.2 Multi-attribute utility theory

Multi-attribute utility theory (MAUT) provides a consistent framework for expressing preferences and trade-offs in a quantitative format suitable for use in computer-based optimization. Analysts first identify a set of variables describing the most important concerns of respondents, and then elicit stated preferences regarding (1) trade-offs between a certain outcome and the expected value of an uncertain gamble, and (2) pairwise comparisons between variables given both certain outcomes and uncertain gambles. This approach forces respondents to consider uncertainty and translates different attribute values into a common denominator expressed as an abstract unit called utiles. Several attributes can be combined into additive or multiplicative multi-attribute utility functions based on assumptions about interactions between attributes. Keeney (1977) was the first to apply the method to fisheries, using Skeena River sockeye fisheries as an example. He illustrated the potential benefits of this approach, particularly the ability to formally quantify value trade-offs and to incorporate the decision-makers' attitude towards risk.

MAUT has a well-established theoretical foundation (e.g. Keeney 1982), but practical implementation is difficult in fisheries management settings, especially in participatory processes. Extensive mathematical expertise is required to elicit and analyse utility judgments, which confines the use of this method to scientific staff. Considerable patience and technical background is also necessary to sensibly answer dozens of questions such as "Do you prefer a guaranteed catch of 500,000 fish for all commercial harvesters, or a 50:50 gamble of catching either 750,000 fish or 250,000 fish? ". Aggregating utility functions from multiple respondents, or from different interest groups, requires relative values for the expressed preferences of different participants in the decision-making process, which managers are hesitant to provide. Conditional weightings, where a person's preference for one attribute is conditional upon the value of another attribute (e.g. abundance), also create problems when eliciting utility functions (Keeney and Raiffa 1976).

Applications of MAUT in fisheries management have therefore been limited to elicitation from experts (Keeney 1977, McDaniels 1995), or theoretical explorations (Walker et al. 1983, Healey 1984, Healey 1985, Bain 1987). In fact, not much seems to have changed since Fischer (1979) highlighted the lack of practical applications and identified commonly held reservations about the predictive validity of utility models.

However, Hilborn and Walters (1977) found that the process of eliciting utility functions from stakeholders and agency staff in a workshop setting is useful because it "forced the [workshop] participants to state exactly why they preferred one outcome to another". Similarly, Walker et al. (1983) observed that the "greatest benefit of [multi-attribute utility analysis] was in isolating major objectives and conflicts, trade-offs, and needed empirical evidence", and that the "process was useful [...] in promoting discussion".

1.4.3 Analytic hierarchy process

The analytic hierarchy process (AHP) is an alternative method for decomposing complex decisions into smaller, more manageable elements. It's development was motivated by the perceived lack of simple, practical methods, and AHP has been applied in a wide range of fields (Saaty 1994, Formann and Gass 2001). Merrit and Criddle (1993), DiNardo et al. (1989) and Leung et al. (1998) applied AHP in fisheries management settings.

AHP differs from MAUT both in the general approach and in its theoretical foundation (Forman and Gass 2001). The most fundamental differences are: (1) AHP preserves the full hierarchy of management objectives, while utility models only aggregate the quantifiable objectives at the bottom of the hierarchy (e.g. Keeney 1977). Figure 6 illustrates this difference. AHP elicits pairwise comparisons for all the objectives in each row of boxes in the figure, while a multi-attribute utility function combines only the quantifiable attributes in the bottom row. (2) AHP is used to elicit preferences regarding objectives, alternative options, or different outcomes, while utility functions evaluate only outcomes. (3) AHP estimates weights based on relative preferences in pairwise comparisons of objectives or alternatives, but does not distinguish between certain outcomes and uncertain outcomes. (4) AHP weights are often elicited without reference to the values of an attribute (e.g. Saaty 1994, Leung et al. 1998), but in some cases the possible range of values for each attribute are shown to respondents (e.g. Hobbs and Meier 2000). (5) AHP practitioners have used simple verbal or numerical scales as well as graphical interfaces for eliciting weights from large groups, whereas utility models require intensive one-on-one interviews. Forman and Gass (2001) summarize the on-going debate around theoretical differences between AHP and MAUT.

Fisheries management applications of AHP illustrate benefits and shortfalls of the method. AHP has successfully engaged large groups of respondents and provided rankings of a large number of elements.

Through a series of phone, fax, and mail interviews, Merrit and Criddle (1993) elicited preferences from 15 stakeholder organizations regarding 93 unique, but not necessarily exclusive, management options. Leung et al. (1998) used mail surveys to elicit preference assessments of 41 objectives and four management options from 66 members of a fisheries management council. However, the respondents were left to make their own assumptions about causal relationships between management options and their associated outcomes. The results therefore don't provide insight into why a particular option was preferred.

1.4.4 Choice Modeling

Choice modeling (CM) provides a third approach to eliciting and understanding preferences, which differs from both MAUT and AHP. Aas et al. (2000) describe an application in recreational fisheries. Respondents choose among two outcomes described as sets of values for all attributes, called profiles, rather than between two aspects of the same attribute as in MAUT, or between two attributes as in AHP. Choice models use statistical survey methods to elicit preferences from numerous respondents, and estimate interactions between attribute levels based on varying the profiles according to factorial experimental designs. Profiles can describe both management options and performance (Aas et al. 2000), but they are paired based on the factorial design, not based on a consistent model of causal relationships. The results therefore can only provide insights such as "A 35 cm minimum size limit is preferred *if* it is expected to result in more than a 2 cm increase in average length, regardless of average catch".

Some recent applications of CM have included uncertain attributes in the profiles presented to respondents. For example, Rasid et al. (2000) asked flood plain residents to consider different probabilities of flooding as one factor when choosing among evacuation strategies. However, this is not the same as choosing between a certain outcome and the expected value of an uncertain outcome, as in MAUT. Both AHP and CM should be easily adaptable for distinguishing between certain and uncertain outcomes, but this aspect has not been explored in any of the studies reviewed here.

1.4.5 Decision Analysis

In the fisheries literature, the term decision analysis (DA) is used in the narrow context of statistical decision theory. Authors in other areas of research use the term to capture all analytical tools designed to support decision makers, which would include most of the methods mentioned in this review. For consistency, I use the term in its fisheries-specific meaning related to statistical decision theory, which captures the steps described below.

Decision analyses focus on establishing a causal link between alternative management actions and their forecasted outcomes given sources of uncertainty. Revisiting the example from the previous section, decision analyses can provide insights such as "A 35 cm minimum size limit *should be* preferred *because* it is expected to result in more than a 2 cm increase in average length, and a negligible decrease in average catch". Keeney (1982) identifies four basic steps of decision analyses: (1) identify management options, objectives and relevant attributes, (2) determine the likely effect of alternative options under uncertainty about underlying mechanisms (e.g. stock dynamics), (3) quantify decision makers' preferences, and (4) evaluate alternatives and test robustness of results. Paulik (1966) first applied the method in fisheries, and many others have used it to evaluate management options and implications of uncertainty. Recent publications focusing on Pacific salmon include Walters (1975), Walters

(1986), McAllister and Peterman (1992), Peterman et al. (1998), Robb and Peterman (1998), Peters et al. (2001), and MacGregor et al. (2002).

Of the decision-support methods discussed here, DA is the only one that emphasizes detailed quantitative models for assessing likely effects of alternative actions, and therefore is the only one that can show which options should be preferred, given the best available data. Respondents express their preferences for different outcomes, and simulations show which option most likely satisfies those preferences. Assessments of objectives and alternative actions are clearly separated. As originally conceived, preferences should be incorporated as multi-attribute utility functions (Keeney 1982), but fisheries management applications have assessed alternative actions using a set of performance indicators that were not combined into a single function (e.g. Robb and Peterman 1998), or economic measures such as net present value (e.g. Walters 1975, MacGregor et al. 2002). Just as for MAUT, practitioners of DA acknowledge a lack of practical implementations (e.g. von Winterfeldt 1983).

1.4.6 Control rules and management procedures

Most evaluations of fisheries management decisions focus on the technical complexity of cause-and-effect modelling, and compare a few control rules with respect to a small subset of operational objectives. Commonly used objectives include (1) maximizing mean abundance, mean catch or net value, and minimizing variability in catch, (Walters 1975, de la Mare 1986, Gould et al. 1991, Eggers 1993, Rosenberg and Brault 1993, Frederick and Peterman 1995, Starr et al. 1997, Shelton 1998, Su and Adkison 2002), (2) avoiding low stock sizes or low recruitment (Butterworth and Punt 1999), (3) maximizing probability of recovery (Polachek et al. 1999), or (4) maximizing the value of information (Collie et al. 1990, Link and Peterman 1998). However, each of these analyses addresses in great detail only one component of the decision environment faced by fisheries managers.

Practical analyses of management options need to go further. Management procedures are one way to do this. They are an extension of harvest control rules, and also specify the data to be used and a protocol for their collection (de la Mare 1998, Butterworth et al. 1997, Butterworth and

Punt 1999, Geromont 1999). Management procedures have the same basic elements as management "clockworks" (Hilborn and Luedke 1987), formal harvesting strategies (Flaaten et al. 1998), management strategies (Kirkwood and Smith 1995, Sainsbury et al. 2000), and applications of fisheries management science (Stephenson and Lane 1995).

1.4.7 Reference points

Reference points (RP) are closely linked to simple decision guidelines (as defined in Section 1.1), but the two concepts are quite distinct. Reference points serve as indicators of resource status, whereas decision guidelines help determine the appropriate management action in response to that information. These two concepts necessarily complement each other, and this close connection is acknowledged in key documents on reference points: RP-based management implies pre-agreed decision-making procedures given an estimated status of the stock (Caddy and Mahon 1995, Caddy 1998, Caddy 2002). In addition, the extensive literature on reference points provides valuable insights into potential pitfalls associated with decision guidelines.

Reference points form an integral part of the precautionary approach to fisheries (FAO 1995a, FAO 1995b, Caddy 1998), and have become a cornerstone of many national and international policy initiatives. However, many misconceptions exist about the purpose and validity of reference points. They are not, by themselves, management objectives, nor are they necessarily trigger points for decisions. They are simply "quantitative indicators of variables such as fishing mortality rate, yield or stock biomass, by which the current state of a fishery can be judged" (Rosenberg and Restrepo 1995). Reference points can be used to define desired and unacceptable states of the resource once clear objectives have been set, but they do not determine what is desirable or unacceptable. Three types of reference points are commonly used: (1) limit reference points (LRP), which define highly undesirable states to be avoided (e.g. stock abundance below which probability of collapse exceeds 30%), (2) target reference points (TRP), which define management objectives (e.g. stock abundance that maximizes recruitment), and (3) management reference points (MRP), which trigger management actions designed to keep the stock away from

LRPs and close to TRPs. An example of a MRP would be a stock abundance at which exploitation rate is reduced.

Conflict arises because some consider reference points equivalent to decisions, whereas others consider them information to be included in decision making. Essentially, LRPs are sometimes interpreted as MRPs, and vice versa. Gauthiez (2000) observes that "precautionary reference points are used for two different purposes at the same time: bounds of confidence intervals and trigger points for decision making. These different purposes are not necessarily compatible."

Most of the scientific work on reference points has focused on biological characteristics such as stock size and fishing mortality (e.g. Rosenberg and Restrepo 1995), but a recent shift towards a broader interpretation of the precautionary approach to include social and economic considerations (e.g. Hilborn et al. 2001) should prompt the development of similar concepts for fishing communities and industry.

1.4.8 Common elements and synthesis: simple decision guidelines

The decision-support tools described in previous sections cover a wide range of theoretical and applied work. However, they tend to be designed for highly-trained technical staff to provide decision support. Their wide application is impeded by the effort and technical expertise required to work through the overwhelming body of literature with inconsistent terminology, and then choose the most appropriate method among similar approaches with subtle differences. After testing different decision-support tools in water use planning, Hobbs et al. (1992) found that "the wide variety of available techniques confuses potential users", "experienced planners generally prefer simpler, more transparent methods", and "many preferred to use no formal method at all". The same seems to hold true in the day-to-day operations of fisheries management organizations. In several other applications of multi-attribute utility functions, the authors also identify the process of developing management objectives and alternative options as the most useful component of the analysis (e.g. Hilborn and Walters 1977, Walker et al. 1983). If the process is the most useful component, why insist on methods that are so complex that the majority of staff in a management agency are effectively prevented from using them?

The concept of simple decision guidelines arises from the observation that all of the complex methods described in earlier sections have basic steps in common, and vary only in technical details. They all encourage decision makers to (1) specify a hierarchy of management objectives, (2) identify alternative management options, and (3) consider their management responses to alternative estimates of the state of the resource. Frameworks developed for fisheries management, such as management procedures (Sec 1.4.6), also emphasize a fourth component: (4) how data are collected and interpreted in terms of the status of the resource. Together, these basic steps correspond to the four components of simple decision guidelines described earlier:

- Management objectives
- Management options
- Guidelines for assessing the status of the resource
- Guidelines for management responses to status assessments

These are very basic steps that experienced practitioners of decision analysis or AHP use when setting up their analyses (e.g. vonWinterfeldt 1983). However, the wide use of these basic steps among the staff of fisheries agencies can at the very least set the stage for more detailed analyses, and has the potential to improve decision-making in these large organizations as well as the performance of fisheries.

2 Methods

2.1 Overview

To develop simple decision guidelines for Atnarko chinook fisheries, I cooperated closely with local fisheries management staff (Fisheries and Oceans Canada, Bella Coola) and participants in the Central Coast Advisory Board. For each of the four components of simple decision guidelines, I worked towards simple methods to elicit information from one respondent, the senior fisheries manager (Lyle Enderud, FOC, Bella Coola) and communicate it to the other participants in the decision-making process, usually other FOC staff and representatives from harvester groups. I elicited management objectives, structured management options, developed an in-season projection model, evaluated the manager's interpretation of model output, and summarized in-season decision making for Atnarko chinook fisheries in two simple decision tables.

The details for each step follow in the next sections, but throughout the entire project I relied heavily on interviews and the detailed records accumulated by local FOC staff. Bella Coola staff have compiled annual summaries of the fishing season since the early 1980s, called *Records of Management Strategies.* These contain weekly records of available information and resulting decisions, minutes of advisory meetings, and post-season summaries of all collected data, resulting in a comprehensive 20-year record of management actions and their rationale. The full set of records is available in electronic format through the Bella Coola office of FOC.

2.2 Eliciting management objectives

Simple decision guidelines are developed through an iterative process (Figure 3), but management objectives are the most appropriate starting point for presenting methods and results. In this section I describe the methods I used to first develop a hierarchy of management objectives, and then to determine their relative importance within that hierarchy.

2.2.1 Structuring management objectives hierarchically

I developed an extensive list of management objectives for the local chinook fisheries based on interviews with local FOC staff and stakeholders, documented management policies, and records from previous management seasons. During these interviews, FOC staff were best able to identify management objectives when discussing past fishing seasons and the regulations implemented at the time. Objectives relating to incidental catches, for example, were determined through asking questions such as: "Why did you close that creek for fishing?" and "Why is there a minimum mesh size specified for the commercial fishery?", rather than through questions such as "What are your by-catch objectives?"

Hierarchical structuring of objectives is a common first step for many decision-support tools (e.g. Borcherding and von Winterfeldt 1988, Keeney and McDaniels 1999, also see Section 1.4), and has several advantages over non-hierarchical methods: (1) Policy and data gaps become obvious when decision-makers are unable to provide quantitative attributes describing higher-level objectives. With non-hierarchical methods, decision-makers may simply choose attributes based on what data are available. (2) By nesting similar attributes within a hierarchy, we can minimize problems with double counting and conceptual interdependence (Hobbs and Meier 2000). (3) For the same number of attributes, hierarchical structuring also simplifies the process of eliciting preferences.

Figure 7 shows how clustered comparisons within a hierarchical structure of management objectives can greatly reduce the number of comparisons required to rank or weight 10 attributes. Using non-hierarchical methods, such as MAUT, respondents have to judge pairwise comparisons between all attributes. For 10 attributes this means at least 45 comparisons, but usually more to allow for consistency checks. When using hierarchical methods, such as AHP, similar attributes are grouped together. Respondents judge pairwise comparisons between attributes within a group, and between groups. For example, nesting the 10 attributes into three groups reduces the minimum required number of pairwise comparisons to 15. Methods that move beyond pairwise comparisons, such as the computer-based graphical ranking described in the next section, further reduce the number of required judgments. With 10 attributes in three groups, as few as 5 judgments may be sufficient. This reduction in required judgments makes the process of eliciting preferences less repetitive and tedious, which should improve the interaction between analysts and respondents and make answers more consistent.

For this case study, I tested several contained hierarchies, in which higher levels consist of, and fully contain, all elements at lower levels. Figure 6 illustrates this type of hierarchy. Different hierarchical structures emphasized different aspects of the management objectives. For example, we tried to structure objectives by geographic scale to match the area-based management organization of FOC, but quickly found that this representation did not provide the kind of information the manager wanted to communicate to other participants in the decision-making process. However, that format may be useful for institutional analysis focusing on policy development processes within FOC. Rather than untangling the web of national, regional and local policies, and determining the spatial extent of their applicability, the manager felt it was more important to show how broad policy is applied and interpreted in this specific fishery. In the end, we grouped objectives by user group and temporal extent into general objectives, multi-year objectives, and annual objectives. Management objectives that did not fit in this hierarchy were also documented.

Where possible, I then defined measurable attributes for the operational objectives using available data, and elicited from the fisheries manager a combination of indifference ranges and verbal assessments for each range. Indifference ranges describe a range of values for an indicator over which the respondent is indifferent, because the data are uncertain and the management response would not change. For example, based on the current management approach and precision of escapement estimates for Atnarko chinook, the manager was indifferent to fluctuations in estimated escapement within the range of 9,000 to 16,000 (see results in Section 3.1), as noted previously.

Verbal assessments were flexible enough for the fisheries manager to be more or less specific in his answers, depending on his comfort level, and to convey nuances of preferences. For example, he used the assessments (1) "best level and long term goal" (2) "acceptable over the medium term", (3) "acceptable over the short term", and (4) "unacceptable" to describe four ranges of hatchery contribution to total returns (see results in Section 3.1). This approach captures more information than simply asking respondents whether different performance measures should be minimized or maximized. Such information may even serve as a reasonable approximation to a univariate utility curve and the indifference ranges can also be used to reduce biases in further elicitation tasks. In aggregate, the verbal assessments define the target state of the fisheries system.

2.2.2 Eliciting relative preferences for management objectives

The qualitative assessments described in the previous sections provide an initial indication of the fisheries manager's preferences, but do not show how he values these objectives relative to each other, and which trade-offs he considers during the management of Atnarko chinook fisheries. In the next step of the analysis, I asked the fisheries manager to rank the objectives and attributes in Table 2 according to their relative importance.

I used three simple methods to elicit quantitative preference information: (1) ranking in a list, (2) a newly developed, computer-based graphical ranking task, and (3) modified swing-weighting tasks. Elicitation for all three methods followed the same structure. First, a set of ranking tasks compared the higher level elements (general objectives, multi-year objectives, and annual objectives). This prepared the respondent for the more detailed tasks by establishing the context of broader management objectives and familiarizing him with the computer-based interface. Then, a set of ranking tasks compared specific attributes and levels of those attributes. Figure 8 and Figure 9 show sample tasks from the swing-weighting and graphical ranking tasks. This top-down move through the hierarchy of management objectives is consistent with the approach for more complex methods (Weber and Borcherding 1993).

Swing-weighting tasks are used in simplified preference elicitation methods (Weber and Borcherding 1993, Edwards and Barron 1994), but I am not aware of any applications in fisheries management. With swing-weighting, respondents identify the order in which they would take action to improve each attribute from its worst to its best level, and ranks are converted into weights for additive utility functions. I used a slightly modified set-up for comparing qualitative objectives, asking the respondent to switch from unspecified undesirable levels to desirable levels (Figure 8). For comparing quantitative attributes, I presented the respondent with full descriptions of attributes at their worst and best levels.

Graphical elicitation methods are potentially useful additions to the decision-support toolkit. Most people can interpret and manipulate graphical information more easily than text or numbers (Tufte 1983), making multiple simultaneous comparisons more feasible in graphical formats. Participants in a fisheries setting may also be more easily engaged in an elicitation method that allows them to capture the vague aspects of management objectives and directly assess the consistency of their responses, rather than a method like MAUT that forces them to provide exact numerical judgments in a series of pairwise comparisons (Sec 1.4.2). Some software applications provide graphical interfaces for eliciting ranks or weights, but no generally accepted format exists. For example, in the ExpertChoice® package for the Analytic Hierarchy Process, respondents can adjust the relative length of vertical bars for pairwise comparisons (Formann and Gass 2001). However, it is not clear whether respondents' preferences correspond more closely to the relative length or area of these bars, and multiple comparisons would be difficult.

To test a possible alternative lay-out, I asked the fisheries manager to express the relative priority of different management objectives by vertically adjusting the locations of a series of equally-sized boxes, each containing a brief description of the management objective, attribute, or attribute level (Figure 9). This approach is analogous to eliciting utility scores for each level of an attribute, but with several advantages: (1) Preference statements can be elicited simultaneously for all elements in the hierarchy of management objectives, and for qualitative objectives lacking measurable attributes. (2) Simultaneous comparisons of multiple elements allow respondents to assess the full context for each comparison. (3) The interface encourages repeated revisions and small adjustments as respondents compare subsets of elements relative to each other. (4) Multiple comparisons within the hierarchy of objectives reduce the number of required comparisons (Figure 7).

2.3 Identifying options for in-season management

In a series of semi-structured interviews, I worked with the fisheries manager in Bella Coola to identify (1) the timeline of main decision points in the annual cycle of pre-season planning, in-season management, and post-season review, (2) factors influencing the decision at each of these points, and (3) the participatory processes in place to arrive at a decision. Graphical aids, such as influence diagrams, decision trees, and flow diagrams proved very useful during the discussions.

The process of developing simple decision guidelines is iterative (Figure 3), and the results for each of the four components influence each other. For consistency, I describe the management options considered by the fisheries manager as part of the Results (Section 3.3).

2.4 In-season model for assessing stock status

2.4.1 Overview

The third step in the development of simple decision guidelines, after eliciting management objectives and identifying management options, is to develop guidelines for assessing stock status. In this case study, I developed simple in-season guidelines for classifying the status of Atnarko chinook into one of four categories. The in-season guidelines capture two analytical steps: (1) using in-season data to calculate projected escapement, and (2) evaluating the projections (Figure 10). In this section, I describe the projection model. Section 2.5 covers the fisheries manager's interpretation of the projections and a method for developing simple summaries of complex models.

I provided the fisheries manager with an in-season model for projecting total end-of-season chinook escapement based on weekly in-season data. I built this model in MS Excel to ensure that it could be easily used and circulated by FOC staff.

2.4.2 Structure of the projection model

To calculate weekly forecasts of total escapement, I applied the Bayesian updating methods described by Fried and Hilborn (1988) and Cox-Rogers (1997) to combine independent weekly estimates ($\hat{E}_{t,w}$) of total end-of-season escapement (E_t) of adult chinook into the Bella Coola/Atnarko watershed. Each week's projection of total escapement for the current year *t*, calculated in week w, is based on n years of observed escapement E_i, n years of historical in-season information $D_{i,w}$, and a new observation $D_{t,w}$:

(1) $$\hat{E}_{t,w} = f(E_i, D_{i,w}, D_{t,w}) \qquad i=1,\ \ldots,\ n$$

where *i* are the years of data used to fit the regression. For example, the projection $\hat{E}_{2002,24}$ of end-of-season escapement in 2002 (E_{2002}), calculated in week 24, is given by:

(2) $$\hat{E}_{2002,24} = f(E_i, D_{i,24}, D_{2002,24}) \qquad i = 1980,\ \ldots,\ 1993,\ 1995,\ \ldots,\ 2001$$

where E_i are the observed escapements from 1980 to 2001 excluding 1994, $D_{i,24}$ are the observed in-season data in Week 24 for those years, and $D_{2002,24}$ is the new observation. The m independent weekly estimates of $\hat{E}_{t,w}$ in the current year, and their estimated uncertainties, are combined to yield the Bayesian projection:

(3) $$\hat{E}^B_{t,w} = f(\hat{E}_{t,w-j}) \qquad j = 1,\ldots,m$$

For example, the Bayesian projection in week 25 of 2002 is given by:

(4) $$\hat{E}^B_{2002,25} = f(\hat{E}_{2002,22}, \hat{E}_{2002,23}, \hat{E}_{2002,24}) \qquad j = 1,2,3$$

2.4.3 Data sources

Information about spawning escapement, catches, effort levels and river conditions forms the basis of weekly status assessments. All data were provided by Lyle Enderud (Fisheries and Oceans Canada, Bella Coola, B.C.).

Consistent estimates of total Atnarko chinook escapement to the spawning grounds are available from 1980 to 2001, except for 1994 which is excluded due to problems with data collection (Figure 4). Estimates of escapement are derived from carcass surveys on the spawning grounds, standardized drift net surveys near the spawning grounds during the peak of the run, and catch-per-unit-effort during harvests of brood stock for the Snootli Creek hatchery.

Weekly estimates of chinook catch and fishing effort in the Nuxalk food fishery are available for that same period and provide the most consistent indicator of total escapement (Figure 11). These estimates are extrapolated from daytime catches and drifts recorded by a contracted observer with close ties to the community. There is only one observer handling commercial, recreational and First Nation data. He spends all day driving up and down the valley swapping information with lodge owners, anglers at fishing holes, and Nuxalk drift netters. The 1994 data gap was caused by a previous arrangement with several contractors. Since 1995, the current observer has consistently compiled all data. Catch and effort in the Nuxalk food fishery are highly correlated during the chinook fishery in May and June (weekly coefficients of determination r^2 ranged from 0.56 to 0.72), probably because fishing only targets chinook, occurs directly on the reserve, and requires little preparation or commitment of resources. Nuxalk harvesters are able to respond quickly to observed fishing success. Correcting for effort removes most of the signal and Nuxalk catch-per-unit-effort is a very poor predictor of escapement ($r^2 < 0.3$).

In-season data from the recreational and commercial fisheries could not be used for in-season projections. Consistent records of catch and effort data from the freshwater recreational fishery are only available since 1995. Commercial catch and effort data from the Bella Coola Gillnet Area are available from 1980 to 2001, but weekly data are inconsistent due to the variable duration of commercial openings, which ranged from 1 to 4 days.

2.4.4 *Regression model for weekly escapement projections*

For weeks 22 to 29, I fit independent linear regressions to estimate total escapement over the season (E_i) from the log of cumulative catch in the Nuxalk food fishery ($C_{i,w}$) observed up through this week in previous years:

(5) $$E_i = aC_{i,w} + b + \varepsilon \quad i = 1980,\ldots,\ 1993,\ 1995,\ldots,\ 2001;\ w = 22 \text{ to } 29$$

where E_i = observed escapement in year *i*, $C_{i,w}$ = log of cumulative Nuxalk catch up through week *w* in year *i*, *a* and *b* are least-squares estimates of slope and intercept, and ε is the random normal error. In-season projections of escapement are defined by:

(6) $$\hat{E}_{t,w} = aC'_{t,w} + b$$

where $C'_{t,w}$ is a new catch observation. For example, the projection $\hat{E}_{2002,24}$ of end-of-season escapement in 2002 (E_{2002}), calculated in week 24, is given by:

(7) $$\hat{E}_{2002,24} = aC'_{2002,24} + b$$

Observations falling further outside the range $C_{i,w}$ that was used to fit the model result in a less certain estimate. To estimate the prediction error (SD_{pred}), I used (Devore 1991, p. 484):

(8) $$SD_{pred} = MSE\sqrt{1 + \frac{1}{n} + \frac{n(C' - \overline{C})^2}{n\sum C_{i,w}^2 - (\sum C_{i,w})^2}}$$

where $\overline{C}$ = mean of observations C_i used to fit the model, and *MSE* = mean square error.

