FRASER RIVER SOCKEYE SPAWNING INITIATIVE

Report of the Technical Working Group

NOTE
This draft document will be revised based on feedback we receive during the upcoming consultations

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CHAPTER 1

MANAGEMENT STRATEGIES FOR FRASER RIVER SOCKEYE: PAST, PRESENT, AND FUTURE

Steps to a sustainable increase in Fraser sockeye productivity

The Fraser River is the greatest producer of sockeye salmon in British Columbia, and possibly in the world. Over the period 1948 to present day average annual abundance has increased from less than 6.7 million in the 1950s to 12 million in the 1990s, and 1993 saw a record return of 23 million fish. At the same time, some individual stocks have declined in abundance, and affect the harvest opportunity in mixed-stock fisheries.

First Nations, commercial and recreational fishermen all target Fraser River sockeye. Fraser River Sockeye have always been essential to the lives of aboriginal people throughout the watershed and in the marine approach waters. In recent times, harvest by First Nations within the Fraser River has averaged more than 700,000 sockeye. The aboriginal catch has two main components: a fishery to meet food, social and ceremonial needs and, more recently, a fishery in the lower part of the river that provides economic returns. The commercial fishery on Fraser River sockeye has been a traditional economic mainstay, averaging 7 million fish in the 1990s with a commercial harvest of more than 16 million in 1993. This is the largest commercial harvest since the early 1900's. Prior to the Hells Gate slide it was estimated that the largest commercial catch was in 1913, when a total of about 31 million fish were harvested. Lastly, while the sockeye catch for the recreational fishery is much smaller (about 50,000 in recent years) it provides significant economic benefits and additional salmon harvesting opportunities for recreational fishermen.

Many of the Fraser River sockeye populations have recovered from the very low levels in the early 1900s and analyses of historic catch and recruitment, as well as habitat capacity, indicate that the Fraser River may have the potential to produce sockeye runs greater than current levels. It has long been the desire of Canadians to protect and where possible develop Fraser River sockeye runs to their full potential. The Pacific Salmon Treaty between Canada and the United States, signed in 1985 and renegotiated in 1999, ensures that Canadians will collect the majority of the benefits of any increased production as the United States is now limited to no more than 16.5% of the total international share.

The 1987 Rebuilding Strategy

In 1987, DFO formed a Task Force with a mandate to develop a plan to increase the average run size of Fraser River sockeye to at least 30 million fish. Specific objectives were to:

- maximize production from natural habitat, with enhancement where appropriate;
- identify effects of increased production on other species of salmon;

- identify uncertainties that could affect the outcome of managing strategies;
- identify necessary changes to current fishing patterns.

The DFO task force evaluated historical catches since 1894. They also looked at spawner-recruit relationships, spawning capacity and lake-rearing capacity. Like the Fraser River Sockeye Spawning Initiative, their work involved extensive computer modeling to evaluate and develop alternative rebuilding strategies. The Task Force concluded that while it might theoretically be possible to produce run sizes of 30 million or more, lower interim goals were more realistic. This conclusion reflected uncertainty about the cause of the cyclic highs and lows in Fraser River sockeye returns and whether all years could be built up to the same extent (the concern about cyclic dominance persists today and is discussed later for the present model). Low escapements for some stocks also raised doubts about the ability for all stocks to produce consistently at high levels. Thus a more conservative approach was adopted, resulting in interim escapement goals for each of the main Fraser sockeye stocks that were expected to produce total average returns between 8 and 23 million fish (16 million average across all cycles years). The Task Force felt it was too risky to try and achieve the same level of production across all four cycle years. Instead they recommended that an experimental reduction in exploitation rates be undertaken on selected times periods during two of the cycles as a method of learning about the mechanisms of cyclic dominance.

Evaluation criteria for rebuilding options included the net present value of the projected Canadian commercial catch over 40 years, the impact of harvest reductions on the first cycle, and how rebuilding one stock would affect the other stocks. The Task Force's key findings and recommendations were:

- Fraser River sockeye production could be increased substantially on all stocks and cycle lines;
- Rebuilding would require reductions in harvest rates to 65-70% within four years or 10-15% percentage points less than historical levels of greater about 80%;
- It was too risky and impractical to manage for the same level of production on all cycle lines of a stock. However, additional reduction in harvest rates for some stocks on two of the four cycles should be used to learn about the mechanisms that may cause cyclic dominance;
- Departures from the projected long-term rebuilding schedule might be expected to reflect variability in marine and freshwater survival. Some stocks would proceed ahead of schedule and others would lag behind. Keeping all co-migrating stocks on a similar rebuilding trajectory would be a major management objective;
- Rebuilding should take 12-16 years with an adjustable escapement schedule that varies with run size. This approach would ensure sharing of the burden of rebuilding between users and the resource. In poor return years, escapement goals and catch should be lowered proportionately. In good years, the escapement goals and catch should increase. Occasional very large runs might allow placing more spawners on the grounds than provided for in the interim goal.

Based on these recommendations, an implementation plan for escapement management was developed. The plan was the basis for Fraser sockeye management from 1987 to 2004. Using pre-season forecasts of adult returns, annual escapement plans were set within a range determined as follows:

- Lower limits based on abundance of spawners for Early Summer, Summer and Late Run aggregates;
- The lower limit for the Early Stuart aggregate was fixed at 66,000, then increased to 75,000 after additional consultation in the late 1990s;
- Upper limits on target escapement for all aggregates were based on a 65% harvest rate cap.

Performance of the 1987 Rebuilding Strategy

The rebuilding strategy coincided with increasing stock productivity up to 1990, followed by declining productivity for the remainder of the time period. Greater benefits could likely have been realized if there had been stable productivity. However, if management had maintained pre-1987 exploitation patterns, spawner levels would have been much lower in abundance for many of the Fraser River sockeye stocks.

Escapement and catches of Fraser sockeye have been affected by many different factors over the 16 years since the 1987 Rebuilding Strategy was implemented. Changes in marine productivity, concerns for weak stocks and unforeseen issues such as high pre-spawn mortality in the Late Run aggregate have all contributed to the patterns of fishing and escapement that we see now. Some aggregates (e.g. the Summer Run) have increased considerably, but some individual stocks, like Cultus Lake, have become conservation concerns.

Over the years, the Rebuilding Strategy also faced increasing criticism from First Nations, commercial harvesters and other interested groups. Some groups disagreed with the specified long-term and interim escapement goals (too high or too low), and the prescribed rate of rebuilding was also criticized as too slow or too ambitious. Others pointed out that managing for a strictly increasing rebuilding trajectory is unrealistic under changing productivity levels. These fundamental disagreements among groups probably reflected different trade-offs between short-term and long-term benefits.

Response: the Fraser River Sockeye Spawning Initiative (FRSSI)

In response to feedback received from First Nations and other groups, Fisheries and Oceans Canada (DFO) committed to reviewing the current approach. This review incorporated new information, on-going policy development, and developed a formal framework for considering conservation and management objectives. The new process was called the Fraser River Sockeye Spawning Initiative (FRSSI), and the group established to undertake it included senior representatives from First Nations, the commercial fishing industry, recreational fishing, environmental non-government organizations, and the provincial and federal governments.

The Spawning Initiative is the logical next step in determining an integrated escapement and harvest strategy for Fraser River sockeye while implementing the Wild Salmon Policy (WSP), the 2002 Ministerial review of Fraser River sockeye fisheries. The WSP proposes an inclusive integrated planning process to balance biological, social, economic benefits and costs when making management decisions. The relative importance of biological, social and economic factors in decision making will vary depending upon the status of the Conservation Unit (CU). The modeling framework under development in the *Spawning Initiative is* consistent with the principles outlined in the WSP consultation document. For example, the draft WSP advocates that for sockeye, the units of genetic conservation correspond to the lake rearing environment with further differentiation corresponding to distinct migratory timing groups within lakes. We refer to each of the lake units and distinct timing groups within lakes as stocks in this report, they could also be called CU's as defined by the WSP.

In its present version, the model has the capacity to assess data grouped by rearing lake. Twelve lakes are presently incorporated in the model. Thirty-five populations are currently not included, as results of not enough data are available to fit Spawner-recruit models, or they are an enhanced stock. We are currently working on extensions of the model to explore the implications of adding simulated stocks into the model that are less abundant and less productive.

Our use of stock-specific escapement reference points for escapement is consistent with the WSP requirement for reducing the probability that the stocks fall significantly below standards of 'wise use'. For CU's in the healthy state or Green zone as defined in the WSP, social and economic factors will be paramount in arriving at management decisions. Moving below the upper benchmark and into the Amber zone, biological considerations will increasingly be important in decision making though social and economic factors will still be considered. Crossing the lower bench mark into the Red zone, where preservation of the stock or CU is at stake, biological considerations will dominate the resource management decisions. As the WSP is finalized, the Spawning Initiative will be revisited to assess compliance with the WSP.

The Spawning Initiative has several goals:

- Manage spawning escapement to ensure conservation while respecting social and economic values;
- Improve the existing consultation processes by focusing on proactive stakeholder discussion of targets and implementation guidelines, rather than reactive, in-season decision making;
- Develop management reference points and a long-term strategy for managing Fraser River sockeye escapements;
- Develop implementation guidelines for achieving long-term spawning objectives, including appropriate in-season adjustment mechanisms;
- Develop processes for reviewing and modifying the harvest rules and escapement targets.

Differences between FRSSI and the 1987 Strategy

The new strategy will retain many fundamental aspects of the 1987 Rebuilding Strategy. **The new term "harvest rules" has the same meaning as the familiar "escapement tables" of past years, and these harvest rules specify target exploitation rates and target escapements for a range of run sizes.** These exploitation rates will still vary with run size, however small, co-migrating stocks will be protected through constraints on mixed stock exploitation rates. Proposed changes include:

- Basing escapement plans for a given year on target exploitation rate, not on a fixed escapement target. Estimates of spawning capacity are highly uncertain for some stocks, thus a harvest strategy based on target escapement will also be uncertain;
- Removing the requirement to stay above brood year escapement, due to fluctuating productivity of many stocks;
- Explicitly basing harvest rules on management objectives to account for conservation, cultural, social and economic values.

The challenge of setting escapement targets

The basic challenge we face when setting escapement targets is to *find a balance between catch and escapement*. Some economic and social considerations emphasize the short-term benefits of harvesting the fish, and may provide a strong rationale for reducing escapement targets. At the same time, concerns about biological implications and long-term stability for harvesters pose good reasons for increasing escapement targets. In addition to this basic challenge, there are several hurdles that are being considered:

> *Hurdle 1:* How should this balance change at small (or large) run sizes?
>
> *Hurdle 2:* How should this balance change as run size fluctuates from year to year?
>
> *Hurdle 3:* How should this balance change when less abundant stocks are also caught in fisheries targeting an aggregate of stocks?
>
> *Hurdle 4:* How should this balance change when we are faced with highly uncertain estimates of run size, in combination with uncertain catches incurred by different fishing plans?

Many considerations go into finding this balance. Some are more of a technical nature, while others are shaped by the preferences of participants and existing policies. Technical considerations center on the stock dynamics of Fraser sockeye stocks, and how the stocks are expected to respond to different harvest strategies. Policy choices focus on trade-offs between different management objectives, such as:

> *Policy Choice 1:* Trade-off between short-term and long-term benefits.
>
> *Policy Choice 2:* Trade-off between stability in catch and maximizing opportunity.
>
> *Policy Choice 3:* Trade-off between benefits from harvesting abundant stocks vs. risks associated with harvesting less abundant, co-migrating stocks.

Throughout this initiative, we have built and revised a simulation model that allows us to explore these hurdles and policy choices in a structured, consistent and transparent manner. Using this model we can develop harvest rules that explicitly incorporate a wide range of management objectives, evaluate these harvest rules through consistent, formal methods, and compare their performance.

The FRSSI process

The new strategy has to this point, been developed collaboratively by a steering committee composed of senior stakeholder representatives, and a technical working group which includes DFO & external experts. Periodic workshops for review and revision are also being held. The main output from the technical working group described in this report, is a simulation model that takes into account not only the biology of individual stocks, but also attempts to quantify the societal values of parties interested in the resource. The simulation model thus represents a new tool for arriving at appropriate harvest policies for Fraser sockeye stocks.

The workshops provided a venue for the technical group developing the simulation model to present their work, obtain direction and feedback, and refine the proposed approach for managing spawning escapement before taking the initiative to broader consultation. As a result of the workshop process and feedback from the steering committee, the initiative has already evolved considerably.

This report presents results from the initial phase of the Spawning Initiative, during which the working group and its advisors developed harvest rules for 5 stock groupings. These groupings were defined by the current management and were based on 12 representative stocks from around the Fraser River watershed. These stocks were also chosen based on data availability. This result will serve as a blueprint or template for escapement strategies and management reference points for all the sockeye-bearing systems of the Fraser River. The management stock groupings and the representative stocks studied are:

- *Early Stuart*, modeled as a single stock with either cyclic or non-cyclic dynamics;
- *Early Summer*, modeled using three stocks with their individual stock dynamics (Bowron, Raft, and Seymour), then extrapolated to represent the full aggregate including Fennel, Gates, Nadina, Upper Pitt, Scotch and miscellaneous others;
- *Summer*, modeled using four stocks (Late Stuart, Quesnel, Stellako, Chilko) to represent the full aggregate. Late Stuart and Quesnel modeled with either cyclic or non-cyclic dynamics;
- *Birkenhead* modeled as a single stock;
- *Late*, modeled using three stocks (Late Shuswap, Cultus, and Weaver) to represent the full aggregate. Late Shuswap and Cultus will be modeled with either cyclic or non-cyclic dynamics. Recently observed early entry and pre-spawn mortality are not currently incorporated in the model, and only a few scenarios are investigated for references. Other on-going initiatives are dealing in more detail with the Late run aggregate as a whole, and with Cultus recovery efforts in particular.

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Some aspects of Fraser sockeye management, though of keen interest to participants in this process, are **not covered** within the scope of this initiative:

- Allocation of available catch among harvesters
- In-season management adjustments to account for environmental conditions
- Development of specific fishing plans for different gear types and areas
- Costs of implementing harvest rules (stock assessment, in-season meetings, staff requirements)

Other participatory processes are established to deal with these considerations (See Appendix 4).

The simulation model

The simulation model developed for this initiative is based on the relationship between the three main quantities:

- Abundance of adult spawners on the spawning grounds,
- Abundance of adult off-spring produced by those spawners and returning three to five years later, and
- Catch taken from those returning adults.

These three quantities are linked by two processes:
- *Stock dynamics*, to calculate how many adults return for a given number of spawners
- *Harvest rules*, to calculate how the returning adults are divided between spawners and catch. The harvest rule specifies the target exploitation rate for a given number of adult recruits.

The schematic in Figure 1 illustrates the two core processes of the simulation model, *stock dynamics* and *harvest rule*, and how they are connected. Chapter 3 provides more details on the Fraser River sockeye life history and Chapter 4 describes the structure of the simulation model.

Stock dynamics
Briefly, adult spawners produce a large number of eggs, fry emerge the following spring and migrate into rearing lakes where over the course of 1 year they grow into smolts, which then migrate into the ocean and return as adults 3-5 years after the spawning event. Many factors influence each stage of this cycle, creating considerable uncertainty and variability.

Harvest rule
The harvest rule is influenced by management objectives, placing more emphasis on catch, or placing more emphasis on escapement depending upon the overall health of the stock or CU. In the example below, a lower catch of four sockeye, would double the abundance of spawners, could possibly increase the catch available four years into future, and may lessen the risk to the stock of extirpation. However, this increased escapement comes with the short-term cost of reduced harvest and loss of potential social and economic benefits. In order to understand the balance between the biological goals and social and economic benefits we have developed a model. It is a tool that improves the ability to choose the ‘best’ strategy for balancing catch; escapement and ensuring the longer viability of the various CU’s that contribute to the total return of Fraser River sockeye.

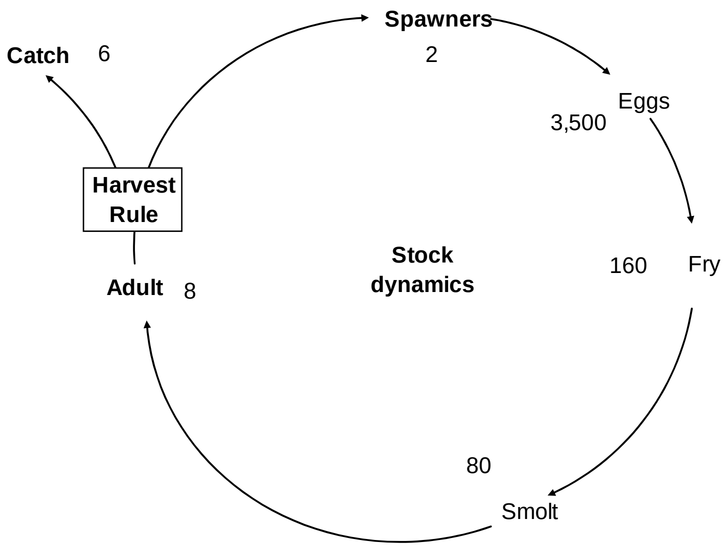


Figure 1: Components of the simulation model

CHAPTER 2

FRASER RIVER SOCKEYE FISHERIES

Fisheries that target Fraser River sockeye

Fraser River sockeye migrating along the northern (Johnstone Strait) and southern (Juan de Fuca) approach routes to the mainstem of the Fraser River are harvested in a number of commercial, First Nations and recreational fisheries in Canadian and U.S. waters. Stocks targeted for harvest are members of a large assemblage of sockeye populations that return to natal streams and lakes throughout the watershed. Returning adults approach the north Coast of B.C., and then migrate south to the Fraser River estuary. They take one of two routes around Vancouver Island: the northern diversion through Johnston Straite or the southern diversion along the west coast of Vancouver Island and through Juan de Fuca Strait. The diversion rate (the percentage of adults following the northern diversion) changes from year to year, and has fishery management implications. Figure 2 shows the fishery management areas on both sides of Vancouver Island, and identifies the main geographic references used in following sections.

Fisheries harvesting Fraser sockeye are also linked to those targeting pink salmon. Fraser River pinks follow a distinct two year cycle, with large numbers of adults returning in odd-numbered years. During these odd-numbered years, fisheries target both species, a situation that affects the geographic distribution of the fleets, fishing plans, and in-season considerations. The sockeye stocks, their biological and management groupings and their status, are described further in Chapter 3.

The major *Canadian commercial fisheries* on Fraser sockeye are the troll fishery off the West Coast of Vancouver Island, purse seine, troll and gillnet fisheries in the Johnstone and Juan de Fuca Straits, and the gillnet fishery in the Fraser River. Smaller commercial catches of Fraser sockeye are taken within the Strait of Georgia. Before 1999, there was a significant seine and troll fishery in the North Coast in Areas 1 and 2 west of the Queen Charlotte Islands, especially in years of high northern diversion when migration routes were more northerly and closer to the B.C. coast. Figure 3 shows all the statistical areas along the coast of B.C. The North Coast fishery on Fraser River sockeye was closed in 1999 as a result of new guidelines established in the Pacific Salmon Allocation Policy.

The principal *U.S. commercial fisheries* harvesting Fraser River sockeye are net fisheries in Juan de Fuca Strait, the San Juan Islands area, and off Point Roberts. Some Fraser sockeye have also been taken in southeast Alaska.

First Nation fisheries for Fraser sockeye mostly take place throughout the waters around Vancouver Island and within the Fraser watershed, but small numbers are caught in waters around the Queen Charlotte Islands and along the Central Coast of B.C.

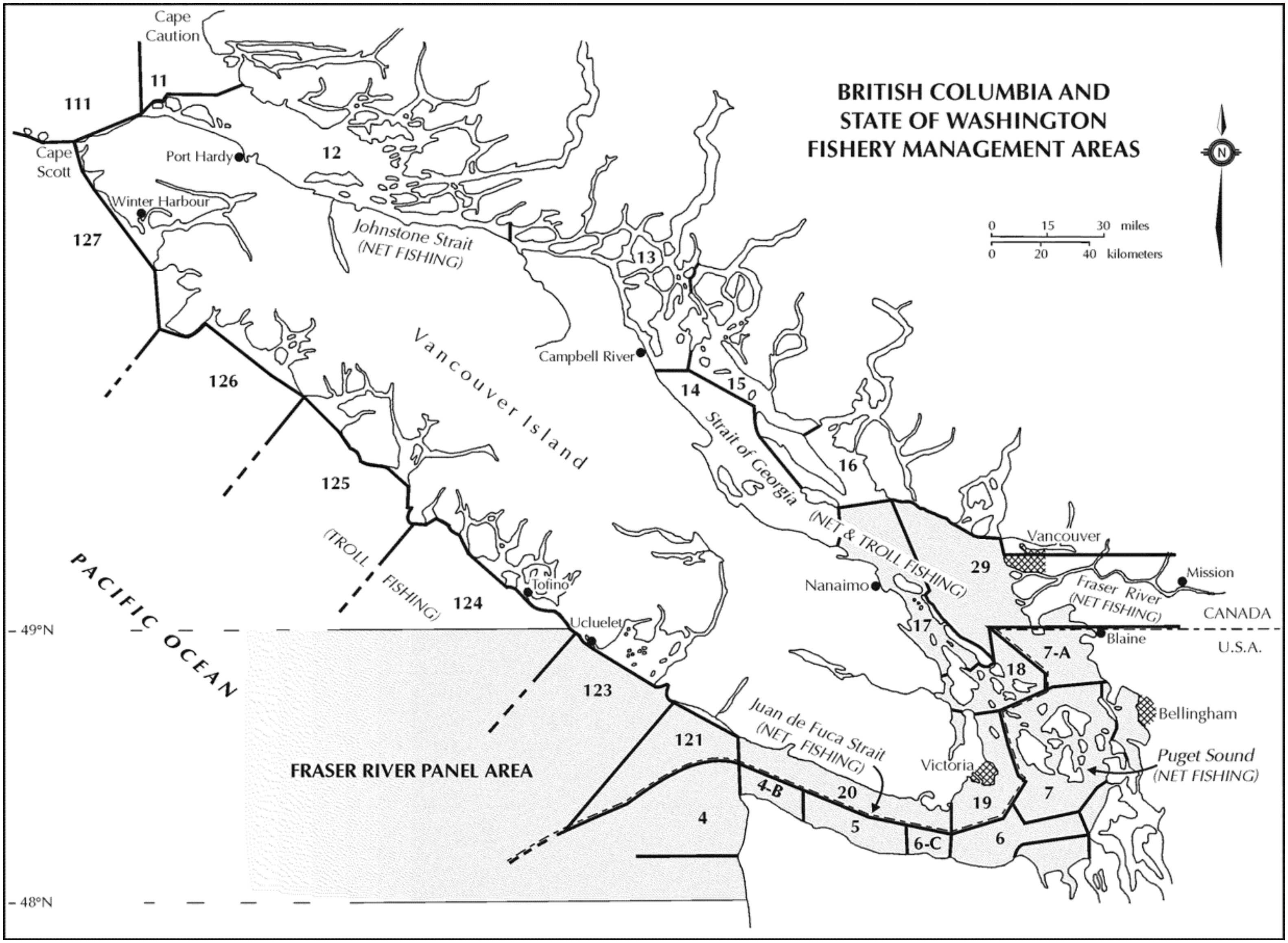


Figure 2: South Coast fishery management areas (Map provided by Pacific Salmon Commission)

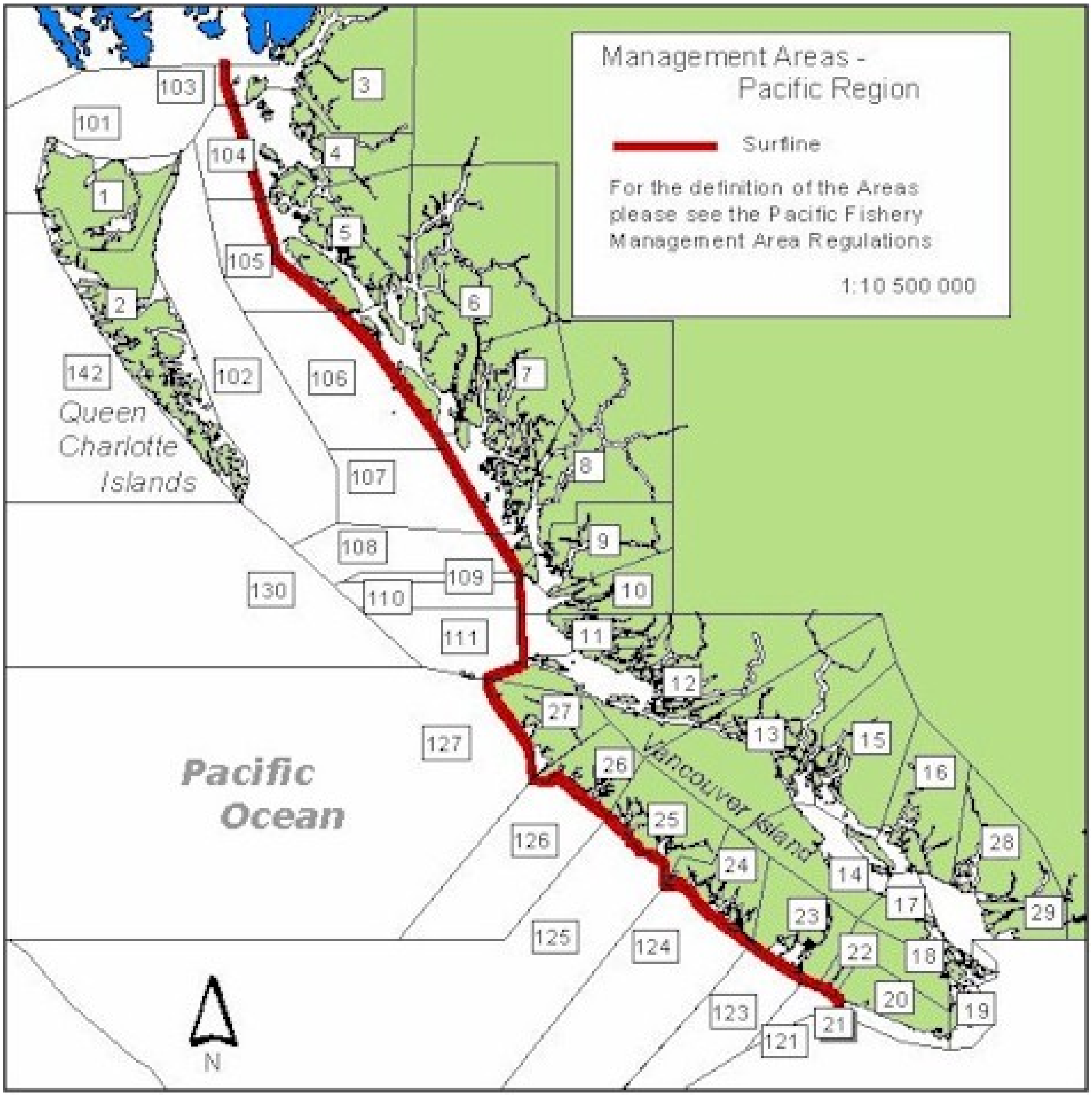


Figure 3: Pacific region management areas

Canadian recreational fisheries for Fraser sockeye in tidal waters is relatively small and catches are low. In recent years, however, the sport fishery has grown rapidly in size and effort in the non-tidal waters of the Fraser River between Mission and Hope.

Before 1914, catches of Fraser River sockeye exceeded 20 million in the dominant cycle years. Between 1916 and 1949, sockeye runs were drastically reduced due to the combined effects of blockage to migration (Hells Gate Canyon slide; dams across the Nadina, Nechako, Quesnel and Lower Adams rivers) and over-fishing. Recovery of runs and catches was slow until the construction of fishways at Hells Gate (1945) and at other areas of difficult passage. These areas of improvement were also coupled with adoption of more conservative management practices.