Log-transformed cumulative catch in the Nuxalk food fishery provided the best fit. Fried and Hilborn (1988) use untransformed cumulative in-season data, while Cox-Rogers (1997) used the log-log transformation. For the Atnarko chinook data, regression using untransformed variables, log-transformed escapement, and log-log transformed data showed poorer fit (lower multiple r^2) or stronger patterns in residuals than log-transformed cumulative catch. Using average weekly catch for the current year as the explanatory variable provided a better fit in later weeks, but forecasts are needed in weeks 22 to 25, when there aren't enough data to estimate this quantity adequately.

Conceptually, food fishery catch should be more closely related to in-river abundance than to post-season escapement estimates. However, terminal returns (escapement plus gill net, recreational and Nuxalk catch) and in-river returns (escapement plus recreational and Nuxalk catch) have several disadvantages as output from the projection model: (1) they are less informative about escapement (lower r^2) in early weeks when projections are needed, (2) they use the Nuxalk catch data twice, once as the indicator, and also as a component of estimated total returns, and (3) they are not variables currently used for management decisions.

2.4.5 *Bayesian updating*

Bayesian methods provide a formal framework for combining information from different sources while explicitly incorporating uncertainty, which can improve estimates of uncertain quantities. Box and Tiao (1973) discuss the theoretical foundation in great detail. Punt and Hilborn (1997) provide a step-by-step description and review fisheries applications. In simple Bayesian estimation, a prior probability estimate for a set of k discrete hypotheses $[H_1,\ldots,H_h,\ldots,H_k]$ is combined with the likelihood of each hypothesis in the light of additional information, resulting in a revised probability estimate (or posterior).

Bayesian updating is a specific type of Bayesian analysis, which revises the current estimate as new information becomes available (e.g. Cox-Rogers 1997, Fried and Hilborn 1988). This is particularly useful when the quality or predictive capability of available data fluctuates over time. A general version of Bayes' formula is (e.g. Fried and Hilborn 1988):

(9) $$P(H_h|D) = \frac{L(D|H_h)\cdot P(H_h)}{\sum_{h=1}^{l} L(D|H_h)\cdot P(H_h)}$$

where $P(H_h)$ = the current probability of hypothesis H_h, $L(D|H_h)$ = likelihood of the new data given that hypothesis H_h is true, and $P(H_h|D)$ = revised probability of H_h being correct given the new data. Here, the alternative hypotheses are 42 discrete levels of total end-of-season chinook escapement ranging from 1,000 to 42,000 in increments of 1,000. Escapement levels outside this range are highly unlikely and were not included in the analysis because observed escapement has not exceeded 36,000 since 1980 (Figure 4). The estimated probability of each hypothesis is updated each week, and the revised probability estimate from the previous week then becomes the new prior probability, and each new single data point is used in the likelihood function. Figure 12 summarizes these steps.

I calculate prior probabilities and likelihoods for Bayes' formula using the normal likelihood function (Devore 1991, p.144):

$$(10) \qquad L = \left(\frac{1}{\sigma\sqrt{2\pi}}\right)\exp\left(-\frac{d^2}{2\sigma^2}\right)$$

where d = the difference between some observed value and the corresponding hypothesized value, and σ is estimated by the standard deviation of the residuals between projected and hypothesized values. To reduce rounding error, intermediate calculations are based on the log-transformed version of this equation:

$$(11) \qquad \ln L = \ln\left(\frac{1}{\sigma\sqrt{2\pi}}\right)-\left(\frac{d^2}{2\sigma^2}\right)$$

For determining the likelihood of each hypothesis (i.e. escapement level) given a new observation, I define d as the difference between the hypothesized escapement and the escapement predicted by Equation 6, and estimate σ as the prediction error, SD_{pred}, in Equation 8. To calculate normal prior probabilities for each hypothesis, I define d as the difference between the hypothesized level and the mean of previously observed escapements, and estimate σ as the sample standard deviation of previously observed escapements. Raw likelihoods L are standardized by the sum of the likelihoods to ensure that the discrete probability approximations sum to 1.

Fisheries managers need to carefully consider the implications of different pre-season estimates of probability for each escapement level (priors). Prior probability distributions can express their expectations for the upcoming season. Both the mean (i.e. peak) and the uncertainty (i.e. spread) of these distributions change, depending on the manager's assumptions regarding the shape of the distribution and the range of years.

I tested three alternatives: (1) normally distributed prior using all available data, capturing the expectation that escapement for the current year will be similar to observed escapement from 1980 to 2001, with a mean of about 19,000 fish, (2) normal prior using only observed escapement from 1995 to 2001, expressing the belief that escapement will be similar to recent years with a mean of about 25,000, and (3) uniform prior, implying that all escapement levels between 1,000 and 42,000 are equally likely. For most observed data, plots of prior probabilities, likelihoods, and revised probabilities showed that this range covered most of 95% of the distribution.

Each alternative assumption about the priors has advantages. The frequency distribution of observed escapements from 1980-2001 approximates a normal curve (Figure 13 A), but escapement has steadily increased since the 1980s (Figure 4). Fitting a normally distributed prior to the entire data set results in a very wide probability distribution and ignores the observed time-trend (Figure 13 B). Assuming that escapement in the current year will be more similar to recent years, I also fit a normal prior using only the 7 most recent years' escapement; this results in a much narrower prior (Figure 13 B). However, recent escapement levels fall on the high end of the observed range, and the resulting prior therefore encompasses the strong pre-season assumption that escapement will be high.

The fisheries manager, the intended user of this model, preferred the more diffuse normal prior, which puts a higher initial probability on the possibility of low escapements. The uniform prior may initially appear to be the most cautious option, because it does not presume any particular escapement and starts each season with a 'clean slate'. However, it is also more sensitive to unusually high catches in early weeks. All three options are included in the user interface.

2.4.6 User interface

The model for projecting end-of-season escapement, as described in the previous section, needs to communicate all the main considerations to the fisheries manager at a glance. I designed the interface to emphasize: (1) uncertainty in individual projections of escapement and the range of plausible escapement levels, (2) discrepancies between projections based on different assumptions, (3) time-trends in weekly projections, and (4) unusually high or low cumulative catch in the Nuxalk fishery.

Figure 14 shows three kinds of information about the uncertainty in weekly forecasts of escapement: point estimates, confidence bounds, and probability of escapement falling into one of four discrete intervals identified by the fisheries manager. Section 2.5.4 describes how these intervals were picked. Point estimates and 80% confidence bounds for three different projections provide a focal point and show the plausible range. For Bayesian projections, the 80% confidence bounds are the nearest escapement levels corresponding to the 10^{th} and 90^{th} percentiles of the cumulative posterior. For the independent weekly regression estimate, 80% confidence intervals use the prediction error (Equation 8).

Trajectories of changing projections throughout each season provide the context for weekly decisions as the fisheries unfold, show the weekly adjustments in projected escapement, and clearly illustrate the difference between projections based on independent regressions for each week (Section 2.4.4) and projections based on Bayesian updating (Figure 15).

To identify outlying observations caused by unusual circumstances or faulty data, the interface also shows the prediction error for new observations relative to the regression error (Figure 16). If a new observation falls close to the average of the data used for fitting the model, then prediction error is similar to regression error. However, the more a new observation differs from the observed average, the more prediction error will exceed regression error.

2.4.7 Evaluating model performance through cross-validation

I tested the performance of the projection model through cross-validation. Cross-validation analyses simulate the use of the model in previously observed conditions. In cross-validation, some of the data are left out when fitting the model, to determine how well it would predict the excluded observations. For forecasting models, the most appropriate type of cross-validation is retrospective analysis, fitting the model to information up to year t - 1 and comparing projections and observed escapement for year t (e.g. Fried and Hilborn 1988). This approach ensures that the model is tested under realistic conditions, but conclusions about performance may be specific to the observed sequence of events. For relatively short time-series like the Atnarko chinook escapements, this approach also requires a trade-off between a better model fit (i.e. more data used to fit the initial regression) and a more informative evaluation (i.e. more test years). In addition, the increasing trend in observed escapements of Atnarko chinook may introduce strong biases in retrospective evaluations, particularly when using normal priors calculated from all the data.

Simple criteria for evaluating projection models include the mean deviation (MD) between projected end-of-season escapement and actual escapement to assess bias, mean absolute deviation (MAD) and mean absolute percent error (MAPE) to assess the magnitude of discrepancies, and the percent of cases falling outside the x^{th}% confidence bound to assess the frequency of large errors.

To assess potential biases introduced by the short time-series and the observed trend in escapement, I complemented the standard retrospective analysis with a more general leave-one-out cross-validation. Specifically, I used the following evaluations to evaluate projections based on simple regression, Bayesian updating with normal pre-season priors, and Bayesian updating with uniform pre-season priors (1994 data were excluded in all analyses):

i. For the years 1990 to 2001, I used data up to year t-1 to fit the weekly regression models and compared each week's projected end-of-season escapement with the observed end-of-season escapement for year t. For example, I used cumulative catch and escapement from 1980 to 1992 to estimate regression parameters, then used 1993 cumulative Nuxalk catch to estimate escapement, and compared it to the observed escapement in 1993.

ii. For the years 1980 to 2001, I used all the data except year t to fit the weekly regression models and compared each week's projected escapement for the season with observed escapement. For example, I used cumulative Nuxalk catch and escapement from all available years except 1993 to estimate regression parameters, then used 1993 catch to estimate escapement, and compared it to the observed escapement in 1993.

2.5 Guidelines for in-season assessment of stock status

2.5.1 From models to guidelines

By themselves, models such as the Bayesian projection model described in the previous section are only of theoretical interest. For models to be used correctly in fisheries management, the decision-makers need to be (1) comfortable with their understanding of the model and its output, and (2) able to explain the link between information that stakeholders are familiar with and the model output (e.g. Hilborn 2002). For the in-season projection model, a direct link between input and final output spans two steps, shown in Figure 10. First, the Bayesian projection model uses the cumulative catch in the Nuxalk food fishery to calculate projections of escapement, expressed as a probability distribution to reflect uncertainty, based in part on different pre-season expectations (priors). Then the fisheries manager interprets the probability distributions and determines the stock status, which then serves as the basis for the next commercial opening in the Bella Coola Gillnet Area.

To investigate this two-step process of in-season assessment, I presented the fisheries manager with a set of scenarios that mimicked the actual flow of information throughout the fishing season: New catch information becomes available, the manager evaluates the projections and determines stock status, and then catch information for the next week becomes available. I then analyzed the manager's responses to create a simple decision table that directly links in-season data to stock status.

This approach can help overcome some of the obstacles to the practical use of models. The fisheries manager becomes familiar with the model and its output, and will more likely use the model for day-to-day operations. The manager can also use the final decision tables to improve communications with non-technical audiences. Finally, the manager's running commentary during the elicitation sessions gives the analyst ample opportunity to clarify any misunderstandings.

2.5.2 *Using classification trees to describe the manager's interpretation of escapement projections*

Classification trees are a versatile tool for summarizing the manager's interpretation of escapement projections into a simple decision table. A classification tree consists of a series of binary choices (e.g. yes-no, if-then), which split a set of observations into discrete categories and identify the appropriate class for a new observation. Common examples are the dichotomous keys used in field guides, which use a series of easily observable characteristics to identify species. A good example is the identification key to Pacific salmon and trout presented by Somerton and Murray (1976). Applying this concept to in-season assessment, the goal is to derive a simple key that links easily observable in-season data directly to a discrete category of stock status that determine harvest opportunity. Classification and Regression Tree (C&RT) analysis is a one of several statistical methods for fitting classification trees.

Similar to regression models, classification trees use the values of explanatory variables to determine the best estimate for a response variable. However, the step-wise structure of classification trees has several practical advantages over regression models. Returning to the heart attack example from Breiman et al. (1984), the response variable was the diagnosis of high-risk cases and the number of explanatory variables was reduced from 19 in the multiple regression to 3 in the classification tree. The simple tree is more easily used in an applied setting. For in-season management of Atnarko chinook fisheries, the response variable is the manager's assessment of stock status; the explanatory variable is the cumulative catch in the Nuxalk food fishery, which is used as input for the projection model.

Breiman et al. (1984) describe the theory and potential applications of C&RT analysis. C&RT models fit the tree structure by recursively partitioning the observations into smaller, more homogeneous sets in a 1-step look-ahead procedure. Partitions are chosen to maximize reductions in some measure of heterogeneity (e.g. proportion of misclassifications), and splitting continues until a set is pure (i.e. all remaining observations belong to the same class) or reaches a minimum size (e.g. fewer than 5 observations remain). The resulting trees generally are too complex and overfit the data, so they are pruned through cross-validation to provide simplified trees that are more robust and predictive.

Breiman et al. (1984), Venables and Ripley (1999), and Yohannes and Webb (1999) describe the strengths and weaknesses of C&RT models. Binary partitioning easily handles combinations of categorical and continuous variables. The assumptions underlying C&RT models are less stringent than for regression or discriminant analysis. For example, complex interactions between variables are handled automatically through the nested structure of recursive partitioning. The tree structure helps assess the adequacy of linear models, and identifies complex interactions between variables. C&RT models are highly robust to monotonic transformations of predictor variables when the relative ordering of classes is preserved. The splitting points are insensitive to outliers, because extreme observations are simply isolated into separate nodes. Missing values are handled through surrogate splits, which approximate the separation of observations based on a different variable. In the above example from Breiman et al. (1984), the classification tree could still be used without data for one of the three variables, while the multiple regression model cannot provide a classification if any one of the 19 variables is missing from a new observation.

I am aware of only a few applications of C&RT in fisheries research. Lamon III and Stow (1999) used it to explore PCB levels in Lake Michigan salmonids, based on variables as diverse as size of fish and agency providing the data. Watters and Deriso (2000) used classification trees to standardize catch-per-unit-effort data for bigeye tuna. Peters et al. (2001) used C&RT to analyse the results of sensitivity analyses and identify the sources of uncertainty which most influenced the performance of recovery actions for Snake River fall chinook. Nelitz (2004) used C&RT to identify the characteristics of temperature-sensitive streams in British Columbia.

In this case study, I worked with the fisheries manager to identify discrete categories of stock status, elicited his assessments of stock status for a set of scenarios, and fitted classification trees to his responses. Using the cut-off points identified in the classification trees, I developed a simple decision table showing weekly reference points for the in-season indicator and the corresponding category of stock status.

2.5.3 *Identifying discrete categories of stock status*

Assessments of stock status need to feed directly into the management process, and the range of available management responses determines the required level of precision. For Atnarko chinook, weekly assessments need only be precise enough to choose one of several options that are actually available for commercial openings. Given the inherent uncertainty of in-season data and the implications for harvest planning, the fisheries manager classified projected escapement into four ranges, rounded to the nearest thousand spawners (0 to 8, 9 to 16, 17 to 24, 25 to 42). These ranges correspond to the four indifference ranges identified for the quantitative indicator of escapement. (For more detail see Table 2).

Out of many suggestions, the fisheries manager carefully chose what he considered the most appropriate labels for the four discrete categories of stock status. Even though the label does not affect the analysis in any way, we extensively discussed the possible associations a general audience might make. The simple letter grades (A, B, C, D) best described the manager's thinking, and provided the least opportunity for misinterpretation. He rejected numbers (1, 2, 3, 4 or 4, 3, 2, 1), verbal descriptions (good, acceptable, undesirable), and color coding (green, yellow, red, and black).

Once we had identified these descriptions of stock status, the next step in the analysis was to determine the corresponding range of values for the in-season data.

2.5.4 *Eliciting assessments of stock status from the manager*

Each week during the fishing season, the manager uses the cumulative catch of chinook in the Nuxalk food fishery to project end-of-season escapement under different assumptions, and assesses the status of the stock based on a range of projections. To create the data set for this analysis, I developed test scenarios that closely mimic the actual sequence of in-season assessments based on cumulative catch in the food fishery. Each scenario consists of a sequence of cumulative catch data for weeks 22 to 25. The 22 observed scenarios (1980 to 2002, excluding 1994) were supplemented by 22 simulated scenarios, for a total of 44.

When eliciting expert judgment, it is important that the scenarios are representative of the respondents' experience. Therefore, I constructed the test scenarios so that the frequency of high and low escapement corresponded to observed frequencies, rather than creating scenarios with roughly equal representation from each category. Simulated scenarios were created by drawing a starting value for cumulative Nuxalk catch in week 22 from a normal distribution fitted to observed data, and adding average weekly catch and a random error. Simulated sequences of cumulative catch were similar to observed sequences.

C&RT models have mostly been used to mine large multivariate datasets (Breiman et al. 1984), and there are no guidelines for determining required sample size. For the simple model used here (four categories A to D, and cumulative catch in the food fishery as the single explanatory variable) a relatively small sample should suffice.

For each scenario, the weekly cumulative catch numbers were provided in sequence, and a judgment regarding estimated status (A, B, C, D) was elicited for each of the weeks. Scenarios were provided in random order (Table 3). Detailed questions regarding the reasoning process were asked for the first 10 scenarios. After that the fisheries manager worked at his own pace.

2.5.5 Fitting the classification trees

I used the CART™ software package from Salford Systems (Steinberg and Colla 1997) to fit the classification trees. Yohannes and Webb (1999) provide a thorough step-by-step guide for using CART™. Throughout this paper, I draw a clear distinction between the method of fitting classification and regression trees (C&RT) and the commercial software package CART™. Other packages, such as the `rpart()` library of S-plus functions (Therneau and Atkinson 1997), are available for implementing C&RT.

The fisheries manager identified four categories of stock status (A, B, C, D), but he provided more detailed responses (e.g. B-) during his assessments of in-season scenarios. Due to the small sample size, I only worked with the four original categories. In CART™, I fitted the following classification trees to the simplified responses:

i. Determine stock status in week t based on cumulative catch from week t-1 (4 trees),

ii. Determine stock status in week t based on cumulative catch from all previous weeks (3 trees), and

iii. Determine stock status in Week 26 given cumulative catch from Week 25, with observed priors, asymmetric loss table, and both (3 trees).

Two competing considerations determine the shape of classification trees. The cost-complexity criterion for pruning incorporates the trade-off between the complexity of the tree, defined as the number of branches, and the expected cost of misclassification based on two components: the prior probability of an observation falling into a particular class, and the cost of wrongly identifying an observation from one class as another, captured in a loss table.

C&RT models use the prior probability of each class, in this case the status of Atnarko chinook (A, B, C, D), analogously to the use of priors in Bayesian updating, described in Section 2.4.5. In C&RT models, the prior defines the probability of a new observation belonging to one of the classes. Table 4 shows the two priors used here, the uniform prior indicating that all classes are equally likely, and the observed prior using the frequency for each class in the available data.

Loss tables specify the penalty applied for incorrect assessments when fitting the classification tree. With symmetric loss tables, an underestimate (e.g. managing based on C when A is the true status) is treated the same as an overestimate (e.g. managing based on A when C is the true status). One of many possible symmetric loss tables assigns a penalty of 1 to each possible mistake, and is referred to as a unit loss table. In many practical applications, however, the cost of mistakes changes considerably with both the magnitude and direction of the misclassifications, so that asymmetric loss matrices are more appropriate. Table 4 shows the two loss tables used here. Based on general statements by the fisheries manager, the asymmetric loss table incorporates the considerations that (1) overestimates of end-of-season escapement are more serious than underestimates because they can result in too much harvesting, and (2) cost of a mistake increases with the discrepancy between true status and assessed status. For example, the penalty for erroneously classifying a very poor status (D) as a very good status (A) is six times larger than for the reverse case. This large penalty reflects the consideration that a large overestimate could lead to a large overharvest, which in turn greatly increases the probability of extinction of the stock.

If the prior probability corresponds to the observed frequency of each class in the data set, and the costs for each possible misclassification are equal, then expected costs are simply the proportion of misclassified observations.

2.5.6 Linking management responses to in-season assessments of stock status

During a final set of interviews, the fisheries manager and I summarized all the elements of in-season decision-making for Atnarko chinook fisheries in two simple decision tables, one mapping weekly in-season data onto a discrete category of stock status estimate, the second specifying management actions corresponding to the estimated stock status for each week of the directed, commercial chinook fishery in the Bella Coola Gillnet Area.

3 Results

The results presented here follow the same order as previous sections, covering management objectives, management options, assessment of stock status, and finally management responses to estimated status. For each, I describe not only the final result, but also discuss the experience of developing these decision-support tools in this type of fishery.

3.1 Structuring objectives hierarchically

3.1.1 The hierarchy of management objectives for Atnarko River chinook fisheries

The fisheries manager identified several possible hierarchical structures to describe his management objectives for Atnarko chinook fisheries (Section 2.2.1). Of these, the hierarchy in Table 2 best expressed the considerations he wanted to capture in the simple decision guidelines. Other hierarchies did not convey the information he was seeking to communicate to other participants in the decision-making process, but the process of trying different structures also helped elicit additional management objectives.

Table 2 shows the management objectives for Atnarko chinook fisheries represented in a contained hierarchy with four main branches, one for each of the four general management objectives (A1 to A4). These four general objectives correspond to the four types of uses of salmon identified in the *Allocation Policy* of Fisheries and Oceans Canada (FOC 1999): Conservation, food fisheries, recreational fisheries, and commercial fisheries. Each of the four branches is further split into two additional levels of detail according to time horizon: multi-year objectives, and annual objectives. The fisheries manager identified 10 multi-year objectives (B1 to B10) as branches within the four general objectives, and 18 annual objectives nested within multi-year objectives (C1 to C18).

For most annual objectives, this table also shows one or more measurable attributes used to assess performance with respect to the objectives (e.g. estimated spawner abundance), for a total of 18 attributes. For most of these attributes, the fisheries manager also identified indifference ranges, which reflect both the effect of different attribute levels on management decisions, and the quality of available data. For example, he felt that there would be no difference in management responses between estimated escapement of 18,000 or 23,000 Atnarko River chinook. For each indifference range, the fisheries manager provided a verbal assessment describing his interpretation. For example, he considered 41-60% of hatchery fish in the run as "*acceptable in the short-term*".

We were unable to identify measurable attributes for five of the 18 annual objectives. We were further unable to identify indifference ranges for 8 of the 18 measurable attributes. These gaps became very obvious in this hierarchical representation, and highlighted the lack of clarity around some of the management objectives. In particular, objectives relating to ecosystem considerations and stability for harvesters have not been developed to the same extent as the more traditional objectives regarding catch and escapement. The fisheries manager pointed to two causes for these gaps: The lack of consensus among other participants in the decision-making process (e.g. regional FOC staff and stakeholder representatives) and the lack of available policy documents. In the absence of this context, he was clearly hesitant to speculate.

The hierarchy of management objectives in Table 2 also showed very clearly that the manager's evaluation of performance with respect to the higher-level objectives often reflected a composite of several attributes. For example, under the general objective of conserving Atnarko chinook (A1), he considered five measurable attributes, while two gaps remain to be filled in (see also Figure 6). It is important to show this hierarchical structure, because other participants may associate different attributes with the same general objectives.

Objectives at each level of the contained hierarchy (Table 2) are loosely sorted by priority within each nested branch, presenting the most important objective first (e.g. B1 to B3 within A1). Moving from left to right through the table, additional levels of detail are displayed to answer the question: "What does that general statement actually mean?" For example, participants in the decision-making process can quickly see that the most important conservation objective is to *rebuild and maintain run size*, which in any particular year implies management to achieve target escapement, as estimated using established methods.

In the following sections, I first describe the management objectives captured in Table 2, and then conclude with a brief discussion of objectives that could not be captured within this hierarchical categorization.

3.1.2 Conservation objectives for Atnarko River chinook

We were able to identify three multi-year objectives for this category: (1) rebuild and maintain run size, (2) maintain stock integrity, and (3) maintain biological diversity. Seven annual objectives are nested within the three multi-year objectives in this category (Table 2).

To rebuild and maintain run size, the fisheries manager tries to achieve or exceed target escapement on the Atnarko River. Escapement estimates are based on a well-established monitoring protocol. Based on his assessment of data limitations and management practice, the fisheries manager also identified four indifference ranges, with the best range of escapement falling on or above the escapement target of 25,000 fish. Figure 5 shows chinook escapement from 1980 to 2002 relative to these ranges.

Maintaining stock integrity encompasses three annual objectives: (1) Dispersing the harvest over the entire time-span of the run by implementing a closed period of at least 3 days each week in the commercial and food fisheries. No weekly closures are in place for the sport fishery, because catches are small, and daily catch limits already disperse effort over time. (2) Keeping the probability of domestication low by monitoring the percent contribution of hatchery fish to the total run, where domestication is defined as changes in genetic structure of the population caused by mixing with hatchery fish. Based on unpublished agency guidelines for salmon enhancement projects, the fisheries manager specified four indifference ranges for the percentage of fish caught that were of hatchery origin, and provided verbal assessments. (3) The fisheries manager implements closed areas to protect spawning chinook, but we could not determine meaningful attributes to assess performance with respect this objective.

The fisheries manager identified three annual objectives under the general objective of maintaining biological diversity: (1) minimizing catches of co-migrating chinook in mixed-stock fisheries, specifically Dean River chinook, (2) maintaining chinook populations in small tributaries of the Bella Coola River by minimizing catch on the tributaries; (3) and minimizing the impact on other species, specifically steelhead trout (*O. mykiss*). Available data and existing policy guidelines were insufficient for identifying quantitative attributes and specifying indifference ranges for the annual objective of maintaining biodiversity.

3.1.3 Objectives for the three harvester groups

Table 2 also summarizes the multi-year and annual objectives for each group of harvesters, so they are not repeated here. However, this section describes the information used to develop attributes and indifference ranges, and highlights gaps in data and policy guidelines.

All three sectors put high emphasis on stable access (Section 1.3.3), but it proved challenging to develop meaningful measurement scales for the objective of providing stable access. One of the attributes under consideration was the number of in-season changes to fishing regulations. However, whether a regulatory change is considered disruptive by the harvesters clearly depends on the specific change and is difficult to quantify. For example, introducing an additional area closure would generally cause much less concern than shortening the weekly opening, but there are some prime areas which could not be closed without strong justification.

In the end, we settled on a combination of attributes related to annual catch, catch-per-unit-effort, and the pattern of openings (see column 4 of Table 2). For example, we identified two multi-year objectives for the Nuxalk food fishery (A2): (B4) satisfy community needs for food fish, and (B5) provide stable access for cultural and community purposes. With respect to community needs for food fish, there are two annual considerations: (C8) provide recent levels of chinook catch, measured as total catch over the season, and (C9) provide adequate chinook fishing success, measured as catch-per-unit-effort early in the season or during the peak of the run.