The increase in total run sizes was followed by a steady increase in total catch since the late 1960s and especially since 1985. Between 1981 and 1998, the total annual commercial catch averaged 7.7 million Fraser River sockeye, with approximately 21% taken by the U.S. Between 1999 and 2002, in contrast, the total commercial catch of Fraser River sockeye declined to an average 1.2 million, approximately 26% of which was taken by the United States (the present portion taken in U.S. fisheries is 16.5%).

West Coast Vancouver Island (WCVI) Troll Fishery

The West Coast Vancouver Island troll fishery (Areas 20-27) is currently the first fishery to target Fraser River sockeye salmon in the course of their return migration. The troll fishery has been a significant harvester of these stocks, especially in years of high sockeye abundance combined with a low northern diversion rate. Major catches of Fraser sockeye in the WCVI troll fishery are taken in late July to mid-August, with the largest catches consistently in the Adams cycle years. The largest troll catch in this area occurred in 1986, with a total harvest of 1.6 million.

Johnstone Strait - Sabine Channel Fishery

The Johnstone Strait - Sabine Channel fishery (Areas 11-16 and 27) has been the major Canadian harvester of Fraser sockeye in the last 15 years, with catches increasing since the late 1970s. In 1993, a record 8.7 million Fraser sockeye were taken.

The Johnstone Strait summer fishery is directed primarily at the dominant Fraser sockeye stocks (and pink stocks in the odd years) approaching the Fraser River via the northern route. Consequently, the catch in this fishery is highly dependent on the diversion rate of these stocks. All three gear types (seine, gillnet and troll) operate in the Johnstone Strait fishery, which encompasses Statistical Areas 11, 12 and 13, and is managed as a unit. These areas typically open simultaneously except when there are specific closures to protect local stocks.

The current fishing pattern for the Johnstone Strait fishery was established between 1978 and 1986, in consultation with harvesters. Management actions are designed to reduce the incidental catch of non-target stocks and species, and include reduction of fishing times, area closures, fishing gear restrictions and, in some cases, non-retention. Since fishing in Johnstone Strait is dominated by net gear, troll management actions have historically been dictated by concerns for meeting allocation targets between the competing commercial gear of purse seine, gill net and troll. Consequently, trolling in Johnstone Strait may depend on catch ceilings or allocations within the troll group. Since 1998, fishing time and catches have been drastically reduced due to conservation of species of concern coupled with relatively poor Fraser River sockeye production.

The Sabine Channel gill net and seine fishery is located in the Strait of Georgia between Texada and Lasqueti Islands (Area 16). The fishery has historically targeted surplus Fraser sockeye and pink salmon prior to their entering the Fraser River. The management goal for the Sabine Channel fishery is to increase the interception of Fraser River stocks without increasing the incidental harvest of other stocks migrating through Johnstone Strait. The fishery is currently managed simultaneously with the Johnstone Strait fishery and consists largely of seine catches. Fishing times are generally limited to less than three days a week, and are more commonly between 12 hours and one day a week. In recent years no fisheries have been permitted, due to conservation concerns for coho stocks and Sakinaw Lake sockeye.

Juan de Fuca Strait Fishery

The Juan de Fuca Strait net fishery operates in a portion of Statistical Area 20 (Area 20 east of Sheringham Point, as well as Area 19, are closed to commercial salmon fishing). The Juan de Fuca Strait fishery is directed at Fraser sockeye and pink stocks approaching the river via the southern route. Historically, both seines and gillnets are used, with seines taking the majority of the catch. Catches of Fraser River sockeye in this fishery have fluctuated considerably over the years, with a maximum of 3.4 million fish recorded in 1989 and 1990.

Management of the Juan de Fuca fishery requires close coordination with the U.S. net and Fraser River fisheries, a task that falls to the Fraser Panel of the Pacific Salmon Commission. The Juan de Fuca fishery is highly efficient, and openings and closures are carefully conducted to ensure that enough sockeye are available for the U.S. and Fraser River fisheries and that the international allocation commitment, as set by the Treaty, is fulfilled. Although the incidental harvest of non-target stocks is unavoidable, management actions are taken to reduce by-catch. These actions include adjusting the number and timing of vessels, relocating the fleet to avoid chinook and coho, closing fisheries inside a 30 fathom shoreline contour to reduce catch of juveniles and non-salmonids, brailing and regulating seine net bunt sizes to conserve juvenile salmon. Since 1998 gill net openings have not occurred and purse seine openings have been reduced in order to ensure impacts on Upper Fraser coho stay within conservation limits.

Strait of Georgia and Fraser River Fisheries

The Strait of Georgia fishery includes Areas 17-18 and Area 29 (including the tidal waters of the Fraser River). This fishery is directed at Fraser River sockeye and odd-year pink stocks, and is primarily a gill net fishery, with occasional troll and seine fisheries. The inside troll fishery in the Strait of Georgia historically targeted chinook and coho salmon, and was not a major harvester of sockeye or pink salmon.

The gillnet fishery fished in the area since the mid-1860s, with the establishment of the first canneries. Total commercial catches of Fraser River sockeye in the Strait of Georgia fishery averaged fewer than one million during the 1960s and 1970s, but reached a record high of 3.4 million fish in 1990.

The Fraser River fishery harvests salmon that migrate from both the northern and southern approach routes. It is managed by the Fraser Panel of the Pacific Salmon Commission in conjunction with the Juan de Fuca and the U.S. net fisheries. DFO also ensures there is a coordinated approach with Fraser River First Nation fisheries. Early-run sockeye are harvested primarily by gill nets from the mouth of the river to Mission, 80 km upstream. Late-run stocks are harvested either in the River or off the mouth of the River in shallow areas of the estuary.

Although the Fraser River fishery is directed mainly at large, productive sockeye and pink stocks, interception of minor sockeye stocks, chinook, chum, coho and steelhead also occurs. Management actions for this fishery have aimed primarily at reducing interceptions of declining coho salmon and steelhead. Changes in management include reduction in total fishing days, elimination of openings when these species are present, and restrictions on net size.

First Nations Fisheries

Fraser River sockeye are of paramount importance to First Nations in the Fraser River watershed and support the largest native fisheries on the South Coast. Catches are taken throughout the Fraser watershed as well as outside areas, primarily Johnstone Strait. Annual in-river sockeye catches have increased substantially since the mid-1970s, with the average estimated catch at 633,000 fish between 1999 and 2002. The highest catch in the Fraser River occurred in 1997, a reported 1,075,000 sockeye. The Fraser River sockeye catch for First Nations food fisheries *outside* the Fraser River occurs primarily in Johnstone Strait, Juan de Fuca and off the mouth of the Fraser River. This fishery has been relatively low in harvest amounts historically but has been increasing in recent years. In 2002, the reported catch reached 264,000, the largest to date.

Gear and fishing methods vary greatly throughout the areas. Fisheries in marine areas mainly use gill net and purse seine. In the lower Fraser River below Hells Gate salmon are harvested using either drift or set gill nets. Further upstream, dip nets, weirs and gaff are also used. In recent years, fish wheels have also been used in a number of areas along the Fraser River in an attempt to harvest sockeye.

Food, social, and ceremonial requirements of First Nations, and treaty obligations to First Nations, have first priority in salmon allocation after conservation needs are met. Since 1992 the lower Fraser River First Nations have had the opportunity to sell a portion of their catch.

Recreational Fishery

The recreational fishery on Fraser sockeye has been minor, representing less than 1% of the total fishery. Historically, the majority of the marine sport catch has been taken in the southern portion of the Strait of Georgia, with minor catches in the Johnstone and Juan de Fuca Straits. However, in very recent years, sport fisheries for sockeye have grown significantly in the non-tidal portion of the lower Fraser River, reaching a catch of 128,000 sockeye in 2002.

U.S. Fisheries

There are three U.S. fisheries on passing Fraser sockeye and pink salmon in Washington State waters in the Fraser Panel Area: on the U.S. side of Juan de Fuca Strait, on Salmon Banks (San Juan Islands), and off Point Roberts. Interception of Fraser River sockeye has also been identified in Alaskan District 104 fisheries, reaching catches up to 270,000 fish in 1990. Between 1999 and

2002, U.S. catches of Fraser sockeye averaged 309,000 in the Panel Area and 17,000 in Alaskan waters.

U.S. fisheries in Washington State waters are managed by the Fraser Panel of the PSC, in conjunction with Area 20 and the commercial fisheries in the Gulf of Georgia and Fraser River. The overall success of the United States fisheries is greatly affected by the amount if fish that migrate via the southern Juan de Fuca route versus the northern Johnstone Strait route. In years of high water temperature a greater number of the returning sockeye migrate through Johnstone Strait in comparison to Juan de Fuca. This requires increased fishing time in United States waters in order for their fishermen to meet their agreed upon Treaty share. Management objectives for the U.S. fisheries include meeting escapement requirements, securing the U.S. share of the Fraser River sockeye and pink catch as specified in the Pacific Salmon Treaty, and domestic catch allocations. The three U.S. fisheries are briefly described below.

The U.S. *Juan de Fuca fishery* harvests only modest numbers of sockeye as a result of most fish migrating along the Canadian side of the Strait. The *Salmon Banks fishery* is diffuse, with no set fishing pattern as migration routes of these sockeye tend to vary. However, catches are substantially greater than in the Juan de Fuca fishery because a higher abundance of Fraser sockeye migrate through the area in comparison to the Juan de Fuca fishery area. The *Point Roberts* fishing area receives limited numbers of migrating sockeye, mainly due to these stocks already being harvested in the Salmon Banks fishery. The fleet directs its initial effort on fish migrating throughout the Point Roberts area (Area 7A). Later in the season the fleet then moves to form a line along the Canadian border in order to target on sockeye holding off the mouth of the Fraser River. In some instances, the area off the west side of Point Roberts is closed in order to protect delaying fish which may move back and forth across the International Boundary.

Incidental catch of other species and stocks

Incidental catch in Fraser sockeye fisheries includes other Canadian sockeye stocks, pinks, summer chum, chinook, coho and steelhead, as well as passing U.S. stocks. Minor interception of fall chum stocks also occurs during the later sockeye and pink salmon fisheries. Most of the incidental catch is taken in the Johnstone Strait, Juan de Fuca Strait and in the lower Fraser River terminal mixed-stock fishery in the lower river. The degree of interception depends on the migration routes and timing of the non-target stocks relative to the dominant stocks targeted by the sockeye fishery.

Due to the four year cycles exhibited by some Fraser sockeye (see Chapter 3), fishing patterns vary each year depending on the timing and abundance of the dominant stocks. Consequently, the amount of interception of other stocks and species in these fisheries also differs from year to year. In recent years, some adjustments in fishing patterns and gear have been made to limit catches of other species, mainly coho and chinook salmon. The problem of harvesting non-target species like coho and chinook is common to all gear types. However, some seine and troll fisheries have demonstrated the ability to successfully release non-target species with high survival rates.

The catch of non-targeted stocks or other species has posed a major challenge in planning Fraser sockeye fisheries. Management actions to limit the harvest of chinook, coho and steelhead in the major commercial fisheries include area and time closures, gear restrictions and non-retention. Time closures include reduction in the length of time spent fishing and elimination of early season fisheries. Area closures focus on locations with high proportions of incidental species. These closures have in the past consisted of corridor closures (the "Ribbon Boundary" in Johnstone Strait) and shoreline boundaries (the “30 fathom shoreline” in Juan de Fuca Strait). Other actions aimed at conserving non-target species are non-retention of incidental species (for example, in the commercial troll fishery), gear restrictions to allow immature salmon to escape (for example, restricted mesh size for seine bunts) and use of “blue boxes” to revive and release live non-target fish.

Many of the First Nations fisheries in the Fraser River are also mixed-stock fisheries, but the exploitation rate is relatively low for most stocks. However, overall impacts on individual stocks can be relatively high, and First Nations effort has thus been limited in order to protect some of the early runs that migrate up-river. Examples include the Early Stuart sockeye stock and early run chinook stocks.

The current management strategy for Fraser sockeye

Before 1985, the International Pacific Salmon Fisheries Commission (IPSFC) was responsible for managing Fraser River sockeye and pink stocks and fisheries within the established "Convention Area". The catch taken within Convention waters was shared equally by Canada and the United States. The Pacific Salmon Treaty, ratified in March 1985, replaced the IPSFC with the newly created Pacific Salmon Commission (PSC), which included a Fraser River Panel with Canadian and American representatives. Under the Treaty, the U.S. share is a percentage of the total allowable catch (TAC).

The Fraser River Panel area (Figure 2) is equivalent to the previous Convention Area and includes Canadian and U.S. waters. The Panel itself is responsible for developing pre-season plans, and for in-season management of Fraser River sockeye and pink salmon within the Fraser River Panel area. Development of management plans for other species and stocks intercepted in the non-Panel waters of the South Coast is the responsibility of the appropriate country. DFO is responsible for managing Canadian fisheries outside the Panel Area, but must coordinate its management actions with those of the Fraser Panel to ensure that escapement and allocation objectives are met. In 1999, the Treaty was renewed through 2010. A number of refinements were made, including a new harvest sharing arrangement and new management guidelines.

The Fraser River Panel makes recommendations to the PSC for development of annual fishery regimes in accordance with the objectives of the Treaty. The Pacific Salmon Commission, guided by principles and provisions of the Treaty, then establishes general fishery management regimes based on conservation concerns and harvest sharing of co-migrating sockeye stocks. The PSC’s recommendations are based on pre-season forecasts of abundance, escapement goals set by Canada, and international and domestic allocation of the TAC. The three main management objectives of the Fraser River Panel for fisheries on sockeye and pink salmon are listed below in order of priority:

- obtain spawning escapement goals by stock or stock grouping;

- meet Treaty-defined international allocations; and
- achieve domestic allocation objectives for harvester groups and licence areas.

The chief domestic objective is to achieve a gross escapement target that consists of the adult spawning escapement plus the anticipated catch in the Fraser River First Nation FSC fishery. DFO sets the initial gross escapement goal, incorporating the pre-season forecast of run size and the First Nations FSC requirements. This goal may be revised several times during the fishing season, based on in-season estimates of actual run sizes. Consideration for en-route loss due to environmental impacts is also factored into the setting of gross escapement requirements. For example in years when water temperatures in the Fraser River exceed preferred migration temperatures the gross escapement target is increased in order to account for mortalities along the migration route to ensure the appropriate number of spawners reach their spawning grounds.

Management of Fraser River sockeye is highly complex due to the predominance of different stocks in each four-year cycle and the resulting variable stock composition and migration timing among cycle years. There is also great (and often unpredictable) variation in: size of the returning run; migration timings of the different stocks and overlap of timing of the different stocks. The diversion rate may also vary considerably from year to year and among the stock groupings within a year.

CHAPTER 3

THE STATUS OF FRASER RIVER SOCKEYE

Life cycle of Fraser River sockeye

The Fraser River system supports the largest number of sockeye salmon in the world (Northcote and Larkin 1989). Sockeye spawn in over 150 natal areas, from areas near the estuary to as far upstream as 1,270 km. Their spawning grounds include small streams, large rivers and lakes throughout the portion of the Fraser system accessible to the species. Figure 4 shows the Fraser River watershed and identifies major sockeye rearing lakes. The resulting fry generally rear in large lakes for one year before migrating seaward as smolts, entering the Strait of Georgia and moving north along the continental shelf into the Gulf of Alaska. The majority of Fraser River sockeye rear in the Gulf of Alaska for two winters before returning to the Fraser River as 4 year old adults. Returning adults approach the North Coast, then migrate south to the Fraser River estuary. Sockeye stocks in the Fraser system are highly productive, with each spawner typically producing an average of 5 adults (known as "recruits"). There is wide annual variation in recruitment, from less than 1 to 20 or more recruits per spawner.

Fraser sockeye stocks and their management groupings

Most of the system's production is accounted for by a limited number of large stocks or stock groups: Birkenhead, Weaver, Chilko, Quesnel, Stellako, Stuart (Early and Late), Adams and Shuswap. Because the Fraser watershed is vast (223,000 km^2) and the spawning migration protracted (June to October), individual stocks have been grouped into four run timing groups, based on the time of entry into the lower Fraser River (Schubert 1997). These groups were established for fishery management purposes and consist of stocks with similar migratory timing during their return from the ocean to the spawning grounds. Because these four run timing groups usually overlap, discrete harvest of individual stocks or stock aggregates downstream of terminal areas is difficult. The aggregates are, in chronological order:

- *Early Stuart*: 32 individual spawning populations (streams or rivers) that spawn in the Takla-Trembuer lake system, arriving in the lower Fraser River from late June to late July;
- *Early Summer*: 34 populations that spawn throughout the Fraser system, arriving in the lower Fraser River from mid July to mid August;
- *Summer*: 33 populations that spawn in the Chilko, Quesnel, Stellako and Stuart systems, arriving in the lower Fraser River from mid July to early September;
- *Late*: 52 populations that spawn in the lower Fraser, Harrison-Lillooet, Thompson and Seton-Anderson systems, arriving in the river from August to mid October.

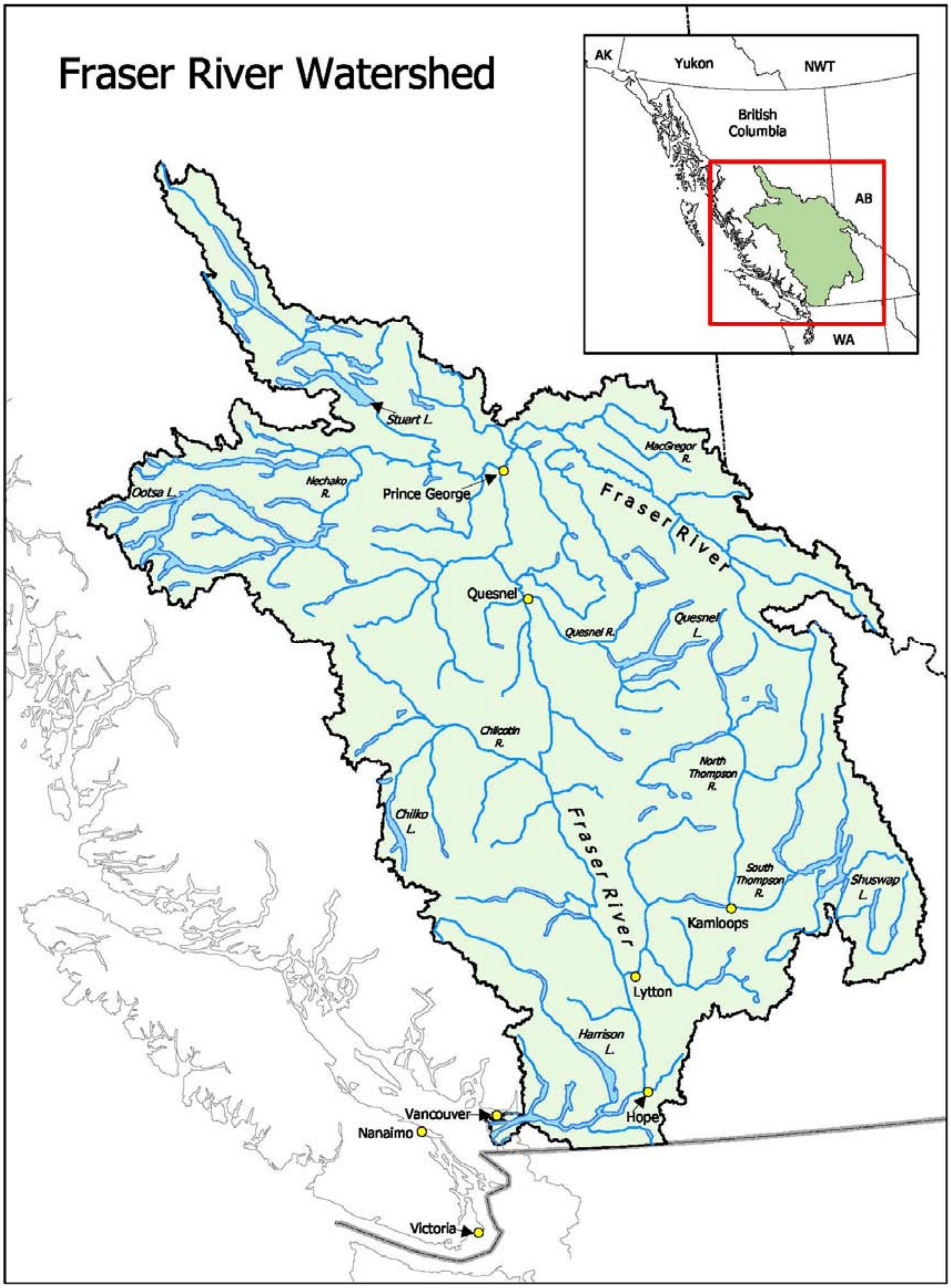

Fraser River Watershed
AK
Yukon
NWT
British Columbia
AB
WA
Stuart L.
MacGregor R.
Ootsa L.
Nechako R.
Prince George
Fraser River
Quesnel
Quesnel R.
Quesnel L.
Chilcotin R.
North Thompson R.
Chilko L.
South Thompson R.
Shuswap L.
Kamloops
Lytton
Harrison L.
Vancouver
Nanaimo
Hope
Victoria

Figure 4: Fraser River watershed and major sockeye rearing lakes

Stock dynamics

Stock dynamics is a general term used to describe the biological characteristics (e.g. age at maturity, number of eggs per female, fish size), environmental processes (e.g. freshwater or marine survival rates) and human factors (e.g. harvest or habitat destruction) that determine a stock's abundance, growth, reproduction and mortality. Understanding stock dynamics is critical to assessing a stock's sustainability as an exploited resource. Unfortunately, the biological mechanisms underlying these dynamics are often poorly understood.

Spawner-recruit models

Statistical methods have been developed to explain the overall relationship between spawners and the number of their offspring that return to spawn (recruits). Several spawner-recruit (SR) models, including those developed by Ricker (1950), Beverton and Holt (1957) and Larkin (1971), which simply describe the relationship between spawning adults and the offspring that return predominantly in four years. The model used in the spawning initiative is a reformulated version of the Ricker model. One benefit of simulation models, like the one used here, is that we can use different SR models and evaluate their implications for management within a consistent framework. As new data and new hypotheses become available, they can be easily incorporated.

Historical observations of spawners and recruits based on catch plus escapement in subsequent years are used to derive a mathematical function describing the fit of the SR model to the data. SR models usually predict increasing production of recruits as the number of spawners increases, eventually leveling off or declining as high spawner abundances exceed the capacity of the environment to sustain the offspring (Figure 5). SR models have a minimum of 2 parameters, with complex models requiring more. One of the parameters is the 'productivity' parameter that determines the number of recruits per spawner at low abundance. The other parameter is the 'capacity' parameter which determines the maximum number of recruits that can be produced by the habitat, or, how big the stock can grow in the absence of fishing. The productivity parameter describes the maximum sustainable exploitation rate for the stock, while the capacity parameter describes the spawning escapement that will maximize recruitment and the size of the catch. Knowledge of both parameters is important for management purposes. In the SR models used here, the productivity parameter is denoted h^* and the capacity parameter is denoted S^*. For more information about these parameters, refer to the technical report (Cass et al. 2004). The actual h^*, S^* values for each stock in the model are listed in Appendix 1.

For most stocks of Fraser River sockeye, there is a long time-series of SR data - more than 50 years - one of the longest running time series of data for fish populations anywhere in the world. However, most of the data points represent relatively low spawner abundances with fewer data points at high abundance. As a result, the productivity parameter is relatively well defined, but the capacity parameter is highly uncertain. This means that the maximum sustainable exploitation rates are known with considerably certainty, but the spawning escapement that maximizes recruitment is poorly known (see below: *Estimating the abundance of spawners that maximizes recruitment*). As a result, a fixed escapement policy is based on a highly uncertain capacity estimates and therefore may be expected to perform poorly when compared to exploitation rate policies based on well defined productivity parameters.

Changing assessment methods may affect the data available for SR analysis in future years. If data are not collected, it will also be hard to detect whether off-cycles are capable of rebuilding.

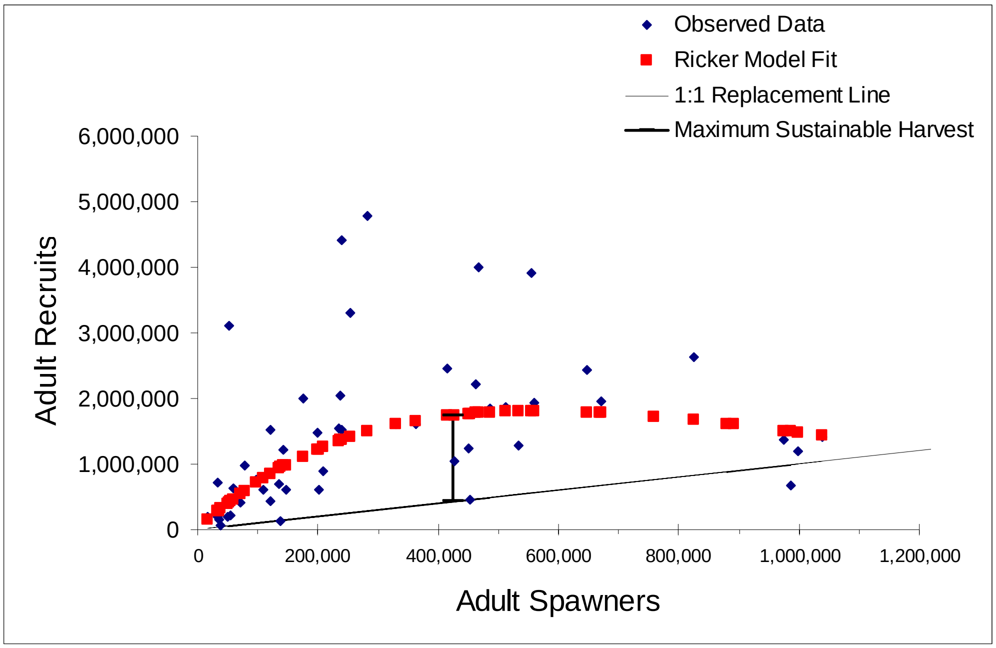


Figure 5: Example of a spawner-recruit model – Chilko Lake sockeye

The question of cycles

To add to the usual complexities of understanding fish stock dynamics, some Fraser sockeye stocks exhibit cyclic fluctuations in abundance. Cyclic fluctuations are characteristic of many fish stocks with single or dominant reproductive age classes, and perhaps the most dramatic examples of population cycles in fishes are seen in Pacific pink and sockeye salmon. Many stocks inhabiting the largest lakes in the Fraser River drainage exhibit persistent 4-year cycles of escapement that gives rise to relatively discrete cycles that vary in both pattern and persistence. Of about 20 sockeye stocks in the watershed that are enumerated routinely, 8 exhibit persistent 4-year cycles with a predictable dominant-year cycle line every four years. The cyclic patterns in total abundance, catches and escapement of Fraser River sockeye are largely driven by cyclic patterns in a few large populations in the Summer run aggregate and the Adams River stock in the Late run aggregate (See *Trends in Abundance* below).

The normal life span for most sockeye stocks is four years. The “dominant” cycle line refers to the sequence of years wherein the run size is persistently larger than the other cycle lines. The “sub-dominant” line is characterized by moderate abundance while “off-year” lines often have extremely low abundance (orders of magnitude smaller). This pattern, in which one cycle line is more abundant than the others, is referred to as "cyclic dominance." The relative importance of cyclic dominance in a given population's dynamics is explicitly considered by the simulation model described in Chapter 4.

What causes cyclic dominance?

Despite 50 years of study, there is still no scientific consensus on the cause of cyclic behavior in Fraser sockeye. The lower Adams River and Shuswap River stocks for example, cycle in a persistent dominant-subdominant-low-low (DSLL) pattern. This cycle pattern has been the focus of debate as it is unknown whether or not intrinsic interactions among year-classes lead to differences in biological productivity or there are no interactions and there is indeed an equilibrium stock size among cycle lines. Various ecological hypotheses have been proposed, including interactions with predators. Disease or parasites might also induce cycles but no mechanisms have been proposed to explain how. Marine influences have been discounted because it is unlikely they could generate asynchronous cycles among the different stocks in the Fraser watershed. The term *asynchronous* means that some stocks are dominant one year, and some stocks are dominant the next. Reduced food availability imposed by dominant cycle lines on off-cycle years is also unlikely since growth rates of highly cyclic Fraser sockeye are highest in off-cycle lines. Other possible causes centre on human impacts: off-cycles are consistently fished at higher relative rates than dominant of subdominant cycle lines. Some researchers have concluded that genetic factors could maintain population cycles or at least slow the recovery of off-cycle lines. The genetic model is conditional on high fishing mortality coupled with strongly inheritable age at maturity and age-dependent mortality.

Understanding the causes of cycles in Fraser sockeye is extremely important for stock rebuilding. Provided there is no biological basis for the observed cyclic pattern, substantially larger run sizes should be possible on off-cycle years. This could be achieved by reducing the exploitation rate, which has the effect of increasing spawning escapements allowing rebuilding these off-cycles. However, if cycles are a result of some biological mechanism, then the potential for increases in run size may be much lower. Rigorous testing of the many hypotheses is only possible with adaptive, large scale experimentation to check whether larger escapements on off-cycle lines produce larger recruitment without significantly affecting the dominant cycle lines. This option has so far been avoided because of the potential for severe fishery disruptions associated with short term reduction in catches from larger stocks co-migrating with smaller off cycle stocks. However, it is possible that large benefits may be created in the longer term if off-cycle lines are capable of rebuilding to higher abundance similar to the returns now produced form the dominant and sub-dominant cycle lines.

We will not be able, for quite some time, to determine with certainty whether stocks are inherently cyclic or not. However, the appropriate strategy for setting escapement targets is very sensitive to whether or not there is an underlying biological process that determines the cycles.

This initiative will not determine whether or not cyclic dominance exists, but will try to find spawning escapement strategies that are as robust as possible to the uncertainty of its existence.

By robust, we mean that the expected value from the resource is as high as possible regardless of whether cyclic dominance is or is not the true underlying dynamic. As new models are developed that provide more insight into the life cycle of these stocks, we can incorporate them into the same framework.

The question of over-escapement

The Pacific Fisheries Resource Conservation Council released a paper entitled “Does Over-escapement Cause Salmon Stock Collapse” in June 2004. The paper examines whether large number of spawners have detrimental impacts on subsequent production. This topic was initiated due to recent large spawning escapements to some Fraser River sockeye salmon populations and the hypothesis that having “too many” fish on the spawning grounds will result in competition for space, nutrients, oxygen, cause diseases and other potential detrimental affects, such that overall survival and growth of the offspring is greatly reduced. The paper examined 21 sockeye stocks and 2 pink salmon stocks. The authors found evidence of declines in production at higher escapement levels, but there was no evidence to support anything like a “collapse” or “near-collapse” in the production of these stocks. This observation is significant because it demonstrates that productive stocks will not suffer drastic reductions in productions as a result of management actions that need to be taken in order to protect weaker co-migrating stocks.

Estimating the abundance of spawners that maximizes recruitment

The abundance of Fraser River sockeye stocks that maximizes their recruitment is thought to be limited in the freshwater environment, either by available spawning habitat or by available lake rearing habitat. Several approaches have been used to quantify spawner capacity for individual sockeye stocks including available spawning area, lake productivity and numerical estimates of the capacity parameter from SR models. For most stocks, however, such estimates are highly uncertain and vary depending on whether the population is thought to follow cyclic dynamics that constrain spawner abundance on off-cycle lines.

Table 1 shows interim escapement goals and estimated spawner capacities for a number of Fraser sockeye stocks based on spawning area, lake productivity, SR parameter estimates. Different methodologies of estimating spawner capacity will provide a range of estimates. For example, there is high uncertainty about the spawner capacity for the Quesnel system, with estimates ranging from 931,000 (based on lake productivity) to over 2,300,000 (based on spawning ground capacity and SR estimate). Conversely, the spawner capacity for Chilko sockeye appears well defined with all methods producing estimates between 500,000 and 600,000 spawners.

The 1987 Fraser River Sockeye Task Force developed interim escapement goals based on assessment of spawning area, lake productivity, historical information and SR analysis. We used the Task Force’s estimates of usable spawning area, based on the estimated amount of usable gravel area for each spawning area multiplied by data on the optimum spawning densities for index streams within four distinct zones classified based on unique bio-geoclimatic indices. Spawner capacity estimates based on lake productivity were derived from relationships between seasonal average photosynthetic rates in sockeye nursery lakes and juvenile sockeye production (Shortreed et al. 2001). Estimates of spawner capacity based on SR analysis were derived from mean parameter estimates from the SR model to the historical SR data for each stock for all years (non-cyclic) and dominant/sub-dominant and off-cycle lines for stocks exhibiting cyclic abundance patterns.

Uncertainty about the spawner capacity of each stock has important implications for the rebuilding potential of stocks and the off-cycle lines within those stocks, and ultimately, on the choice of harvest rules designed to meet different objectives. These uncertainties are captured by the range of capacity parameter values that were used in the SR analysis (refer to Chapter 4 for a definition of these terms). Recent large escapements to the Quesnel and Shuswap systems in 2001 and 2002 may provide some insight about the limits of freshwater capacity when the recruits from these spawners return in 2005 and 2006.

Abundance and exploitation rate: Definitions

Estimates of total abundance, catch, exploitation rate and spawner abundance are derived from information gathered by the Pacific Salmon Commission (PSC, formerly the International Pacific Salmon Fisheries Commission, IPSFC) and the DFO.

Total abundance is the sum of all fish caught in fisheries plus those arriving at the spawning grounds, including in some instances fish thought to have died along the migratory route in the Fraser River (en-route loss). The PSC provides 'in-season' estimates of total abundance for each sockeye stock aggregate based on several methods that include catch per unit effort data from test fisheries, abundance estimates from a hydro-acoustic counting facility at Mission, and stock identification data to determine which stocks the catches came from. These in-season estimates of total abundance are used for planning sockeye fisheries but are generally not used to produce the final estimate of total abundance for each stock, unless data on spawner abundance or catches is insufficient to derive an estimate of abundance after the fishing season is over. However, in-season estimates of total abundance are sometimes used to estimate en-route losses in some stocks (e.g. unreported harvest or mortality that occurs between the lower Fraser River near Mission and terminal spawning areas). En-route losses are calculated as the difference between the gross escapement at Mission minus the upstream catches and abundance of spawners in spawning areas. En-route losses are added to catches and spawner abundance to determine total run size in situations where poor environmental conditions such as high flows or water temperatures are thought to have caused mortalities.

Catch of each stock is determined from samples collected from fisheries. Catches of Fraser River sockeye are monitored by the countries and reported to PSC staff. PSC staff then use unique scale characteristics or DNA stock identification methods to determine how much each individual stock contributed to the catch.

Spawner abundance is estimated directly in terminal areas for each stock. Spawner abundance is estimated by DFO using a two-tiered system where the method selected for a particular stock is based on its forecast return for any given year. For stocks with small expected returns (less than

25,000), a variety of stock-specific estimation methods are used, including visual surveys. For stocks with larger expected returns (more than 25,000), abundance is estimated using enumeration fences and mark-recapture studies.
Exploitation rate is the proportion of each stock caught in all fisheries and is calculated by dividing the catch by the total abundance. More specifically, the exploitation rate is calculated as

$$h = \frac{C}{C + Mort + E}$$

where h = total exploitation rate, C = estimated catch, $Mort$ = estimated en-route mortality, E = estimated escapement.

The SR analysis for the present model uses the number of recruits produced by the spawning population from each brood year. How is this number derived? The PSC uses annual data about total abundance, spawner abundance and age composition data (determined from ring patterns in scales and otoliths) for each stock to determine the number of recruits produced by a parental spawning population. For example, in any given year the total abundance of any individual sockeye stock is composed of age 3, 4 and 5 fish produced by spawners 3, 4 and 5 years earlier. In other words, the total run in any year is composed of recruits from 3 different sets of spawners. However, when we do SR analysis we wish to know the total number of recruits produced by a single year's spawners (i.e. the brood year). Using age data, PSC staff is able to allocate which fish in the total run came from each brood year. The total recruits for each brood year's spawning population can then be determined by adding up the age 3, 4 and 5 year old fish.

Historic abundance of Fraser sockeye runs

Historic abundance of Fraser River sockeye runs is difficult to determine because catch records and spawning escapement estimates for most stocks are incomplete, and reliable stock identification methods were not developed until the 1940s. The best estimates for the late 1800s and early 1900s come from records of catches landed at canneries. From 1894 to 1913, the average catch on the 2001 cycle was estimated at 23 million with averages on the other cycles ranging from 3.5 to 5 million (IPSFC 1972). However, these estimates are conservative because spawning escapements were not available and many commercial catches and catches in First Nations fisheries were unreported.

In 1913, a blockage in Hells Gate Canyon destroyed a substantial part of the dominant sockeye run by restricting access to upstream spawning grounds. An intensive fishery in 1917 further reduced the abundance of the dominate 2001 cycle line to levels approximately the level of the other cycles (Aro and Shepard 1967). Other obstructions also affected spawning stocks. From 1908 to 1922, a dam at the mouth of Adams Lake virtually eliminated a major spawning stock in the Upper Adams River. However, recently one of the cycle lines from this stock has shown signs of recovery. A dam at the outlet of Quesnel Lake from 1898 to 1921 also contributed to the decline of stocks returning to that system. A fishway constructed in 1903 helped to mitigate the loss of salmon due to the dam. Additionally, placer mining taking place downstream of the dam on the Quesnel River probably had an adverse affect on fish. Between 1918 and 1927, following the collapse of the runs due to Hells Gate and these other factors, the total run was thought to average only 1.6 million sockeye per year. Construction of fishways at Hells Gate, removal of dams and increased regulatory control of the fisheries through the IPSFC led to higher escapements and production.

Between 1952 and 2001, total abundance of Fraser sockeye has averaged over 7.6 million for 22 of the largest sockeye stocks. This is an under estimate, however, as the abundance of many smaller stocks is not included. The five largest stocks, including Adams (Late aggregate) and the four Summer stocks (Chilko, Quesnel, Late Stuart and Stellako) contributed over 75% of the total Fraser River sockeye abundance during this period. Early Stuart sockeye, Seymour (Early Summer), Birkenhead and the Late run stocks Weaver and Shuswap are the next five largest Fraser sockeye stocks. The remaining stocks in the top 22 all have average run sizes less than 100,000 and are included in the Early Summer or Late run aggregates.

Trends in abundance

As mentioned in Chapter 1, management of Fraser River sockeye has been based on a rebuilding strategy since 1987. In the most recent years for which data are available (1990-2001), the average total abundance for the 22 stocks has increased to over 11 million (Table 2). The 10 largest stocks have remained unchanged and most of the other stocks are at higher abundance levels than the long term average. Notable exceptions include: Upper Pitt and Bowron in the Early Summer run aggregate and Late run stocks including Harrison, Adams and Cultus, have all suffered high mortalities in recent years. Cultus Lake sockeye have recently been designated as *endangered* by COSEWIC as a result of these declines in abundance.

Total abundance of Fraser River sockeye has increased steadily from less than 5 million in the 1960s to a peak of over 23 million in 1993, although there are large variations in cycle line abundance. Figure 6 shows a stacked plot of escapement (black area), catch (gray shaded area) and the corresponding exploitation rate (solid line). The upper edge of the gray shaded area shows total returning adults (i.e. catch + escapement). Before rebuilding began in 1990, average abundance was 6.6 million with exploitation rates above 70% on most years and frequently over 80%. In the 12 years since the start of the rebuilding strategy (1990-2001), average exploitation rates have been reduced to 55% and the total abundance of Fraser River sockeye has nearly doubled to 11.1 million (Table 2). Average catches have also increased to over 7 million and spawner abundance has more than doubled to 3.4 million (Figure 6). However, total abundance of Fraser River sockeye has declined from the peak in 1993. This has been due in part to declining productivity of summer run stocks (Figure 7) and high mortality affecting Late run stocks. Since 1995, management measures put in place to protect stocks in the Late run aggregate have further reduced average exploitation rates to 41%, with a low of 15% in 1999. Average catches since 1995 have also decreased substantially to 3.3 million including the lowest catch on record of less than 600,000 in 1999. Dramatic reductions in exploitation rates have resulted in the largest escapements on record on several cycle lines.

Stock Group	Interim Goal 2002	2003	2004	2005	Spawning Ground Capacity	Nursery Lake(s)	Optimum Escapement Predictions for Nursery Lake (PR Model)	SR estimates non-cyclic	dom/sub-dom	off cycle
Early Stuart	150	280	150	500	1505 a	Takla, Trembleur	779 b	473	563	95
Bowron	45	45	45	45	45 c	Bowron	n/a	22	22	22
Raft	13	13	13	13	13	Kamloops L. ??	n/a	15	15	15
Seymour	117	117	117	117	117	Shuswap	1,897	126	126	126
sub-total	175	175	175	175	175		1,897	163	163	163
Early Summer Ag	399 d	399 d	399 d	399 d						
Late Stuart	300	200	50	500	1317 e	Trembleur, Stuart	1985 f	918	925	53
Quesnel	2200 g	250 g	250 g	2200 g	2243 h	Quesnel	931	2320	2145	150
Stellako	300	300	300	100	429	Fraser	601 i	268	268	268
Chilko	824 j	824 j	824 j	324 j	593 k	Chilko	513	550	550	550
sub-total	3624	1574	1424	3124	4581.8		4030	4056	3888	1021
Summer Aggrega	3624	1574	1424	3124	4582		4030	4056	3888	1021
Birkenhead	300	300	300	300	278	Lillooet, Harrison	966 l	162	162	162
Late Shuswap	3500	3500	150	150	3477 m	Shuswap	1897 n	2191	2288	7
Cultus	56	56	56	56	56	Cultus	84 o	33	103	37
Weaver	50	50	50	50	48	Harrison	796	133	133	133
sub-total	3606	3606	256	256	3580.8		2777	2357	2524	177
Late	3714 p	3714 p	364 p	364 p	3588.6					
Stocks in analysis	7,855	5,935	2,305	4,355	10,121		10,449	7,211	7,300	1,618
Aggregate total	8,187	6,267	2,637	4,687	9,954		5,775	4,691	4,613	1,278

Note: 100k = 100,000

a - Takla and Trembleur Lake spawning streams; **b** - Takla (453k) and Trembleur (326k) Lakes; **c** - Bowron River; **d** - includes Upper Pitt R. (69k), Gates Cr.(21k), Fennel Cr.(15k), Nadina R.(35k) and Scotch Cr. (84k) does not include miscellaneous Early Summer stocks (e.g. Eagle, Chilliwack, Upper Adams, etc…); **e** - Stuart Lake spawning streams (Kuzkwa cr., Tachie R., and Pinchi Cr.), Trembleur Lake spawning streams (Kazchek Cr. and Middle R.) and Takla Lake spawning streams (Sakenichie R.); **f** - Trembleur (326k) and Stuart (1659k) Lakes; **g** - Horsefly interim goal only; **h** - "Quesnel Lake" includes: Cameron R, Horsefly R (upper and lower), Little Horsefly R, McKinley R, Mitchell R, Penfold Cr, Quesnel L, Summit Cr, & Wasko Cr); **i** - Fraser Lake PR model optimum escapement; **j** - includes 224K for Chilko Lake; **k** - Chilko River (369k) + Chilko Lake (224k); **l** - Lillooet Lake (170k) and Harrison Lake (796k); **m** - includes: Adams R, Little R, Lower Shuswap R, Lake & S. Thomopson R, Middle R., and Middle Shuswap R.; **n** - Adams River and Lower Shuswap River; **o** -data from Schubert, N.D. et al. "Status of Cultus Lake sockeye salmon (Oncorhynchus nerka). (PSARC 2002, paper S2002-11); **p** -includes Portage Cr. (8k) and miscellaneous other stocks (100k)

Table 1: Estimates of spawner capacity for Fraser sockeye stocks and stock groupings used in the simulation model and interim goals for Fraser River sockeye stocks.

(Interim goals from 1989 Rebuilding Strategy, Lake capacity estimates from Shortreed et al. 2001, Median estimate of Smax from S-R analysis

Early Stuart runs

Early Stuart sockeye total abundance, exploitation rates, catches and escapements have shown a highly variable but pronounced cyclic pattern (Figure 8). From 1952 to 1989, exploitation rates averaged 69% across all cycle lines. Total abundance during this period averaged 317,000 with average catches of 237,000 and spawner abundance averaging 77,000. In the last 3 cycles, exploitation rates were reduced on Early Stuart sockeye to 33%. Average spawning escapements were doubled to 151,000 with only a relatively small reduction in average catch at these higher run sizes.

Early Summer runs

Before 1990, Early Summer sockeye were harvested at an average exploitation rate of 78% (Figure 9). Total abundance during this period averaged 435,000 and did not exceed 1 million in any year. Large catches each year (average 340,000) maintained relatively stable but low spawner abundances (average 95,000). In the last 12 years, exploitation rates have declined to an average of 50% and spawner abundance has more than doubled to an average of 248,000. Average catches have remained nearly unchanged at 353,000 despite lower exploitation rates because of higher average total abundance of 659,000.

Summer runs

Trends in exploitation rates for the summer run aggregate (Figure 10) are similar to the Early Summer. Before 1990, exploitation rates averaged 78%. Total abundance averaged 3 million with average catches of 2.4 million. Average spawner abundance was 602,000 and did not exceed one million spawners with the exception of one year before 1980. Cyclic differences were minor until 1981 when the 2001 cycle line began a period of explosive growth to a peak of 19.4 million in 1993. Favorable marine conditions likely led to large increases in all cycles through the early 1990s (Figure 7) although productivity and total abundance have declined in the last part of the decade. Since the start of the rebuilding strategy, average exploitation rates have decreased to 58%, largely due to harvest constraints on late run sockeye since 1995 that has dramatically reduced exploitation rates on these overlapping run timing groups. As a consequence of lower exploitation rates, average spawner abundance has more than tripled to 2.1 million. Despite lower exploitation rates, average catches have also increased to 4.4 million largely because total abundance has also increased to 6.7 million.

Late runs

Total abundance of Late run sockeye is highly cyclic and driven by the dominant 2002 and the sub-dominant 2003 cycle lines of Shuswap stocks (e.g. Adams and Shuswap; Figure 11). Total abundance often exceeds 10 million on the dominant line with an average abundance of less than 500,000 on the two smallest cycle lines. Average catches are quite variable due to the cyclic nature of these stocks. As with the other stock aggregates, exploitation rates that averaged 76% before 1990 have been dramatically reduced in recent years to 57% with a low of 13% in 1999.

Spawner abundance has only increased slightly during the rebuilding period because of recent episodes of high en-route and pre-spawning mortality related to infection with the kidney parasite *Parvicapsula minibicornis*.

Stock Aggregate	Stocks	Historical Average Run Size (1952-2001)	Historical Ranking	Last 12yrs Average Run Size (1990-2001)	Last Decade Ranking	Enhancement Activities
Late	Adams	1,824,805	1	1,646,846	3	
Summer	Chilko	1,487,288	2	2,497,161	2	
Summer	Quesnel	1,334,999	3	2,626,713	1	
Summer	Late Stuart	586,784	4	1,070,901	4	
Summer	Stellako	478,956	5	542,508	5	
Late	Birkenhead	379,871	6	468,094	7	
Early Stuart	Early Stuart	345,595	7	436,229	8	
Late	Weaver	279,682	8	412,213	9	Sp. Channel
Late	Shuswap	256,190	9	536,330	6	
Early Summer	Seymour	130,093	10	164,797	10	
Early Summer	Nadina	82,060	11	96,546	12	Sp. Channel
Early Summer	Upper Pitt	73,997	12	55,594	17	Sp. Ch./ Hatchery
Late	Harrison	52,099	13	36,403	18	
Early Summer	E. Summ. Misc. a	47,423	14	104,929	11	
Early Summer	Bowron	44,812	15	21,146	21	
Late	Cultus	43,131	16	13,296	22	
Early Summer	Gates	40,499	17	80,487	13	Sp. Channel
Late	Late Misc. b	39,449	18	78,079	14	
Late	Portage	39,190	19	75,037	15	
Early Summer	Scotch	36,128	20	72,336	16	
Early Summer	Raft	28,757	21	30,656	20	
Early Summer	Fennel	19,820	22	32,671	19	
Total		7,651,627		11,098,971		

a - Early Summer Miscellaneous stocks includes: Taseko, Upper Adams, Barrier, N. Thompson, Momich, Chilliwack Lk, Nahatlatch, Eagle, Anstey, Hunakwa, Celista, Cayenne, Misc. Lower Fraser, Bridge, and McNomee; **b -** Late Misceallaneous stocks include: Big Silver, Misc. Harr., Widgeon sl., Railroad, Thompson, Late Misc., Eagle, and Scotch.

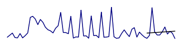
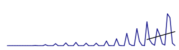
Table 2: Ranking of average annual run sizes for Fraser River sockeye stocks.

Summary of stock status

The spawner abundance for individual Fraser River sockeye stocks is summarized in (Table 3), and the change in this number over the last 12 years provides an indication of stock status.

- *Early Stuart* sockeye have declined by over 70% over the last 3 generations to a recent low of 13,000 spawners, due to several consecutive years of high en-route losses and poor freshwater productivity.
- The spawner abundance of the *Early Summer* aggregate has grown substantially during the last 12 years, in part due to the recovery of the Upper Adams stock. It should be noted that some of this growth has been due to improved assessment on some stocks and increased number of stocks assessed. The Fennell, Scotch and Seymour stocks have declined.
- The *Summer* run aggregate has grown in the last 12 years with the notable exception of the Late Stuart stock. Given that exploitation rates are similar for all stocks in the Summer aggregate, declines in the Late Stuart may be environmentally driven and are consistent with those observed for Early Stuart stocks.
- *Birkenhead* sockeye have declined substantially over the last 12 years.
- The overall spawner abundance in the *Late* run stock aggregate has remained constant over the last 12 years, largely as a result of the contribution of the Shuswap stock. However, many other stocks in the aggregate have declined dramatically as a result of early entry into the Fraser River and high en-route and pre-spawning mortality. Declines would in fact have been represented by even larger numbers if the number of adult spawners had been adjusted to reflect the number of successful spawners. Growth of the "miscellaneous other" group is driven largely by stocks entering the Harrison system (e.g. Cogburn, Big Silver, etc…) that have not experienced high mortalities. It should be noted that some of this growth has been due to increased assessment effort on some of the stocks.

Table 3: Summary of adult spawner abundance and recent trends for assessed Fraser River sockeye stocks from 1938-2003.

Management Unit	Stock	Historical Spawner Abundance (1938-2004)	2004 Near-Final Estimate	Minimum (1)	Median	Maximum	% Change over last 12 years (2)
EARLY STUART	Early Stuart		9,281	118	30,191	688,013	-79%
EARLY SUMMER	Aggregate		150,039	4,135	88,949	574,334	95%
	Fennell		2,718	-	355	32,279	-46%
	Bowron		916	916	6,395	35,000	30%
	Raft		5,611	411	5,537	66,292	737%
	Gates		9,606	-	2,173	99,836	-8%
	Nadina		22,603	-	3,705	199,381	249%
	Pitt (3)		60,942	-	17,950	131,481	489%
	Seymour		1,323	-	10,870	272,041	-43%
	Scotch		783	-	409	101,269	-11%
	miscellaneous other (4)		45,537	-	4,423	125,498	213%
SUMMER	Aggregate		271,756	3,957	571,085	5,071,720	36%
	Chilko		91,903	1,365	244,631	1,037,737	-9%
	Quesnel (5)		10,222	-	2,155	3,510,789	133%
	Stellako		87,669	2,585	72,072	373,369	115%
	Late Stuart		81,962	-	14,229	1,804,969	-69%
BIRKENHEAD	Birkenhead (5)		37,617	10,950	48,893	335,630	-24%
LATE	Aggregate		54,253	19,705	116,346	5,727,320	79%
	Late Shuswap		2,994	34	31,590	5,532,263	92%
	Cultus		52	52	11,067	73,536	-59%
	Portage		1,287	-	1,800	31,343	-47%
	Weaver		25,379	1,196	25,504	294,083	-37%
	miscellaneous other (6)		24,541	1,904	12,903	74,198	297%
TOTAL AGGREGATE	All stocks		522,946	154,277	1,333,463	10,231,944	38%

Notes:

1. Before 1986, zeroes entered in the data record may actually indicate that no assessment was done or that an assessment was done and no adult spawners were observed. The zero entries are currently being reviewed.

2. % change over last the last 12 years was calculated from the regression of log-transformed, 4-year running average of adult spawner data versus time for the last 3 generations (e.g. running 4 year average data from 1993-2004, where the data point for each year includes the current and prior 3 years; 1993 is average of 1990, 1991, 1992, and 1993). This is the same methodology recommended by the International Union for the Conservation of Nature (IUCN) for assessing species at risk.

3. For Pitt, % change over 3 generations was calculated as in (2) but with 5-year running averages over 15 years to account for predominately 5 year old spawners.

4. Includes misc. early S. Thompson stocks (incl. Eagle R., Anstey R., Upper Adams), misc. N. Thompson stocks, Chilliwack Lake, Nahatlatch Lake and River, and Taseko L.

5. The 2002 escapement was not enumerated on the spawning grounds. The spawner estimate was based on Mission escapement estimate less upstream removals.