The fisheries manager had to choose these attributes, indifferences ranges and verbal assessments based on catch and effort data collected by FOC, because harvesters have not provided clear statements of their preferences, and no data is available to judge whether socio-economic objectives are being met. In the absence of this information, he can only assume that recent levels of catch and fishing success were acceptable (e.g. Nuxalk FSC catch between 1,000 to 2,900 chinook). Hierarchical summaries like Table 2 encourage all participants to think about their goals and expectations for the fishery, and provide a starting point for more specific discussions.

3.1.4 Target state of chinook fisheries in the Bella Coola area

The fisheries manager provided indifference ranges for most of the measurable attributes, and verbal assessments of each indifference range (Columns 5 and 6 of Table 2). Together, they clearly describe the target state of the Atnarko chinook fisheries.

With respect to conservation objectives (A1) the fisheries manager is working towards chinook escapements of 25,000 fish or more, weekly fishing closures in the food and commercial fisheries of at least 3 days, less than 20% hatchery fish in the run, minimal incidental catches of Dean River chinook, and minimal chinook catch in the tributaries of the Bella Coola River.

To address management objectives for the Nuxalk food fishery, the manager tries to achieve total chinook catch of at least 3,000 fish, catches of 3-4 fish per drift during the peak of the run, and four open days each week. He also seeks to maximize the number of open weeks in the Nuxalk fishery, which is currently open year-round, and to minimize regulatory restrictions on gear and fishing methods.

For the recreational fisheries in the Bella Coola/Atnarko watershed, the manager works towards an average catch of at least 3 fish for every 10 angler days during the peak of the run, while maintaining the current coast wide catch and possession limits, maintaining the current length of the recreational opening, and minimizing changes to fishing regulations, both within a season and from year to year.

For the commercial gill net fishery, the manager works towards a target of 8-12 chinook per boat day during the peak of the run, and a 1-to-2-day opening during each week of June. He also attempts to provide catch of adequate value, where adequate value has not been defined, and to minimize the frequency of short-notice changes to the length of each weekly opening.

Thus, using indifference ranges, the manager was able to provide a clear and comprehensive description of his management goals in a format that can be easily shared with other participants in the decision-making process.

3.1.5 Objectives that could not be captured in the hierarchy

Objectives relating to the body size of returning chinook, interaction with other fisheries, allocation of staff and funds, compliance, enforcement, and public participation could not be captured in the contained hierarchy displayed in Table 2. Agency staff did not provide detailed responses for these aspects of the management system, but identified three reasons for their reluctance. They considered the topics either (1) unrelated to the focus of this study (e.g. allocation of budgets within the agency), (2) insufficiently documented for an informed judgment (e.g. size of fish), or (3) highly controversial and prone to legal challenges (e.g. requirements for public participation).

The average body size of returning chinook is important to all harvesting sectors as well as the productivity of the stock. For harvesters, size of harvested chinook affects the value of the catch. Regardless of the measure of value (dietary value for the food fishery, catch value for the commercial fishery, or satisfaction for anglers), this could be particularly crucial in systems like the terminal Atnarko chinook fisheries where all sectors have very low catch-per-unit-effort. However, there is no available information on body sizes, possible interactions between size and abundance, or stakeholder preferences for trade-offs between more fish and larger fish. Consequently, management decisions are made assuming that (1) the size of returning Atnarko chinook is independent of spawning escapement over the observed range of escapements, (2) the current size distribution in both catch and spawning adults is adequate, and (3) there is no long-term effect of size-selective harvest methods. To some extent, this concern is captured by the identified conservation objectives. Size distribution should remain stable if the harvest is dispersed throughout the run, genetic mixing with hatchery fish is minimized, and escapement remains at or above the target.

Management objectives for Atnarko chinook fisheries may be affected by the performance of other local fisheries, but other species of salmon do not serve as direct substitutes and potential interactions are complex. For example, the Nuxalk use salmon for diverse dietary, social and cultural purposes (Winbourne 1998), and require not only a specific number of salmon, but also a specific species composition of the food fishery catch throughout the entire season. They catch chinook salmon returning to the Atnarko in early June mostly for immediate consumption, and this important need cannot be compensated with other fish caught at a later time. Sockeye salmon can be better preserved and are caught in preparation for winter and for trade. In years of low sockeye salmon abundance, coho salmon serve as a substitute. Pink salmon (*Oncorhynchus gorbuscha*) are very abundant in the Bella Coola/Atnarko system, but have little value to any of the harvesters. Therefore, these can compensate to some extent for ecosystem roles of the harvested fish.

Fisheries managers dealing with numerous small fisheries face complex decision problems when allocating agency staff and budgets. The objectives associated with their allocation of resources between data collection, analysis, participatory processes, and enforcement of regulations are difficult to elicit because agency staff consider these operational details confidential. However, all participants in the decision-making process are acutely aware of the eventual impacts of shortfalls in staffing and funds. Given the stated priority of conservation and risk-management considerations, for example, fishing closures may be necessary simply due to a lack of monitoring and enforcement staff or concerns regarding inadequate control over fishing effort. During the interviews for this study, the fisheries manager pointed out repeatedly that objectives related to data collection, compliance monitoring and enforcement could not be directly compared to, or traded off with, the objectives listed in Table 2. Rather, they form basic operational requirements underlying the ability to make adequate harvest decisions. For example, data collection needs to be sufficient for accurate identification of stock status and consistent estimates of catch and effort from each harvester group. The specific objectives and trade-offs associated with organizing stream walks, drift net surveys during peak migration, carcass pitch surveys on the spawning grounds, aerial gear counts during commercial openings, and dockside monitoring fall outside the scope of this study. In theory, these decisions should be based on formal comparisons of information value and costs of data, but in practice funds are often shifted to monitor stocks in critical condition, resulting in a lack of baseline data.

Objectives relating to enforcement and compliance proved difficult to specify in any level of detail and meaningful attributes were hard to define. For example, a small number of reported violations could be a result of inadequate monitoring rather than general compliance. Similarly, a large number of convictions for fishing violations cannot be interpreted as successful fisheries management. Agency staff offered the general observations that enforcement and compliance become a higher priority at low abundance levels, due to the increased risk associated with violations, and that enforcement priorities change frequently based on the social dynamics among harvesters.

Legal requirements and public expectations for participatory processes continue to evolve rapidly, and agency staff wanted to wait for the development of policy guidelines before commenting on objectives for consultation, consensus building, and information sharing.

3.2 Eliciting relative preferences for management objectives

3.2.1 Observations during preference elicitation

I determined relative preferences for management objectives using the three previously described methods in the following order: (1) ranking in a list, (2) new computer-based graphical interface, and (3) modified swing-weighting. In this section, I describe my interaction with the fisheries manager during the elicitation tasks. In the next section, I compare the ranks produced by the three different methods.

While performing the different ranking tasks, the fisheries manager repeatedly pointed out that his responses reflected his “particular knowledge and background”. For example, the relative priority of stock integrity over biological diversity reflects the focus of fisheries management, the fact that no clear policy guidance or even definition is available for "biological diversity", and that most of those considerations fall outside of his control anyway. The underlying rationale is that an escapement near target and a harvest spread out over the entire run should address ecosystem concerns within the management of this fishery. He also made it clear that the rankings are specific to this particular fishery, and cannot be generalized. For example, in his responses, the objective "*minimize the impact on other species*" has the lowest priority of all conservation objectives, because in this fishery there are no identified by-catches of concern. The manager felt that this objective had low priority because it is currently not an issue in this fishery. Alternatively, one could argue it has a high priority, but performance of the fishery with respect to this objective is currently satisfactory without requiring any management actions.

Ranking elements of a list

During the initial interviews, the fisheries manager ranked the objectives at each level within each branch of the contained hierarchy in Table 2. For example, he first ranked the general objectives A1 to A4, then the multi-year objectives B1 to B3 within A1. This was an easy task, but did not encourage him to consider the larger context of management objectives. In particular, this method does not elicit comparisons between annual objectives falling into different general objectives (e.g. C1 vs. C16)

Using the computer-based graphical interface

The computer-based preference elicitation consisted of 19 panels (e.g. Figure 9) and required about 90 minutes. This included extensive discussions. The respondent took his time to think about each panel, frequently referred back to the summary table for context (Table 2), and made several adjustments on each panel, while explaining his reasoning process out loud. This triggered helpful discussions about individual objectives and their interconnection, and we identified additional changes in the wording of objectives. He often tried one ranking, thought about it for a while, and then tried several others to compare. This approach is consistent with the observation that highly motivated respondents may cut preference surveys into pieces and move the elements around on the table to provide better answers (Wolfgang Haider, SFU, pers. comm.). The respondent was very comfortable with the loose concept of "priority" as an axis for ranking, and the general representation of his objectives in this graphical format. To determine a particular ranking, he used a combination of two approaches: (1) first moving the extremes (highest to the top, lowest to the bottom), and then adjusting the remainder, (2) first ranking objectives within a branch of the hierarchy (e.g. B1 to B3 within A1), then moving branches relative to each other (e.g. B1 to B3 relative to B4 and B5), and finally adjusting individual boxes to fine-tune comparisons between elements across higher-level objectives.

The fisheries manager generally used the upper edge of the box to indicate priority, used the relative horizontal overlap between boxes to express the possibility of trade-off between objectives, and frequently drew horizontal lines across the screen to check for overlaps. The limitations of the current interface layout became a serious handicap during the comparison of all annual objectives, when the respondent worked with 18 elements on the screen. He was sufficiently motivated to work with print-outs and frequent scrolling across the screen, but this interfered with his ability to see the bigger picture.

The left-to-right sequence of management objectives (i.e. boxes) within each panel followed the loose order developed for Table 2. However, the respondent frequently changed the rank-order, and did not appear to be influenced by the left-to-right sequence of the boxes.

During the graphical ranking, the fisheries manager identified the rank for some objectives as conditional upon the performance of other attributes. For example, "*minimize the disturbance of spawning chinook* is generally not so important if the escapement is near target and harvests are dispersed over the entire run. However, some stakeholders consider it unethical to go after the fish once they have reached the spawning grounds, and would give this objective a much higher priority under all circumstances" (Lyle Enderud, FOC, pers. comm.). However, the interface did not allow him to capture that aspect of his preferences.

Using modified swing-weights

The fisheries manager performed swing-weighting tasks later on the same day, but was more rushed and quickly lost enthusiasm as he started to go through the panels. During this session, he also frequently referred to the summary table developed earlier (Table 2). Comparisons with few elements were ranked quickly and did not generate much discussion. During complex ranking tasks with 10 or more elements, discussions focused not on the objectives, but on the challenges associated with this method for eliciting preference statements. The respondent identified several problems: (1) the panels did not emphasize the hierarchical structure of management objectives, (2) working with a print-out discouraged trying out alternative rankings, and (3) using integer ranks implied equal distance between ranks, and did not allow him to express nuances of relative importance. Due to these challenges, the respondent tried to visualize the graphical rankings performed earlier in the day and rank the elements accordingly. The swing-weighting task was eventually aborted, and results are incomplete.

3.2.2 *Preference rankings of management objectives*

The preference statements elicited from the fisheries manager yield three types of information. (1) All three elicitation methods produced relative ranks for each component in the hierarchy of management objectives. (2) The graphical interface also captured additional nuances regarding possible trade-off between objectives, and the distance between ranked elements. (3) Preferences for different levels of a quantitative attribute indicate the respondent's attitude towards risk.

Table 5 shows the full hierarchy of management objectives and ranks for each element. Each cell shows three values (L/G/SW), corresponding to the ranks elicited using a simple list (L), the computer-based graphical interface (G), and the modified swing-weighting (SW), respectively. Elements of the hierarchy are identified as A1 to A4 for the four general objectives, B1 to B10 for the multi-year objectives nested within the general objectives, and C1 to C18 for the annual objectives nested within multi-year objectives. Ranks were elicited within each branch using all three methods, and across branches using the graphical interface.

All three methods produced remarkably consistent ranks for objectives nested within each branch of the hierarchy, shown in columns 1, 2, and 4 of Table 5. For only two of the elements, shaded in gray, did the ranking change with the more formal methods of elicitation (SW, G).

The manager was able to rank up to 10 elements (B1 to B10, shown in column 3 of Table 5) in a single panel with both SW and G, resulting in identical rankings. For the final across-branch comparison with 18 elements (C1 to C18, column 6 of Table 5), only the graphical ranking was completed. These across-branch comparisons illustrate an interesting aspect of the manager's objectives: Not all components of an important objective are necessarily important. For example, even though A1 (conservation) has clearly stated priority over A2 (Nuxalk food fisheries), one of its components (B3) is less important than both components of the A2 (B4 and B5), as marked by the ellipse and dotted line.

The results show no indication of rank reversal, as discussed by Forman and Gass (2001). Adding additional elements to the comparison did not change the internal order within each nested branch of the hierarchy. For example, in columns 4, 5, and 6 of Table 5, the ranks of elements C2 to C4 with respect to each other stayed the same regardless of the number of elements being compared.

Results from computer-based graphical ranking yielded additional information. Based on the respondent's description of his reasoning process, I used the standardized distance between a reference line and the upper edge of box to quantify the relative priority he expressed through vertical adjustments, as illustrated in Figure 9. Table 5 shows priorities relative to the highest value in column 7, and emphasizes two aspects that cannot be expressed in simple ranks: (1) non-constant differences in priority, and (2) attitude towards risk.

The difference in priority between elements is not as constant as a simple ranking implies, and for some elements the fisheries manager indicated strong horizontal overlap, indicating similar priority. For example, the annual objectives ranked 2^{nd} to 5^{th} (column 6 of Table 5) all show overlap with the top-ranked objective (see shaded cells in column 7 of Table 5), indicating the fisheries manager considers trade-offs between them.

Preference statements elicited with the computer-based graphical interface also indicate the respondent's attitude towards risk. The top panel of Figure 17 shows the manager's assessment of relative priority for different levels of chinook escapement. Additional increases in escapement become less important as escapement increases. This marginal decrease in priority is conceptually similar to the concave shape of risk-averse utility curves. Using the simple assumption that "low priority" corresponds to "does not add much utility" this graphical preference statement can be converted to a utility curve (bottom panel of Figure 17) to verify this interpretation. To obtain this utility curve, I first assumed that the cumulative priority value for the highest level of escapement shown in the interface (25,000) corresponds to a utility of 0.9 and that the upper limit for Bayesian projection model corresponds to a utility of 1. In this context, it is reasonable to assume that the utility curve also intersects the origin, with zero utility for zero escapement. One could argue that the utility reaches zero at some non-zero escapement corresponding to minimum viable abundance, but fisheries managers working on recovery efforts for salmon stocks such as Cultus sockeye would probably agree that even a dozen fish is better (i.e. higher utility) than no fish. To calculate the remaining two points, I used the relative priority expressed by the fisheries manager. For example, the cumulative priority value for escapement larger than 16,000 is 190.8, or 77.5% of the priority value for escapement larger than 25,000 (246.1). The utility value for 16,000 is therefore 77.5% of 0.9, or 0.698. Converting graphical preference statements into utility curves is possible when comparing different *levels of an attribute*.

Priority values elicited for different *objectives* can be converted into weights for an additive utility function. Multi-attribute utility functions consist of utility curves like the one in the bottom panel of Figure 17 to calculate a score for each attribute, and a weighting function to calculate an overall score. The weights determine how much the performance with respect to each attribute contributes to the total score. To calculate the weights in column 8 of Table 5, I simply rescaled the relative priority values so that the least important objective (C17) corresponds to a weight of 1. For the annual management objectives compared here, the weights in that column show that the manager considered the first-ranked objective 2.4 times more important than the last-ranked objective, and that the priority for the three top-ranked objectives is so similar that the weights are identical.

3.3 Identifying options for in-season management

In-season management of terminal Atnarko chinook fisheries is not as complex as the hierarchy of objectives in Table 2 may suggest. The fisheries manager opens and closes the commercial fishery to achieve target escapement, within some constraints. Not all of the objectives are relevant to in-season decisions, and some objectives can easily be addressed by constraints on decision options.

3.3.1 Pre-season vs. in-season decisions

As described in Section 1.3.3, most management decisions for two of the three groups of harvesters generally happen on an annual basis, before the fishing season starts. The Nuxalk food fishery is open 4 days a week, with effort regulated indirectly through dietary demand, river conditions, and chinook abundance. Accordingly, food fishery catch is a good indicator of abundance and expected escapement. Region-wide regulations for the recreational fishery specify daily, yearly, and possession limits for individual anglers. Time and area closures are determined locally, but are also published prior to the season. There is a short time-window of about 4 weeks in June (Weeks 23 to 26) during which Atnarko chinook, and the commercial fishery targeting them, are actively managed in-season while other fisheries, stocks, and species are incorporated as considerations or act as constraints. Before and after that time-window, other stocks and fisheries are actively managed, while Atnarko chinook are considered in their management.

Of the seven annual conservation objectives listed in Table 2, five are incorporated into pre-season decisions as constraints through area and time closures (C3, C5, C6, C7), and the maximum weekly opening length (C2). For one conservation objective (C4), there is currently no management mechanism but performance is monitored, and there remains only a single conservation objective that drives weekly harvest management throughout the season: target escapement. In-season harvest management of terminal Atnarko chinook fisheries therefore reduces to opening and closing the Bella Coola Gillnet Area for commercial fisheries, and monitoring the returning stock.

3.3.2 Interaction between fisheries

Available catch and effort data indicate little in-season interaction between harvester groups, once they are corrected for year to year variations in abundance. Correlations between annual catches in the commercial gill net fishery, the recreational fishery, and the Nuxalk food fishery were not statistically significant ($p > 0.39$). Based on these weak correlations, it's reasonable to assume that commercial openings have little effect on the catch in food and recreational fisheries within a year over the historically observed effort levels and corresponding terminal returns. Indirectly, each sector's catches each year affect future catches for all sectors via the spawning escapement. However, this is assumed to be addressed through the target spawning escapement. Catches and spawning escapements are summarized in Table 1.

3.3.3 In-season options for Bella Coola Gillnet Area commercial chinook fishery

For each week in June, the fisheries manager determines the duration of commercial openings based on estimated stock status. Openings can range from one to three days, and incorporate the following considerations: (1) Earlier openings tend to be shorter, because early migration may result in overestimates of abundance. (2) The first opening is usually a 1-day assessment fishery, to gauge the number of participating vessels and provide an independent indicator of abundance. (3) If estimated status is poor, there may be a 1-day opening during the second week of June because potential impacts on the stock are less severe early in the run. However, during the third week of June, the fishery would probably be closed to protect the peak of the run.

3.4 In-season model for assessing stock status

The fisheries manager evaluates projections of total escapement to assess stock status during the fishing season. I developed a Bayesian projection model, which combines weekly projections based on simple linear relationship between post-season estimates of total escapement and the log of cumulative Nuxalk catch. In this section, I first present results from fitting the independent weekly regression models, and then compare projections based on different assumptions

3.4.1 Regression fit

The predictive quality of the in-season indicator (i.e. cumulative catch in the Nuxalk food fishery) varied throughout the season. As a result, the fit of the independent weekly regression models, as indicated by regression error r^2, first improved and then worsened (Figure 16). Regression error is lowest in weeks 23 and 24, around the peak of the run. Bayesian updating capitalizes on that information during later weeks, increasing the precision of projections.

3.4.2 Comparison of projections

I compared four in-season projections of chinook escapement: independent regressions, and Bayesian updating with three different priors. Bayesian projections were more precise and more stable throughout the season than projections based only on independent regressions for each week.

The Bayesian projections incorporate information from previous years and previous weeks in the current year, and carry over data from more informative weeks into later predictions. This updating improved projections in two ways. First, confidence bands for Bayesian projections were considerably narrower than for simple regression, indicating more precise predictions of escapement. Second, confidence bands for Bayesian projections converged as each season progressed, while confidence bounds for simple regression projections converged and expanded according to the prediction error associated with each week's model fit and data point. This observation held true for all three priors. Figure 15 shows a typical example.

The predictive quality of the in-season indicator did not show steady improvement throughout the season, and these are the situations where Bayesian updating is particularly useful. Bayesian updating also reduces week-to-week fluctuation in projections, because each new observation represents only a part of the information used. Fried and Hilborn (1988) also observed this for in-season information in Bristol Bay sockeye fisheries.

Bayesian updating is more precise and more stable than simple regressions, but is it more accurate? Figure 18 shows trajectories of projected escapement throughout two seasons, for two different projections. Table 6 and Table 7 summarize the results from two cross-validation tests (i.e. retrospective analysis and the leave-one-out method) of the four different methods for projecting end-of-season abundance, identified as panels A to D.

Figure 18 illustrates the information that would have formed the basis for in-season decisions during the 1988 and 1996 seasons, if this projection model had been used with the benefit of data from 1980 to 2001 (excluding 1994 and the year of interest). In both 1988 and 1996, the best estimate provided by Bayesian updating is less sensitive to in-season variability in cumulative food fishery catch than the independent regressions for each week. Also, the Bayesian projections for 1988 and 1996 are generally more accurate than independent regressions during weeks 22 to 24, when the Atnarko chinook fishery is actively managed. For example, in the first four weeks of the 1996 season, the Bayesian projection would have overestimated escapement by no more than 2000 fish (0 to +8% error), while the independent regressions would have fluctuated from an overestimate of 5,000 to an underestimate of 5,000 (+20% to -20% error).

The type of method for comparing models affects the performance measures considerably (Table 6 vs. Table 7). For all four projections, the retrospective analysis indicates a much stronger bias (i.e. larger mean deviation) when only data up to year t-1 are used to fit the regression equations (Table 6). When dropping only a single observation for the evaluation, estimates of regression parameters become more stable, and the sample size almost doubles, and bias all but disappears (Table 8). For in-season assessment, projected escapements are rounded to the nearest thousand, and mean deviations in the latter case never exceed about 300 fish (Table 7). However, mean absolute percent error (MAPE) is consistently about 10% larger when all data are used.

For all four projections, both retrospective evaluations show that bias, or mean deviation (MD), decreases as the season progresses. Mean absolute deviation (MAD) and MAPE decrease consistently for the three Bayesian projections, but increase in week 25 for the independent regressions, corresponding to the reduced predictive ability of cumulative catches later in the season as shown in Figure 16. The Bayesian projections successfully carry over information from earlier weeks with better data.

The benefits of Bayesian updating strongly depend on the choice of prior probability. Bayesian updating with a narrow prior based on escapement in the 5 most recent years (t -1 to t-5) performed best, with the lowest absolute deviation (MAD) across all weeks in both evaluations, and up to 50% reduced bias in evaluation 1 (Table 6). Bayesian updating with the uniform prior performed about as well as independent weekly regressions, and Bayesian updating with the more diffuse normal prior actually did slightly worse than the uniform prior, in both evaluations.

For both evaluations, the proportion of observations falling outside the 80% confidence band tends to be smaller for simple regression than for any of the Bayesian projections. However, the Bayesian confidence intervals are much narrower (e.g. Figure 15).

Some numbers appear repeatedly in Table 6 and Table 7 (e.g. 48). This is simply due to the relatively coarse resolution of the analysis. Observed escapement data were rounded to the nearest thousand, and Bayesian projections also fall into these discrete intervals. For example, if the sum of deviations is 1000 for 21 observations, then MAD equals 48.

In summary, the Bayesian projections can be more accurate than independent regressions if pre-season assumptions about escapement (i.e. the priors) are chosen correctly. Bayesian updating provides more confident projections with narrower bounds, but bias and accuracy can be worse than for independent regression if priors are incorrectly chosen. All projections tend to underestimate chinook escapement in the retrospective evaluation, because of the observed steady increase from 1980 to 2002 (Figure 5).

3.5 Guidelines for in-season assessment of stock status

3.5.1 Observations during status assessment tasks

The process of eliciting assessments of stock status was very useful. Discussions during the session improved the manager's familiarity with the behaviour of the projection model, helped clarify the correct interpretation of output, and provided direction for improving the user interface. For example, the manager insisted on plots of posterior probabilities "to remind him of the full range of possible outcomes" (Lyle Enderud, FOC Bella Coola, pers. comm.), even though this information is not usually presented to decision makers in fisheries agencies. The fisheries manager provided assessments of stock status at a finer resolution than the four original categories (e.g. A-, B+), and the task also triggered discussions of likely management responses under these scenarios. For example, in several scenarios he indicated that and A- or B+ expressed his judgment equally well, and that either designation would result in the same planned opening for the next week. Scenarios were presented in random order, and the respondent was instructed to treat each scenario independently. However, he commented repeatedly that the sequence of scenarios affected his assessment of stock status, just as a series of good or poor seasons would influence his judgment in the actual management of these fisheries.

3.5.2 In-season considerations not included in the analysis

The fisheries manager assesses the quantitative catch information in the broader perspective of additional factors that may have an effect on catch and effort in the food fishery, such as river condition (e.g. high water levels or glacial silt) and social occasions on the reserve. These variables could not be included in the analysis due to lack of baseline data, but the fisheries manager still adjusts his assessments of stock status based on his experience and was able to provide a very detailed description of his judgments (Lyle Enderud, FOC Bella Coola, pers. Comm.). Water levels have not been extreme in recent years, and have been high only infrequently since 1980, so that river condition probably was a minor factor in food fishery effort. The manager estimated that extreme river conditions or community events may change a week's catch by 30 to 50%, but fisheries staff would be aware of the circumstances (e.g. major potlatch). These week-to-week variations probably have very little effect on projected escapement, because the cumulative catch is used in the projection model, and the extreme value is integrated with the previous projections in the Bayesian updating framework.

As a result of these discussions we developed a qualitative classification of river status and a classification key for the observer, who started recording water level based on a simple gauge, and turbidity using a Secchi disc.

3.5.3 The manager's assessments of stock status

The fisheries manager evaluated 44 scenarios in random order, where each scenario consisted of a sequence of in-season data (i.e. cumulative catch in the Nuxalk food fishery for Weeks 22 to 25). For each of these scenarios, the manager provided weekly assessments of stock status based on his interpretation of the model's output. Table 3 lists all 44 scenarios and his responses. Each line in the table shows either a simulated or observed sequence of in-season data (i.e. cumulative catch in the food fishery), and the manager's corresponding estimate of stock status, which potentially incorporates the data from all previous weeks.

Status assessments were very consistent throughout each fishing season. In 11 of the 44 scenarios (four simulated, seven observed), the assessed status changed once over the four weeks, but only by one category. For the remaining 33 scenarios, assessments stayed the same or changed within a category (e.g. B- to B).

There are several plausible explanations for this result: (1) responses are strongly anchored on the initial assessment, (2) food fishery catch data is remarkably consistent throughout each season, (3) the projection model and assessment are very robust to random variability of in-season information, or

(4) classification categories are too crude. All four factors may contribute. The respondent repeatedly emphasized that he assesses each weeks' status in the context of previous weeks, thereby anchoring responses on the initial value. Cumulative food fishery catch data is quite consistent throughout each season, and the projection model is specifically based on the Bayesian updating approach to be more robust to week-to-week variability of in-season data (Section 2.4). The number of status categories is based on the indifference ranges elicited from the manager, which capture uncertainty in the data and implications for management responses. Therefore, consistent assessments at this level of resolution should translate into consistent fishing patterns over a season. This does not mean that the fishery openings will be the same each week, but that the same "regime" is in place.

Eight of the 11 changes were downward adjustments, indicating that either the model or the manager tend to overestimate stock status early in the season. Retrospective evaluations showed that escapement projections can be biased to the high side under some circumstances (Table 6).