6. Includes stocks returning to Harrison R., Harrison L. tribs (incl. Big Silver), and Widgeon Slough.

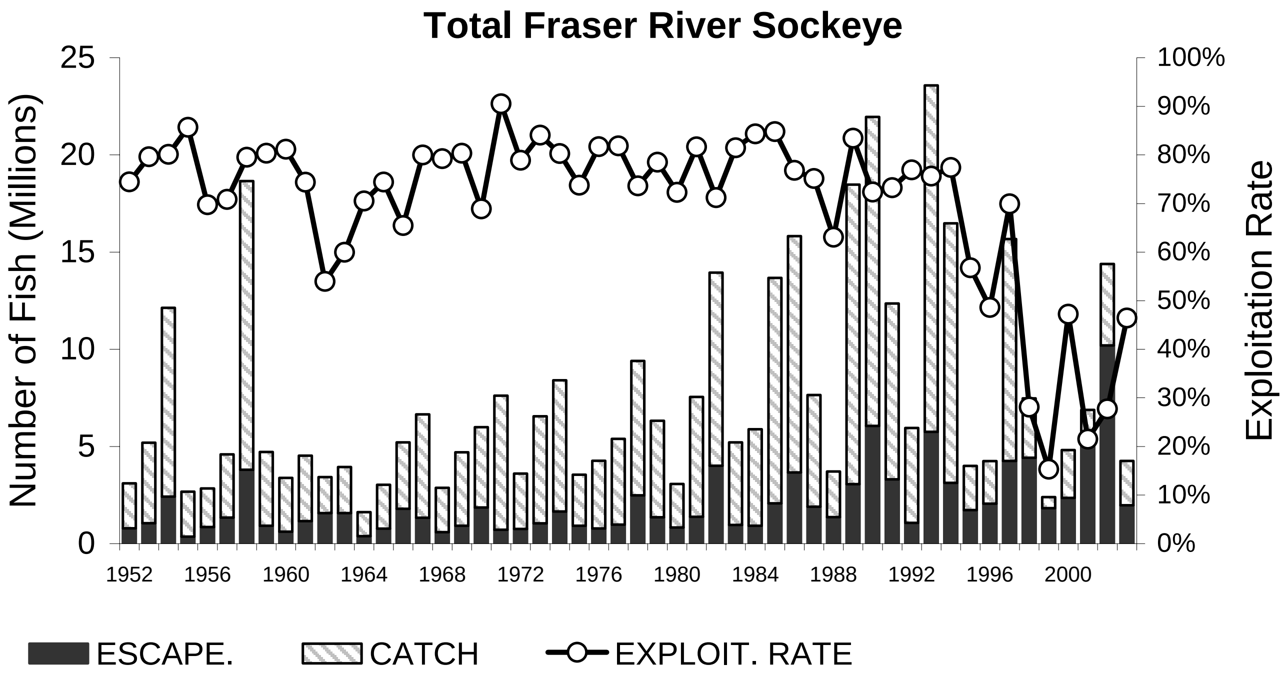


Figure 6: Trends in total abundance of Fraser River sockeye

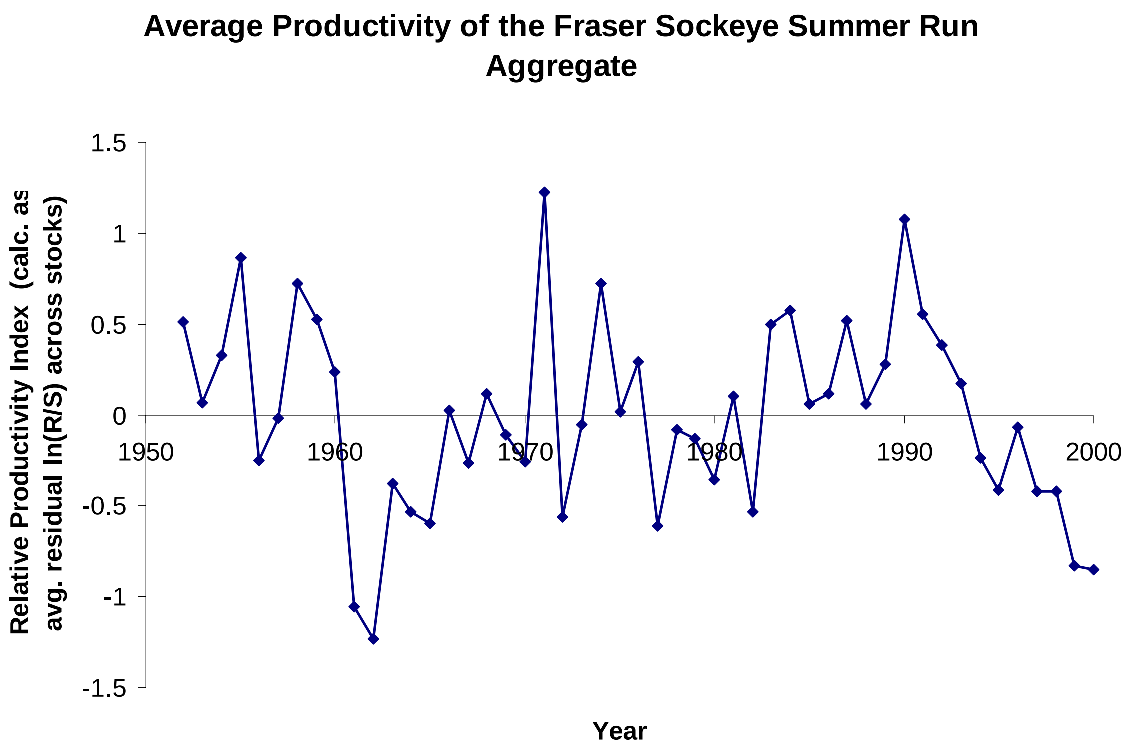


Figure 7: Changes in productivity of the Summer Run aggregate.

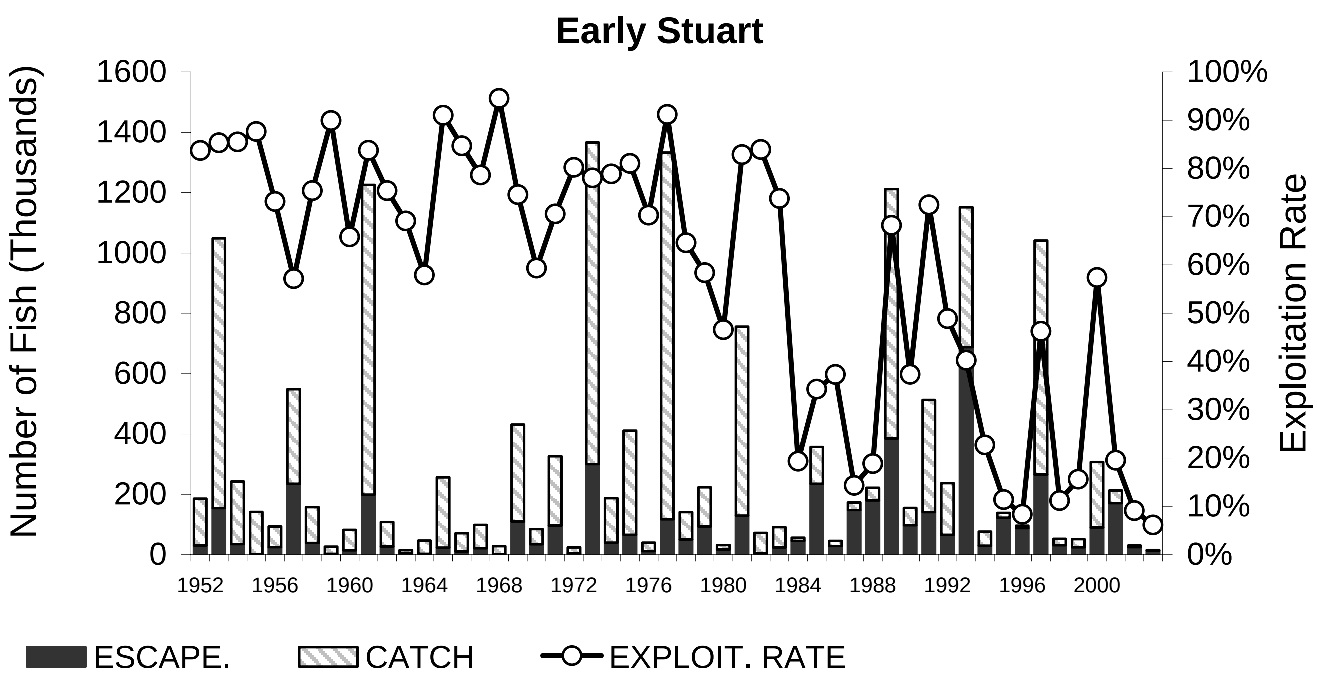


Figure 8: Trends in total abundance of Early Stuart sockeye

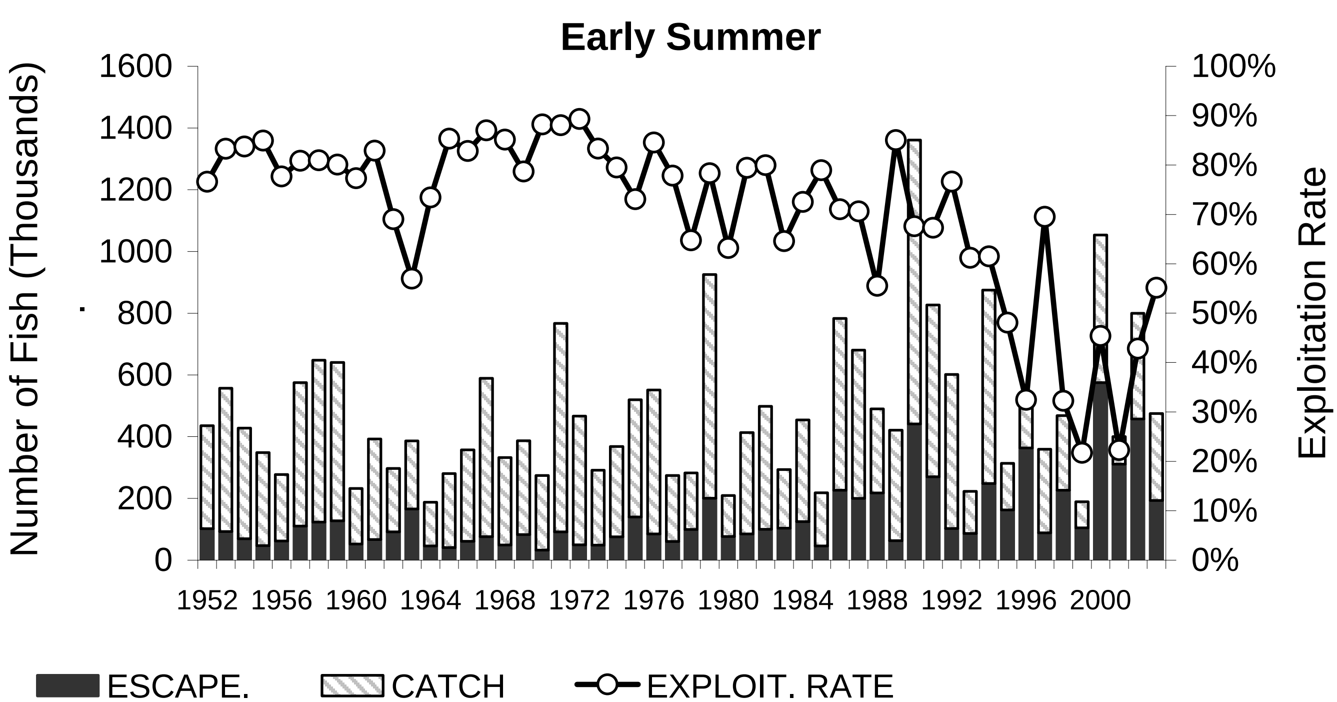


Figure 9: Trends in total abundance of Early Summer sockeye

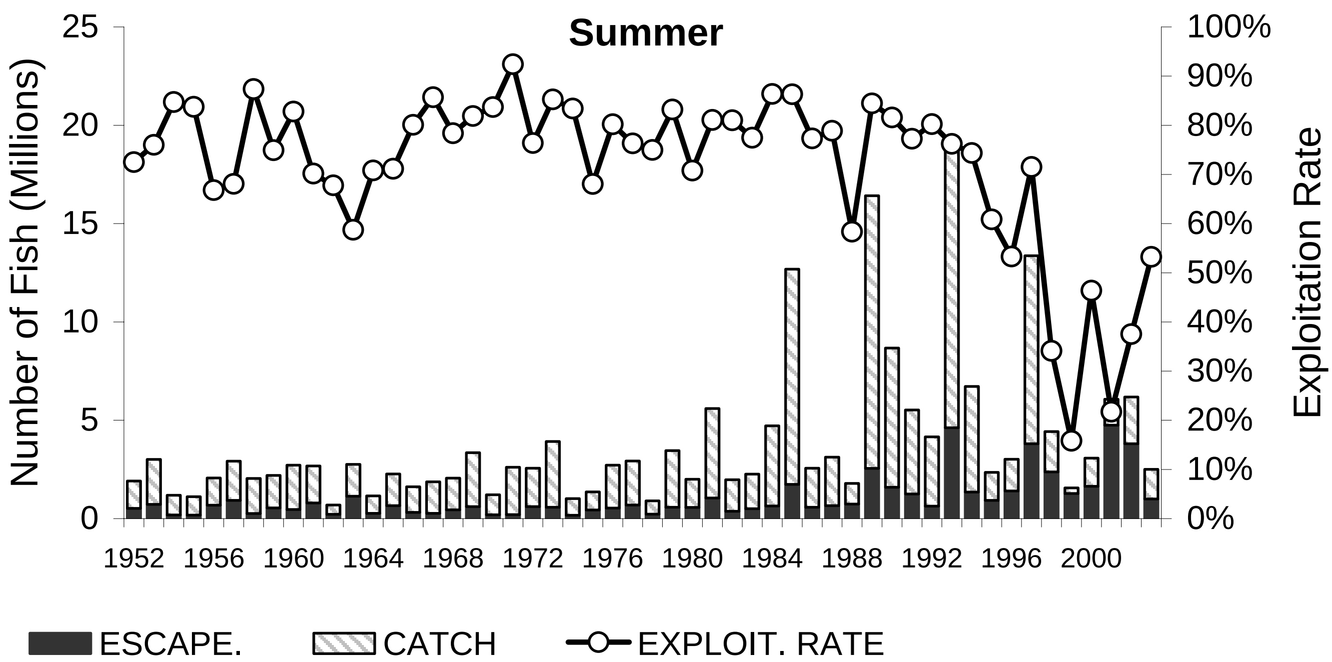


Figure 10: Trends in total abundance of Summer run sockeye

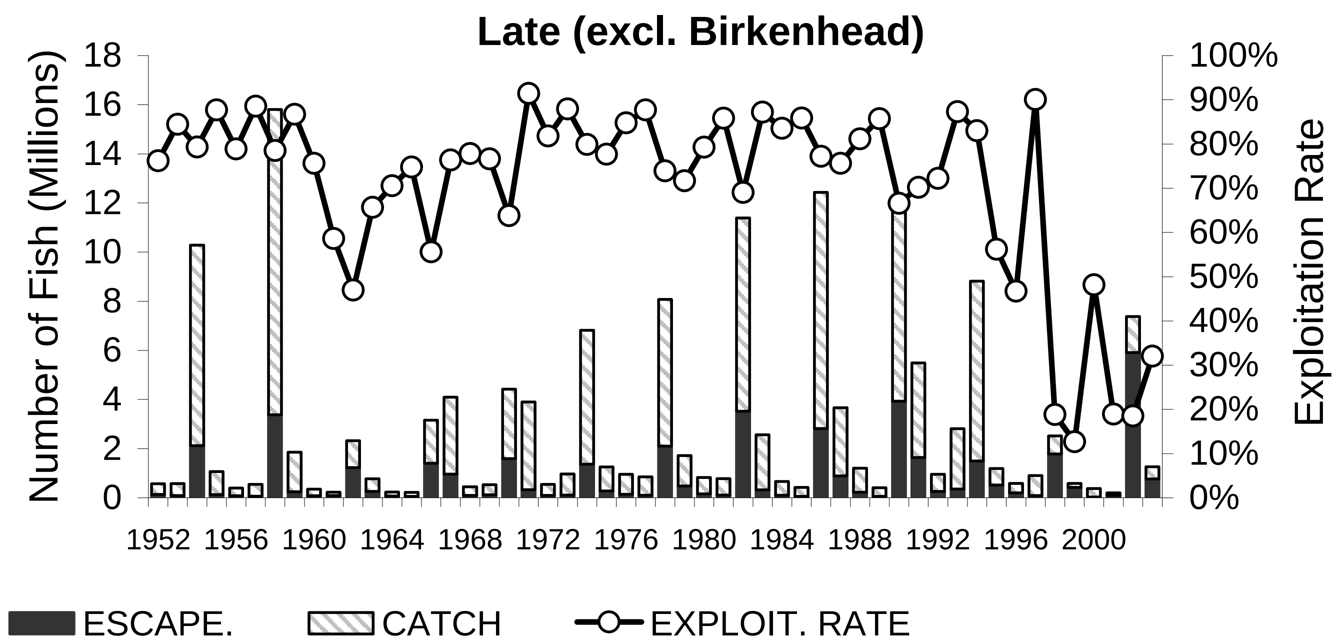


Figure 11: Trends in total abundance of Late run sockeye

Enhanced populations

Some Fraser sockeye populations have been directly enhanced through spawning channels and lake fertilization.

The use of spawning channels has been limited to the 7 systems describes below. The design capacity for each channel is summarized in Table 4. The table shows total females, rather than effective females. Both pre-spawning mortality and egg retention rates are monitored in the channel. Reloading is generally not an option because late-migrating fish do not move into the channel and there is usually not an excess of adults available to seed the channel at this time. While reloading has been done to some extent at both Weaver and Nadina in the past due to pre-spawn mortality, most often these are within the channel, are subtracted from the total numbers of females loaded.

The *Weaver Creek spawning channel* has been in operation since 1965 and has a total adult female loading capacity of about 22,000 fish. Maximum channel fry production is 55 million, with an average over the last ten years of 32.7 million. Given the early entry into the Fraser River and associated pre-spawning mortality, very few adults have been available to load into the channel since the mid 1990s. Also there is most likely very low wild production. In past years when the creek was fully loaded, the average wild fry production was just over 2 million, with a maximum of approximately 6 million.

SOCKEYE SPAWNING	DESIGN CAPACITY	
CHANNEL	No. of Female Spawners	Maximum Fry Production
Weaver Creek	22,000	55,000,000
Gates Creek	18,000	20,000,000
Nadina River	17,000	18,000,000
Horsefly River	12,000	25,000,000
Chilko River	9,000	

Table 4: Sockeye spawning channels and their design capacity

The *Nadina River spawning channel* has been in operation since 1972, with a total adult female loading capacity of 17,000 fish. Maximum fry production is around 18 million, with a recent average of 4.5 million. In all but the largest escapement years, the majority of adult returns are loaded into the channel, so the enhanced component is very high. A downstream trapping program in the 2001 brood year, a year in which there was significant river spawning component, resulted in an estimated wild/enhanced ratio of 28% / 72%.

The *Gates Creek spawning channel* has been in operation since 1968, with a total adult female loading capacity of 18,000 fish. Maximum fry production is 20 million, with a recent average of 7.7 million. In all but the largest escapement years, the majority of adult returns are loaded into the channel, so the enhanced component is thought to be high (>90%).

The *Horsefly River spawning channel* has been in operation since 1989, with a total adult female loading capacity of 12,000 fish. Maximum fry production is 25 million, with an average of 10.4 million. Channel production is thought to be a large proportion of the total only in weak cycle return years. It was recently calculated at 13 – 45% of the total watershed, dependent upon wild survival.

The *Pitt River* stock has been exposed to ongoing enhancement/fish culture techniques since 1963, primarily spawning channel and fry release. For the first two decades, the yearly average production of enhanced fry was roughly 3 million, compared to an estimated yearly average wild production of 5 million. Throughout the 1980s and early 1990s, the average enhanced proportion was estimated at 68%. Since 1996, a combination of increased escapements and better watershed conditions have led to an increase in wild production, with the average enhanced component estimated at 52%.

Fish culture/fry release projects on the *Upper Adams River* have taken place on four consecutive dominant cycle returns since 1988. The first subdominant year fish culture/fry release program occurred in brood year 2001. Given the proportionally large (in numbers of broodstock) programs in 1992, 1996 and 2001, the contribution of enhancement to returns from those brood years has been and will likely continue to be high.

In response to conservation concerns for the *Cultus Lake* stock, a captive broodstock program was initiated with the 2000 return. Juveniles surplus to the needs of the captive brood program have periodically been released as fry. Smolt enumeration in the Spring of 2003 revealed a calculated enhanced contribution of approximately 17%; in 2004 the contribution had fallen to 2.5%. The first marked returns are expected in the fall of 2004.

Lake enrichment is a another enhancement technique that has been used by the Department of Fisheries and Oceans since the early 1970's to improve the freshwater rearing conditions of wild sockeye salmon. A nutrient solution (nitrogen and phosphorus compounds) is added to the surface waters of the lake during the growing season to increase the amount of plankton food for juvenile salmon . In the Fraser River watershed, this technique has been used in Chilko Lake (1988 and 1990-1993) and Adams Lake (1997 and 2001) and has been shown to increase the growth of sockeye salmon in freshwater by about 1.5 times. This results in improved marine survival and increased numbers of returning adults.

Although there are many good candidates, there are no lakes currently being enriched in the Fraser River watershed,

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CHAPTER 4

HOW THE SIMULATION MODEL WORKS

The Fraser River Sockeye Spawning Initiative uses a simulation model to evaluate different management objectives and assumptions about stock dynamics in a consistent framework. Appendix 4 describes how this model is used in a participatory process to develop alternative harvest strategies for Fraser River Sockeye. In this chapter, we describe how the model works and what kind of information it can provide to participants in that process. In Chapter 5, we present the results of various simulations using the model, leading up to recommendations for 2005 in Chapter 7.

Building a practical model

Simulation models like the one used here represent a tradeoff between detail and utility. The big challenge for modelers is to capture the most important characteristics of the real system, in this case Fraser River sockeye. How much detail actually goes into the model depends on its intended use, our understanding of underlying mechanisms, and the amount and quality of data available.

In the present case, the model is used to develop harvest rules, which identify target exploitation rates and escapement targets for each of the Fraser sockeye management units described in Chapter 3. These harvest rules can be translated into an escapement table format similar to that used in past seasons. In order to accomplish our task, two main components need to be incorporated: the population dynamics that influence productivity and capacity of Fraser River sockeye (capturing their *life cycle*) and the preferences of different participants in the management process (the *management objectives*).

Life cycles and the spawner-recruit relationship

The population dynamics of Pacific salmon have been studied in great detail for some stocks (Chapter 3). However, for most stocks the only information available for extended time periods is the number of adult spawners and the number of adult offspring (recruits) produced by those spawners and returning to spawn three to five years later. Therefore, simulations of salmon population dynamics generally use *spawner-recruit models,* which establish a direct link between the spawners and recruits. The most commonly used spawner-recruit relationship is the curve developed by the Canadian fisheries biologist Bill Ricker in the 1950s. In spawner-recruit models like the Ricker model, mechanisms determining survival at each stage in the life cycle (egg to fry, fry to smolt, ocean migration) are not explicitly considered, but are introduced indirectly through their cumulative effect on recruitment. SR models, and the data used in them, are described in Chapter 3.

Management objectives

Management objectives for Fraser River sockeye consider a wide range of biological, social, and economic issues. Groups participating in the management process weigh these issues differently. Ideally, for these groups to contribute to decision-making, they need to see how their preferences shape the harvest strategy, and how stocks and socio-economic performance measures are expected to respond. Therefore, the model needs to include some numerical representation of the basic management objectives, and allow comparison of the results of following different preferences. In simulation models, objectives are expressed as a *value function*, which is simply an equation that calculates an overall score for the performance of the stocks under different harvest strategies.

The approach is similar to that used by testers of consumer products. Testers must first identify the most important indicators of performance, then determine how each product scores for each indicator, and finally assign relative weights to the indicators to arrive at an overall score. For example, indicators for refrigerators may include storage capacity, energy efficiency, and average maintenance costs over ten years. Testers use an equation (the value function) to convert the value of each indicator into a standard score, and add the separate scores based on relative weights. For each refrigerator tested they thus create a single score that is then compared to other scores for other refrigerators. Substitute “harvest rule” for “refrigerator” and performance measures like “proportion of years with low escapement” for “energy efficiency” and you have the idea behind the value function.

Optimization

One advantage of using a numerical value function in the simulation model is that it can be used for *optimization*. Rather than requiring analysts to compare performance in many different combinations of simulated scenarios and harvest rules, the optimization procedure automatically searches for the specific harvest rule that performs best (i.e. maximizes the score of the value function). Changing the weightings in the value function can be used to see how optimal harvest rules are affected by different management priorities.

When searching for optimal solutions, complex models can converge on sub-optimal harvest rules, trying to fine-tune a specific result rather than trying a completely different harvest rule that may perform much better, similar to searching for the way out of a labyrinth and getting stuck in a dead end. Simple optimizers will backtrack a little, turn this way and that, and give up, concluding that they have gone as far as possible. The model developed for this initiative uses a state-of-the-art optimizer that continuously starts from many different points in the labyrinth and follows many different paths at the same time, which greatly increases the chances of converging on a truly optimal harvest rule. In technical terms, the model changes the parameters that determine the shape of the harvest rule, starting from many different combinations, until arriving at the best one. In earlier work for this initiative, the model first calculated a sequence of optimal exploitation rates for each replication, and then fitted a harvest rule through the resulting scatter plot. This method was rejected during the PSARC review, because many more variables need to be optimized, and the step of fitting a curve through the scatter plot produces sub-optimal results. See Cass et al. (2004) for more details.

Features and options

For each of the two components described above (salmon life cycle and management objectives), the simulation model has a series of *features*, and options for each feature. For the salmon population dynamics, these features include shape of the spawner-recruit curve (cyclic or non-cyclic), uncertainty in recruitment, and other factors that may influence the number of returning adults, such as increased mortality at low run sizes. For management objectives, the main feature is the relative preference for avoiding low spawner abundance and for avoiding low catch.

It helps to visualize the model as a machine with buttons and sliders corresponding to each feature, and the settings available on the dials corresponding to the options for each feature. The diagram below (Figure 12) illustrates this concept for two features of the model discussed in more detail in Chapter 5: the trade-off between avoiding low spawner abundance and avoiding low catches, and the implications of cyclic or non-cyclic stock dynamics. These and other features (knobs and dials) and options (settings on dials) are discussed in more detail in the following sections of this chapter.

We can use these buttons and sliders to specify different scenarios that we want to explore. Management objectives can be expressed by increasing the emphasis on avoiding low catch from an aggregate, avoiding low spawning abundance on components of an aggregate, or both. For stock dynamics, we can choose one of several options, but in this report we focus on two alternative hypotheses: cyclic or non-cyclic. Once we press *Simulate*, the model produces the harvest rule that best achieves the management objectives, under the specified stock dynamics, and shows how the harvest rule is expected to perform.

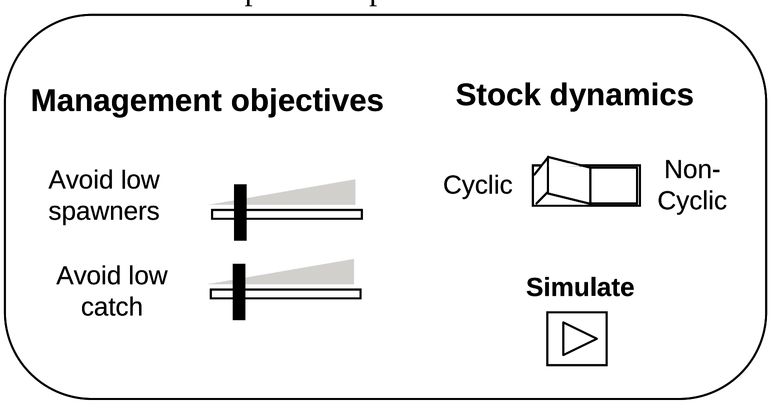


Figure 12: Thinking of the simulation model as a machine

A simulation model with more features and options is more versatile but also more complicated and potentially less reliable. More complicated models are based on more assumptions, which introduce additional uncertainty.

Steps in the simulation model

The model goes through two steps, illustrated in Figure 13. Using a particular set of assumptions and objectives, the model first calculates the best harvest and escapement goals, expressed as a harvest rule that specifies a target exploitation rate for a range of run sizes. Second, it applies this harvest rule to predict how the stocks will perform. After reviewing the stock's performance in this consistent modeling framework, users can then adjust the assumptions and objectives, and see how harvest rule and performance change. By running through many repetitions like this, we can gain insight into the advantages and disadvantages of different harvest rules, and develop recommendations for future seasons.