3.5.4 Classification trees

I used classification trees to analyze the fisheries manager's assessments of stock status and infer the reference points he applies each week when evaluating the in-season indicator, cumulative catch in the Nuxalk food fishery. Figure 19 shows the responses ordered by cumulative catch along the horizontal axis. Each letter corresponds to one response from the fisheries manager (i.e. statement of the stock's status), and its position along the x-axis reflects the cumulative catch. To clarify the display, scenarios are also ordered vertically according to the sequence in which they were elicited. Fitting a classification tree to these data by recursive partitioning along a single variable (Nuxalk catch) is analogous to picking the vertical lines that separate the data into the most homogeneous subsets possible (i.e. according to category A, B, C, or D). The location of the "best" partitions depends on the expected frequency of each class in future observations and the loss associated with misclassifications. The dashed lines in the bottom right panel of Figure 19 show one possible set of partitions.

Figure 20 to Figure 22 show classification trees for determining stock status in preparation for fisheries in Weeks 23 to 26. The trees were fitted using (1) data from the previous week (Figure 20), (2) data from all previous weeks in a season (Figure 21), or (3) data from the previous week with alternative priors and loss matrices (Figure 22).

Figure 20 shows classification trees for planning fisheries in Weeks 23 to 26, based on data from the previous week. Classification trees consist of round splitting nodes and rectangular terminal nodes. Each node shows two types of information: the number of observations from each category that fall into the node, and the classification of each node that minimizes expected loss. Classifying a new observation is equivalent to answering a series of yes-no questions corresponding to criteria specifying the binary splits. Even a simple classification tree like the one for fisheries in week 24 (top right tree in Figure 20), conveys a lot of important information to decision-makers. Without any in-season information, the best assessment is status B, which is expected to be correct 64% of the time (28 of 44 cases; top node of tree), and therefore minimizes the expected loss when the unit loss matrix and observed priors are used. If cumulative catch in week 23 was less than 482, but more than 254.5, class C is the best assessment, because 6/9 of the observations in this subset fall into class C (third splitting node in top right tree in Figure 20).

Figure 21 shows classification trees for planning fisheries in Weeks 24 to 26, fitted with cumulative catch observations from each of the previous weeks as explanatory variables (as opposed to one number that sums across all previous weeks). In-season information from week 23 is the best splitting variable for identifying good stock status (A,B), while data from Week 22 best identified poor stock status (C,D). This may very well reflect the dynamics of Nuxalk fisheries described in Section 1.3.3. Chinook caught early in the season, up to Week 22, are mainly for immediate consumption, and increased effort may compensate for lower catch-per-unit-effort if returns are poor, unless returns are very low. Near the peak of the run, in weeks 23 and 24, effort may plateau when the run is abundant, so that catches are more sensitive to run size. This observation is a good example of the complex interactions that C&RT models can identify through recursive partitioning. In the regression models, Week 22 simply shows a much weaker correlation (lower r^2, see Figure 16), but in the classification tree, the data from Week 22 can be used to identify poor years, and later data to identify good years.

In this case with several explanatory variables, C&RT models also calculate surrogate splits, which separate the data into similar subsets as the original splitting criterion. Even though the four explanatory variables here are clearly interrelated, there may still be situations where new catch data are not available in time, and the manager has to assess stock status based on information from earlier weeks. The majority of surrogate splits identified the same cut-off points as the corresponding trees based on a single variable. For example, the original split for identifying category A in Week 26 (bottom right tree in Figure 20) is at a cumulative catch of 1296.5 in Week 25. The surrogate splits are 857 in Week 23, and 1101 in Week 24.

Figure 22 shows how the classification tree for planning fisheries in Week 26, with catch data from Week 25 as the explanatory variable, changed under different assumptions about the prior probability of each category (priors) and with asymmetric losses. Observed priors were calculated from the observed proportion of each class in the observed data. The asymmetric loss table incorporated the consideration that large mistakes (e.g. D classified as A) are worse than small mistakes (e.g. B classified as A), and that overestimates (e.g. C classified as A) are worse than underestimates (e.g. A classified as C).

The observed prior and the asymmetric loss table influenced: (1) the number of splits in the tree, ranging from two to five, (2) the sequence of splits isolating either poor status (C,D) or good status (A,B) first, (3) the purity of terminal nodes (i.e. the number of misclassified observations), and (4) the split between categories A and B. The original tree (top left tree in Figure 22; showing a part of the bottom right tree in Figure 20) distinguishes between categories A and B in the last of three splits, based on whether or not cumulative catch in the previous week exceeded 1296.5 fish. This cut-off separates the remaining 36 observations into two groups, one with mostly B (22 of 23) and one with mostly A (7 of 13).

However, given the observed prior (case 2 in Figure 22), new observations are four times more likely to fall into category B than into category A (Table 4), and the resulting classification tree attempts to better isolate observations from category B. This adds two splitting points to the 1296.5 identified by the original tree. However, this tree clearly overfits the responses provided by the fisheries manager, because category B would now be identified as *either* falling into the range of 694 to 1296.5 *or* falling into the range of 1363 to 1506. Category A would correspond to *either* the range between 1296.5 and 1363, *or* larger than 1506.

Given the asymmetric loss table, overestimates are much more serious than underestimates, and the resulting classification trees hedge against overestimates by lumping categories A and B together (cases 3 and 4 in Figure 22). As the original tree (top left) shows, it is difficult to distinguish between categories A and B because any split isolating A also produces misclassifications of category B. With the asymmetric loss table, this incurs the increased penalty for overestimates. The responses for poor stock status were more consistent, and the CART™ algorithm had no problem finding splits to fully isolate categories C and D. The splitting points for those two categories were therefore not affected by the asymmetric loss table.

Given both observed priors and the asymmetric loss table (Figure 22; bottom right tree), the resulting tree lumps categories A and B together to hedge against misclassifications of B, and reverses the sequence of splits to isolate the most frequent category first (B).

CART™ provided a quick and simple tool for analyzing the fisheries manager's responses, and the resulting classification trees were consistent with the manager's intuitive understanding of the available data.

3.6 Simple decision guidelines for in-season management of Atnarko chinook fisheries

To develop in-season guidelines for assessing stock status of Atnarko chinook, I combined the information from four classification trees, one for each week, into a single table that captures both the properties of the projection model and the fisheries manager's interpretation of the model's output (Table 8). Of the various assumptions explored in Figure 20 to Figure 22, I used the classification trees with uniform priors and symmetric loss tables (Figure 20), because (1) the Bayesian projection already incorporates prior information, and (2) the loss table used here is simply an example, and was not elicited from the fisheries manager to reflect his assessment regarding the consequences of different misclassifications. For each week of the fishing season, the table shows the management reference points (cut-off points) associated with each category of stock status (A to D), as well as a range of best estimates for projected end-of-season escapement. These reference points do not directly correspond to the four ranges of escapement identified in the hierarchy of management objectives in Table 2. Rather, they were inferred from the manager's interpretation of more than 700 posterior distributions of projected escapement (44 scenarios * 4 weeks * 4 projections) and reflect how he hedges his weekly assessments against uncertainty.

This simple table is transparent and easy to communicate, but still captures both of the complex steps of in-season assessment shown in Figure 10. Through further interviews with the fisheries manager, I then mapped the previously identified management options onto the four categories of estimated status (Table 9).

Together, these two tables capture the full sequence of steps for weekly management decisions, from the new observation of cumulative catch in the Nuxalk food fishery to the likely opening in the Bella Coola gill net fishery. All participants in the decision-making process can see (1) how the in-season data are used, (2) what the management options are, and (3) which reference points the manager uses to choose among the available management options.

I presented a draft version of these tables to the Central Coast Advisory Board during their 2003 post-season meeting. They considered the precision of cut-off points (e.g. 1296.5) misleading, given the inherent variability and uncertainty in food fishery catch estimates, and worried that this analysis was intended to replace the judgment and experience of the local fisheries manager. This is not the case. These guidelines provide benchmarks describing the manager's judgment and experience, which facilitate communication among participants, encourage consistent decision-making, and ease the transition for new individuals taking over the management of these fisheries. To emphasize that these are guidelines rather than hard-and-fast rules, the manager suggested rounding the weekly reference points to the nearest 10 fish, as shown in Table 8.

4 Discussion

In this section, I first discuss the concept of simple decision guidelines and its practical use in the management of Atnarko River chinook. I then consider the benefits of each step in the analysis, the limitations of this case study, unresolved questions, and future research. I conclude with a summary of the 2002, 2003, and 2004 fishing seasons during which these guidelines were used by fisheries staff in Bella Coola. I also include recommendations for the management of Atnarko chinook fisheries.

4.1 Simple decision guidelines

The concept of simple decision guidelines was well received among fisheries staff and stakeholders interviewed for this study. Fisheries staff in particular identified the need for quick-and-easy rules of thumb that would allow them to communicate with stakeholder representatives during in-season meetings and public consultation. The fisheries-specific definition of simple decision guidelines was well-suited for developing a comprehensive summary of the decision environment faced by managers responsible for numerous small, local fisheries. The definition focused the analysis on determining the four key components of (1) management objectives, (2) management options, (3) guidelines for assessing status of the resource, and (4) guidelines for management responses to status assessment, and ensured that each of these components was addressed in the same level of detail.

For this fishery, management options and response guidelines could be developed much easier than the other two components. This does not necessarily hold true for other fisheries, where managers actively manage more than one fishing area. In those cases, the concept of simple decision guidelines could still be applied, even if the methods need to be adapted.

The process of developing simple decision guidelines for Atnarko Chinook fisheries realized some of the potential benefits identified in Section 1.1. Once an initial summary of management objectives had been drafted, it triggered focused discussions among fisheries staff in the Bella Coola office, and encouraged them to make explicit statements about preferences for different outcomes. While revising guidelines for assessing stock status, fisheries staff identified sources of uncertainty and discussed their use of qualitative indicators, such as condition of the river, which in turn prompted them to devise additional, cost-efficient methods for collecting data (Section 3.5.2). Discussions regarding response guidelines encouraged all participants to consider a wide range of plausible scenarios (i.e. what-if planning). Overall, simple decision guidelines allowed the fisheries manager to easily document knowledge he had acquired over many years. As previously observed by researchers using other decision-support tools (Hilborn and Walters 1977, Walker et al. 1983), the process of eliciting the information can be the most useful aspect of the analysis.

The concept of simple decision guidelines fits firmly within the precautionary approach to fisheries (FAO 1995 a, FAO 1995b), which prescribes clearly specified management objectives and pre-agreed management actions for achieving these goals. All fisheries agencies are struggling to find practical tools for implementing these principles. The approach used in this case study offers a much-needed template for developing simple summaries of objectives and management responses.

Calls for improved management of Canadian fisheries (e.g. Hutchings et al. 1997, deYoung et al. 1999, Pinkerton 1999, FOC 2003) usually include recommendations for increased information sharing (e.g. publicly accessible data bases) and more transparent decision-making (e.g. control rules). However, most stakeholders are probably not interested in access to the raw data, nor do they expect to be fully involved in every operational detail of managing the fisheries. Rather, they expect a simple, comprehensive description of how available data are used to choose a management action. The simple decision guidelines developed in this case study convey the most important information without too much technical detail, and helped the fisheries manager communicate with stakeholders in the Bella Coola area.

4.2 Benefits and challenges

Most of the work for this case study focused on management objectives and guidelines for assessing stock status, because management options and response guidelines needed little clarification. Accordingly, the benefits and challenges discussed below only reflect my experience with these first two of the four components of simple decision guidelines, and only for this particular fishery.

4.2.1 Hierarchical structuring of management objectives

Hierarchical structuring is a common first step for many decision-support tools, but not all of them retain the full hierarchy throughout the analysis (Section 1.4). One of the challenges of working with a nested hierarchy of management objectives is that they can be unwieldy to display, particularly if each element requires lengthy text. Table 2 proved to be a workable compromise between showing the nested structure and providing sufficient explanation for each element. The table captures some simple priority rankings within each branch of the hierarchy, but does not allow for direct comparisons among lower level elements.

The simple hierarchical summary of management objectives (Table 2) was very useful. It clearly displays the connection between general management objectives, such as "maintain biological diversity", and the specific attributes considered by the decision-makers, such as "minimize incidental catch of Dean River Chinook". This kind of clarification is crucial in participatory processes like the Central Coast Advisory Board, where participants often agree on general objectives, but disagree on which attributes best reflect those objectives. Even if participants cannot agree on the details of a single hierarchy of management objectives, each group can still develop their own hierarchy and use this to communicate their concerns to other participants. This would still facilitate discussions and make public consultation more effective (Keeney and McDaniels 1999).

The hierarchical structure of management objectives emphasized gaps in available data and policy direction. When we were unable to specify meaningful attributes to reflect higher-level objectives, the fisheries manager generally pointed to a lack of consensus among FOC and advisory groups, and the absence of any documented policy to draw from. For example, Table 2 lists five quantitative attributes for assessing the performance of the fishery with respect to conservation objectives. However, the objectives relating to ecosystem considerations remain vague, probably due to a lack of consensus about the appropriate definitions, and a corresponding lack of data. How should the fisheries manager in Bella Coola evaluate "impacts on other species", without some clear guidance from the scientific community, and the budget to pay for additional data collection? Similarly, all three harvester groups in the area seek "stable access". However, the fisheries manager had to specify attributes for this general objective based mostly on his own judgment, rather than based on clear advice from harvesters. These gaps are not unique to Atnarko chinook fisheries. All fisheries agencies and advisory bodies struggle with the same concerns, and a simple hierarchical summary like Table 2 can help these groups to be more specific and focused in their discussions.

The combination of indifference ranges and qualitative assessment, in the two right-most columns of Table 2, provides a simple and effective format for defining the target state of the fishery, and then revising it with others in a participatory process. With respect to conservation objectives, for example, the table shows at a glance that the fisheries manager is working towards escapements above 25,000 fish, weekly fisheries closures of at least 3 days, less than 20% hatchery fish in the run, minimal incidental catches of Dean River chinook, and minimal chinook catch in the tributaries of the Bella Coola River. Others involved in the participatory process may well disagree with the managers' choice of attributes and target levels, but at least they can now provide constructive feedback on specific aspects of the management of the stock and fisheries.

4.2.2 Eliciting preferences

I tested three methods for eliciting relative preferences regarding management objectives. They produced almost identical rankings, but differed considerably in terms of interaction with the fisheries manager and additional information captured in the results. All three methods worked well within the hierarchical structure of management objectives, which helped establish the context for the more specific questions and reduced the number of required comparisons. All three required very little time to complete.

The similarity in rankings elicited by the different methods can be partly explained by two observations. All three rankings were provided by the same expert within a short-time period, which should increase consistency in the responses. However, the degree of consistency is still surprising, given that Hobbs et al. (1992) found preferences expressed by experts could differ more between methods than between individuals. Another explanation could be that the respondent, a highly experienced fisheries manager, was already very sure of his management priorities, and used the different methods simply to express them. An inexperienced manager, using these tools to explore vague priorities, may have been much less consistent. However, the fisheries manager also provided a running commentary describing his reasoning process, and with the computer-based graphical weightings, he considered different possible rankings before settling on the final result. More case studies are needed to investigate this unexpected consistency.

During the elicitation tasks, each of the methods focused the fisheries manager on different issues. Working with a list, the fisheries manager saw the entire hierarchy of management objectives at glance, and discussions focused on the content. Was the list comprehensive? Were the attributes appropriate? While working with swing-weights, we mostly discussed the limitations of the method. Based on the running commentary and frequent revisions, the third approach, the computer-based graphical weighting, seemed to be most useful as a tool for thinking about the relative priority of management objectives. It was also the only method that triggered discussions about conditional preferences, where the relative priority of one objective depends on the performance with respect to another. Conditional preferences could not be captured with the current interface, but it did help the fisheries manager think about complex interactions between different objectives.

The graphical interface showed potential for capturing some of the same information as multi-attribute utility methods, but should be easier to apply within the constraints of small fisheries. At the very least, the computer-based graphical weighting can set the stage for more rigorous trade-off analyses. As for simple decision guidelines as a whole, the process of eliciting preferences from the fisheries manager may be the most useful part of the analysis.

All three methods revealed an interesting point -- not all components of an important objective are necessarily important (Table 5, Figure 9). The respondent generally had a single important attribute in mind for each higher-level objective. As mentioned in the previous section, participants in advisory meetings may well agree on the ranking of high-level objectives (e.g. "Conservation has priority over commercial catch"), but each participant can still have very different preferences regarding the trade-off between two attributes from these general objectives (e.g. incidental catch of Dean River chinook vs. commercial catch-per-unit-effort). Advisory processes can benefit from any method that encourages participants to be more specific in their recommendations.

4.2.3 Bayesian in-season model for projecting escapement

Bayesian updating improved in-season projections of escapement for Atnarko chinook. Cross-validation showed that weekly projections of end-of-season spawner abundance using Bayesian updating were more precise, had narrower confidence bounds, and were more stable throughout the season than independent regression estimates for each week. However, the accuracy of Bayesian projections strongly depended on pre-season expectations in the form of prior probabilities. A normally distributed prior, using escapement data from the five most recent years, produced the most accurate projections for this chinook stock. Projections based on a very diffuse normal prior, using data from 1980 to 2001, were slightly less accurate than independent regression estimates, but still more precise and stable.

Bayesian updating is most useful when the predictive quality of data fluctuates over time, because earlier information is carried over. For Atnarko chinook fisheries, the quality of the in-season indicator, cumulative catch in the Nuxalk food fishery, is poorest in the weeks when the best opportunities for commercial harvest are available (Weeks 23 and 24). Projections based on Bayesian updating could be more precise and more accurate because they incorporated the strong signal from earlier weeks.

Bayesian updating allows the fisheries manager to express his expectations for each fishing season, explore the implications of different assumptions (i.e. different priors), and solicit feedback from the advisory group in a form that they all can relate to. For example, he could ask them whether they expect the upcoming season to be similar to the last few years, or whether they see any indications that it could be similar to some earlier period (e.g. the 1980s). The Bayesian projection model provides a simple, intuitive way of converting that feedback into quantitative information.

The design of the user interface for the Bayesian projection model and its ease-of-use determine whether or not in-season tools like this projection model are actually applied by the intended user. These considerations influenced my choice of computing platform, as well as the structure of the program. Despite its limitations, MS Excel was the obvious choice for this model, because it is available to all FOC staff and the spreadsheet structure makes it possible to show each step in the calculations, allowing the manager to work through and gain confidence in the output. A statistical package, such as S-plus, would have been much more efficient, but would probably exceed the budget of the Bella Coola office and would require programming skills beyond those of Excel, which would introduce yet another learning curve. I designed the user interface to emphasize the effect of different pre-season expectations, uncertainty in each projection, and the full range of plausible escapements.

4.2.4 Eliciting assessments of stock status

This step of the analysis had two very different purposes, and was successful in both.

The *process of eliciting* assessments of stock status trained the fisheries manager in using the Bayesian projection model and interpreting its output. The manager's running commentary triggered very specific discussions about the qualitative indicators he uses in addition to the quantitative projections of end-of-season escapement, and by now the Bella Coola office has collected three years of cost-effective, relevant data on river condition using a simple gauge for recording water level and a Secchi disc for measuring turbidity. As observed previously by others working with B.C. fisheries (e.g. Hilborn et al. 1984, Hilborn and Luedke 1987), this kind of close interaction with the intended end-user is necessary to overcome the usual barriers to practical implementation, for both the projection model and for the simple decision guidelines as a whole.

The *assessments of stock status* provided a comprehensive data set for identifying the in-season reference points that the manager uses to determine openings in the commercial gill net fishery.

4.2.5 *Classification trees*

Classification trees proved to be a very useful tool for analyzing the assessments of stock status provided by the fisheries manager. As in many other applications (e.g. Breiman et al. 1984), the C&RT method helped reduce a substantial amount of expert judgment (700+ posterior distributions) into a very simple aid to decision making. The resulting in-season guidelines for assessing stock status (Table 8) capture the complex interaction between pre-season assumptions (priors), in-season data, and the manager's attitude towards risk.

The classification trees identified robust cut-off points (i.e. management reference points) for three of the four categories of stock status (D, C, B), but the cut-off between categories A and B was sensitive to assumptions about the prior probability of each category and the losses associated with misclassifications. This lack of distinction between the two best categories was apparent throughout this analysis. The manager's assessments show an area of overlap in the values of the in-season indicator corresponding to these two categories (Figure 19), and the management options also show a similar overlap (B: 1-2 days; A: 2-3 days; see Table 9). The apparent inconsistency in assessments therefore disappears in the full context of in-season decision-making, because any in-season observation near the vague benchmark separating A and B still results in the same management action.

The fisheries manager and the stakeholder representatives at the meetings of the Central Coast Advisory Board found the concept of classification trees very intuitive. Each node of tree shows the number of observations from each category, as well as the classification for this set of observations. This simple format shows natural frequencies rather than proportions, and helps lay-persons understand probabilities (Gigerenzer and Hoffrage 1995). For example, if fisheries have to be planned for Week 23 in the absence of catch data from the Nuxalk fishery in Week 22, the stock status is most likely B (28/44), but either A (8/44) or C (8/44) are also plausible (first node of the top left tree in Figure 20).

Based on my experience in this case study, I see great potential in the two-step approach of eliciting assessments of stock status from agency staff and then fitting classification trees to their responses. In small fisheries like the terminal fisheries targeting Atnarko chinook, this approach can capture the acquired experience of a single individual and document it in a simple aid to decision making. In more complex settings, this approach can facilitate the communication between the technical teams responsible for providing assessments of stock status, and the managers responsible for choosing appropriate responses to these assessments.

4.3 Limitations of this case study and future research

The most serious limitation of this study is its narrow scope, dealing only with a single stock and a single fisheries manager. In addition, the manager first helped shape the methods for this study, and then served as the main respondent for interviews and elicitation tasks. The encouraging observations while using computer-based graphical weighting and the ability to develop such a comprehensive description of management objectives may be specific to this one highly enthusiastic fisheries manager. Future expansions of this work need to address three specific questions.

How do we define "importance" of different management objectives in a fisheries context, and how can we elicit meaningful statements of relative importance from fisheries managers and advisory bodies?

There is currently no agreed-upon concept of "importance" for discussions of fisheries management objectives. Quantitative decision-support methods use either abstract units such as utiles, or fall back on economic measures such as net present value. Neither is very useful in a participatory process involving stakeholder representatives from diverse backgrounds.

The fisheries manager interviewed for this study found the loosely defined concept of "relative priority" very useful and intuitive. He felt clearly hesitant to provide direct statements such as "Achieving target escapement is

2.4 times as important as providing predictable openings for the gill net fishery". The graphical interface allowed him to explore his general thinking and express it imprecisely, with less potential for misinterpretation by others. These graphical expressions of relative importance should also facilitate group discussions with advisory bodies, because the focus shifts from specific numbers (e.g. "Why 2.4 rather than 2.2?") to the bigger picture.

Future work with larger groups can show very quickly whether this graphical approach is suited for the policy context of fisheries management, and whether it can facilitate the interactions between advisory bodies and management agencies.

Can computer-based graphical weighting be used to elicit preference statements, and what is its theoretical foundation?

In this initial test, the computer-based graphical weighting showed potential for engaging decision-makers in discussions of management objectives and the exploring the relative importance of objectives, attributes, and levels of attributes.

As for all steps in this case study, I worked towards simple methods that could be easily by agency staff managing many small fisheries. Rather than starting from the desired theoretical properties of preference statements (e.g. reciprocal consistency) and devising some format for eliciting the necessary information, I used an interface designed to promote discussion, engage the decision-maker, and capture some basic information about value judgments. The preference statements elicited with this graphical method can of course be converted into quantitative values, but much more work is required to develop a theoretical foundation for this method, and explore the mathematical properties of the weights, ranks, and utility curves derived this way. One specific extension is to explore whether the responses elicited with the graphical interface correspond more closely to methods using rating or alternative approaches based on ranking.

How can simple decision guidelines be integrated into other developments in B.C. fisheries?

Two on-going initiatives in British Columbia fisheries are closely linked to the concept of simple decision guidelines. FOC is pursuing "Objective-based

Fisheries Management" (OBFM), and the Nisga'a Nation is developing "Fisheries Operating Guidelines" (FOG). Both of these initiatives aim to improve decision-making and the interaction between managers and harvesters.

OBFM focuses on developing measurable goals for individual fisheries, similar to the quantitative attributes and indifference ranges shown in Table 2, and pre-agreed management actions for achieving these goals. OBFM was initially triggered by recommendations from the Auditor General, requesting that FOC clarify its management objectives. Currently, there are pilot projects for Pacific herring (*Clupea pallasi*), harp seals (*Phoca groenlandica*), and snow crab (*Chionocetes opilio*); these will provide a template for other fisheries.

The approach tested in this study should be a valuable addition to the OBFM initiative. First, tabular and graphical displays of management objectives in a nested hierarchy would help FOC staff develop a more comprehensive list of quantitative attributes, and establish a general context for each of the attributes. Using the snow crab example (FOC 2001b), what are the specific attributes considered under the general objective of "stabilizing the operating environment"? Second, indifference ranges and verbal assessments would help with describing a target state for each of the fisheries, and would provide a solid starting point for public consultation. For example, given that the incidental catch of immature crab should not exceed 20%, what level of this attribute is generally acceptable? Third, an interactive tool for expressing relative preference, based on the simple interface used in this study, could support discussions between FOC and advisory groups when trade-offs between attributes have to be considered.

FOGs are emerging as part of treaty negotiations between British Columbia First Nations, federal agencies, and provincial agencies. They are intended to provide detailed instructions for the management of fisheries under the treaty, and are in principle very similar to simple decision guidelines. So far, only the Nisga'a Treaty has been finalized (TNO 2000) and the Nisga'a Nation is developing FOGs for implementing fisheries provisions of the treaty. The current draft of the Nisga'a FOG includes general management goals and detailed accounting procedures for estimating and allocating total allowable catch. It also outlines the contents of annual management plans, which should include more detailed descriptions of management objectives, stock assessment, and management responses for each of the fisheries.

The simple methods used in this study could be directly applied by Nisga'a fisheries staff working on annual management plans. For example, biologists and managers could run through a series of fictional seasons, test the forecasting models, evaluate the output, and use C&RT models to summarize the whole process in a simple decision table. This summary would then help them explain their management approach to others in the community as well as their counterparts in FOC.

4.4 Use of the simple decision guidelines in Atnarko chinook fisheries

I developed these simple decision guidelines for terminal Atnarko chinook fisheries with the local fisheries manager during the 2002 season, based on data from 1980 through 2001. The hierarchy of management objectives (Table 2), the Bayesian projection model, guidelines for assessing stock status (Table 8), and guidelines for responding to status assessments (Table 9) have been used by Bella Coola fisheries staff since 2002. In this section, I briefly discuss the 2002 through 2004 fishing seasons and the use of these decision tables. Table 10 summarizes the 2002-2004 fishing seasons. It shows in-season data, weekly projections, duration of the weekly commercial opening, and the resulting catch.

During these three years, two occurrences had the potential for seriously disrupting the management of this fishery: (1) The abundance of returning adults and the resulting spawning escapement both dropped considerably. Escapement in 2002 was only 14,000 chinook, just over half the escapement in the three preceding years. (2) The fisheries manager interviewed for this study gradually handed over the management of this fishery to another individual. Despite these changes, management actions over all three seasons were consistent with the guidelines summarized in Table 8 and Table 9.

In 2002, in-season information put stock status squarely in category B for all four weeks, but at the high end of B during Weeks 24 and 25. The resulting pattern of weekly openings in the commercial gill net fishery is consistent with these assessments of stock status (Week 23: B leads to 1-day opening, Week 24: B leads to 1-day opening, Week 25: B/A leads to 2-day opening, Week 26: B/A leads to 2-day opening). Commercial catches were good, so that there was no in-season indication of poor returns. However, the in-season assessments of stock status turned out to be overestimates.

In both 2003 and 2004, early data from Weeks 22 and 23 indicated that stock status fell into category C, while projections improved during Weeks 24 and 25 indicating category B. The commercial fisheries again followed the guidelines, with 1-day openings throughout Weeks 23 to 26.

The simple decision guidelines developed in this case study probably did not cause this consistency in management actions, but they were substantiated as a comprehensive, accurate description of the actual management approach.

4.5 Recommendations for Atnarko chinook fisheries

The hierarchy of management objectives (Table 2) lacks detail regarding ecosystem concerns and harvesters' preferences for stable access to the fish. The local fisheries manager provided as much information as he could, relying on the existing departmental policy and the data available to him. These policy gaps are not unique to the Atnarko chinook fishery, and a regional effort, such as the OBFM initiative, is required to fill them in.

Chinook fisheries in the Bella Coola area provided an ideal setting for this initial study of simple decision guidelines, because the fisheries manager has good rapport with local stakeholders, and detailed records of past management actions are available. Both of these conditions can only be maintained through sustained effort by local fisheries staff.

FOC is currently establishing new advisory processes for Pacific salmon fisheries, shifting to integrated regional stakeholder groups. The Central Coast Advisory Board, the current forum for interaction between the local fisheries manager and local stakeholders, will probably be absorbed by a larger body dealing with the entire North Coast of B.C. Any reorganization disrupts established participatory processes, but simple decision guidelines can capture the hard-earned experience of the existing advisory group, and serve as a starting point for the newly established groups. For example, the hierarchy of management objectives developed for this fishery can be used to communicate local concerns to regional stakeholder representatives.

The *Records of Management Strategies* have been compiled annually in Bella Coola since the 1980s, but this takes up substantial amounts of staff time and resources. This effort might possibly be discontinued due to future budget reductions or changes in staff, but this would not be advisable. These comprehensive, publicly available records are important, and keeping them up to date should be explicitly included in the job requirements for local staff.

5 Conclusions

Simple decision guidelines are a useful addition to the decision-support toolbox. The four basic components of (1) management objectives, (2) management options, (3) guidelines for assessing stock status, and (4) guidelines for management responses to status assessments provide a template for eliciting comprehensive descriptions of the management approach for small fisheries.

The methods developed for this case study allowed the fisheries manager to quickly develop a useful representation of his management objectives, to identify dominant concerns, and summarize his in-season decision process in two simple tables. For small fisheries, a simple summary of management objectives, such as the hierarchy in Table 2, may be all that is necessary. If more complex analyses are required, the components of simple decision guidelines could serve as quick consistency checks or building blocks.

Simple decision guidelines provide at least a solid basis for future work, require much less effort from fisheries managers than other methods such as decision analysis, and have potential for much wider use in fisheries agencies.

6 Tables

Table 1. Salmon catches in terminal fisheries in the Bella Coola area.

			Mean annual catch		
		Mean adult spawners	Nuxalk food fishery	Bella Coola/Atnarko recreational fishery	Bella Coola Gillnet Area commercial fishery
Chinook	1980-1989	15,000	1,091	350	2,299
	1990-2001*	25,000	2,642	966	4,752
Sockeye	1980-1989	30,000	4,888	0**	15,207
	1990-2001*	36,000	3,794		3,133
Pink	1980-1989	1,093,000	744	1519**	83,560
	1990-2001*	1,348,000	1,131		50,336
Chum	1980-1989	52,000	921	293**	80,917
	1990-2001*	80,000	462		113,871

* excluding 1994, because of irregulaties in observations.

** 1996 to 2001 data

Table 2. Hierarchy of harvest management objectives for the terminal Bella Coola / Atnarko chinook salmon fisheries.

The management objectives are nested within a hierarchy of general objectives, multi-year objectives, and annual objectives. This table has four parts, one for each of the general objectives. Within each general objective (e.g. A1), thick lines indicate the split into multi-year objectives (e.g. B1 to B3). Within multi-year objectives, thin lines indicate the split into annual objectives. The objectives are loosely ranked by importance within each branch, so that moving down the table generally indicates a lower priority, while the level of detail increases to the right.

GENERAL OBJECTIVE	MULTI-YEAR OBJECTIVE	ANNUAL OBJECTIVE	ATTRIBUTE	INDIFFERENCE RANGES	QUALITATIVE ASSESSMENT
A1: Atnarko Chinook Conservation	B1: Rebuild and maintain run size	C1: Achieve or exceed target escapement on indicator stock (Atnarko)	Estimated escapement based on established monitoring protocol	25,000 and over 17,000 to 24,000 9,000 to 16,000 0 to 8,000	Best Worst
	B2: Maintain stock integrity	C2: Disperse harvest over entire run	Length of minimum weekly closed period for commercial and food fishery.	3 or more days 2 or less days	Acceptable Unacceptable
		C3: Keep probability of domestication at low levels	Estimated % hatchery fish based on head recovery in Nuxalk food fishery	0 to 20% 21-40% 41-60% 61-100%	Best level, long term goal Acceptable: medium term Acceptable: short term Unacceptable
		C4: Minimize disturbance of spawning chinook			
	B3: Maintain biological diversity	C5: Minimize catches of co-migrating chinook stocks of concern in mixed-stock fisheries	Minimize catch of Dean River chinook		
		C6: Maintain chinook populations in small tributaries of the Bella Coola	Minimize chinook catch in Bella Coola tributaries		
		C7: Minimize impact on other species, specifically steelhead			

Table 2 continued.

GENERAL OBJECTIVE	MULTI-YEAR OBJECTIVE	ANNUAL OBJECTIVE	ATTRIBUTE	INDIFFERENCE RANGES	QUALITATIVE ASSESSMENT
A2: Nuxalk Food, Social and Ceremonial Chinook Fisheries	B4: Satisfy community needs for food fish	C8: Provide recent levels of chinook catch	Catch of chinook in Nuxalk food fishery over entire season	3,000 and over 1,000 to 2,900 0 to 900	Best Acceptable Worst
		C9: Provide adequate chinook fishing success	Chinook catch-per-unit-effort (fish per drift)	Early / Peak 1 / 3-4 <0.5 / < 2	 Target Worst
	B5: Provide stable access for cultural and community purposes	C10: Minimize restrictions to food fishery methods, timing and access	Maximize open weeks		
			Open days per week	4 1 to 3 0	Best Worst
			Minimize regulatory restrictions to gear and method		
A3: Bella Coola / Atnarko Recreational Chinook Fisheries	B6: Provide a satisfactory fishing experience	C11: Provide adequate chinook fishing success	Avg. catch-per-unit-effort during peak timing (catch / 10 angler days)	> 3 1 to 3 <1	Best Acceptable Worst
	B7: Provide adequate opportunity	C12: Provide full limits as described in the Allocation Policy	Maintain current coast wide limits (daily, possession, annual)		
		C13: Provide opening of adequate length	Maintain current weeks open		
	B8: Provide stable and predictable access	C14: Minimize in-season changes to pre-season fishing regulations			
		C15: Minimize between-season changes to fishing regulations			

Table 2 continued.

GENERAL OBJECTIVE	MULTI-YEAR OBJECTIVE	ANNUAL OBJECTIVE	ATTRIBUTE	INDIFFERENCE RANGES	QUALITATIVE ASSESSMENT
A4: Bella Coola Gillnet Area Commercial Fisheries *	B9: Ensure fleet viability.	C16: Provide steady supply of fish	Avg. weekly catch-per-unit-effort during targeted chinook fishery in June (fish/boat day)	Early / Peak >6 / >12 4 to 6 / 8 to 12 <4 / <6	 Best Target Undesirable
		C17: Provide catch of adequate value			
	B10: Provide stable access	C18: Provide stable and predictable pattern of weekly openings	Number of weekly openings in June (chinook)	4 1,2,3 0	Best Undesirable Worst
			Avg. length of weekly openings in June (chinook)	> 2 days 1 to 2 days <1 day	Best Target Undesirable
			Avoid closing and reopening (i.e. missing a weekly opening)		
			Minimize short-notice changes to weekly opening lengths		

*currently only Area C gillnet licence holders can participate in the terminal fishery, and all the attributes refer specifically to the fisheries in the Bella Coola Gillnet Area.

Table 3. Scenarios for in-season assessment of stock status and fisheries manager's responses.

Each scenario consisted of a simulated or observed sequence of cumulative catch in the Nuxalk food fishery. For each week, the fisheries manager classified stock status into one of four categories (A to D), by entering the data from all previous weeks into the Bayesian projection model and interpreting the output. For example, the manager used cumulative catches from weeks 22 and 23 to classify stock status for week 24. The ID number shows the sequence of in-season information presented to the fisheries manager.

		Information Cumulative catch in Nuxalk food fishery (fish)				Classification Stock Status			
ID	Type	Week 22	Week 23	Week 24	Week 25	Week 23	Week 24	Week 25	Week 26
1	Sim	226	297	398	436	B-	C	C	C
2	Sim	377	536	843	1,032	B	B	B	B
3	Obs	415	749	1,003	1,457	B+	B+	B	B
4	Sim	490	595	973	1,163	B	B	B+	B+
5	Obs	384	760	1,064	1,381	B	B+	B+	B+
6	Obs	415	749	1,003	1,457	B	B	B+	B+
7	Sim	176	240	313	375	C-	C-	D+	D+
8	Sim	273	381	512	678	C-	C-	C-	C-
9	Obs	389	556	679	947	B	B	B	B
10	Sim	593	922	1,305	1,361	A-	A-	A	A
11	Sim	601	948	1,139	1,555	A-	A-	A-	A-
12	Sim	459	823	870	1,251	B+	B+	B+	B+
13	Sim	452	762	980	1,005	B+	B+	B+	B+
14	Obs	358	565	907	1,365	B	B	B	B+
15	Obs	384	831	936	1,632	B	B+	B+	B+
16	Obs	488	885	1,134	1,319	B+	A-	A-	A-
17	Obs	665	906	937	937	A	A	A	A-
18	Sim	620	995	1,252	1,791	A	A	A	A
19	Sim	442	752	1,068	1,335	B+	B+	B+	B+
20	Obs	394	607	935	1,274	B	B	B+	B+
21	Sim	436	819	990	1,356	B+	B+	B+	A-
22	Sim	328	497	625	754	B	B	B-	B-
23	Obs	524	667	742	857	A-	B+	B+	B+
24	Obs	222	481	759	996	C+	C+	B-	B-
25	Sim	591	883	1,165	1,352	A-	A-	A-	A-
26	Sim	382	662	698	915	B	B	B	B
27	Sim	348	460	488	749	B	B-	B-	B-
28	Obs	166	242	307	365	C-	D+	D+	D+
29	Obs	388	478	597	747	B	B	B-	B-
30	Sim	344	520	576	854	B	B-	B-	B-
31	Obs	352	489	644	953	B	B	B-	B-
32	Obs	165	213	243	279	C	D+	D	D
33	Obs	202	313	421	513	C	C	C	C
34	Obs	436	751	1,011	1,189	B+	B+	B+	B+
35	Obs	545	740	907	1,242	A-	B+	B+	B+
36	Obs	815	1,254	1,628	2,104	A	A	A+	A+
37	Sim	383	495	653	860	B	B-	B	B
38	Sim	271	503	539	710	C+	B-	B-	B-
39	Obs	280	326	409	503	B-	C+	C+	C+
40	Obs	242	267	327	377	C+	C	C	C-
41	Sim	410	466	611	872	B	B-	B-	B-
42	Sim	388	628	862	1,015	B	B	B+	B+
43	Sim	473	594	1,011	1,249	B+	B+	B+	B+
44	Obs	356	483	610	867	B	B	B	B

Table 4. Loss tables and priors used in fitting classification trees. Classification trees incorporate information about the cost of errors and the probability with which each category occurs. Loss tables (A) specify the penalty applied for each possible combination of true status (i.e. stock status in the elicited responses) and assessed status (i.e. stock status identified by the classification tree). In a unit loss table all possible errors receive the same penalty. The symmetric unit loss table is one of many possible symmetric loss tables which treat an underestimate the same as an overestimate. The asymmetric loss table shown here combines the considerations that overestimates are more serious than underestimates, and that the cost of error increases with the discrepancy between true status and assessed status. Priors (B) specify the probability of occurrence assigned to each category of stock status. A uniform prior assigns equal probability. The observed priors show the frequency of each category in the 44 responses elicited from the fisheries manager (see Table 3). The observed priors are very similar if simulated scenarios are excluded (difference ≤ 0.05).

(A) Loss tables

	Symmetric unit loss table				**Asymmetric loss table**			
True	Status Assessment				Status Assessment			
Status	A	B	C	D	A	B	C	D
A	0	1	1	1	0	1	2	4
B	1	0	1	1	6	0	1	2
C	1	1	0	1	12	6	0	1
D	1	1	1	0	24	12	6	0

(B) Priors

Status	**Uniform prior**	**Observed prior** Week 23	Week 24	Week 25	Week 26
A	0.25	0.18	0.16	0.16	0.18
B	0.25	0.64	0.64	0.66	0.64
C	0.25	0.18	0.16	0.11	0.11
D	0.25	0	0.04	0.07	0.07

Table 5. Management objectives ranked by three different methods. This table shows the full hierarchy of management objectives and ranks for each element. Each cell contains three values (L/G/SW), showing the ranks elicited using a simple list (L), the computer-based graphical interface (G), and the modified swing-weighting (SW), thereby retaining the sequence in which they were elicited. Elements of the hierarchy are identified as A1 to A4 for the four general objectives, B1 to B10 for the multi-year objectives nested within the general objectives, and C1 to C18 for the annual objectives nested within multi-year objectives.

For example, 2/1/1 indicates that an objective was ranked second using the list, but first in both of the more formal elicitation methods. Missing values are shown as *x*. Dotted ovals and shaded cells highlight results that are discussed in Section 3.2.2.

Columns 1 to 6 show the ranks for the following comparisons:

Column	
1	Comparing overall objectives
2	Comparing multi-year objectives *within* overall objectives
3	Comparing multi-year objectives *across* overall objectives
4	Comparing annual objectives *within* multi-year objectives
5	Comparing annual objectives *across* multi-year objectives
6	Comparing annual objectives *across* overall objectives

Column 7 shows priority values for the comparison of annual objectives *across* overall objectives, derived from the vertical distance between boxes in the graphical interface (Figure 9), with the highest ranked objective set to a value of 100 (see Figure 9). In Column 8, these priority values are converted to weights, with the lowest-ranked objective set to a value of 1.

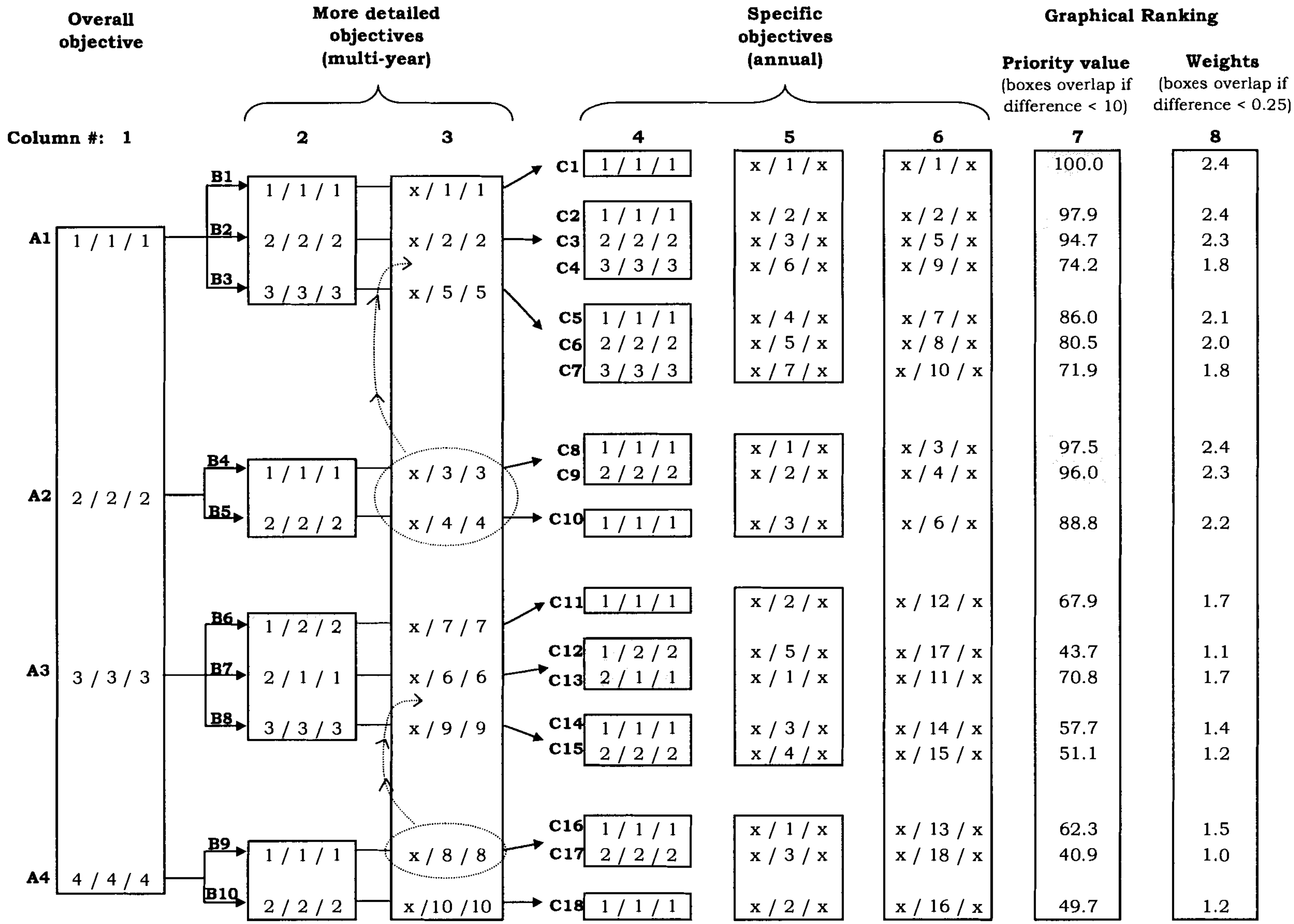

Overall objective
More detailed objectives (multi-year)
Specific objectives (annual)
Graphical Ranking
Priority value (boxes overlap if difference < 10)
Weights (boxes overlap if difference < 0.25)
Column #: 1
2
3
4
5
6
7
8
A1 1 / 1 / 1
A2 2 / 2 / 2
A3 3 / 3 / 3
A4 4 / 4 / 4
B1 1 / 1 / 1
B2 2 / 2 / 2
B3 3 / 3 / 3
B4 1 / 1 / 1
B5 2 / 2 / 2
B6 1 / 2 / 2
B7 2 / 1 / 1
B8 3 / 3 / 3
B9 1 / 1 / 1
B10 2 / 2 / 2
x / 1 / 1
x / 2 / 2
x / 5 / 5
x / 3 / 3
x / 4 / 4
x / 7 / 7
x / 6 / 6
x / 9 / 9
x / 8 / 8
x /10 /10
C1 1 / 1 / 1 x / 1 / x x / 1 / x 100.0 2.4
C2 1 / 1 / 1 x / 2 / x x / 2 / x 97.9 2.4
C3 2 / 2 / 2 x / 3 / x x / 5 / x 94.7 2.3
C4 3 / 3 / 3 x / 6 / x x / 9 / x 74.2 1.8
C5 1 / 1 / 1 x / 4 / x x / 7 / x 86.0 2.1
C6 2 / 2 / 2 x / 5 / x x / 8 / x 80.5 2.0
C7 3 / 3 / 3 x / 7 / x x / 10 / x 71.9 1.8
C8 1 / 1 / 1 x / 1 / x x / 3 / x 97.5 2.4
C9 2 / 2 / 2 x / 2 / x x / 4 / x 96.0 2.3
C10 1 / 1 / 1 x / 3 / x x / 6 / x 88.8 2.2
C11 1 / 1 / 1 x / 2 / x x / 12 / x 67.9 1.7
C12 1 / 2 / 2 x / 5 / x x / 17 / x 43.7 1.1
C13 2 / 1 / 1 x / 1 / x x / 11 / x 70.8 1.7
C14 1 / 1 / 1 x / 3 / x x / 14 / x 57.7 1.4
C15 2 / 2 / 2 x / 4 / x x / 15 / x 51.1 1.2
C16 1 / 1 / 1 x / 1 / x x / 13 / x 62.3 1.5
C17 2 / 2 / 2 x / 3 / x x / 18 / x 40.9 1.0
C18 1 / 1 / 1 x / 2 / x x / 16 / x 49.7 1.2

Table 6. Evaluating the in-season status assessment model through cross-validation – Retrospective evaluation.

In-season forecasts based on independent regressions and three types of Bayesian updating (*predicted*) are compared to post-season estimates of escapement (*observed*). Mean deviation (MD) and mean absolute deviation (MAD) use deviations calculated as *observed – predicted*, so that positive values for MD indicate a bias towards underestimates. MAD is always positive, but better expresses the magnitude of errors. Mean absolute percent error (MAPE) uses (*absolute deviation / observed*)*100. A MAPE of 10% indicates that the mean absolute deviation is 10% of the observed escapement. Proportion below lower bound and proportion above upper bound are calculated using 80% confidence intervals for independent regressions, and 80% of the posterior distribution for Bayesian forecasts.

A) Independent regressions

	Week 22	Week 23	Week 24	Week 25
Mean Deviation (fish)	3358	1702	1371	801
MAD(fish)	4889	3986	3312	4156
MAPE(%)	18.3	15.2	12.8	16.9
Proportion below lower bound	0.0	0.0	0.0	0.1
Proportion above upper bound	0.3	0.2	0.1	0.1

B) Bayesian Updating, normal prior using 5 most recent years

	Week 22	Week 23	Week 24	Week 25
Mean Deviation (fish)	2182	2000	1818	1727
MAD(fish)	4545	4545	4000	3909
MAPE(%)	17.4	17.7	15.6	15.3
Proportion below lower bound	0.1	0.1	0.1	0.1
Proportion above upper bound	0.3	0.3	0.3	0.3

C) Bayesian Updating, normal prior using all previous years

	Week 22	Week 23	Week 24	Week 25
Mean Deviation (fish)	4727	3273	2636	2364
MAD(fish)	5091	4182	3727	3636
MAPE(%)	18.5	15.4	13.9	13.6
Proportion below lower bound	0.0	0.0	0.0	0.0
Proportion above upper bound	0.3	0.4	0.3	0.3

D) Bayesian Updating, uniform prior

	Week 22	Week 23	Week 24	Week 25
Mean Deviation (fish)	3273	2364	2182	1727
MAD(fish)	4909	4182	3636	3545
MAPE(%)	18.3	15.6	13.5	13.4
Proportion below lower bound	0.0	0.0	0.0	0.0
Proportion above upper bound	0.3	0.3	0.3	0.3

Table 7. Evaluating the in-season status assessment model through cross-validation – Leave-one-out.
Comparisons and performance measures as in Table 6.

A) Independent regressions

	Week 22	Week 23	Week 24	Week 25
Mean Deviation (fish)	48	-7	15	0
MAD(fish)	4825	3921	3653	4310
MAPE(%)	33.1	23.0	21.2	24.5
Proportion below lower bound	0.0	0.0	0.0	0.0
Proportion above upper bound	0.2	0.1	0.1	0.1

B) Bayesian Updating, normal prior using 5 most recent years

	Week 22	Week 23	Week 24	Week 25
Mean Deviation (fish)	190	333	143	238
MAD(fish)	3238	3190	3286	3381
MAPE(%)	20.4	19.5	20.5	20.3
Proportion below lower bound	0.0	0.0	0.0	0.0
Proportion above upper bound	0.1	0.3	0.3	0.3

C) Bayesian Updating, normal prior using all previous years

	Week 22	Week 23	Week 24	Week 25
Mean Deviation (fish)	48	95	48	0
MAD(fish)	5190	4286	4143	4095
MAPE(%)	38.8	29.5	27.1	26.6
Proportion below lower bound	0.1	0.1	0.0	0.0
Proportion above upper bound	0.1	0.3	0.3	0.2

D) Bayesian Updating, uniform prior

	Week 22	Week 23	Week 24	Week 25
Mean Deviation (fish)	-48	48	48	-48
MAD(fish)	4905	4238	4048	3952
MAPE(%)	33.6	27.6	25.1	24.3
Proportion below lower bound	0.0	0.0	0.0	0.0
Proportion above upper bound	0.2	0.2	0.2	0.2

Table 8. In-season guidelines for assessing stock status of Atnarko chinook.
Each week, the fisheries manager assesses stock status based on the observed value of the in-season indicator, cumulative catch in the Nuxalk food fishery. The status of the stock then determines the opening in the gill net fishery for the following week (Table 9). Breakpoints shown here are the splitting points from the classification trees with unit loss tables and uniform priors (Figure 20), rounded to nearest 10 fish. Expected escapement given is the range of best estimates for projections using Bayesian updating with normal prior (1980 to 2001), over Weeks 22 to 25.

Indicator: Cumulative catch in the Nuxalk food fishery				**Classification of stock status**	**Expected escapement for these benchmarks**
May	**June**				
Week 22	Week 23	Week 24	Week 25		
>510	>860	>1100	>1300	**A**	23,000 to 25,000
>280	>480	>530	>700	**B**	17,000 to 18,000
170 or less	>250	>320	>380	**C**	10,000 to 13,000
				D	

Table 9. Guidelines for opening the Bella Coola Gill Net Area (BCGNA) commercial gill net chinook fishery, based on estimated stock status.
Based on the assessments of stock status in Table 8, this decision table shows the likely pattern of openings for the commercial fishery throughout June. Expected escapement defined as in Table 8.

		Expected BCGNA opening in June			
Classification of stock status	**Expected escapement**	Week 23	Week 24	Week 25	Week 26
A	23,000 to 25,000	1-day assessment	2 days	2-3 days	2-3 days
B	17,000 to 18,000	1-day assessment	1 day	1-2 days	1-2 days
C	10,000 to 13,000	1-day assessment	1 day possible, because early in the run	No opening (to protect peak of run if returns are low)	No opening
D		1-day assessment possible	No opening	No opening	No opening

Table 10. Summary of in-season data and management responses for Atnarko chinook fisheries during the 2002 through 2004 fishing seasons. During these three fishing seasons, the fisheries manager in Bella Coola used the simple decision guidelines developed in this case study as part of the in-season decision-making process. While the hierarchy of management objectives (Table 2), in-season guidelines for assessing of stock status (Table 8), and guidelines for opening the gill net fishery (Table 9) remained unchanged during these three years, the decision-making responsibility was gradually shifted to a different individual. For each year, this table traces through the weekly management actions and their result. Arrows indicate the sequence from in-season data to projected escapement and the resulting opening in the commercial fishery for the next week.