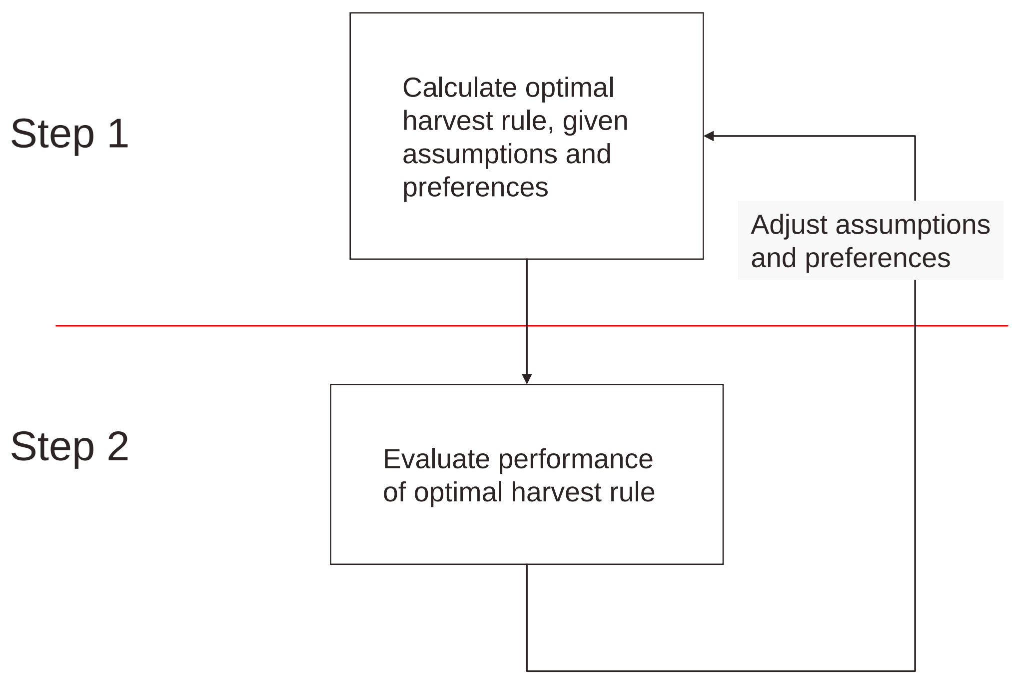


Figure 13: Steps in the simulation model

Taking the stock dynamics and management objectives as *input*, the model simulates each individual stock into future, while accounting for uncertainty in population dynamics. The model then estimates the optimal harvest rule for the aggregate of stocks, and produces as *output*: the harvest rule, trajectories of adult returns and spawners abundance for each stock, and trajectories of catch for the aggregate. These trajectories serve as the basis for calculating performance measures (e.g. average spawner abundance over 4 generations for each cycle line). Figure 14 summarizes input and output of the simulation model.

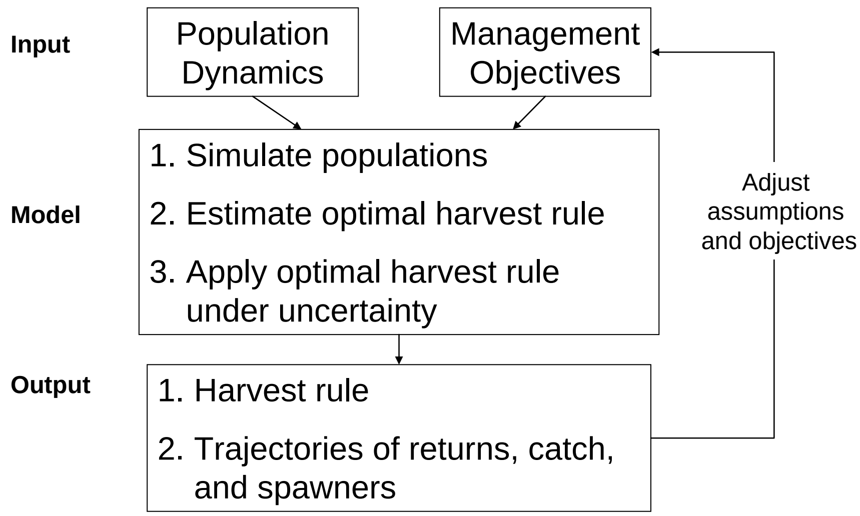


Figure 14: Model input and output

Simulating salmon life cycles

As described earlier, salmon life cycles are generally represented as spawner-recruit (SR) curves. Given the uncertainty in available spawner-recruit data, many different assumptions about the SR curves can be made. These assumptions are the subject of on-going debate in the scientific literature. In this initiative we do not identify one form of stock dynamics as the preferred or correct one, but assess the robustness of harvest strategies using different assumptions (e.g. cyclic or non-cyclic).

Past management: cyclic or non-cyclic?

Past management of Fraser stocks was not based exclusively on either one of these SR models, and for the last 15 years followed the conclusions of the 1987 Rebuilding Strategy (Chapter 1). Escapement targets and interim goals were set recognizing cyclic differences in Early Stuart, Late Stuart, Quesnel, and Shuswap stocks. Different goals were also set for each cycle line of some "non-cyclic" stocks, such as Chilko and Stellako. The 1987 rebuilding strategy explicitly stated that interim escapement goals were based on the assumption that not all cycles could produce at dominant cycle levels. If this assumption is incorrect, the production potential of the Fraser River could be underestimated by a large margin. Recognizing the potential costs of reduced exploitation rates, the rebuilding strategy task force recommended that such experimentation occur only for some cycle lines of some stocks. Because additional management objectives were also taken into account during implementation in different years, and sockeye survival appeared to take a downturn in the 1990s, it is difficult to assess the efficacy of the 1987 rebuilding strategy.

How the model simulates cyclic patterns in abundance

Non-cyclic and cyclic dynamics reflect assumptions about distinctive 4-year patterns in returns of some stocks (Early Stuart, Late Stuart, Quesnel, Late Shuswap). For modeling non-cyclic dynamics, a Ricker curve is estimated for each stock using spawner-recruit data for all years. It assumes that cycle lines currently showing low abundance can increase to the same level as dominant/subdominant lines. For the cyclic dynamics, two separate Ricker curves are estimated, one for dominant/subdominant years, and one for the two off-cycle years. This data splitting results in the assumption that off-years have a different capacity and productivity, and cannot increase to the same abundance as dominant years. Neither of these models incorporates direct interactions between cycle lines (i.e. dominant cycles suppressing off-cycles). However indirectly there is interaction between cycle lines from the overlap through age-structure (i.e. 3 and 5 year olds from other cycle lines). Both non-cyclic and cyclic dynamics are used to develop the results presented in the following chapters.

We initially considered separating dominant and subdominant cycle lines and estimating three separate Ricker curves. However, this further reduces the available data from a total of 48 data points to about 12 data points each for these two cycle lines. This reduction creates significant bias problems in estimating parameters for the spawner-recruit curves, and was not explored further.

A single optimal harvest rule is estimated for all four cycle lines when non-cyclic stock dynamics are used, but two separate harvest rules are estimated for the cyclic model. Off-cycle years show lower capacity, and higher exploitation rates at low run sizes. If the dominant/subdominant lines show higher capacity than under the non-cyclic assumptions, the optimal strategy is to build the stock to a higher abundance, shifting the harvest rule to the right (Figure 15). Simulation results have shown that applying a harvest strategy based on the cycle aggregate assumption will tend to propagate the cyclic pattern even if the underlying population dynamics are not cyclic.

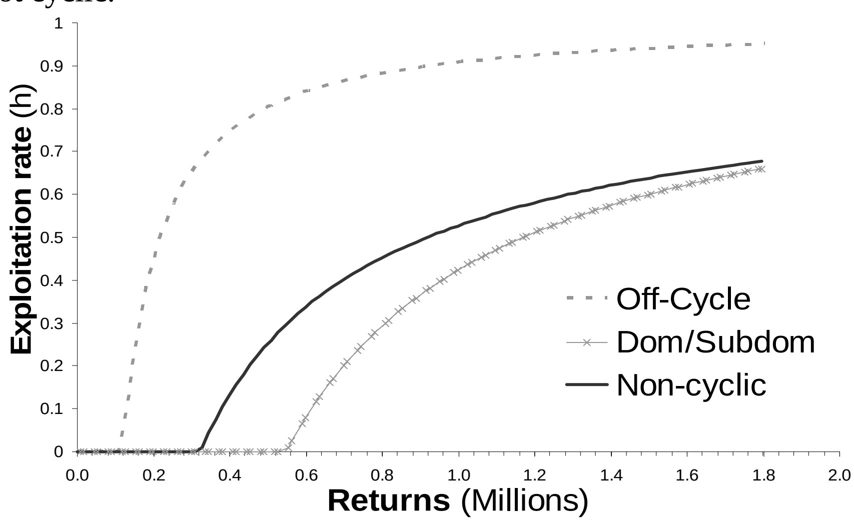


Figure 15: Illustration of cyclic and non-cyclic harvest rules

Possible alternatives for SR models

One benefit of using a simulation model is that new information or new hypotheses can be incorporated and tested. If new SR models with more detailed mechanisms for the various life stages of Pacific salmon become available, we can explore the effect on harvest rules in the same consistent framework. For example, a model based on the link between escapement, juvenile growth, and adult returns could provide further insight into the interaction between cycle lines.

Simulating salmon stocks into the future

In order to begin simulations, the spawner abundance of each cycle line of each stock needs to be specified, for example, as a fraction of the most recent brood year escapement. Reducing the starting abundance has little effect on the harvest rule, but does influence the performance measures (e.g. lower average catch over 40 years, increased occurrence of low escapements).

Accounting for uncertainty in spawner-recruit models

Spawner-recruit (SR) models, discussed in Chapter 3, are an attempt to explain the relationship between the abundance of spawners and the number of adult offspring they produce. Many factors influence these observed data, ranging from biological mechanisms, such as freshwater and ocean survival, to observation errors, such as uncertain estimates of spawner abundance. Not all of these factors can be incorporated into SR models. As a result, there are discrepancies between the recruitment predicted by the model, and actual recruitment. This basic *uncertainty* is different from the *variability* (year-to-year fluctuations) discussed earlier.

Bayesian statistics are becoming a widely used tool for capturing uncertainty in simulation models. The basic idea of Bayesian methodology is that an estimate, for example the optimal abundance of adult spawners in Quesnel Lake, can be derived from two separate quantities: prior assumptions about optimal abundance (the *prior*), and the probability of this assumption being correct (the *likelihood*), calculated from the available data. These two quantities are combined to yield the probability for each value in a range of abundances (the *posterior*). Often, the prior is used to establish a reasonable range for the estimate (upper and lower limits) and the likelihood is used to check which estimates in this range are the most probable. If the data are very informative (*i.e.* not very uncertain), then the range chosen for the prior has little effect on the final estimates. However, if the data are very poor (*i.e.* highly uncertain), then assumptions about the prior can have a considerable effect.

The SR models used here are defined by two parameters, the productivity parameter h^* and the capacity parameter S^*, as described in Chapter 3. Using the Bayesian methods described in Cass et al. (2004) we calculated a joint posterior distribution to capture uncertainty in both productivity and capacity. In the simulations, the model uses 250 combinations of h^* and S^* sampled randomly from this distribution, which corresponds to 250 different SR curves for each stock. In general, the productivity parameter h^* is well determined by the data because there are numerous data points at low levels of abundance, so that estimates of h* are not affected by prior assumptions. However, the capacity parameter S^* is poorly determined in some of the data sets because there are few data points at high run sizes, making prior assumptions more influential. In the current analyses we explored two options to study the effect of uncertainty in the capacity parameter. The upper limit of the prior is either a) the maximum observed escapement; or b) double the maximum observed escapement. If the available data are relatively uninformative (e.g. few data points at high spawner abundance levels or large variability in observations), then a higher limit on the parameter results in a higher estimate for the optimal capacity, which in turn results in a higher escapement target at a given run size. The harvest rule shifts to the right, because the optimal strategy is to build the stock to a higher abundance (Figure 16).

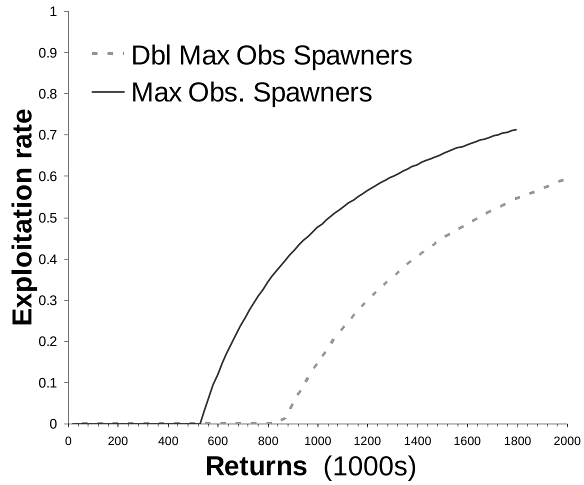


Figure 16: Illustration of assumptions about capacity

Patterns in recruitment

Stock dynamics can be simulated using either the historical observations of variation (*retrospective mode*) or random variation based upon an assumed error distribution in historically observed data (*forward mode*). Forward simulations are used here. Each simulation run produces many trajectories of catches and escapements, which are then summarized according to performance measures (e.g. variability in catch, occurrence of low escapements). At the very least, 250 trajectories are simulated, one for each of 250 spawner-recruit parameter sets that capture uncertainty. Additional simulations can be run to improve the estimates of performance measures. The examples here use 10 replications, producing 2500 trajectories of catch and escapement for each stock.

Patterns in recruitment over time can be created by specifying different levels of correlation in survival (i.e. deviations from the Spawner-recruit curve). With this feature, we can explore hypotheses about the effect of shared environmental conditions on components of a run aggregate. For individual stocks, *temporal auto-correlation* can introduce patterns so that years of poor returns tend to be followed by poor years, and years of good returns tend to be followed by good years. For run-timing aggregates, *between-stock correlation* means that all components tend to show below-average or above-average returns at the same time. Typically for Fraser sockeye, the estimated auto-correlation is low to moderate ($r<0.3$) but simulations show this is likely biased low. For correlation among stocks, the value is low to moderate and estimated to be about 0.25. These patterns can affect the harvest rules considerably and future sensitivity analyses will explore this feature more thoroughly. For example, if stocks in an aggregate show high correlation in abundance, and tend to be abundant in the same years, then harvests of the aggregate are less likely to result in low spawner abundance for any individual stock.

Stock groupings

Stocks can be modeled *individually* or *in aggregate*. For aggregates, population dynamics are simulated separately for each stock and the optimal harvest is calculated based on the assumption that these individual stocks are all harvested with the same exploitation rate. Penalties for low escapement are assigned individually for each stock, but performance measures for catch are evaluated in the aggregate.

Accounting for depensatory mortality

The term *depensatory mortality* refers to reduced survival associated with decreases in abundance (*depensation* means the opposite of *compensation*, in which a declining population would "make up" for its losses through other survival mechanisms). Depensatory mortality actually accelerates population declines and can be caused by a number of factors. Spawner densities may be so low that fish cannot easily find mates, inbreeding may occur and result in increased mortality. Predators may be more effective when the population numbers are low (also called a *predator pit*, in which at some point the rate of replacement is less than the mortality rate).

How important is depensation in fish population dynamics? Since the amount of uncertainty (noise) in stock-recruitment data can mask the effects of depensatory mortality, there is general agreement that analyses of stock recruitment data should incorporate stock-recruitment curves that at least allow for the possibility of it occurring. Several approaches have been used to incorporate the possibility of depensatory effects in the analysis of stock recruit data. The purpose here is not to estimate depensatory mortality, but to simulate its potential effects on performance. In the present model, if escapement falls below a critically low value ($S_{critical}$), depensatory mortality is triggered. Users can specify the amount of depensatory mortality by assigning fewer recruits/spawner than prescribed by a standard stock-recruitment model. If $S_{critical}$ is set to the lowest observed escapement for each stock, then turning this feature on has not had an effect in simulations so far. Escapement levels simply did not fall below $S_{critical}$ in most trials.

Harvest rules

The model focuses on determining target exploitation rates and target escapements for the different stock groupings. All harvests and en-route losses are combined into a single number, calculated as the percentage of returning adults that do not reach the spawning grounds. This approach is appropriate for investigating overall targets, but does not incorporate all the finer details of developing a fishing plan.

The *harvest rule* is an equation that specifies target exploitation rates and target escapements over a range of run sizes, and corresponds to the escapement tables used in the past. Many different shapes of harvest rules are possible. In response to feedback from the first two workshops, two possible curve shapes, which we call "*s-shape*" and "*cut-off*", were investigated further. The main difference is their behavior at low run-sizes. The s-shape curve tends to taper off at small run sizes, while the other curve shows an abrupt cut-off (Figure 17). At the fourth workshop, participants chose the s-shaped harvest rule for closer investigation, because it captures the expectation that some low level of catch could be taken in food fisheries and test fisheries even at low run sizes.

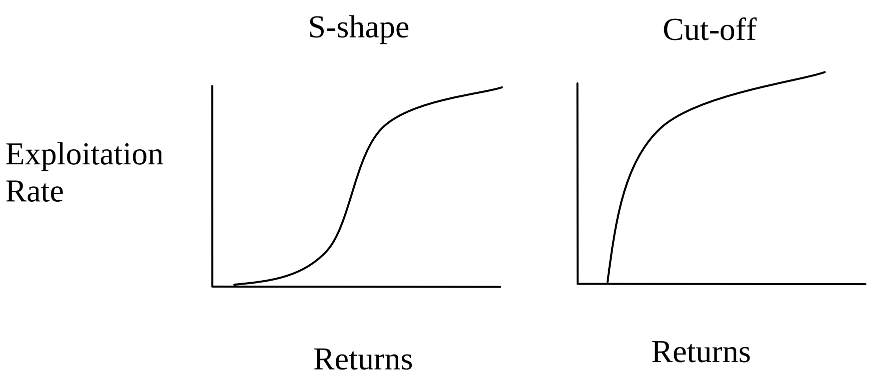


Figure 17: Two possible shapes for harvest rules

Errors in estimating run size and errors in implementing a target exploitation rate (i.e. the actual catches in all openings) can affect the shape of the optimal harvest rule as well as its performance. In the model, users can specify the extent of these two components on implementation error through the standard deviation of random errors in run size and exploitation rate, sampled for each simulated year.

Accounting for implementation error

Implementation error refers to how well fisheries managers are able to achieve harvest targets given changing and uncertain information. It is calculated as the difference between the target exploitation rate or escapement targets for a given run size and the exploitation rate or escapement that actually results after all fisheries are complete and spawning is complete. Implementation error can occur as a result of uncertainty about the run size, unexpected or unfavourable environmental conditions that impact on spawning escapements, or failure of fisheries to achieve catch objectives (e.g. over or under harvest relative to objectives). For example, an undetected and smaller than expected run size could result in exploitation rates higher than target levels. There are several in season tools, such as, environmental management adjustments and in season updates to run size estimates that can be used to minimize implementation errors. However, despite in season management actions, implementation errors still appear to be common in some management aggregates (e.g. Early Stuart). Currently, work is ongoing to try and quantify the magnitude of implementation errors over a range of run sizes for each of the management aggregates. Once this is completed, relationships to represent typical implementation error rates for each management unit can be incorporated into the simulation model and harvest rules can be generated that take these systematic errors into account. Past work suggests that in cases where implementation errors are large or frequent then this will lead to optimal harvest rules that compensate for these errors with lower exploitation rates, but the effects may differ with run size (e.g. it may be more of an issue for very small run sizes there are difficult to assess compared with large run sizes). Results from these analyses will be incorporated into future discussions.

Management objectives and the value function

Choices regarding harvest policies depend on a wide range of conservation and socio-economic objectives. The current policy context for the management of Fraser River sockeye is summarized at: http://www.pac.dfo-mpo.gc.ca/ops/fm/salmon/policy_e.htm . The relative importance placed on the different objectives is critical to determining the management actions that will ultimately determine future escapements and catches. For example, a conservation objective could be expressed as "Avoid low spawning abundances below which there is a high chance the population will collapse or result in low sustained future economic benefit". An economic objective could be expressed as "Avoid the catch level below which an industry can no longer remain viable".

Management objectives are introduced into the model as attributes in a *value function* for optimization and can include benchmarks or biological reference points such as desirable levels of run size, spawning escapement or catch. Conservation and economic objectives are included in the value function with appropriate penalty weights that affect the probability of an undesirable outcome occurring. Additional performance measures can be assessed from the model output.

The value function (Fig. 13 and Fig. 14), along with the parameters describing population dynamics (see above), is used in the simulation model to estimate the optimal harvest rule. The optimization procedure described earlier searches automatically for the specific harvest rule that performs best (i.e. maximizes the value function), thus liberating analysts and decision makers from the need to compare performance in many different combinations of simulated scenarios and harvest rules. The optimization function adjusts the harvest rule to optimize the overall performance with respect to the management objectives and stock dynamics, as defined by the combination of all the model features describe in this chapter. Therefore it is difficult to make general statements about the expected effect of any single model setting.

Different weightings in the value function can be used to investigate how the optimal harvest rule and its performance are affected by different management priorities. This process allows resource managers and stakeholders to see the effect of conflicting objectives and often allows areas of common ground to be identified.

The value function used in this model incorporates trade-offs between catch size, catch stability and escapement. A positive value is assigned to larger catches, but the overall score includes penalties for years in which catch or escapement fall below the corresponding stock-specific benchmarks. By adjusting the weights associated with each component of the value function, the relative emphasis can be shifted between objectives. The desire for a stable harvesting environment is explicitly included through the penalty for years with low catch.

Evaluation, performance measures and benchmarks

Management objectives need to reflect the specific requirements of Fraser River sockeye, and need to be described in a form that can be evaluated in a model. Recall the example of comparing refrigerators in the introduction to this section, and the use of performance measures illustrated there. Quantitative performance measures are an attempt to capture the outcomes associated with different management objectives in a form that can be easily compared and summarized. Carefully chosen performance measures can provide a comprehensive summary of the expected performance of different harvest guidelines. Many possible performance measures may be of interest to stakeholders, and the challenge for modelers is to find a manageable set for the analysis, while including the most important considerations.
Benchmarks are specific levels of a performance measure used for quantitative assessment. Returning to the refrigerator example, product testers could pick a storage capacity of 15 cu ft as an evaluation benchmark for separating the fridges into “small” and “large”. Applying the same concept to Fraser sockeye, we need to choose benchmarks to quantify the concepts of “low spawner abundance” and “low catch”. For example, the benchmark identifying an undesirably low escapement is defined as the escapement level that allows rebuilding to the abundance at maximum sustainable yield within 1 generation in the absence of fishing. Escapement levels below this benchmark are then penalized in the value function used to compare harvest rules. This type of benchmark is called a *relative benchmark*, because it is calculated based on the spawner-recruit model, and is therefore relative to assumptions about the stock dynamics. Relative benchmarks are different for each stock, and for different spawner-recruit models. *Absolute* benchmarks are based on independent considerations. For example, spawner abundance could be considered “low” if it is less than 10,000. In this paper, only relative benchmarks are used. Relative benchmarks are more consistent with developing policy guidelines, but make it difficult to compare performance between simulations when comparing different stock recruitment models. Stock-specific benchmarks are listed in Appendix 2.

Benchmarks vs. reference points

Earlier materials distributed for the Fraser River Sockeye Spawning Initiative used the term "management reference points" to describe these benchmarks, which was inconsistent with the technical definition of reference points. Management reference points can *directly* trigger management actions. Thus, changes in variables (e.g. run size) that cross a management reference point cause changes in management actions (e.g. fishery closure). Benchmarks only affect management actions *indirectly*, by altering the evaluation of fishery performance so that another management action may produce a higher score in the value function.

Expressing management objectives through the value function

Management objectives are incorporated into the optimization analysis in the form of an additive value function with four components:

- Maximize average annual catch
- Avoid low catch in any year
- Maintain MSY catches
- Avoid low abundance of spawners in any year

Benchmarks are used to quantify the objectives of "avoid low escapement" or "avoid low catch". For now we use a percentage of stock-specific benchmarks:

- S_{low} = Spawner abundance that allows rebuilding to S_{msy} within 1 generation
- C_{low} = 10% of catch at maximum sustainable yield (C_{MSY})
- C_{high} = 100% of catch at maximum sustainable yield (C_{MSY})

Weights are assigned to each of the four components (Maximize catch, Avoid low catch, Maintain maximum sustainable catch, Avoid low escapement). Weights can range from 0 (i.e. not important) to a large number (i.e. very important) and many different combinations are used to explore the effect of different management priorities on the outcome. One starting point for exploring the model is to assign equal weighting to all four components (components (Maximize catch=1, Avoid low catch=1, Maintain maximum sustainable catch=1, Avoid low escapement=1).

By changing the relative weight assigned to the four components of the value function we can capture a wide range of management objectives. These weights are simply a way of converting general statements about management objectives into a form the model can use for calculation. For example, participants at a workshop may agree that "*Avoiding low spawner abundance is more important than avoiding low catches, which we also care about. We still want to maximize our yearly catch, as long as this does not unduly affect the other two objectives. Achieving MSY catches every year is not important to us*." In the model this policy can be represented as a set of weights, such as (1, 5, 0, 10), which translates into a positive score of 1 for average annual catch, a penalty of 5 for each year where catch is less than C_{low} , no penalty for each year where catch is less than C_{high}, and a penalty of 10 for each year and each stock where spawner abundance is less than S_{low} .

The *shape* of the value function can be changed to reflect stakeholder preferences. With linear value functions each increment (for example, each ten thousand additional catch) receives the same score, regardless of the status. The exponential value function incorporates diminishing returns, so that the score for additional catch depends on current catch levels. For example, ten thousand extra fish may be very important if catch is 0, but not so important if catch is already at four hundred thousand.

A *discount rate* can be applied in order to express time preferences, so that catches (or escapements) in the future are considered less important than catches (or escapements) in the short term. The results presented in this report do not use discounting.

We use the simple additive value function for the reference scenario, with the four components based on linear scoring, without discounting, and with the following stock specific benchmarks (actual benchmarks for each stock are tabulated in Appendix 2):

What the model <u>can</u> do

The model first simulates the dynamics of an individual stock or aggregate into the future and applies different harvest rules (i.e. escapement tables) while searching for the optimal harvest rule based on the specified management objectives. It then applies this optimal harvest rule over many different trajectories of future returns in order to evaluate performance.

Both population dynamics and harvest are modeled in yearly steps without spatial detail. The effect of assumptions about stock dynamics and different management objectives can be explored thoroughly in an open and transparent manner, and the results are available to support discussions during the consultation process.

What the model <u>does not</u> do

Scope
No model can incorporate all the biological and social details of Fraser River sockeye management. Some policy issues (e.g. allocations, selective fishing), some in-season management decisions, and the development of gear and area-specific fishing plans fall outside the scope of this model, and the scope of the Fraser River Sockeye Spawning Initiative itself.

Implementation
The feasibility of implementing these harvest rules by translating them into coast-wide, coordinated fishing plans for the different harvester groups is not explicitly considered in the model, but some of the implementation challenges are being considered in the recommendations in Chapter 7. However, one the most important elements of in-season management and is included in the model is error in estimates of run size,. It is important to recognize that the harvest rules produced by the model are theoretical, optimal curves. They serve to guide decision making. Managers may need to over-lay the optimal curves with other considerations such as mixed-species concerns that may impose exploitation ceilings, for example, to reduce harvest of non-target species or to minimize errors in implementing high exploitation rates.

Aggregation
As discussed earlier, much thought goes into choosing *level of detail* in the model and the resulting management strategy. For example, consider the potential benefits of managing towards specific objectives for more stock groups (smaller management units), or harvesting more selectively in terminal areas. Benefits can be approximated by first simulating a run-timing aggregate assuming that all component stocks are exposed to the same exploitation rate, then

comparing the results to simulations performed for each individual component stock. This aspect is part of the sensitivity analyses. The next higher level of aggregation (several overlapping timing groups) is not currently incorporated. At this time, we do not model the possible overlap in migration between stock aggregates. For example, when conservation concerns for some Late run stocks indicate a strongly reduced exploitation rate, harvest opportunities on the more abundant Summer run aggregate may be constrained. However, this extension will be explored in future work.

Currently we evaluate the performance of stock aggregates by applying penalties in the value function if any one stock within the aggregate falls below its S_{low} benchmark. We can also explore the merits of modifying that objective to only applying a penalty if more than one stock falls below S_{low}, or applying rapidly increasing penalties as more components fall below the benchmark (e.g. 1 stock = 1, 2 stocks=10, 3 stocks=100). Guidelines describing how the management of a stock aggregate should respond to a severe conservation concern for an individual stock are currently being developed as part of the recovery planning process for Cultus Lake sockeye. We can use this model to assess the inherent management objectives and implications of these recovery plans.