2002 fishing season

Post-season estimate of escapement : 14,000

	W 22	W 23	W 24	W 25	W 26
Cumulative catch in Nuxalk food fishery (fish)	360	553	941	1270	
Projected escapement (1000s)	12-24	13-25	18-32	20-32	
Opening of BCGNA (days)		1	1	2	2
Chinook catch in BCGNA (fish)		136	257	1390	550

2003 fishing season

Post-season estimate of escapement : 15,000

	W 22	W 23	W 24	W 25	W 26
Cumulative catch in Nuxalk food fishery (fish)	187	400	665	986	
Projected escapement (1000s)	6-19	9-18	11-18	12-19	
Opening of BCGNA (days)		1	1	1	1
Chinook catch in BCGNA (fish)		160	239	250	386

2004 fishing season

Post-season estimate of escapement : To be determined

	W 22	W 23	W 24	W 25	W 26
Cumulative catch in Nuxalk food fishery (fish)	263	378	582	854	
Projected escapement (1000s)	10-22	10-19	11-18	12-19	
Opening of BCGNA (days)		1	1	1	1
Chinook catch in BCGNA (fish)		70	166	300	386

7 Figures

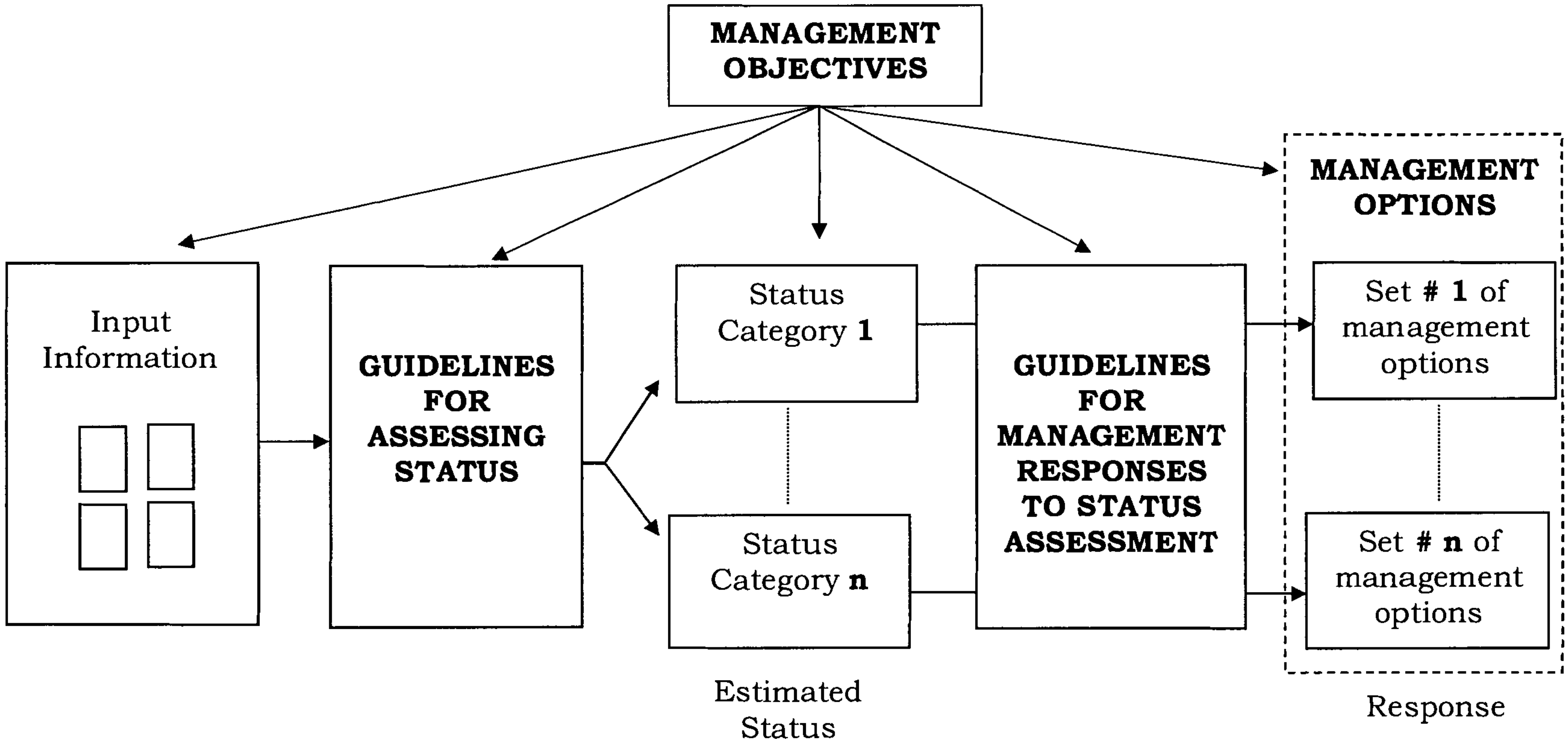


Figure 1. Four components of simple decision guidelines.
Simple decision guidelines have four components (**bold font**), describing how input information is used to choose a management response. Arrows indicate the flow of information. *Management objectives* set the context for the entire decision-making process. *Guidelines for assessing stock status* describe how input information from different sources is used to identify the current status as one of *n* categories. *Guidelines for management responses to status assessment* describe which of *n* sets of *management options* will most likely be chosen for a given category of stock status. To ensure clarity, these guidelines should include exactly one set of options for each category of stock status, but these options don't have to be unique.

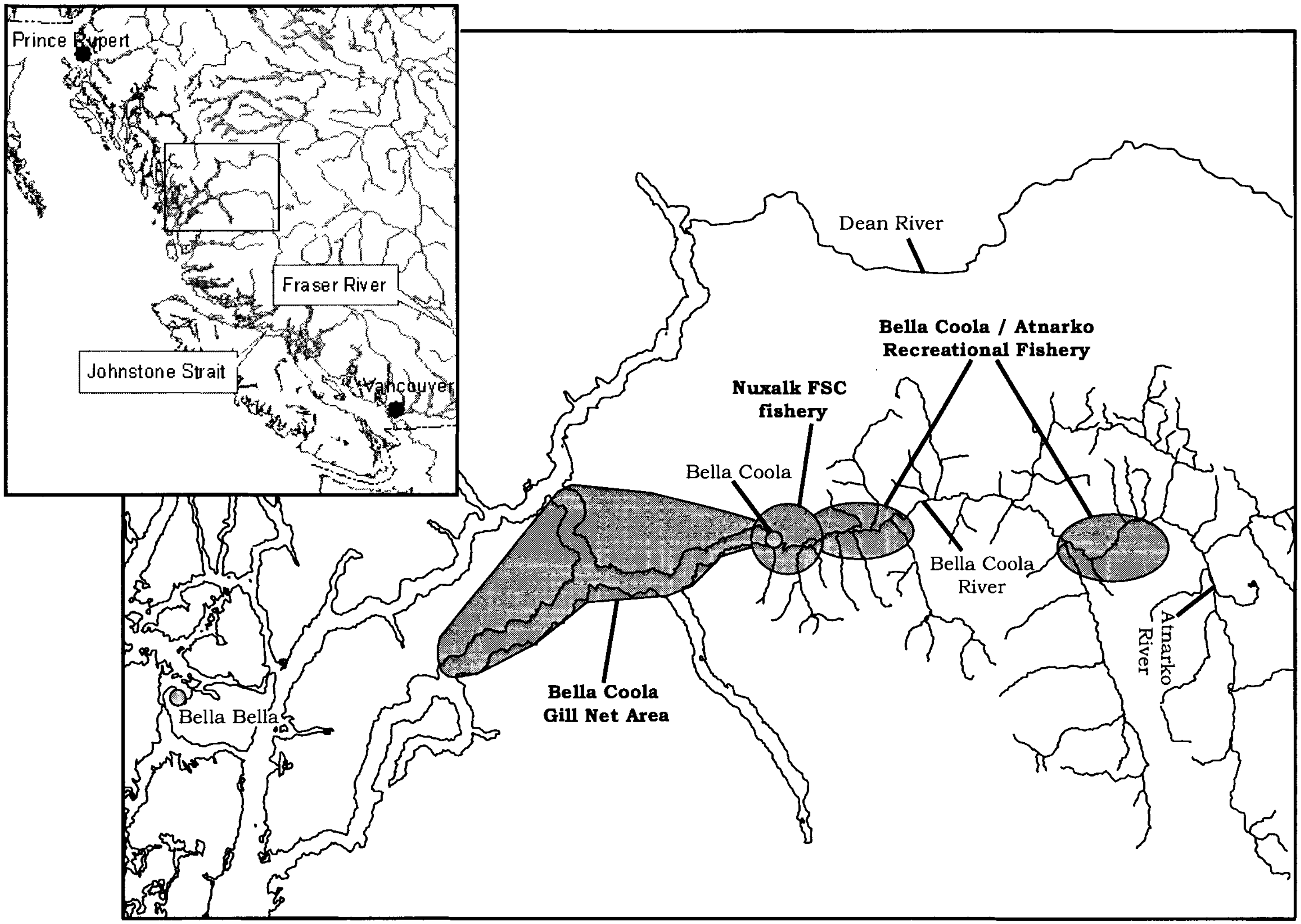


Figure 2. Coast of British Columbia and the Bella Coola fishing areas.
(Based on a map provided by Kay Kennes, Fisheries and Oceans Canada, Vancouver)

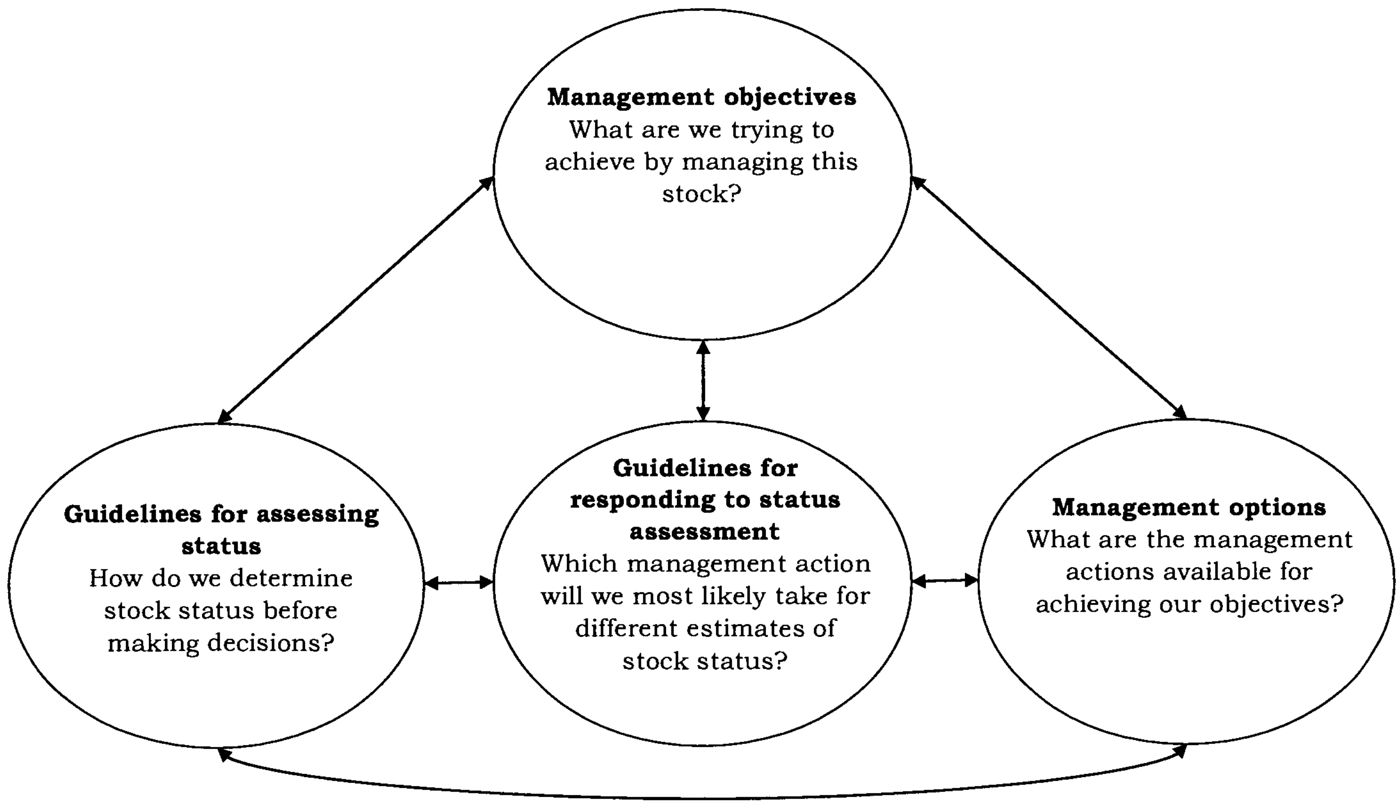


Figure 3. Iterative process of developing simple decision guidelines.
When developing simple decision guidelines, each of the four components is refined based on the other three, as respondents revisit four fundamental questions. Arrows indicate the flow of information.

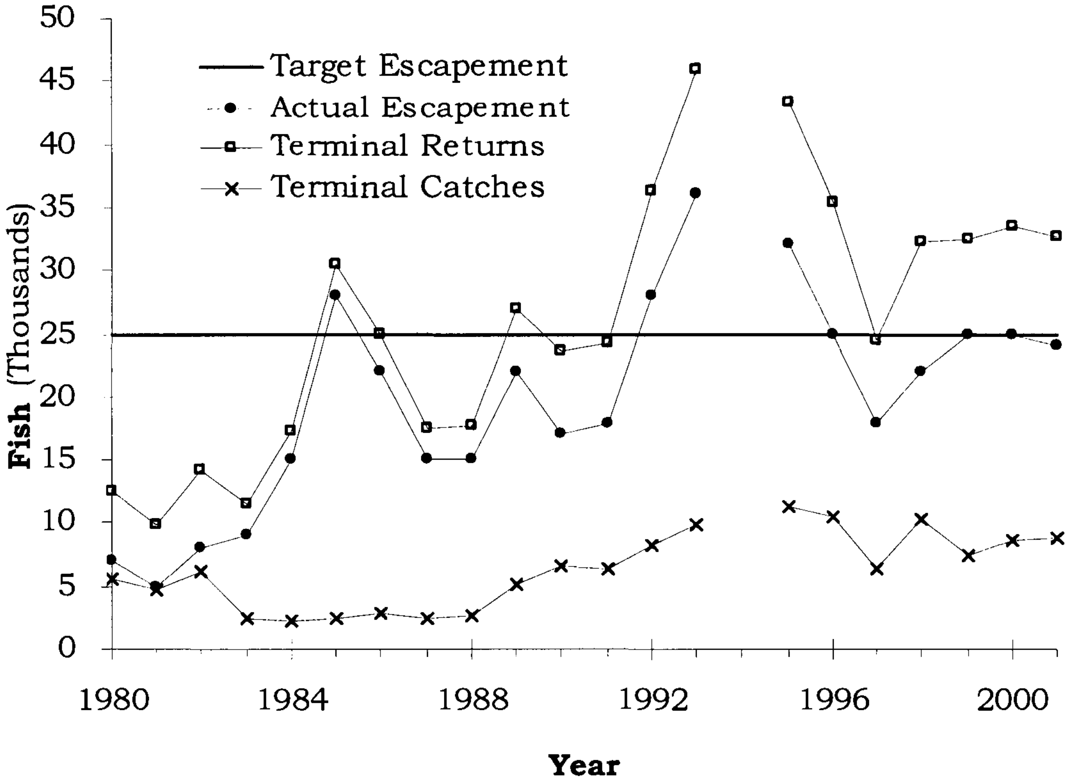


Figure 4. Observed escapement and catch of Atnarko chinook 1980-2001. Consistent post-season estimates of the total number of spawners (actual escapement), and catches from all three harvester groups (terminal catches) are available since 1980. Actual escapements, rounded to the nearest thousand, can be compared to the management goal of 25,000 spawners (target escapement). Terminal catches include all observed catches from the commercial fishery in the Bella Coola Gillnet Area, the Bella Coola / Atnarko recreational fishery, and the Nuxalk food fishery. Terminal returns are the sum of observed escapement and terminal catches. 1994 data are excluded due to problems with data collection.

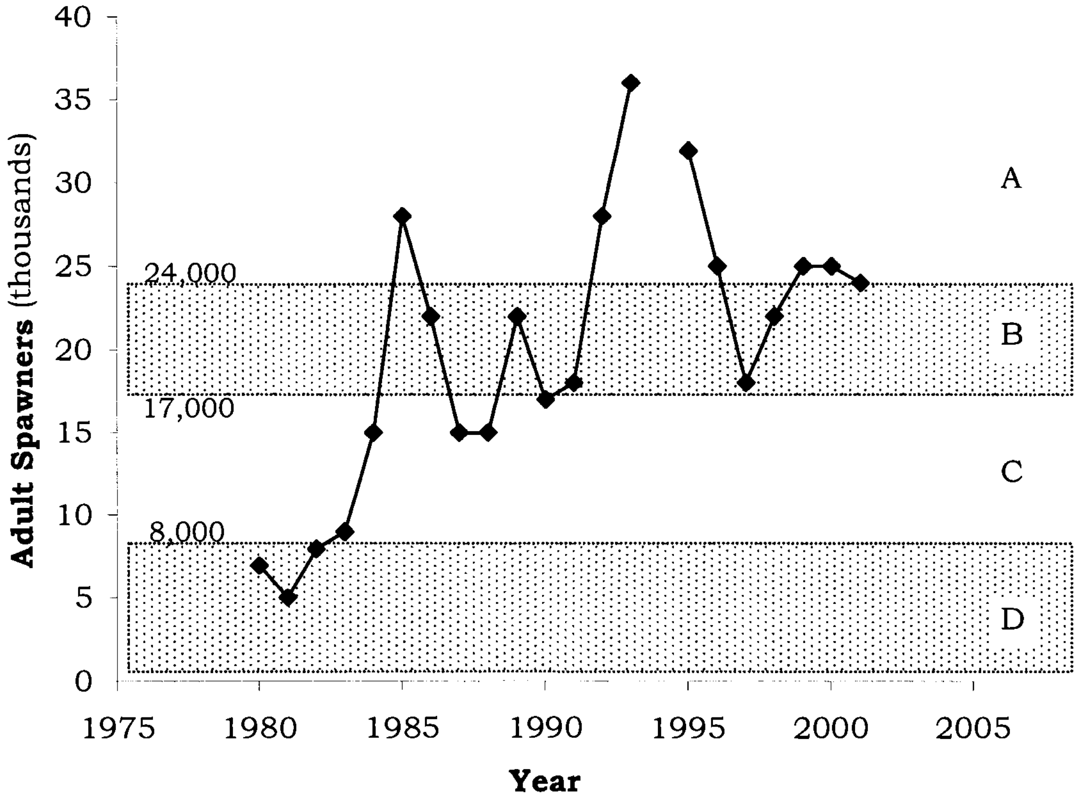


Figure 5. Escapement indicator for Atnarko chinook 1980-2001.
The fisheries manager identified four categories of stock status (A to D), which roughly correspond to four ranges of observed escapement. Escapement shown here is defined as in Figure 4.

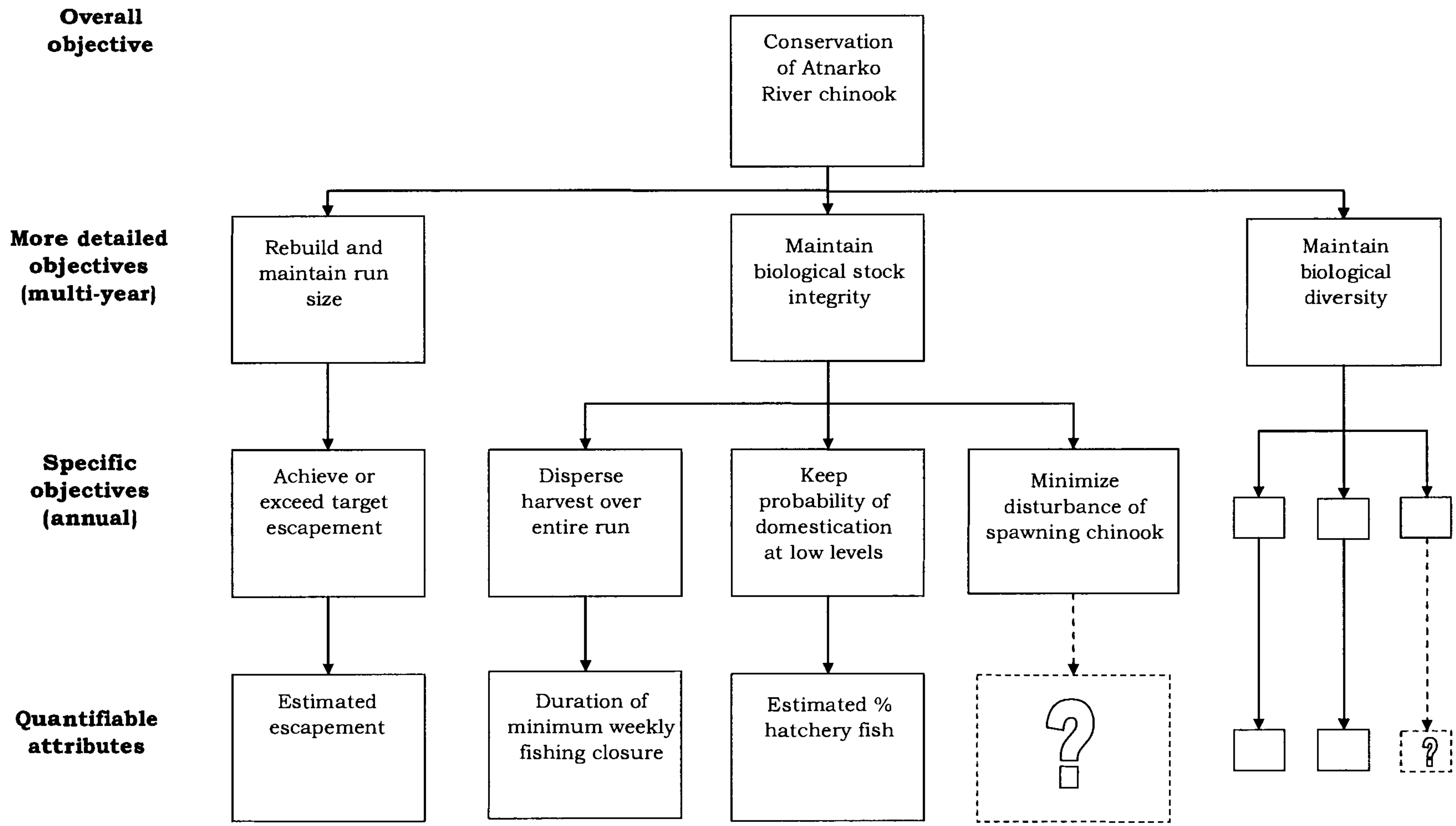


Figure 6. Hierarchical structure of management objectives.
This figure shows part of the management objectives displayed in Table 2 to illustrate their nested hierarchical structure. Solid boxes, with or without text, represent elements elicited from the fisheries manager, while dashed boxes indicate gaps in existing data or policy. Arrows show the nesting within higher-level elements (e.g. annual objectives within multi-year objectives).

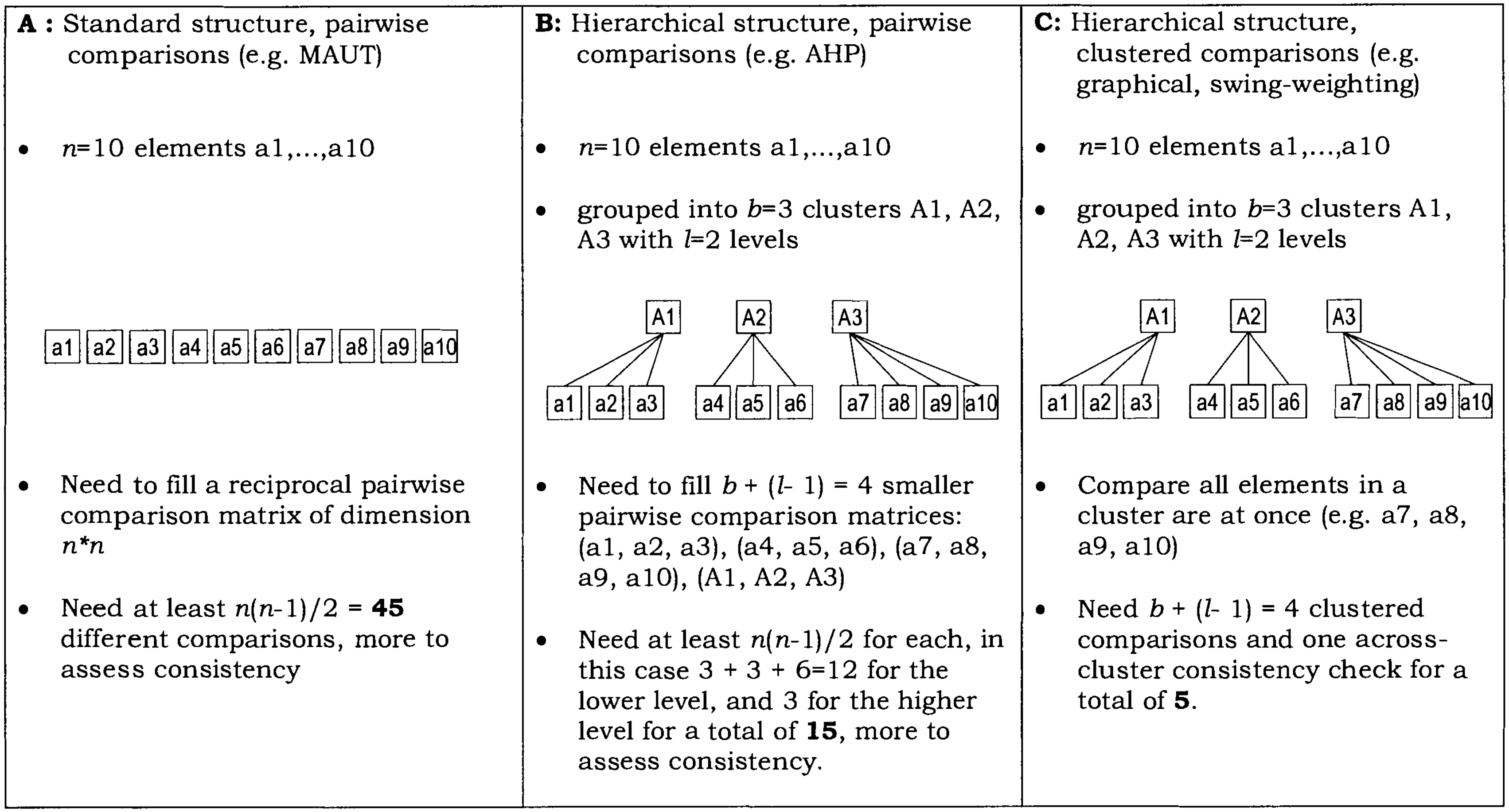


Figure 7. Hierarchical structuring and clustered comparisons reduce the number of required judgments.
Using the example of ranking 10 elements nested within three groups, this figure compares the number of judgments required from the fisheries manager under three different methods for eliciting preferences. The 10 elements (e.g. management objectives) can be evaluated in pairwise comparisons (A), pairwise comparisons within a nested hierarchy (B), or clustered comparisons within a nested hierarchy (C).