Value of Learning
We place great emphasis upon improving our knowledge regarding stock dynamics. Within the model framework, we can explore the risks associated with pursuing an escapement strategy based on the wrong assumption about stock dynamics, and use this information to focus future research. At this point, the value of learning more about stock dynamics has not been included as an explicit management objective, but this aspect is an interesting extension that should be explored.

Over-escapement
Penalizing very high spawner levels (considered over-escapement by some stakeholders) was frequently discussed as an additional component of the value function. However, we decided against that approach. From a technical perspective, the modeling becomes more complicated as additional components are added in the optimization step, and we feel that the current set is flexible enough to capture a wide range of objectives and develop candidate escapement strategies. The resulting escapement strategies will then differ with respect to average spawner abundance, variability in spawners, and frequency of very large (or very small) escapements. These performance measures can then be discussed with stakeholders.

Population dynamics
Like any quantitative representation of a highly complex natural process, the Ricker curve itself has limitations. Our goal is to ensure that we understand those limitations and ensure that we fully explore the model’s limitations across different forms of population dynamics (e.g. cyclic vs. non-cyclic) and over a wide range of uncertainty. Using the Ricker curve to represent stock dynamics does not imply there is only one objective, namely managing for maximum sustainable yield (MSY). The management objectives assessed in this analysis in fact range from a strong emphasis on avoiding low spawner abundance to an emphasis on ensuring some harvest every year. The strategy adopted depends upon the weight placed on those competing objectives.

Rather than specifying a specific strategy, such as a fixed exploitation rate strategy, we can use this model to assess which management objectives would push the harvest rule in a particular direction. Finally, we acknowledge the divergent views about sockeye population dynamics held by different stakeholders and consider them in the recommendations.

Costs

Only one of the costs associated with different harvest rules is included in the calculations and comparisons. As management objectives change, the balance between increased escapement and the cost in terms of foregone catch is considered as a trade-off. However, other costs of achieving these management objectives are not modeled (e.g. costs of stock assessment, in-season meetings, consultation, administration, staff requirements). Such costs can only be determined through a rigorous socio-economic analysis, itself a complex process.

References

Cass A., Folkes .M. and, G. Pestal. 2004. Methods for Assessing Harvest Rules for Fraser River Sockeye Salmon. Canadian Stock Assessment Secretariat. Research Document 2004-025.

CHAPTER 5

SIMULATION RESULTS 1: EXPLORING THE MODEL

The simulation model developed for this initiative is a tool for exploring how different management objectives and different assumptions about stock dynamics affect the harvest strategy for Fraser River sockeye. Appendix 4 describes how this model was developed, and how it is used in the participatory process for this initiative. Chapter 4 provided a description of how the model works. In this chapter we present simulation results for a wide range of scenarios, and in Chapter 7 we make recommendations for the 2005 season.

This chapter has two sections. First, we describe the *reference scenario* chosen based on feedback received from the Steering Committee and during workshops. Then we move to a series of *sensitivity analyses*, which explore the effects of changing settings individually or in combination.

The reference scenario

A reference scenario is a suite of conditions that collectively provide a starting point for comparing performance measures, and refining the modeled dynamics, harvest curve shape, and values in the objective function. When exploring the characteristics of a model, we need to pick initial settings for each of the many model features described in the previous chapter (corresponding to the buttons and dials in Figure 12). These initial settings give us a first idea of the model output, and together provide a reference point for further analyses. For model components of major interest during the initial investigation (e.g. management objectives), we generally chose the simplest option for the reference scenario, then explore the effect of changing the settings individually or in combination. For the rest of the model components we simply chose the most reasonable option (e.g. correlation between stocks in an aggregate), and investigate further only if results suggest that they may have a strong effect. Chapter 4 provides detailed descriptions of the model components and available options for each. The following sections summarize attributes of the reference scenario for all stock groupings.

Stock dynamics

For all scenarios we compare two aspects of the stock dynamics. Individual stocks follow either cyclic or non-cyclic spawner-recruit curves, and the capacity parameter is constrained to either the highest observed spawner abundance or twice that number. Spawner-recruit parameters are explained in Chapter 3 and Chapter 4, and tabulated in Appendix 1.

Forward simulation

For all scenarios, we start stocks at recent escapements and project them 50 years into the future. To capture uncertainty, we use 3 to 10 replications for each of the 250 spawner-recruit parameter sets for each stock, producing up to 2500 trajectories of catch and escapement for each stock in a simulated aggregate. The number of replications was limited by the increase in computing time as additional stocks are added. Depensatory mortality is not modeled. Based on available spawner-recruit data, the correlation between stocks in an aggregate is set to 0.21, and the correlation in recruitment over time (temporal autocorrelation) set to 0.3.

Implementation error

Implementation error has two components in this model: run size estimation error and exploitation rate implementation error. Based on observed discrepancies between final in-season estimates and post-season estimates of adult returns, we use a random run size estimation error with a mean of 8%. This is assumed to also cover exploitation rate implementation error, for which no data are available. This does not imply that these two types of error are correlated, we simply assume that the error covers random variation in both. On-going work explores alternative ways for modeling implementation error, intended to capture the observed interaction between run size and implementation error.

Value function to capture management objectives

As described in the previous chapter, we use a value function to express the relative importance of four attributes. Two management objectives (weightings) are used as a reference for further analyses. They are:

- "*Only maximize average annual catch*" (1,0,0). This is a useful reference from a technical perspective, because only one component of the value function is included. However, based on existing conservation priorities and the high variability in catches associated with this objective, workshop participants considered this single objective an improper starting point for their considerations;
- "*Equal weighting on all components*" (1,1,1), which incorporates a compromise between maximizing average catch, avoiding low catch, maintaining MSY catches, and avoiding low spawner abundance.

Shape of the harvest rule

Based on discussions at the fourth workshop, we are now working with the *s-shape harvest* rule (see Chapter 4), which corresponds more closely to the observed pattern of exploitation and reflects the fact that, even at lower run sizes, some catch is usually taken in food fisheries and test fisheries.

Outline of sensitivity analyses

Sensitivity analyses start with the reference scenario, explore model features in more detail, and identify factors that most influence the outcome. Conducting a sensitivity analysis is like testing the buttons and dials in Figure 12 to see which ones actually change the workings of the machine. Based on workshop discussions, the two main questions are:

- *How do different management objectives affect the harvest strategy for Fraser River sockeye?* To address this question, we considered a range of weights for the four components of the value function, combined with a range of stock-specific benchmarks.

- *Given a specific management objective, how do stock dynamics affect the harvest strategy for Fraser River sockeye?* To explore this issue, we compared harvest strategies and their performance using two different assumptions about stock dynamics (e.g. cyclic vs. non-cyclic spawner-recruit models).

Specifically, we explored the following:

- Effect of changing the penalty for catch falling below C_{low};
- Effect of changing the penalty for catch falling below C_{high};
- Effect of changing the penalty for spawner abundance falling below S_{low};
- Effect of combining different penalty weightings;
- Effect of different spawner-recruit relationships.

General observations

In this section, we describe the observations that held true for all the analyses, then discuss each stock grouping in more detail.

Result 1: If the management objective is to maximize average yearly catch over 50 years, without consideration for year-to-year fluctuations in catch or spawner abundance, then the best harvest rule resembles a fixed escapement policy. In a fixed escapement approach, no catch is taken if adult returns are less than the target escapement, and all returning adults in excess of the target are caught. Year-to-year fluctuations and uncertainty in estimates of adult returns are fully absorbed as fluctuations in catch, while striving to achieve a target escapement every year.

Result 2: When additional management objectives are introduced one at a time, the shape of the harvest rule is most influenced by the objective of avoiding low catch. The objectives of avoiding low spawner abundance or maintaining MSY catches have very little effect on the harvest rule, which indicates that these objectives are already achieved by the harvest rule that maximizes average yearly catch. For example, the fixed escapement policy described in *Result 1* specifies that no harvest should be taken until target escapements can be achieved. This also means that stocks at low abundance are allowed to rebuild as quickly as possibly, which minimizes the number of years with low spawner abundance.

Result 3: With increasing emphasis on avoiding low catches, the harvest rule shifts to prescribe higher catches at low run sizes. If years with low catch are highly undesirable (high penalty) then the harvest strategy begins to resemble a policy of fixed exploitation rate over a wide range of adult returns. Under a harvest strategy based on fixed exploitation rates, the same percentage of adult returns is taken as catch, at all levels of abundance.

Result 4: Average values for adult returns, spawner abundance and catch stabilize within two to three cycles (8 to 12 years) for most of the simulations. This indicates that trade-offs between different harvest rules are most pronounced in the short-term, particularly in the first eight years after implementation. This is a very important consideration for the planning process in the near future.

Result 5: For single stocks (Early Stuart, Birkenhead), the objective of avoiding low spawner abundance has little to no effect. The harvest rule for stock groupings (Early Summer, Summer, Late) is slightly more sensitive to this objective for each of the individual stocks. Also, the objective of avoiding S_{low} becomes more important in combination with the objective of avoiding low catches, because each moderates the effect of the other, resulting in a compromise. These benchmarks and their values are listed in Appendix 2.

Result 6: The effect of different assumptions about stock dynamics (cyclic or non-cyclic) is consistent across many different management objectives. Off-cycle years have much lower target escapements, resulting in substantially higher total exploitation rates than for the non-cyclic dynamics for a given run size. Separating out the low abundance years (i.e. off-cycle years), raises the target escapement for dominant/subdominant years relative to the non-cyclic harvest rule, resulting in lower total exploitation rates which increases spawner abundance in order to build the stocks to higher levels.

Result 7: The question of cyclic or non-cyclic spawner-recruit models also has important implications for the performance of the harvest rules. Four possible cases need to be considered:

1. Cyclic stocks are managed using a cyclic harvest rule (Correct assumption)
2. Non-cyclic stocks are managed using a non-cyclic harvest rule (Correct assumption)
3. Cyclic stocks are managed using a non-cyclic harvest rule (Incorrect assumption)
4. Non-cyclic stocks are managed using a cyclic harvest rule (Incorrect assumption)

Result 7a: The effect of changing management objectives is similar for all four cases. For example, increasing emphasis on avoiding years with low catch reduces the proportion of years with low catch. However, actual results differ. For example, the proportion of years with low catch is highest when cyclic stocks are managed using non-cyclic harvest rules because off-cycles don’t rebuild as expected.

Result 7b: If stocks are managed based on a harvest rule that assumes cyclic stock dynamics, then the cyclic pattern will be propagated even if the stocks are modeled as non-cyclic. This is due to the much lower target escapement associated with off-cycle years (see *Result 6*). Any additional returning adults are taken as catch, so that the stocks are held at low abundance, regardless of the simulated reproductive capacity.

Result 7c: If stocks are managed based on a harvest rule that assumes non-cyclic stock dynamics, then the cyclic pattern will prevail only if the underlying stock dynamics are modeled as cyclic. In this case, however, the harvest rule will keep trying to increase the abundance of off-cycle years, taking little or no catch during these off-years, and forgoing opportunity on co-migrating stocks.

In the following sections, each of the stock groupings is used to illustrate specific aspects of the simulation model:

- *Early Stuart* is used to illustrate the effect of different management objectives and to compare cyclic with non-cyclic stock dynamics;
- *Early Summer* is used to introduce the additional element of dealing with an aggregate of stocks, and to illustrate how conservation objectives for individual stocks are traded off against harvest objectives for the aggregate. For Early Summer we also show how the results from simulating a few stocks are expanded to provide information about the full aggregate;
- For the *Summer* aggregate, emphasis is on the effect of managing cyclic and non-cyclic stocks in aggregate, using a single harvest rule.

Early Stuart

Reference Scenario

Figure 18 shows the harvest rule for Early Stuart, using the settings described earlier as the reference scenario, and the single management objective of maximizing the average yearly catch over 50 years. The harvest rules based on the cyclic spawner-recruit model (dotted lines) and the non-cyclic spawner-recruit model (solid line) are both included. The figure has two panels, showing two different representations of the same harvest rule. In the top panel, the harvest rule is expressed as total exploitation rate (see Chapter 3 for a definition). In the bottom panel, the harvest rule is expressed as spawner abundance. In both panels, the harvest rules show a target (either exploitation rate or spawner abundance) for different numbers of returning adults.

NOTE: Appendix 3 contains helpful tips for reading these graphs, as well as the other graphs and tables used in this section.

For adult returns of 1 million, the target exploitation rate is about 50% for the non-cyclic harvest rule (solid line, top panel), resulting in a spawning escapement of 500,000 (solid line, bottom panel) and a catch of 500,000. For the cyclic spawner-recruit model, two harvest rules are shown (dotted lines): one to be used in off-cycle years, the other for dominant and subdominant cycle years. For returns of 1 million in a dominant or subdominant year, the target exploitation rate is about 38%, for a catch of about 380,000, and a spawning escapement of about 620,000. For returns of 1 million in an off-cycle year, the target exploitation rate is much higher (about 90%), resulting in a spawning escapement of about 100,000 and a catch of about 900,000. The exploitation rate for the dominant/subdominant harvest rule is lower than for the non-cyclic harvest rule, because estimates of optimal escapement are higher. The exploitation rate for the off-cycle years is much higher than for the other two harvest rules, because estimates of optimal escapements for these cycle lines are much lower (Result 6). This is a direct result of the way the spawner-recruit models are calculated using available data. For the non-cyclic model, we use all the available data and assume that all cycle lines follow the same spawner-recruit curve. For the cyclic model, we first separate the available data, generally 50 years' worth, into data from years with low abundance (off-years) and data from years with high abundance (dominant or subdominant years). The implicit assumption is that off-years have lower abundance for a biological reason and therefore the optimal escapements are much lower.

To put these harvest rules into a more realistic context, both panels of Figure 18 also include horizontal lines indicating the range of observed returns, and vertical lines to show the range of forecasted returns for 2004. The range of observed returns show that adult returns up to 2 million for Early Stuart are at least possible, and need to be considered. Over the range of the 2004 forecast, bounded by dashed lines, there is very little difference between the non-cyclic harvest rule and the harvest rule for dominant/subdominant cycle lines. Both indicate exploitation rates less than 10% over the forecast range. By comparison, if 2004 is considered an off-cycle year, and the distribution of forecasted return is correct, then 40% to 75% can be taken in the catch.

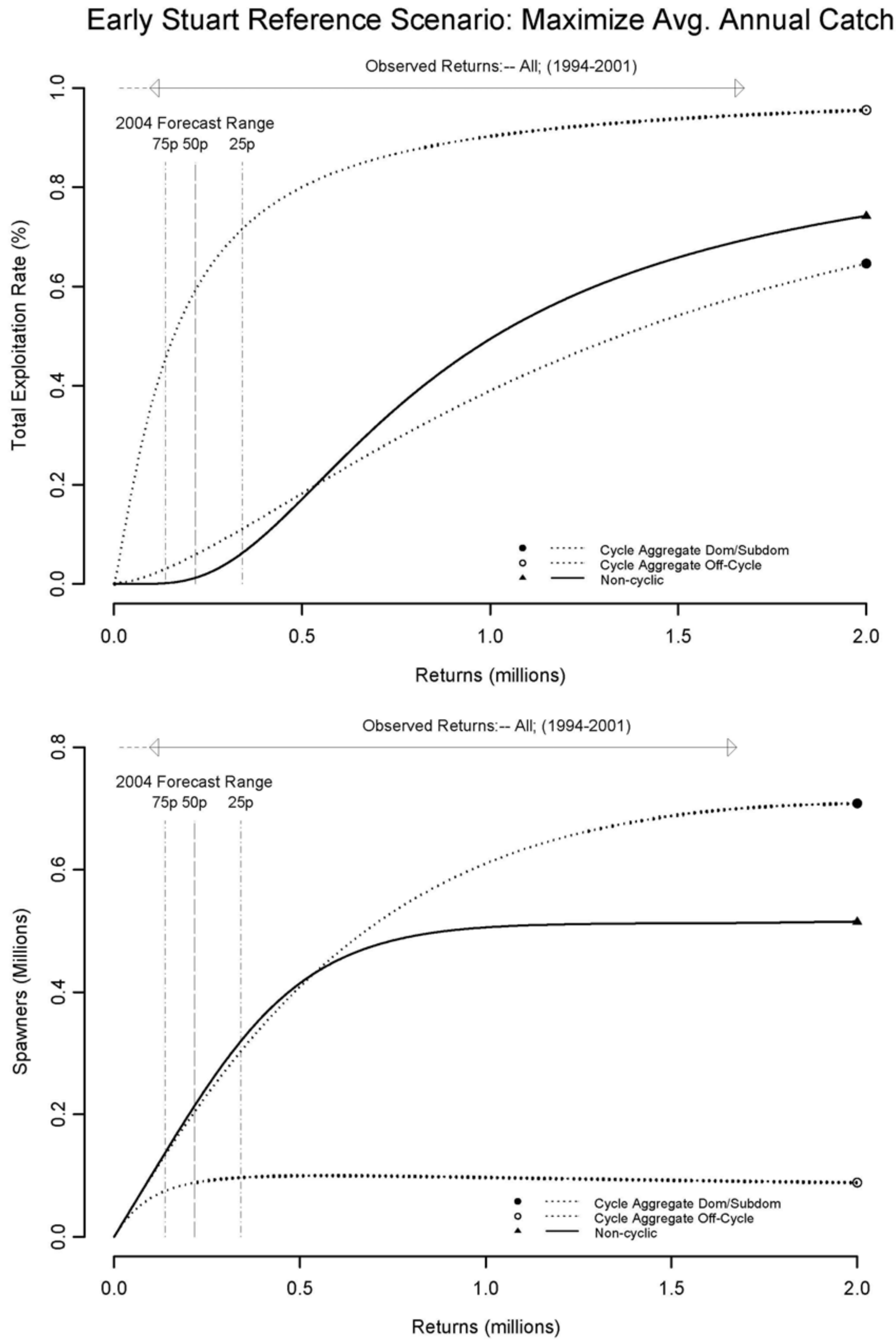


Figure 18: Early Stuart reference scenario

The bottom panel of Figure 18 also illustrates *Result 1* as introduced earlier. For the management objective of maximizing average yearly catch, without additional consideration of year-to-year fluctuations in catch or spawner abundance, all three harvest rules show a fixed escapement policy. Almost all the returning adults escape to the spawning grounds, until an optimal abundance of spawners is reached. All additional returning adults are taken in catch. However, it is important to realize just how different these targets of spawner abundance are, ranging from 100,000 to 620,000. Assumptions about the form of the spawner-recruit curve can change target escapements considerably.

Sensitivity Analysis Part 1 – Effect on shape of the harvest rule

The first step of the sensitivity analysis was to explore how different management objectives affect the harvest rule. When incorporating each of the three additional management objectives individually (avoid years with low catch, maintain MSY catches, avoid years with low abundance of spawners), the objective of avoiding low catch has the most influence on the shape of the harvest rule. The objectives of avoiding low spawner abundance or maintaining MSY catches have very little effect on the harvest rule, which indicates that these objectives are already achieved by the harvest rule that maximizes average yearly catch. For example, the fixed escapement policies shown in of Figure 18 specify that no harvest should be taken until target escapements can be achieved. This also means that stocks at low abundance are allowed to rebuild as quickly as possible, which minimizes the number of years with low spawner abundance.

Figure 19 shows how the harvest rules change with increasing emphasis on avoiding low catch (i.e. higher penalty if catch falls short of C_{low}). The thick solid line is the reference scenario shown in Figure 18, and the lines fade as penalties increase. The dotted line, therefore, shows the harvest rule for a management approach which puts a high priority on avoiding years with low catch, but still attempts to maximize average yearly catch. The figure has two panels. The top panel shows four harvest rules for the dominant/ subdominant component of the cyclic stock dynamics, while the bottom one shows the same for non-cyclic stock dynamics. The effect of including this additional objective is the same for both. With increasing emphasis on avoiding low catches, the harvest rule shifts to the left, prescribing higher total exploitation at low run sizes. With a large penalty on low catch (dotted line), the harvest strategy begins to resemble a fixed exploitation policy over a wide range of returns (Result 3). For example, for the non-cyclic harvest rule in the bottom panel, the target exploitation rate is about 50% to 60% for returns ranging from 500,000 to 2 million. Target escapements, accordingly, show a steady increase over the same range of returns (not plotted). For 400,000 returning adults, the target escapement would be 200,000 (50% of return), rising to 800,000 for a return of 2 million (60%).

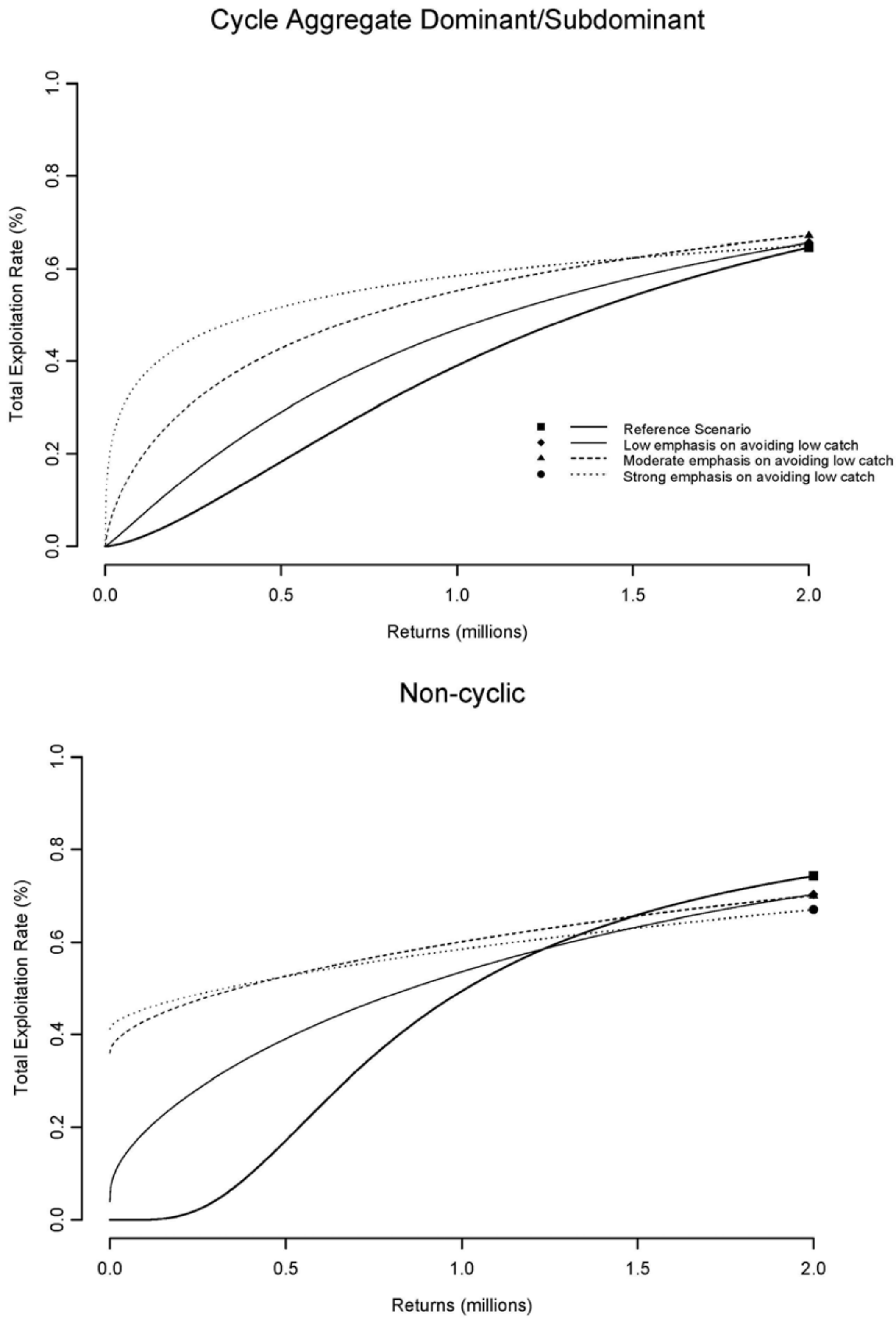


Figure 19: Early Stuart - Increasing emphasis on avoiding low catches

Sensitivity Analysis Part 2 – Decision Trees

Figure 19 shows how the harvest rule changes for different management objectives, but how does that affect the stocks and the harvests?

The outcomes are affected by whether the harvest rules from different underlying stock dynamics were correct or incorrect. In reality, we are uncertain about whether the 'true' underlying dynamics of a stock are cyclic or non-cyclic, however, managers must still make decisions based on some assumption about the 'true' stock dynamics. One way of thinking about the different possible outcomes is to draw out a decision tree (Figure 20), that shows the outcomes of using harvest rules based on cyclic or non-cyclic stock dynamics and being incorrect or correct; a total of 4 possible outcomes. For each choice of harvest rule, there are then two possibilities, called states of nature: the stocks are in reality either cyclic or non-cyclic, resulting in <u>four possible outcomes</u>. If managers choose a cyclic harvest rule and the stocks are actually cyclic, they've made the correct decision. Conversely, if the stocks are actually non-cyclic, they've made the incorrect decision. Two analogous outcomes are possible if they choose to manage based on a non-cyclic harvest rule.

The first consideration is how the harvest rule affects the cyclic pattern. If we choose to manage based on the cyclic harvest rule, the cyclic pattern will be maintained by high exploitation rates on 'off-cycles' whether or not the stock is actually cyclic. On the other hand, if we choose the non-cyclic harvest rule then exploitation rates will be lower on 'off-cycle' lines, and we'll observer either (1) a cyclic pattern with reduced year-to-year variability in spawners if the stocks are truly cyclic, or (2) off-cycles rebuild over time and the cyclic pattern disappears. Therefore, the non-cyclic harvest rule is the only one of the two options that will allow us to learn whether the cyclic pattern is due to an underlying mechanism (i.e. it does not disappear) or simply a result of harvest patterns (i.e. we can make it disappear). The opportunity to learn is not the only issue however, we also need to consider trade-offs in catch and potential interactions between cycle lines.

The decision tree in Figure 5 shows median catch and median spawners over both the long term and the short term for each of the four possible outcomes. For example, if stocks are managed as non-cyclic the median abundance of spawners over the long term is higher for both possible outcomes because exploitation rates will be lower, producing more spawners in off cycle lines. With respect to median catch over the long term, the non-cyclic harvest rule results in either the highest catch, if the off-cycles can rebuild, or the lowest catch, as a result of foregone catch if off-cycle lines don't rebuild. Under the cyclic harvest rule, the median catch over the long term for both outcomes falls in the middle of the two extremes for the non-cyclic management. However, if we are more interested in median catches over the short term managing based on the cyclic assumption results in the highest median catch relative to the non-cyclic harvest rule because the cyclic harvest rule prescribes higher exploitation rates and catches in off-cycle years. Thus, managing based on non-cyclic harvest rule will achieving the highest median spawner abundance and median catch over the long term**,** but at a cost of reduced catch over the short term. A possible compromise might be to manage based on cyclic dynamics with restricted exploitation rates on some off-cycles to explore the possibility of the population to rebuild.