Task 4: Multi-Year Objectives for Atnarko Chinook

CATEGORY	MULTI-YEAR OBJECTIVES	RANK
Conservation of Atnarko River chinook	Rebuild and maintain run-size	1
	Maintain stock integrity	2
	Maintain biological diversity	5
Nuxalk Food, Social and Ceremonial Chinook Fisheries	Satisfy community needs for food fish	3
	Provide stable access for cultural and community purposes	4
Bella Coola / Atnarko Recreational Chinook Fishery	Provide satisfactory fishing experience	7
	Provide adequate opportunity	6
	Provide stable access	9
Bella Coola Gillnet Area Commercial Chinook Fishery	Ensure fleet viability	8
	Provide stable access	10

Figure 8. Ranking objectives by the swing-weighting method (sample task).
The fisheries manager expressed the relative priority of different management objectives by indicating the rank order in which he would improve performance of the fishery with respect to each of these multi-year objectives from their worst level to their best level. In the sample shown here, the fisheries manager compared 10 multi-year objectives, nested within four general objectives. Table 2 presents the full hierarchy of management objectives, and provides more detail about each of the objectives listed here.

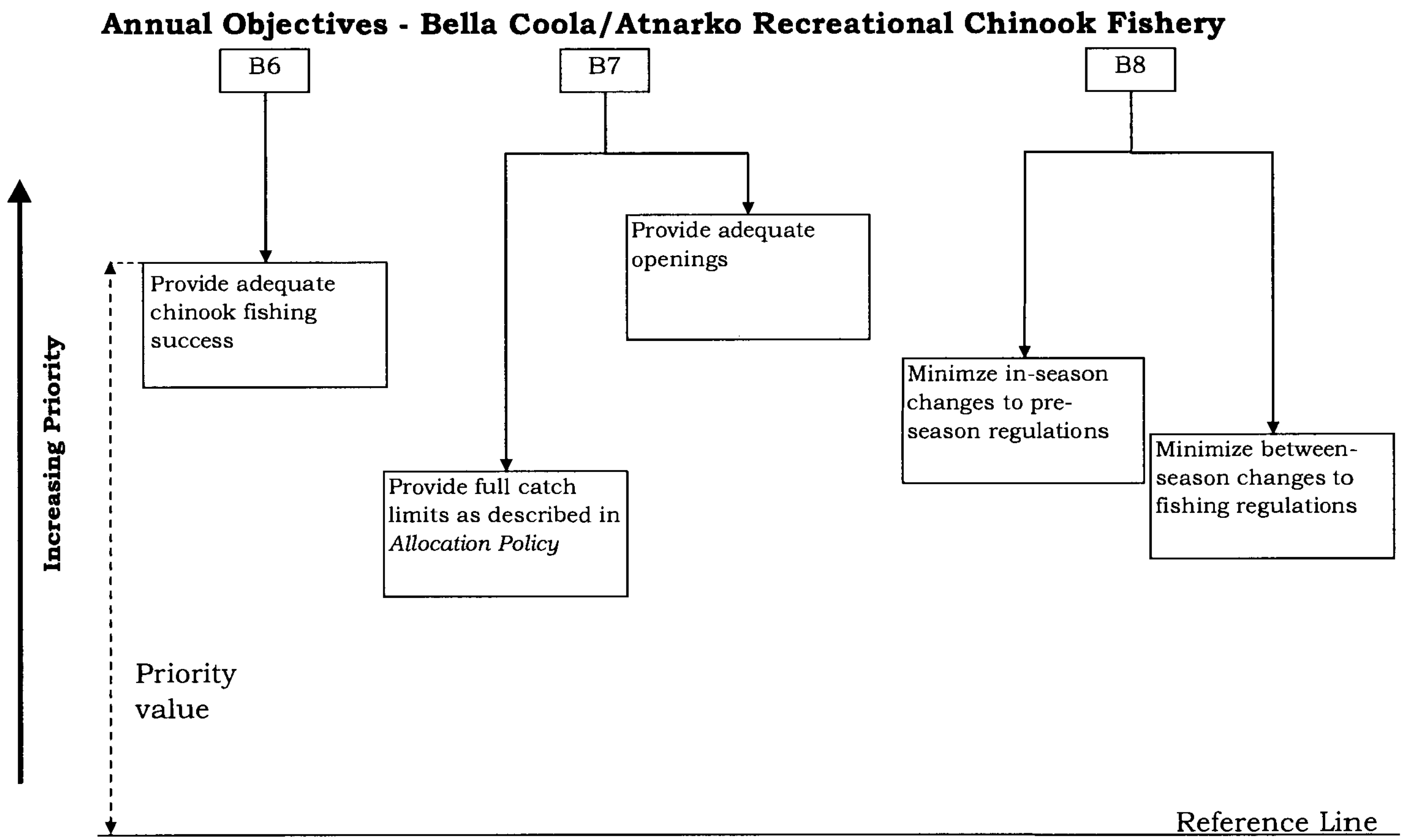


Figure 9. Ranking objectives by the computer-based graphical weighting method (sample task).
The fisheries manager expressed the relative priority of different management objectives by vertically adjusting the boxes corresponding to qualitative objectives (shown) or levels of quantitative attributes (not shown). In the sample shown here, the fisheries manager compared five annual objectives, nested within three general objectives: (B6) provide a satisfactory fishing experience, (B7) provide adequate fishing opportunity, and (B8) provide stable and predictable access. Table 2 presents the full hierarchy of management objectives, and provides more detail about each of the objectives listed here.

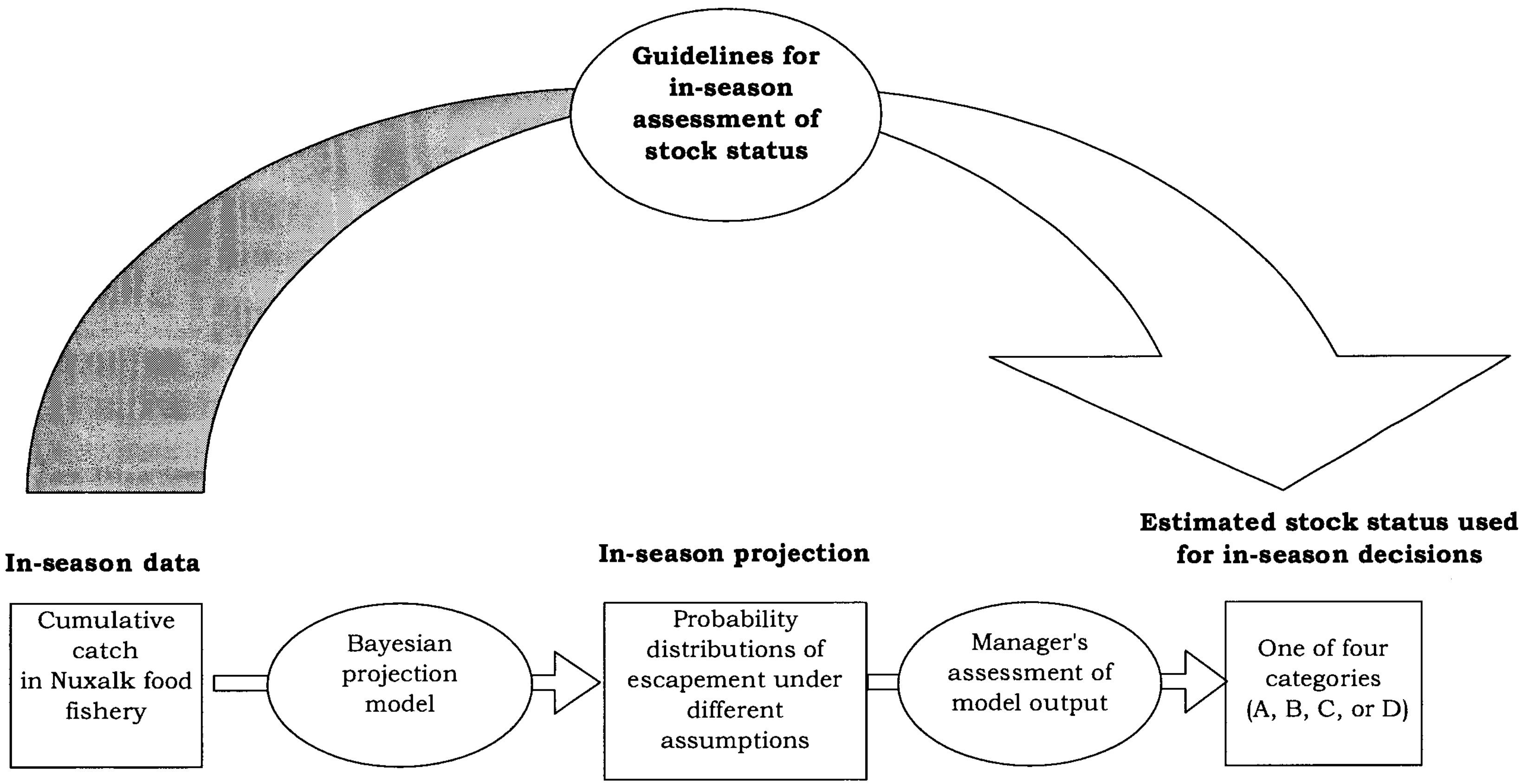


Figure 10: Steps in the in-season assessment of stock status.
In-season guidelines for assessment of stock status describe the full sequence of steps from in-season data to estimated status. For Atnarko River Chinook fisheries, in-season assessment of stock status follows a two-step process of calculating projected escapement under different assumptions, and then assessing the model output. Rectangles represent information, and ovals represent analytical steps for processing that information.

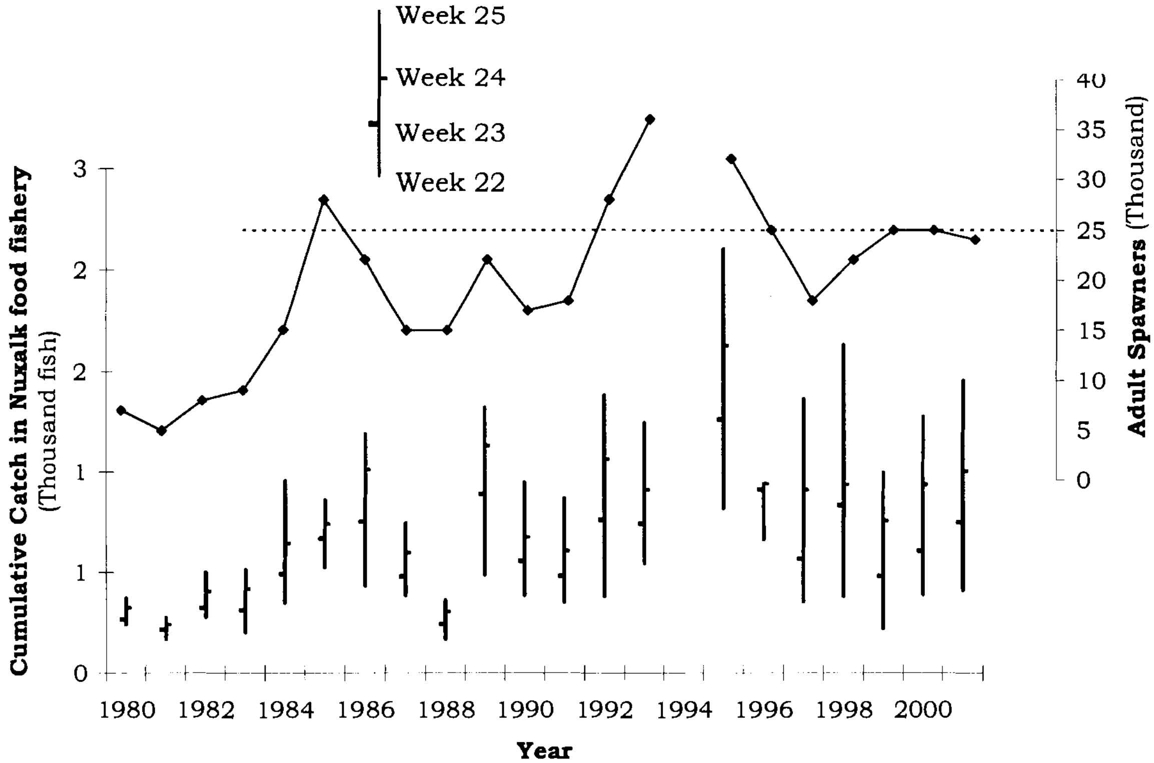


Figure 11. Nuxalk food fishery catch as an indicator for escapement. Cumulative catch in the Nuxalk food fishery is the best available in-season indicator of Atnarko chinook escapement, based on the coefficient of determination. This figure shows how closely cumulative catches have tracked observed escapement from 1980 to 2001. Cumulative catches for weeks 22 to 25 are shown as horizontal bars, placed on vertical lines. Observed escapement is overlayed (solid line; right-hand axis). The dashed line shows the target escapement of 25,000 for reference. 1994 data are excluded due to problems with data collection.

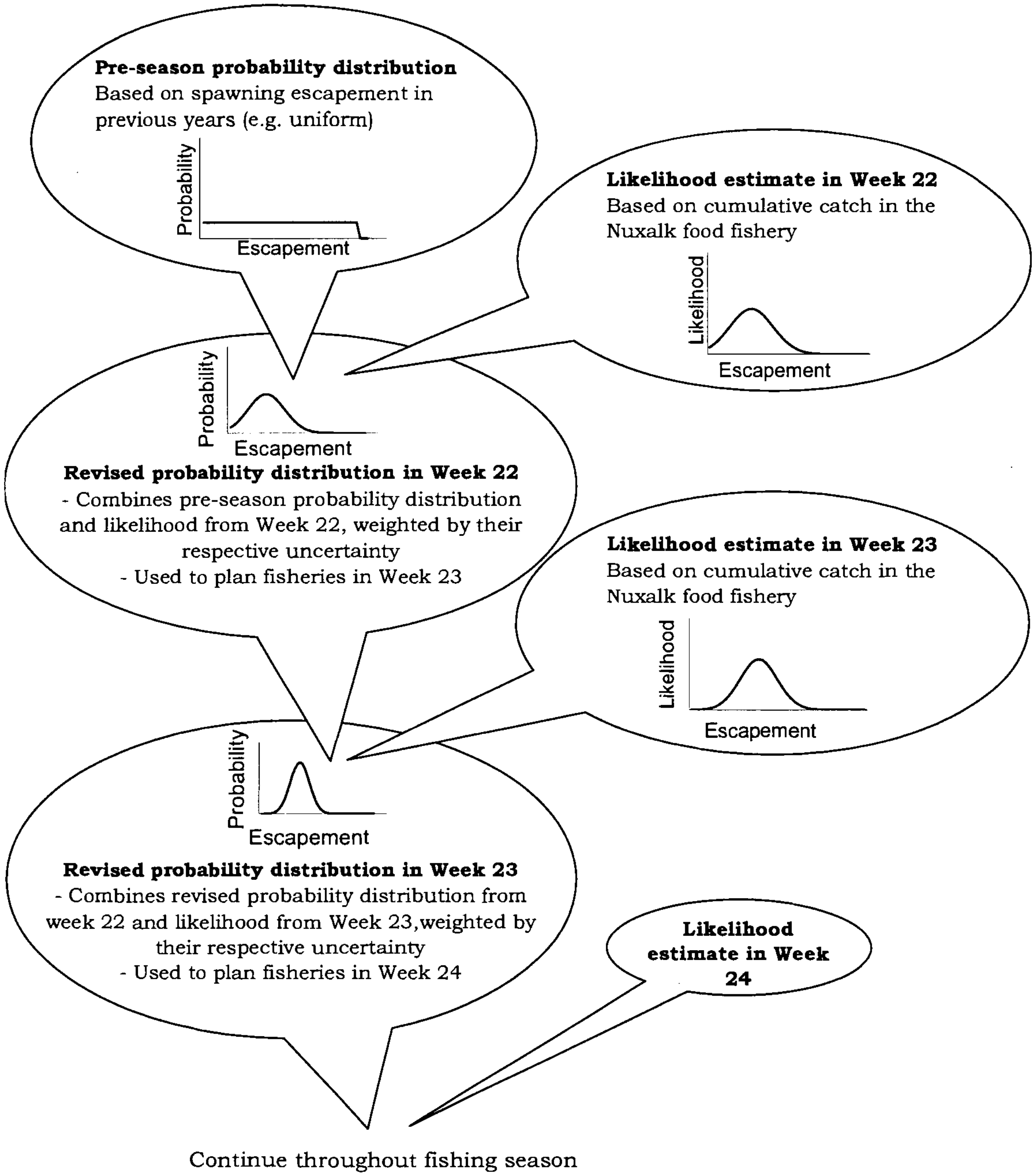


Figure 12. General procedure for Bayesian updating of projected end-of-season escapement of Atnarko chinook.
Each weekly projection combines a prior probability estimate and a likelihood estimate to determine a revised probability distribution for post-season escapement. The fisheries manager then uses the revised probability distribution to plan fisheries for the upcoming week.

(A)

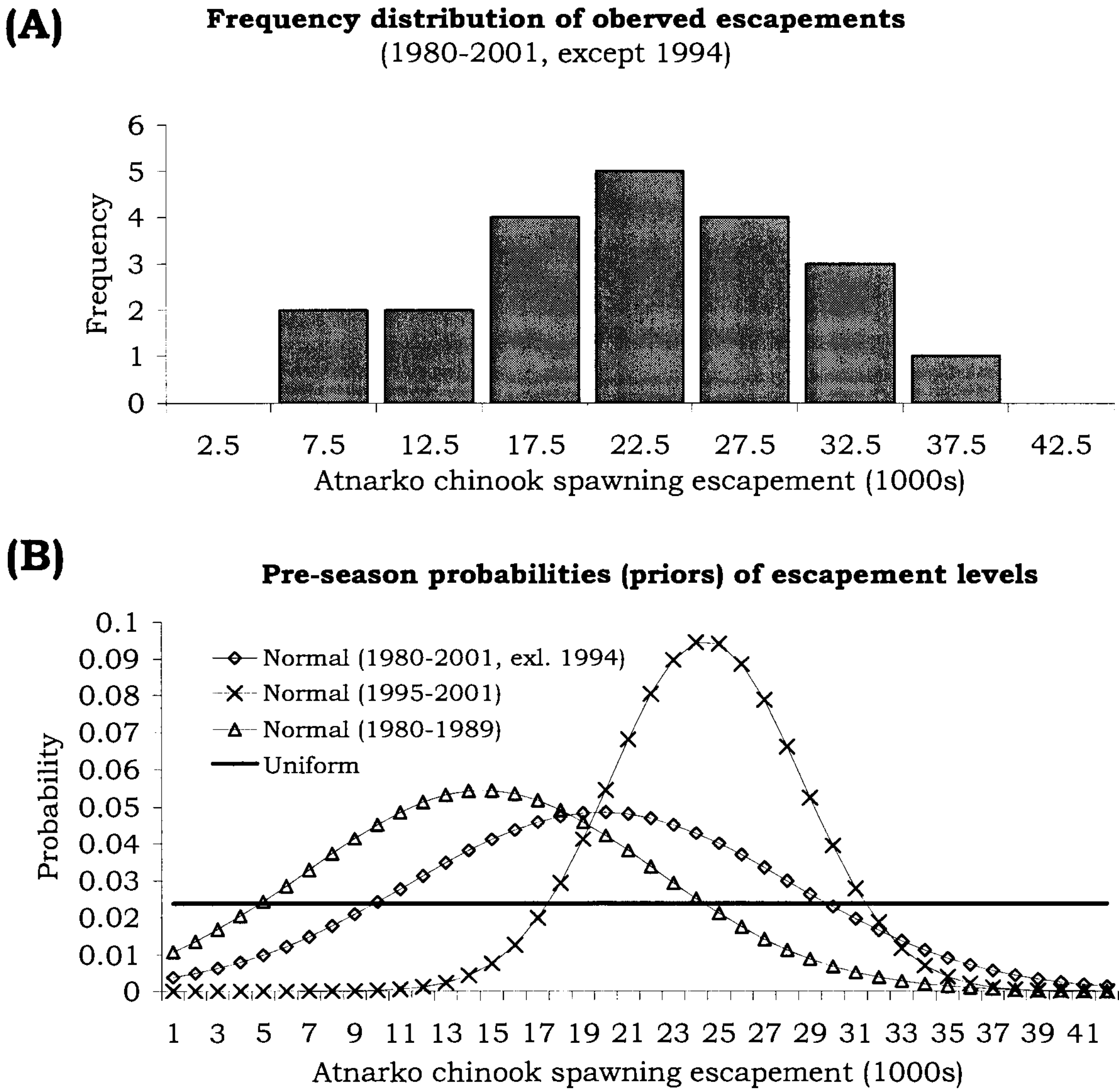


Figure 13. Frequency distribution of observed Atnarko chinook escapements and four alternative prior distributions for Bayesian projections.

The frequency distribution of observed escapements (A) closely approximates a normal distribution. Pre-season probability distributions for Bayesian projections (B) were calculated using discrete approximations to the normal or the uniform distribution. Normal priors were fitted either to all available data (1980 to 2001, excl. 1994), to early data only (1980 to 1989), or to recent data only (1995 to 2001).

WEEK 22: Updated Projection

	Projection of post-season escapement			Classification probability of projected escapement (1000s)			
	Low	Best	High	0 to 8	9 to 16	17 to 24	25 to 42
Independent Regression	4,811	**12,688**	20,564	0.23	0.51	0.23	0.03
Bayesian w/ Normal Prior	15,000	**21,000**	24,000	0.00	0.12	0.76	0.12
Bayesian w/ Uniform Prior	5,000	**13,000**	19,000	0.22	0.51	0.24	0.02

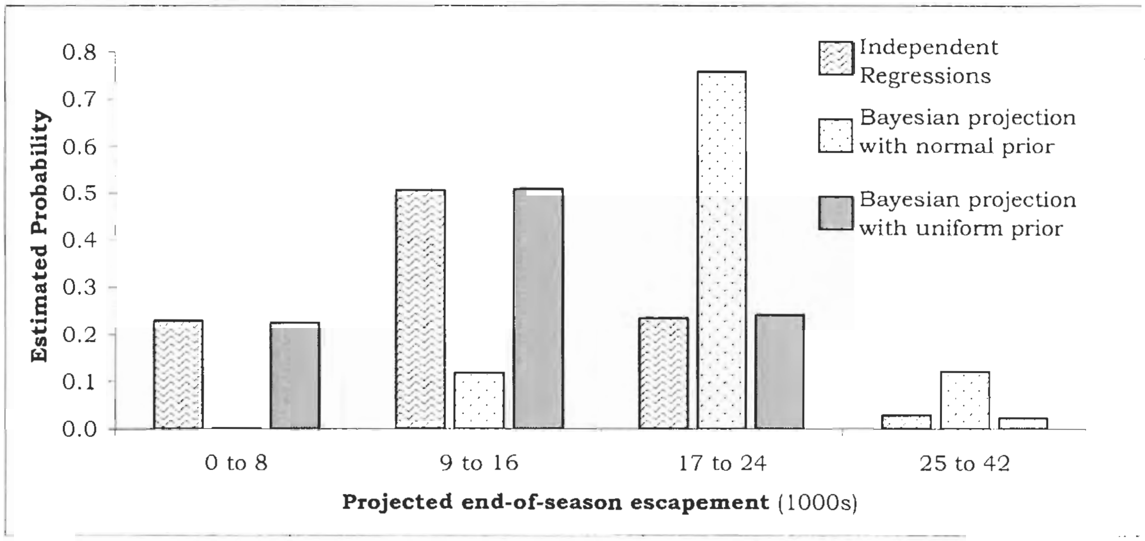


Figure 14. Sample output from the in-season projection model: Projections, confidence bounds, and classification probabilities.
The model output emphasises the differences between projections based on (1) independent regressions for each week, (2) Bayesian updating using normal pre-season priors, and (3) Bayesian updating using uniform priors. For each of the three projections, the output shows best estimates and 80% confidence bounds (Low, High) in the top left table. The probability of escapement falling into one of four ranges identified by the fisheries manager is displayed numerically (top right) and graphically (bar chart). To illustrate the possible influence of pre-season assumptions and Bayesian updating, the example shown here used 1995 to 2001 data for estimating the normal prior, all available data to fit the regressions, and 1999 in-season data for the projections.

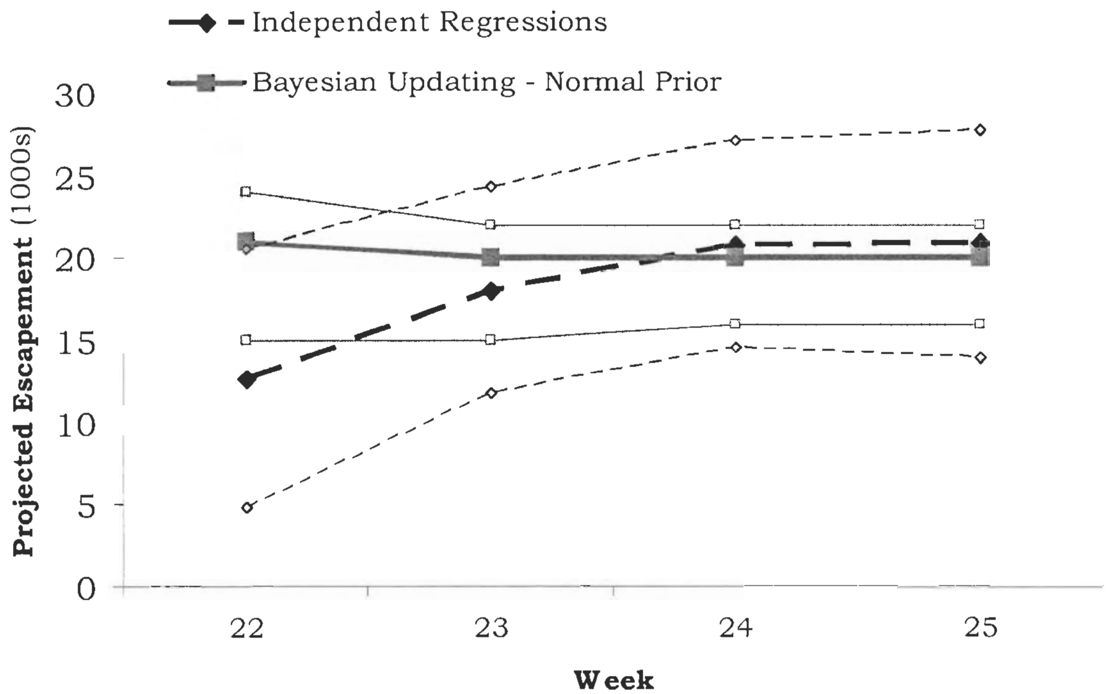


Figure 15. Sample output from the in-season projection model: In-season trajectory of projected escapement.
The model output shows how projections of post-season escapement change throughout each fishing season. This example compares weekly projections based on independent regressions (dashed lines) to projections based on Bayesian updating using a normal distribution as the pre-season prior (solid lines). The thick lines show changes in the best point-estimates for the two projections, and the thin lines show 80% confidence bounds. The example shown here is the same as in Figure 14.