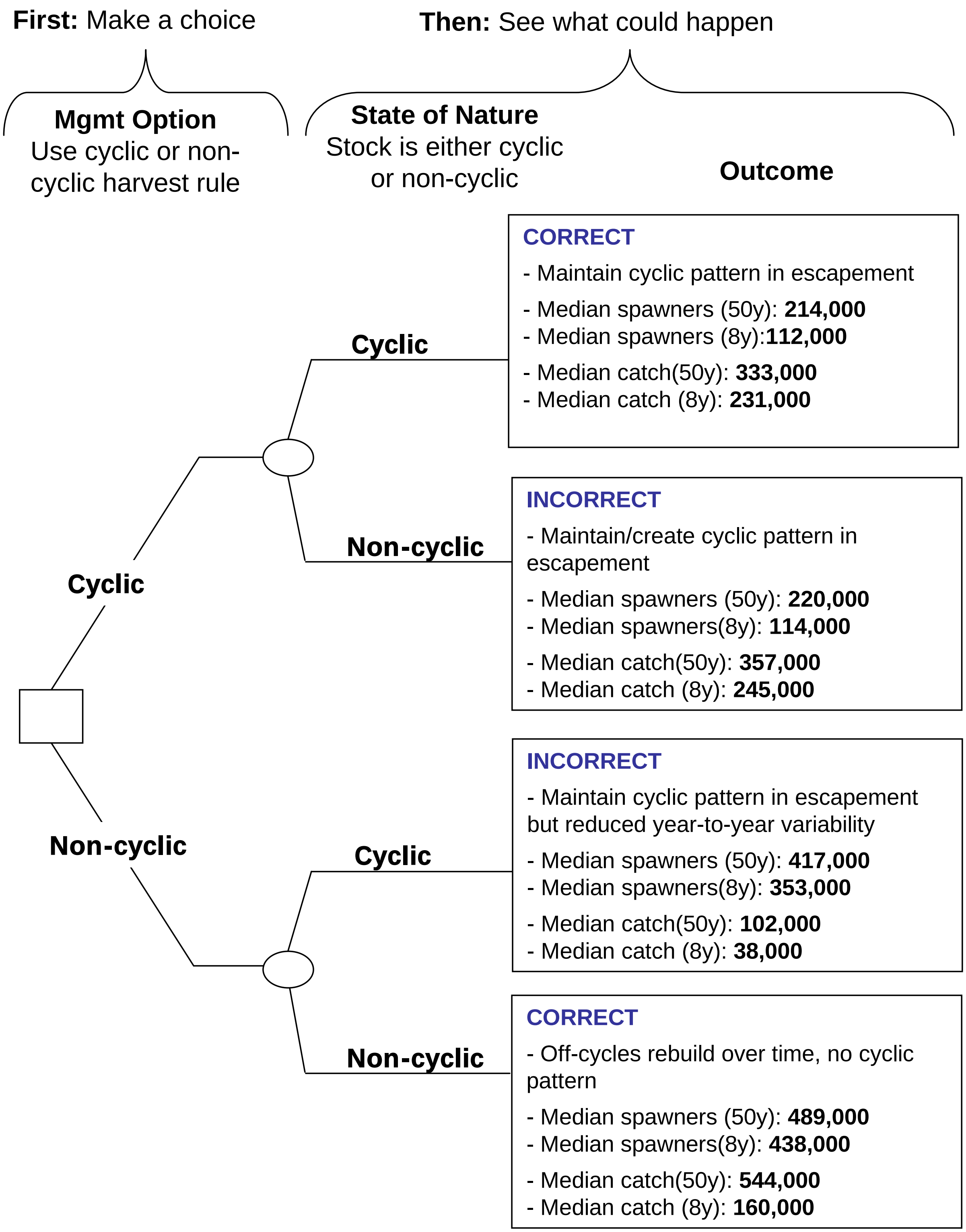


Figure 20: Decision tree for choosing between cyclic harvest rule and non-cyclic harvest rule

Sensitivity Analysis Part 3 – Trade-off Plots

Trade-off plots contain a lot of information, but can make comparisons between options easy, by showing what is given up on one performance measure as you improve another.
The diagram below illustrates this for three performance indicators (A, B, C). As management objectives change moving from left to right, A stays the same, B increases slightly, and C decreases considerably. With plots like this, we can then consider whether the observed improvement in one indicator is worth the degradation in another. For example, is a 10% increase in average catch over 50 years worth a 30% increase in fluctuation of spawner abundance?

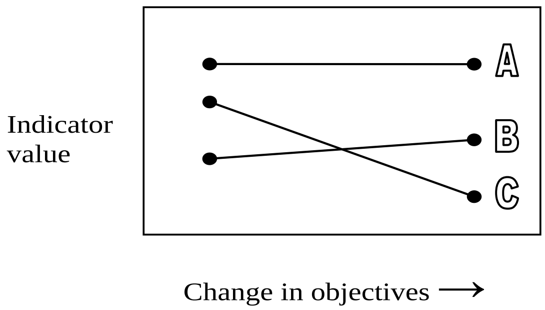


Figure 21: How to read the trade-off plots

Figure 22 shows the change in four performance measures as management objectives change from the reference scenario (maximize average yearly catch) to a strong emphasis on avoiding years with low catch. The left-hand side of each trade-off plot corresponds to the thickly plotted harvest rules for the reference scenario in Figure 19, and the right-hand side corresponds to the strong avoidance of low catches. The other two scenarios are plotted in between. These trade-off plots have four panels, one for each of the four eventualities identified earlier in *Result 7*:

Top left: Cyclic stocks managed using a cyclic harvest rule (Correct assumption)	**Top right:** Cyclic stocks managed using a non-cyclic harvest rule (Incorrect assumption)
Bottom left: Non-cyclic stocks managed using a cyclic harvest rule (Incorrect assumption)	**Bottom right:** Non-cyclic stocks managed using a non-cyclic harvest rule (Correct assumption)

These four possible outcomes correspond to the four branches of the decision tree in Figure 20.

As the management objectives change moving from left to right, some performance measures stay the same, some decrease, and some increase. Each trade-off plot needs to be carefully interpreted, because for some indicators, an increase is good, (e.g. average catch), while for others an increase is bad (variability in catch). For example, the bottom right panel of Figure 22 shows that the desired decrease in the proportion of years with low catch, from about 4 in 10 (40%) to less than 1 in 10, also results in (1) an increase in median catch from about 160,000 (shown as 0.16 Million) to almost 300,000; (2) a decrease in median spawner abundance from about 450,000 to about 230,000; (3) a very slight increase in the proportion of years with low spawner abundance. This is the kind of information participants need to consider when choosing between harvest rules.

The result from these plots depends very much on the definition of the performance measures plotted. While the median catch shows a pronounced increase, the average catch (not plotted) shows a considerable decrease. Averages can be influenced by a few very large or very small values, while *medians* are less affected by extreme values. Medians always show the value with half the observations on either side. The increase in median catch observed here occurs because there are fewer years with small catches. Average catch decreases because stocks build up more slowly, reducing the abundance of returning adults.

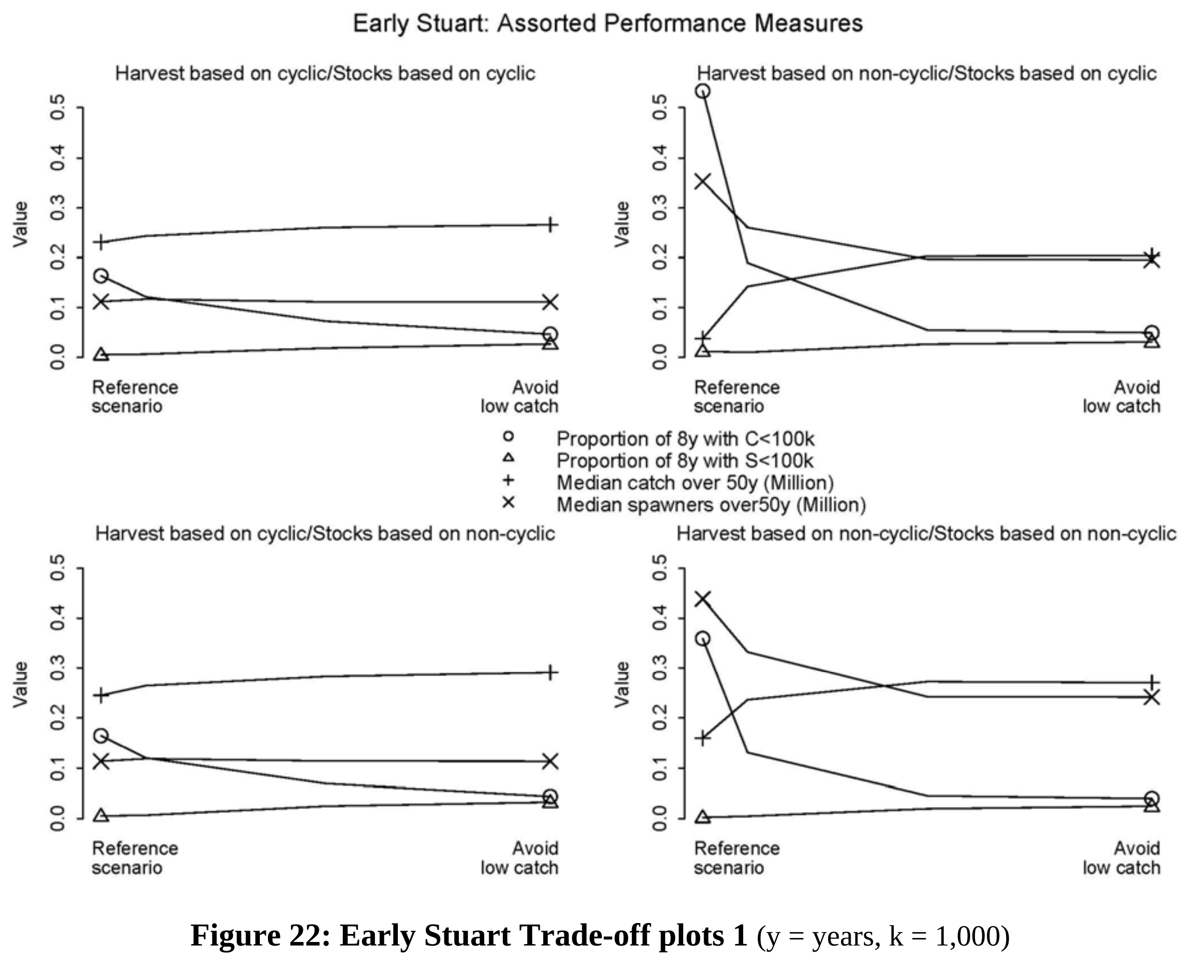


Figure 22: Early Stuart Trade-off plots 1 (y = years, k = 1,000)

The four panels of Figure 22 also illustrate the observations presented earlier in *Result 7*. Changing management objectives has the same general effect whether stocks are managed based on cyclic or non-cyclic harvest rules, and whether these harvest rules are correctly or incorrectly applied. The only difference between the four cases illustrated in the four panels is the extent of the effect. For example, median catch increases in all four panels. However, the increase is most pronounced in the top right panel. In the reference scenario, if a stock is managed based on a non-cyclic harvest rule but actually follows cyclic stock dynamics, the harvest rule will restrict harvest on two out of every four years while unsuccessfully trying to rebuild the off-cycles as quickly as possible to maximize average catch. This results in many years with no or low catches. The shift in harvest rules associated with increasing emphasis on avoiding low catches (Figure 19) therefore has the most pronounced effect in this case. There is very little change in median catch in the two left-hand panels, which show the results for cyclic harvest rules. As shown earlier, the target escapement for the off-cycle component is much lower, and therefore the harvest rules already prescribe low catch in two of those four years. The objective of avoiding low catch therefore only affects the early years of the simulation, where all four cycle lines build up to their optimal escapement.

Figure 23 shows the trade-off between variability in catch and variability in spawner abundance. The large, naturally occurring year-to-year fluctuations in the number of returning adults needs to be shared between fluctuations in catch and fluctuations in spawner abundance. As it becomes more important to avoid years with low catches (moving left to right in each panel), more of the variability is shifted from catch to escapement. The *coefficient of variation (CV)* is a simple, standardized measure of variability useful for comparisons. A larger CV indicates larger variability. In all four panels the CV of catch decreases and the CV of spawner abundance increases. More stable catches come at the expense of less stable escapement. Median catch and spawner abundance plotted here are the same as in Figure 22.

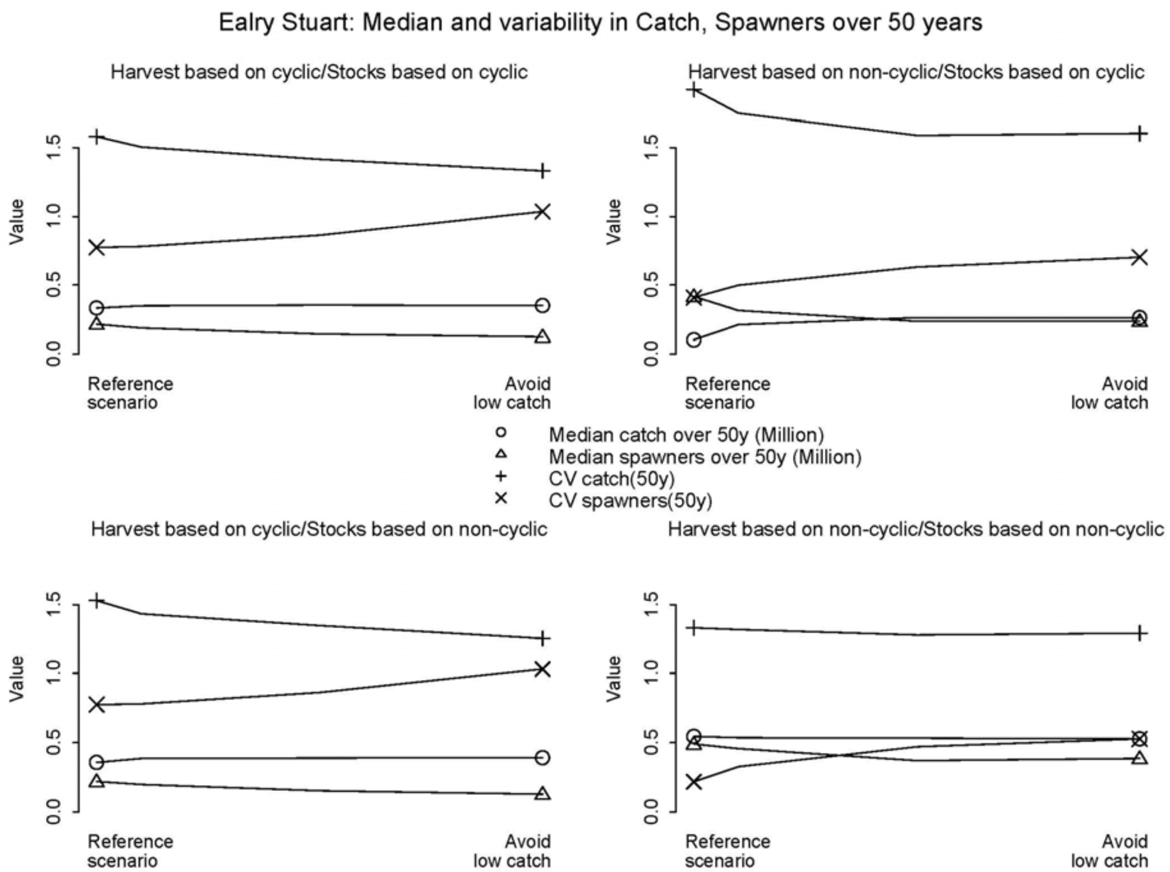


Figure 23: Early Stuart Trade-off plots 2

Figure 24 shows the median spawner abundance for each cycle line after 50 simulated years. Once again, the four panels have the same basic results. As the penalty for years with low catch increases, spawner abundance decreases. However, the four cycle lines respond differently, depending on the combination of harvest rules and actual stock dynamics. If a non-cyclic stock is managed using a non-cyclic harvest rule (bottom right panel), all four cycle lines rebuild to the same spawner abundance and the four lines overlap. If the stock is managed as cyclic (left-hand panels), the off-cycle lines remain at much lower spawner abundance than the dominant/ subdominant cycle lines, regardless of whether this assumption is correct (top left) or incorrect (bottom left). If a cyclic stock is managed using a non-cyclic harvest rule (top right), then the median spawner abundance on off-years increases above the estimated optimal escapement for these cycle lines (i.e. +,x in top right panel higher than in top left panel, where they overlap), but does not get as high as for the dominant/subdominant cycle lines. If stocks are managed as non-cyclic, and we try to rebuild off-cycle years, then we can over time find out which assumption is correct. This information has the potential to confirm that stocks are actually cyclic, but comes at the substantial cost of forgone catch. If stocks are managed as cyclic, we have less opportunity to find out which assumption is correct, possibly forgoing the additional catch available from building up the off-cycles.

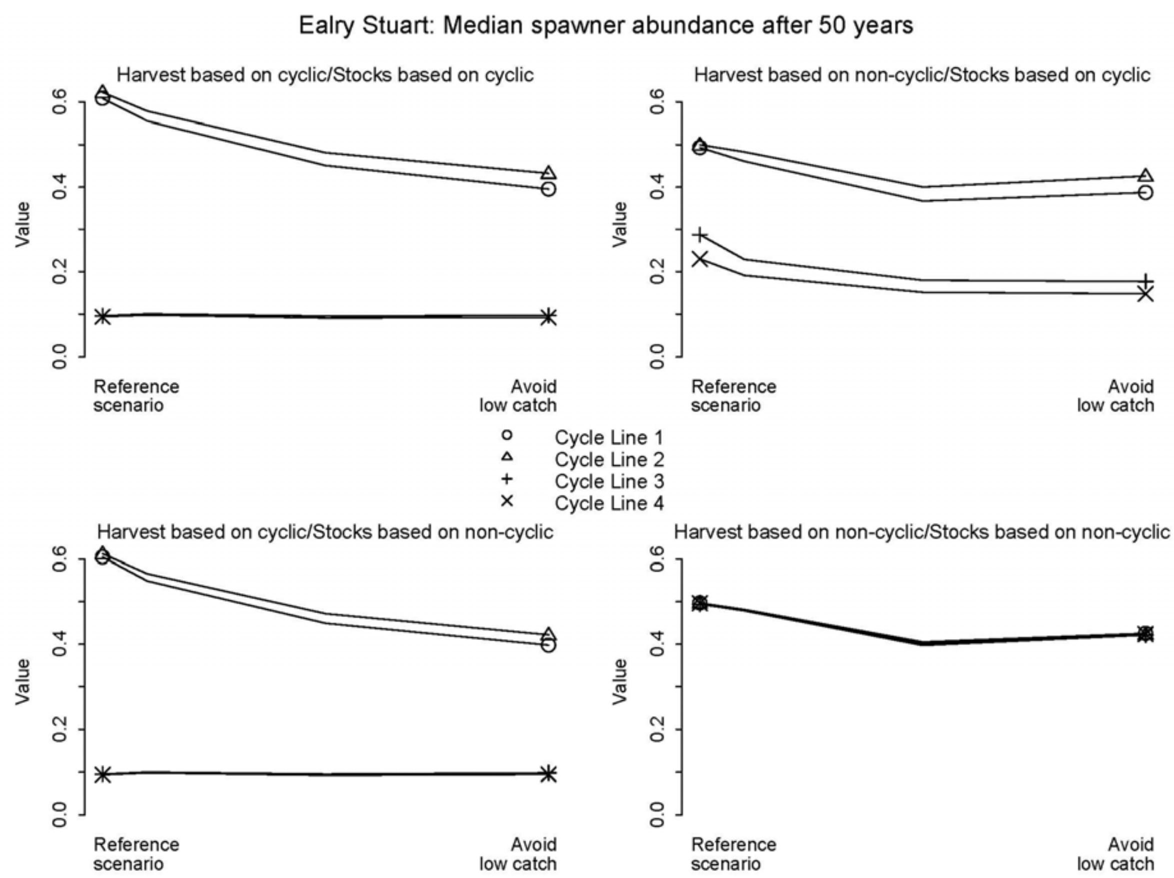


Figure 24: Early Stuart Trade-off plots 3

Sensitivity Analysis Part 4 – Trajectories of catch and escapement

We combine two types of graphs to show how catch or escapement change over time. *Boxplots* to capture variability, and *trajectories* to show the changes from one year to the next. Remember that we test harvest rules by applying them under many different conditions, with many replications. This produces several thousand trajectories of catch and escapement. Boxplots can summarize this bulk of information at a glance, and convey a lot of information about the distribution of values. The boxplots we use show two ranges, one that covers half the observations (box), and one that covers most of the observations (whiskers).

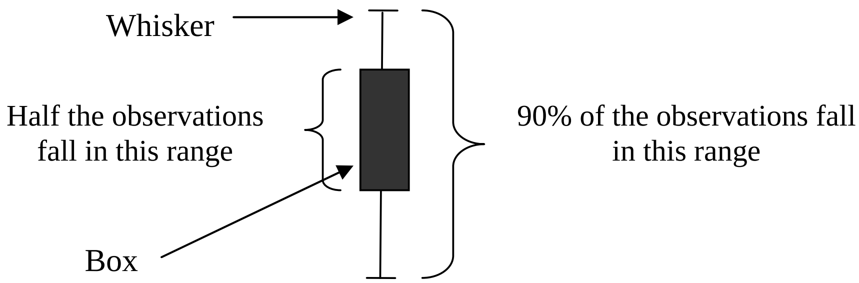


Figure 25: How to read boxplots

By drawing a boxplot for each simulated year, we can show how the distribution of values changes over time. For direct comparisons between harvest rules, we draw two boxplots side-by-side. For example, the diagram in Figure 26, shows the year-to-year fluctuations in spawning escapement for a cyclic stock (year 1,5=dominant, year 2,6= subdominant, year 3,4 = off-cycle). Boxes and whiskers are longer for the dominant and subdominant years, indicating that spawner abundances vary over a wider range of values. The average spawner abundance for each year, generally a bit below the middle of each box, is also higher for dominant and subdominant years. Harvest rules affect the range of spawners and catches over time. The difference between white and black boxes illustrates a general result described earlier. Compared to the reference scenario (white boxes), a harvest rule designed to avoid low catches will increase the occurrence of low spawning escapement, which stretches the boxes downward (black boxes).

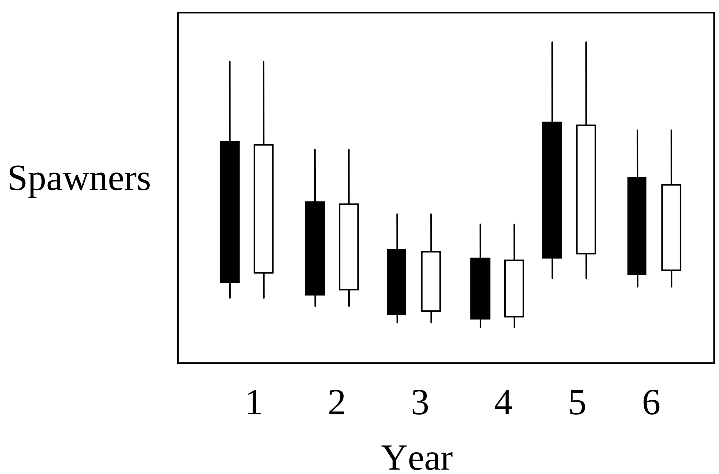


Figure 26: How to read trajectories of boxplots

Figure 27 shows trajectories of spawners (top panel) and catch (bottom panel) for Early Stuart, modeled as *non-cyclic*, under two different harvest rules. The trajectory for the reference scenario (maximize average catch) is shown with black boxes, and for comparison the harvest rule designed to avoid years with low catch is shown with white boxes. In most of the simulations spawner abundance and catch stabilize within two to three cycles, so the plots show only the first two cycles. The long-term equilibrium after 45 to 48 years is plotted on the far right, separated by a toothed line to emphasize the jump in years.

On these plots, you can either follow one of the trajectories through time from left to right, or you can compare the two boxes in a given year. As discussed earlier, the objective of maximizing average yearly harvest produces a harvest rule that closely approximates a fixed escapement policy (Figure 18). When this harvest rule is applied, the stock quickly builds up to the target escapement of about 500,000, and stays within a narrow range of that target (i.e. *short* black boxes centered around 500,000 on the right hand side of the top panel). However, natural variability in the abundance of returning adults is mostly shifted onto catches, resulting in highly variable catches (i.e. *long* black boxes in bottom panel).

Applying a harvest rule designed to avoid years with low catch reduces the variability in catch (i.e. white boxes in bottom panel are shorter than black boxes), but increases the variability in spawner abundance (i.e. white boxes in top panel are longer than black boxes). The same trend is shown earlier in Figure 23, where the CV of catch decreases, and the CV of spawner abundance increases.

These observations also hold true if the stock is modeled as cyclic, shown in Figure 28. Under the harvest rule for maximizing average yearly catch, each cycle line quickly rebuilds to its target escapement, and stays within a narrow range of that target. The main distinction from the non-cyclic case in Figure 27, is that here the dominant and sub-dominant years have one escapement target, the off-cycle years another. The target escapement for dominant and sub-dominant years is higher than for the non-cyclic model (Figure 18).