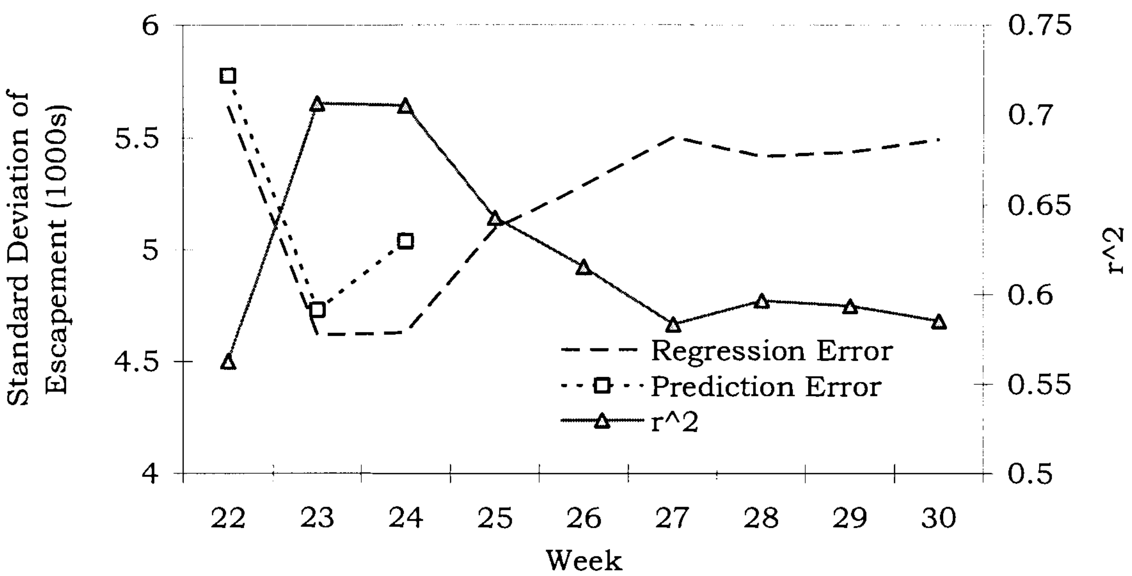


Figure 16. Sample output from the in-season projection model: Comparison of prediction error and regression error.
All projections use the underlying regression models linking each week's cumulative catch in the Nuxalk food fishery to observed end-of-season escapement. This diagnostic plot shows regression error, prediction error, and the coefficient of determination r^2. Regression error and r^2 show how well the independent weekly regressions predict escapement. Both quantities show the same information, but r^2 values can be directly interpreted, while regression error serves as a reference for prediction error. This hypothetical example shows the prediction errors associated with a projection based on average cumulative catch for Week 22 (388 fish) and Week 23 (596 fish), which are only slightly larger than the corresponding regression errors. The more a new observation differs from the observed average, the larger the difference between prediction error and regression error. For example, if cumulative catch in Week 24 is twice the observed average (1560 fish), the resulting increase in prediction error clearly identifies the new data point as unusual. Note that both vertical axes are stretched for emphasis and do not show the origin.

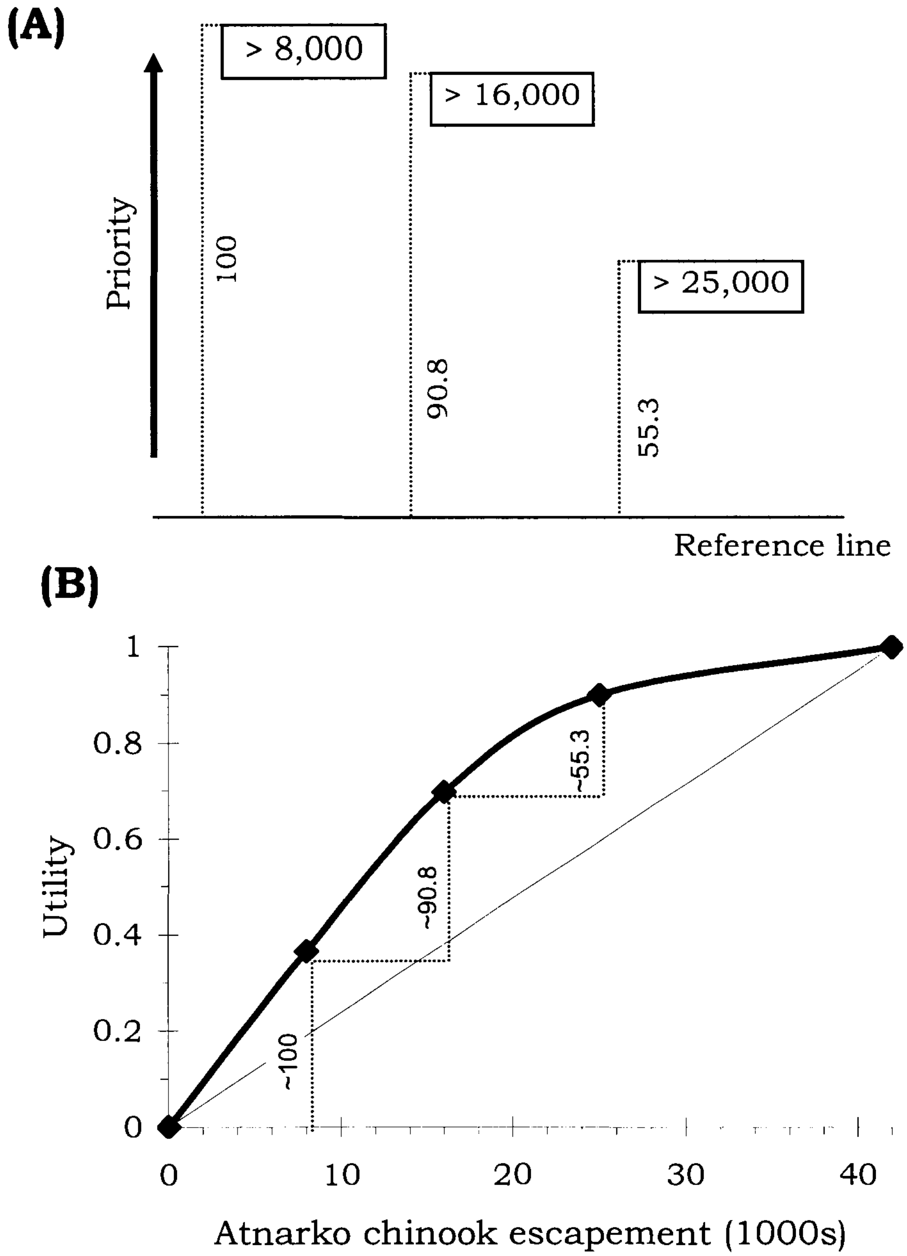


Figure 17. Risk-averse preference for chinook escapement.
Panel A shows the preference statement elicited from the fisheries manager with the computer-based graphical interface, as illustrated in Figure 9. The vertical distance of each box from the reference line reflects the relative priority assigned to achieving escapements above the three cut-off values (e.g. escapement larger than 8,000). Panel B shows one possible conversion of these stated preferences into a concave utility curve typical of risk-averse preferences.

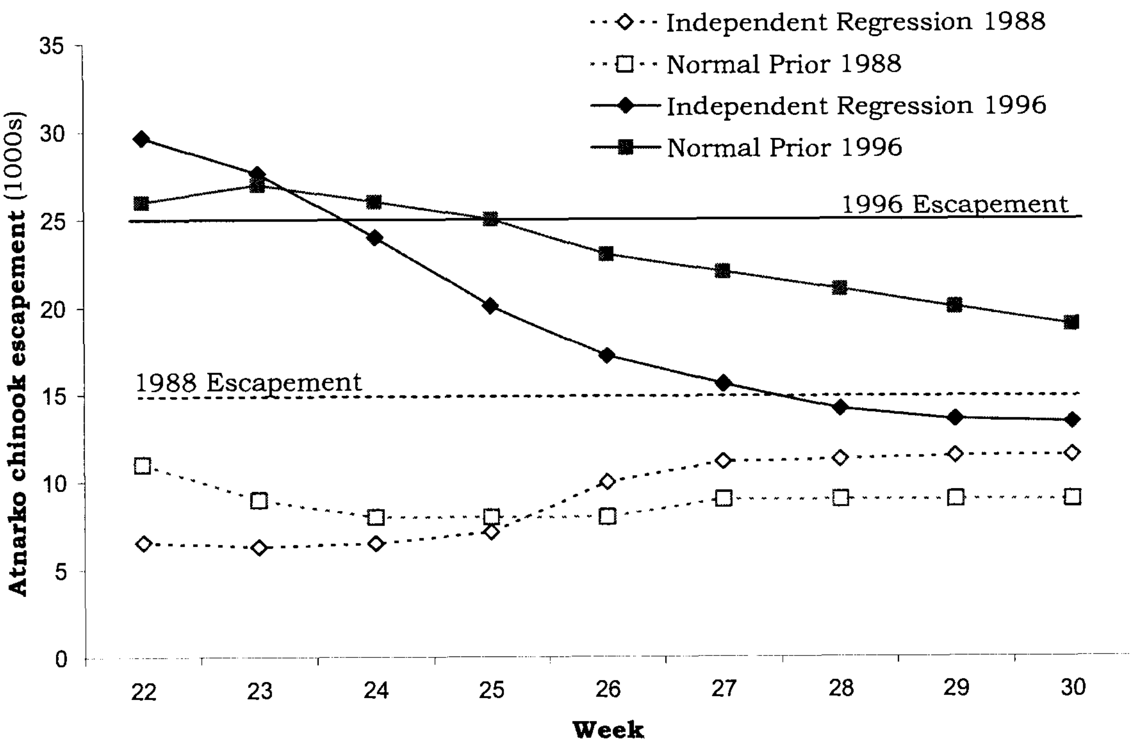


Figure 18. Accuracy and in-season revisions of projected Atnarko chinook escapement.
This example compares weekly projections based on independent regressions (diamonds) to projections based on Bayesian updating using a normal distribution as the pre-season prior (squares). These in-season trajectories of projected end-of-season escapement (best estimate) were calculated from cross-validations using all data except 1996 (solid lines and symbols) or 1988 (dashed lines, open symbols), which correspond to two of 21 time series used to calculate the performance measures in panels A and B of Table 7.

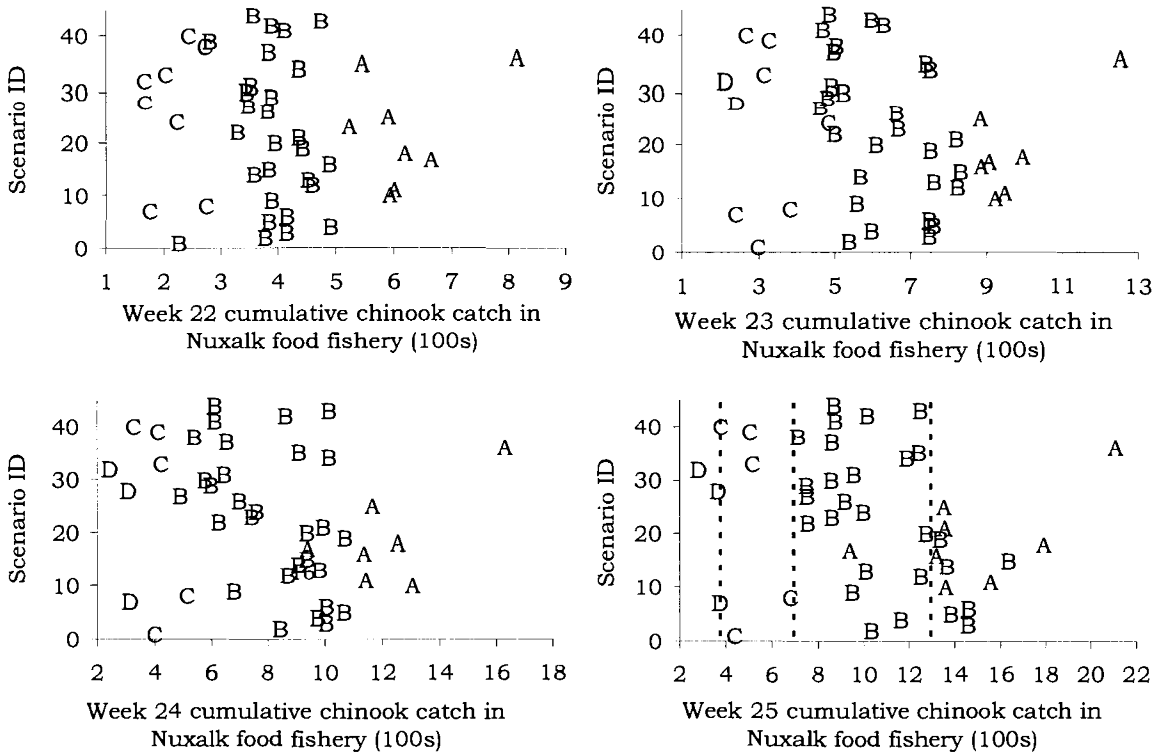


Figure 19. Weekly assessments of stock status based on in-season data. The fisheries manager evaluated 44 sequences of cumulative catch in the Nuxalk fishery, and provided a weekly assessment of stock status as one of four categories (A to D). The scenarios and responses are shown in Table 3. The four panels of this figure display the weekly assessments, ordered by cumulative catch along the horizontal axis. Each letter corresponds to one response from the fisheries manager, and its position along the x-axis indicates the data point that he used (i.e. cumulative catch in the Nuxalk food fishery). To clarify the display, scenarios are also ordered vertically according to the sequence in which they were elicited. The fisheries manager started with the bottom-most scenario on each y-axis. For example, he classified stock status as category B, given a cumulative catch of 226 in Week 22 (top left panel). I used classification trees to identify cut-off points for assessing new observations. For example, the dashed lines in the bottom right panel show the best cut-off points between the four categories under the assumption that all categories are equally likely and that all misclassifications are equally costly. This corresponds to the bottom right classification tree in Figure 20.

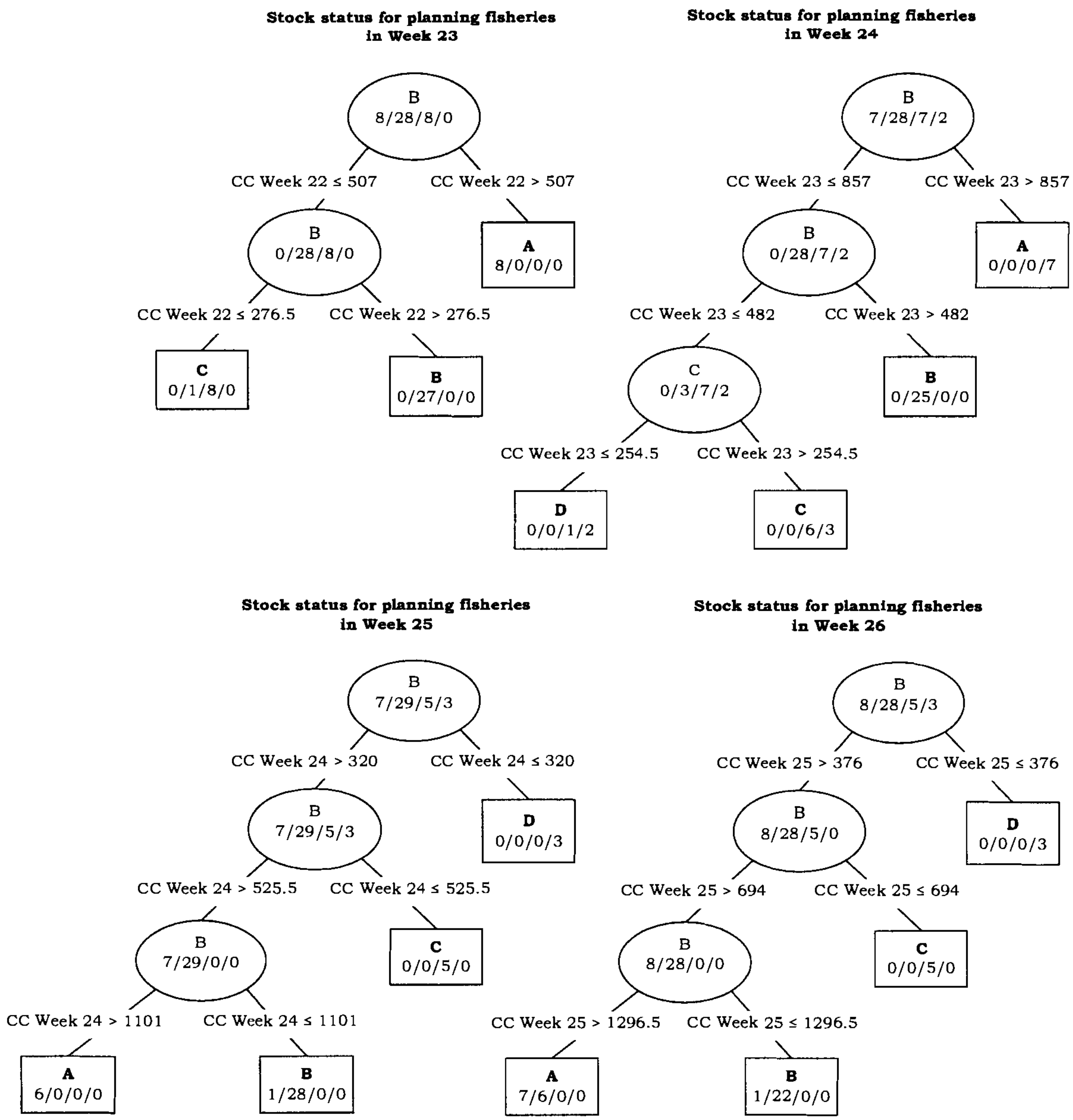


Figure 20. Classification trees for assessing the status of the Atnarko chinook stock, based on cumulative food fishery catch from the previous week only.

Classification trees have two types of nodes, oval splitting nodes and rectangular terminal nodes. To classify a new observation, one starts at the top-most splitting node, and follows the appropriate branches (lines) to a terminal node. Each branch displays the splitting criterion (e.g. "cumulative catch in Week 22 > 276.5" in the case of "Stock status for planning fisheries in Week 23"; top left). Each node displays the number of observations from each class that fall into the node in the order A/B/C/D. Each node also displays the classification of that node. For example, the left-most node of the top-left tree contains 9 observations (0/1/8/0) and the status of the chinook stock is classified as category C for the purpose of planning fisheries in Week 23 if the cumulative catch in Week 22 is ≤ 276.5.

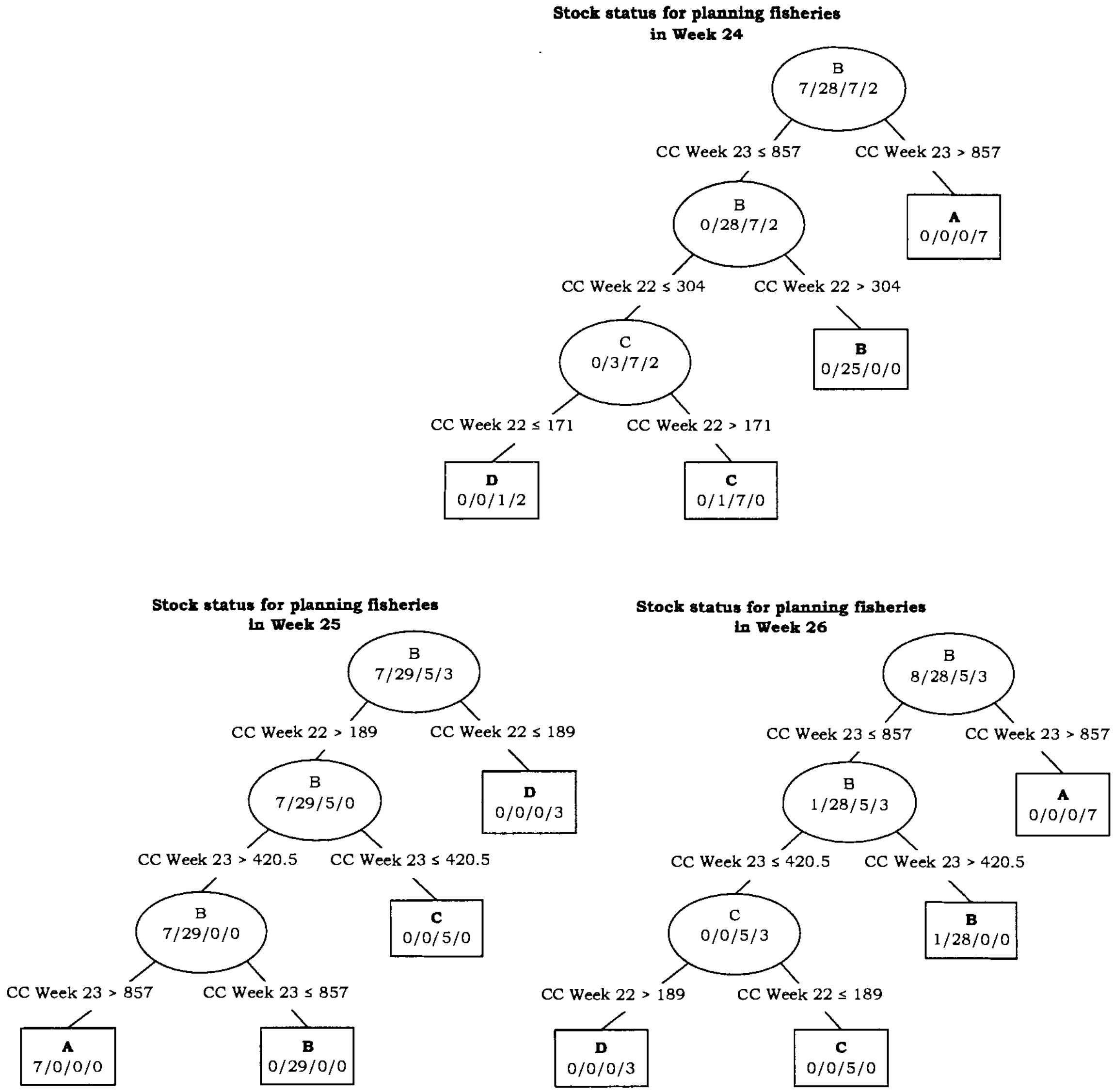
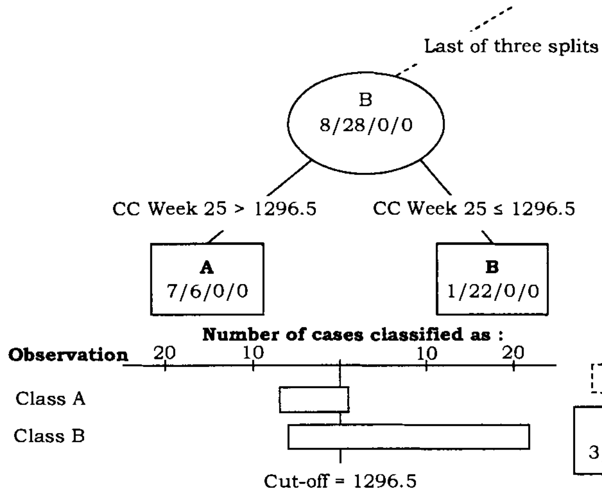


Figure 21. Classification trees for assessing the status of the Atnarko chinook stock, based on cumulative food fishery catch from all previous weeks.

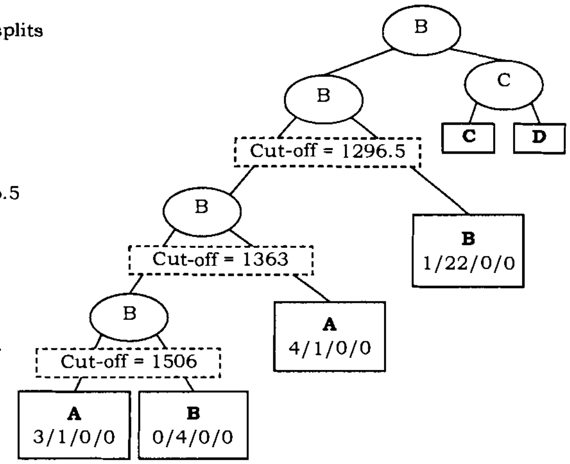
Classification trees displayed in this figure follow the same lay-out as the ones in Figure 20

Figure 22. Effect of observed prior and asymmetric loss matrix on the classification tree for week 26.
The structure of classification trees can be sensitive to assumptions about prior probabilities and the consequences of misclassifications (i.e. loss tables). The four panels of this figure show how the cut-off between two categories of stock status (A, B) changes when using the observed prior (top right), an asymmetric loss table (bottom left), or both (bottom right). Dendrograms underneath each plot indicate how the observations from each class are split into two subsequent nodes. The length of each bar corresponds to the number of observations.

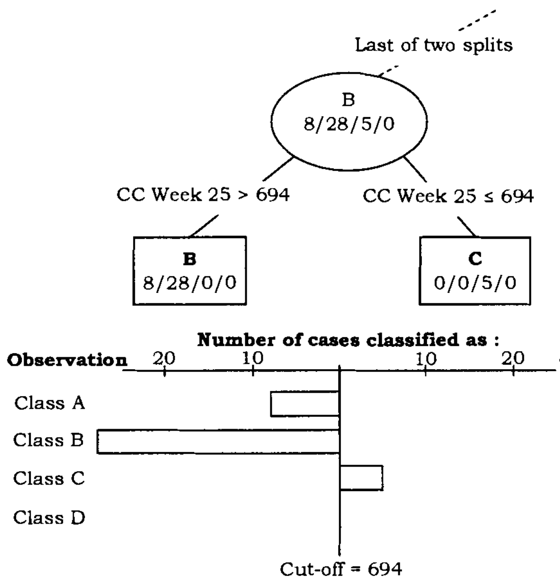
Case 1
Uniform prior, Symmetric unit loss table



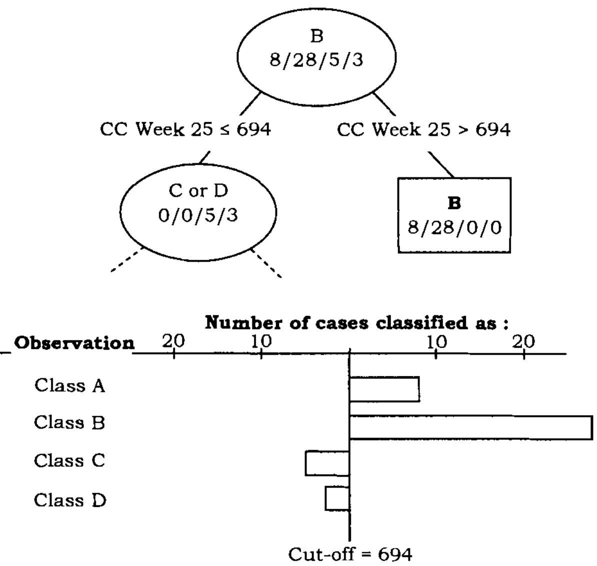
Case 2
Observed prior, Symmetric unit loss table



Case 3
Uniform prior, asymmetric loss table



Case 4
Observed prior, asymmetric loss table



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