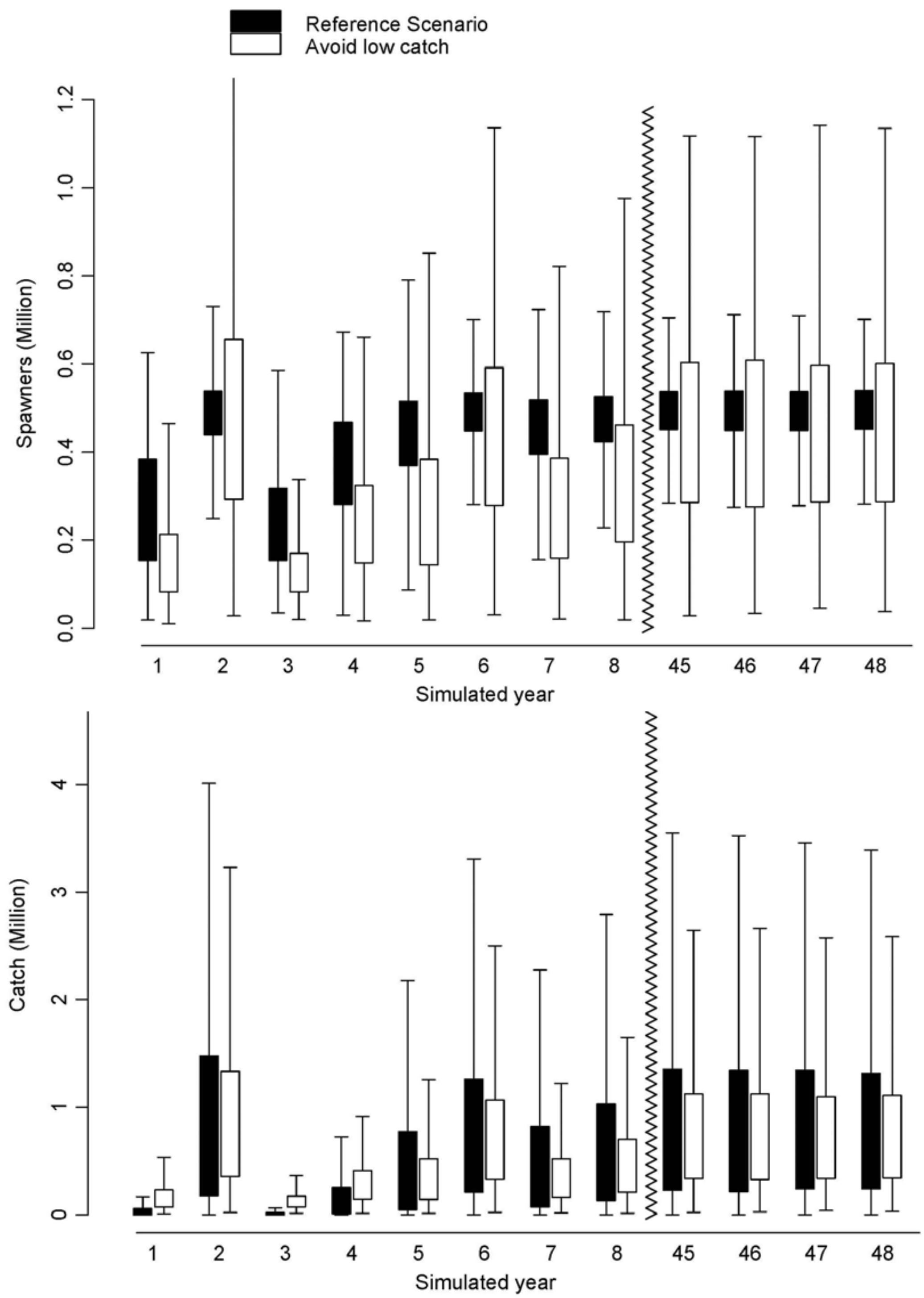


Figure 27: Early Stuart – Trajectories of catch and escapement for two harvest rules (Non-cyclic)

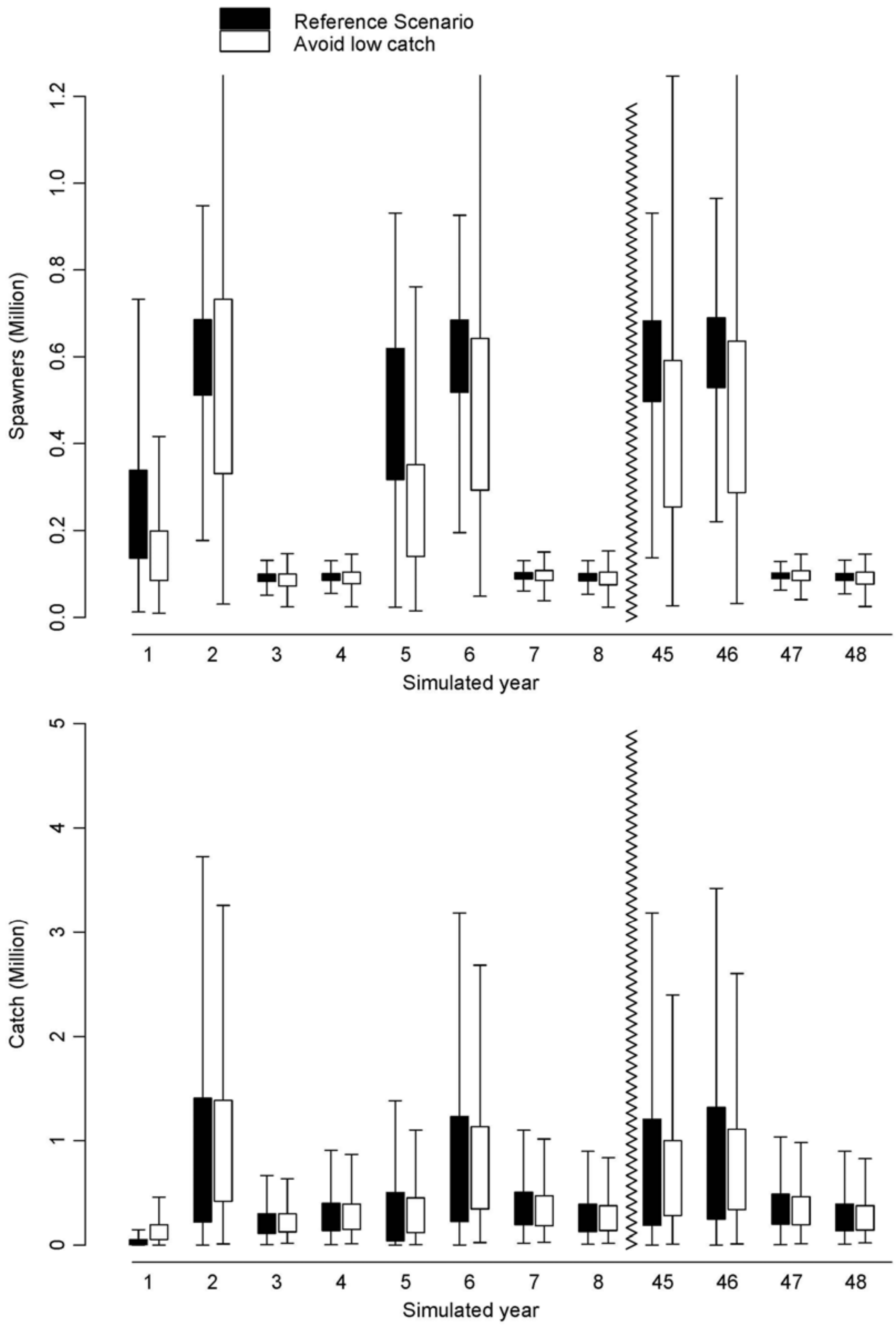


Figure 28: Same as Figure 27, but for cyclic stock dynamics

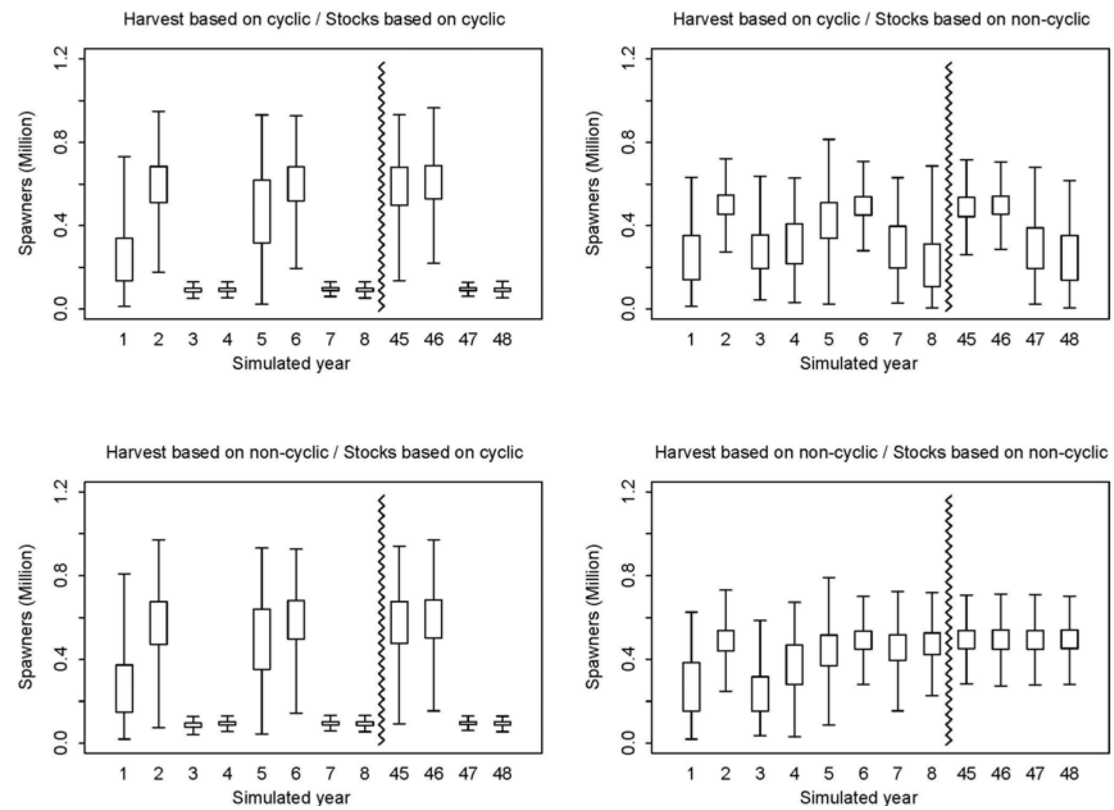


Figure 29: Early Stuart reference scenario – Effect of correct and incorrect assumptions about stock dynamics

As for the trade-off plots shown in Figure 22 to Figure 24, these trajectories are affected not only by the underlying stock dynamics, but also by whether or not the harvest rule was correctly or incorrectly matched to the stock dynamics. Figure 29 shows four panels, corresponding to the four panels of the earlier trade-off plots (e.g. Figure 22) and the four branches of the decision tree (Figure 20). The trajectories show at a glance whether a cyclic pattern is maintained under the different circumstances.

If the underlying stock dynamics are cyclic, the cyclic pattern clearly persists in to the future (left-hand panels). However, *if a non-cyclic stock is managed with a cyclic harvest rule, then the cyclic pattern will persist* (top right panel).

Sensitivity Analysis Part 5 – Decision Tables

The trade-off plots and trajectories shown to this point emphasize two different aspects that go into choosing a harvest strategy for Fraser River sockeye:

- The change in performance indicators as the balance between competing objectives is shifted.
- The pattern of catches and escapements, including variability.

These results are useful to narrow the range of potential harvest rules for closer inspection, but more detailed information is necessary to make the final decisions. Decision tables contrast the numerical results for two alternatives, giving decision-makers a score-sheet.

The information in the decision tables is a part of the data shown in the trade-off plots, just presented as the actual numerical value. Once again, four possibilities need to be considered, as shown in Figure 30. The shaded boxes list the performance indicators for the cases where cyclic or non-cyclic stocks are managed with the correct harvest rules; the white boxes show results for the incorrect cases. Displaying the results in this format encourages three different comparisons:

- For a given assumption about stock dynamics, what are the implications of choosing a cyclic or non-cyclic harvest rule? (e.g. comparing top left and bottom left boxes)
- For a given harvest rule, what are the implications of being wrong? (e.g. comparing bottom left and bottom right boxes)
- Which of the four possible outcomes is the best? The worst?

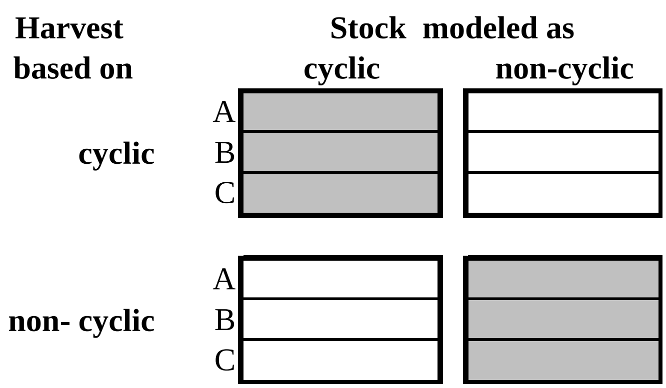


Figure 30: How to read decision tables

As with trade-off plots, the message conveyed by these decision tables can be strongly influenced by the performance indicators presented, and their exact definition. We have chosen the following performance indicators

- Proportion of years in which catch or spawner abundance fall below 100,000.
- Median catch and spawner abundance over the first 8 years after implementation
- Variability in catch and spawner abundance over 50 years, once again using *coefficient of variance (CV)* explained earlier in this chapter.
- Median catch and spawner abundance after about 50 years

Table 5 shows the decision tables for the reference scenario used in the trade-off plots (i.e. maximize average annul catch). The numbers in the table correspond to the points at the far left of the trade-off plots in Figure 22 to Figure 24. Table 6 shows the decision table for the harvest rules resulting from the objective of avoiding low catch, and the number correspond to the points on the far right of the trade-off plots.

Both tables also include a second piece of information, intended to simplify the comparisons. For each performance indicator, the best possible outcome is marked as +1, the worst as -1. If two results are very similar, they are marked as either + or – 0.5.

In both tables, the best outcome (i.e. the most + 1's) materializes if the stocks are managed based on non-cyclic harvest rule, if you're right (bottom right box), with the highest median spawner abundance over the first 8 years, and low variability in both catch and spawners. The worst outcome is the result of applying the non-cyclic harvest rule if you're wrong (bottom left box), with the highest proportion of years with low catch (1 out of 2 years), the lowest median catch, and the highest variability in catch. When applying the cyclic harvest rule, the results are quite similar, whether you are correct or incorrect.

The choice between the cyclic and non-cyclic harvest rule depends on the decision-makers' attitude towards risk, and the strength of their belief in one of the two assumptions about stock dynamics. To avoid the worst outcome, one would choose the cyclic harvest rule, and consciously forego the potential benefits that could materialize under a non-cyclic harvest rule. Conversely, one could take the chance of the worst outcome, while hoping on the possibility of the best outcome. One's willingness to take the gamble also depends on the relative credibility assigned to the two alternative assumptions. A decision maker who is strongly convinced that the stock is non-cyclic will be more willing to accept the gamble than somebody who beliefs that both assumptions have an equal chance of being correct.

The choice between the cyclic and non-cyclic harvest rule also depends on decision maker's emphasis on the different performance indicators. In both tables, looking only at median catch over the first eight years, one would choose the cyclic harvest rule. However, considering only median spawner abundance, one would choose the non-cyclic harvest rule.

Relative to the reference scenario (Table 5), the objective of avoiding years with low catch (Table 6) improves catch-related performance measures, but lowers spawner-related performance measures. The median catch increases for all four possible cases, but more so for the non-cyclic harvest rule, and most if the non-cyclic harvest rule is incorrectly applied (bottom left box). Similarly, the proportion of the first eight years in which catch is less than 100,000 drops from 6 in 10 (0.53) to less than 1 in 10 years. Both of these results can be explained based on the trajectories shown in Figure 27. In the reference scenario, the off-cycle years recover faster, because catches in those two years are more restricted. The objective of avoiding years with low catches slows down the recovery to reduce the short-term impact on the fisheries.

Harvest based on	Performance measures	Stock modeled as cyclic	Stock modeled as non-cyclic	Stock modeled as cyclic	Stock modeled as non-cyclic
cyclic	Proportion of first 8 years with catch < 100,000	0.27	0.27		
	Proportion of first 8 years with spawners < 100,000	0.38	0.38		
	Median catch over 8 years (1000)	231	245		**+1**
	Median spawners over 8 years (1000)	112	114		
	Variability in catch over 50 years (CV)	1.58	1.53		
	Variability in spawners over 50 years (CV)	0.77	0.77		
	Median spawners after 50 years (1000s)	609 / 622 / 95 / 93	605 / 612 / 95 / 94	**?**	**?**
non-cyclic	Proportion of first 8 years with catch < 100,000	0.61	0.44	**-1**	
	Proportion of first 8 years with spawners < 100,000	0.06	0.03		
	Median catch over 8 years (1000)	38	160	**-1**	
	Median spawners over 8 years (1000)	354	439		**+1**
	Variability in catch over 50 years (CV)	1.92	1.33	**-1**	**+1**
	Variability in spawners over 50 years (CV)	0.41	0.22		**+1**
	Median spawners after 50 years (1000s)	493 / 499 / 287 / 230	497 / 497 / 495 / 496	**?**	**?**

Table 5: Early Stuart decision table – reference scenario

Harvest based on	Performance measures	Stock modeled as cyclic	Stock modeled as non-cyclic	Stock modeled as cyclic	Stock modeled as non-cyclic
	Proportion of first 8 years with catch < 100,000	0.15	0.15		
	Proportion of first 8 years with spawners < 100,000	0.40	0.36	**-1**	
	Median catch over 8 years (1000)	266	291		**+1**
cyclic	Median spawners over 8 years (1000)	111	114		
	Variability in catch over 50 years (CV)	1.33	1.26		**+1**
	Variability in spawners over 50 years (CV)	1.04	1.03		
	Median spawners after 50 years (1000s)	396 / 433 / 97 / 92	398 / 422 / 99 / 95	**?**	**?**
	Proportion of first 8 years with catch < 100,000	0.21	0.16	**-1**	
	Proportion of first 8 years with spawners < 100,000	0.17	0.14		
	Median catch over 8 years (1000)	204	271		
non-cyclic	Median spawners over 8 years (1000)	195	241		**+1**
	Variability in catch over 50 years (CV)	1.60	1.29	**-1**	
	Variability in spawners over 50 years (CV)	0.70	0.53		**+1**
	Median spawners after 50 years (1000s)	387 / 426 / 177 / 147	426 / 423 / 421 / 424	**?**	**?**

Table 6: Early Stuart decision table – avoid low catch

Early Summer

Exploring harvest rules for the Early Summer aggregate introduces two new challenges:

- Harvests taken from the aggregate need to find a compromise between the stock dynamics of the component stocks.
- Stock composition is an additional source of uncertainty, because only a part of the Early Summer aggregate can be modeled.

The simulation model includes three stocks from the Early Summer aggregate for which there is acceptable data: Bowron, Raft, and Seymour. They are modeled as non-cyclic components in an aggregate, which introduces a new element that was not an issue in the results for Early Stuart. When stocks are modeled in aggregate, all components are subjected to the same exploitation rate, but each component responds to this harvest based on its individual stock dynamics (p. 56). Management objectives relating to catch are evaluated for the aggregate, while objectives relating to spawning escapement are evaluated for each component, and then added up. For example, the objective of avoiding low catch is achieved if the total catch from the aggregate exceeds the benchmark.

For the Early Summer aggregate, the data limitations introduce an additional challenge: How to extrapolate from the three stocks in the model to the full Early Summer aggregate? Fennel, Gates, Nadina, Upper Pitt, Scotch, and other miscellaneous stocks are not currently included, because data are insufficient for fitting SR models. Due to the increasing contribution of Nadina, Upper Adams, and Pitt, the modeled stocks only account for a small proportion of the current returns in this aggregate.

The stock composition of the Early Summer aggregate fluctuates considerably over the years. Different methods for calculating the relative contribution of Bowron, Raft, and Seymour, can result in different target escapements for the aggregate. The implications of uncertain stock composition are discussed in detail later in this section. The results shown in the first part of this section, (to Figure 34), deal only with Bowron, Raft, and Seymour.

Sensitivity Analysis Part 1 – Effect on shape of the harvest rule

The harvest rule for the aggregate of Bowron, Raft and Seymour responds to the objective of "avoid years with low catch" (Figure 31) the same way as observed in the single stock simulation for Early Stuart (Figure 19).

Two strategies help with achieving this objective. Most pronounced is the increase in exploitation rate at run sizes below 600,000, which helps satisfy the short-term objective of having at least some catch. For example, for 200,000 adults returning to the three systems, the exploitation rate increases from about 20% to almost 60%. Less pronounced, but also important, is the corresponding reduction in exploitation rate at larger run sizes above 600,000, which helps ensure that spawning escapement for each component is sufficient to produce some harvestable surplus four years later. For example, for 1.2 million adults, the exploitation rate drops from about 85% to about 75%. Interestingly, the additional catch taken at lower run sizes is about the same as the catch given up at larger run sizes (45% of 200,000 ≈10% of 1.2 Million).

As observed for Early Stuart, the harvest rule for the reference scenario (i.e. maximize average annual catch) resembles a fixed escapement policy, and shifts towards a fixed exploitation rate policy as avoiding low catch is given more importance.

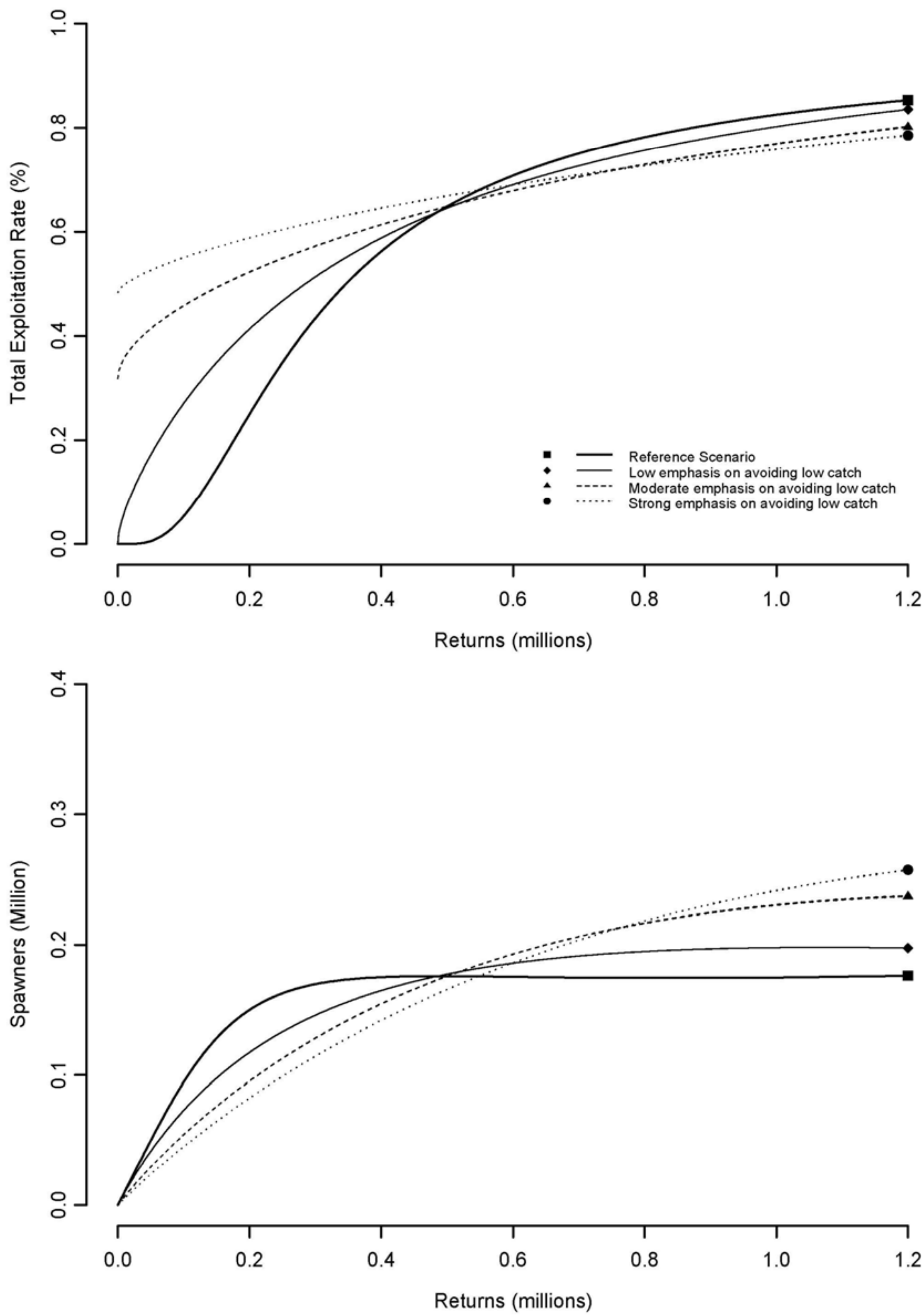


Figure 31: Bowron,Raft,Seymour - Increasing emphasis on avoiding low catch

The objective of avoiding years with low abundance of spawners has a very pronounced effect on the shape of the harvest rule for this aggregate of three stocks (Figure 32). The harvest rule shifts as it attempts to ensure adequate escapement for each of the three components, even as stock composition fluctuates from year to year and in-season estimates of run size are uncertain (i.e. implementation error). The more importance is given to avoiding low escapement, the further exploitation rates are reduced. At larger run sizes, this reduction is by up to 10%. For example, at a run size of 1.2 million, target exploitation rates drop from about 80% to about 70%.

For Early Stuart, which is modeled as a single stock, the objective of avoiding low spawners did not affect the harvest rule, except in combination with other objectives, such as "avoid low catch". When modeling aggregates, the effect of "Avoid low spawner abundance on each stock in the aggregate" becomes more pronounced. (See *Result 5* earlier).

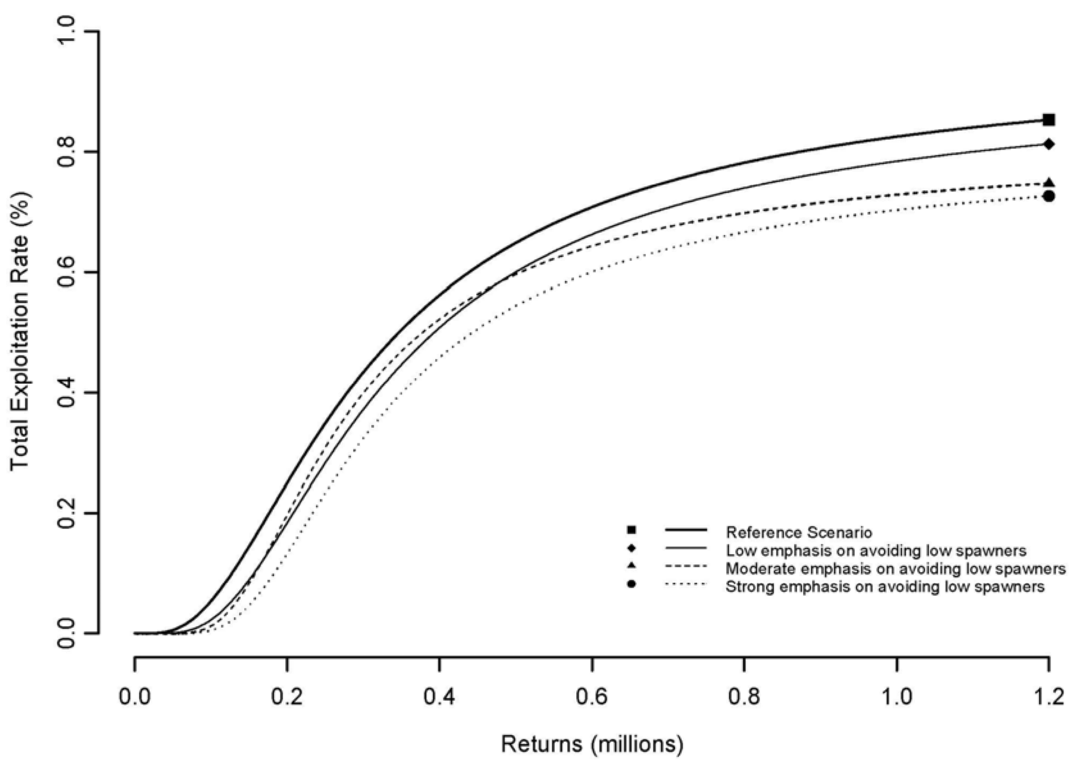


Figure 32: Bowron,Raft,Seymour - Increasing emphasis on avoiding low spawners

Sensitivity Analysis Part 2 – Trajectories of catch and escapement

Figure 33 shows how catch and escapement change over time for the aggregate of Bowron, Raft, and Seymour, as the management objectives shift from a high emphasis on avoiding low spawner abundance (dark boxes) to a high emphasis on avoiding low catch (light boxes).

The response to this change in management objectives follows the same trend as observed with Early Stuart (Figure 27). Placing a higher emphasis on avoiding years with low catch reduces average spawner abundance (i.e. light boxes below dark boxes in bottom panel of Figure 33), while reducing the occurrence of years with low catch (i.e. light boxes above dark boxes in bottom panel).

There is one crucial difference between the results for this aggregate of three stocks and the results for Early Stuart. The natural variability introduced by combining three stocks results in much larger variability in both catch and escapement (i.e. longer whiskers on the boxplots). Interestingly, the objective of avoiding years with low spawner abundance results in a much larger variability in spawner abundance.

Figure 34 shows the trajectory of spawning escapement for the aggregate, and for each individual component. For the management objective of "*maximize average yearly catch*", the aggregate responds like single stock (Figure 34, top left panel). The harvest rule for this objective resembles a fixed escapement policy; escapements rebuild to target level within 8 years, and are kept quite closely around that target escapement (i.e. short box with short whiskers).

But how do the three component stocks respond to this harvest from the aggregate? Seymour, the major contributor in terms of abundance drives the harvest rules and stabilizes quickly, showing a trajectory much like the aggregate. Borwon and Raft, the less abundant stocks, fluctuate more from year to year, and do not show an increase in spawning escapement over time, indicating no rebuilding over current levels. By satisfying the catch objective by a harvesting the aggregate according to its most abundant component, the two smaller stocks are kept at lower levels. The harvest rule does not capitalize on very good returns to these smaller stocks, and in the case of Raft actually reduces spawner abundance from current levels.

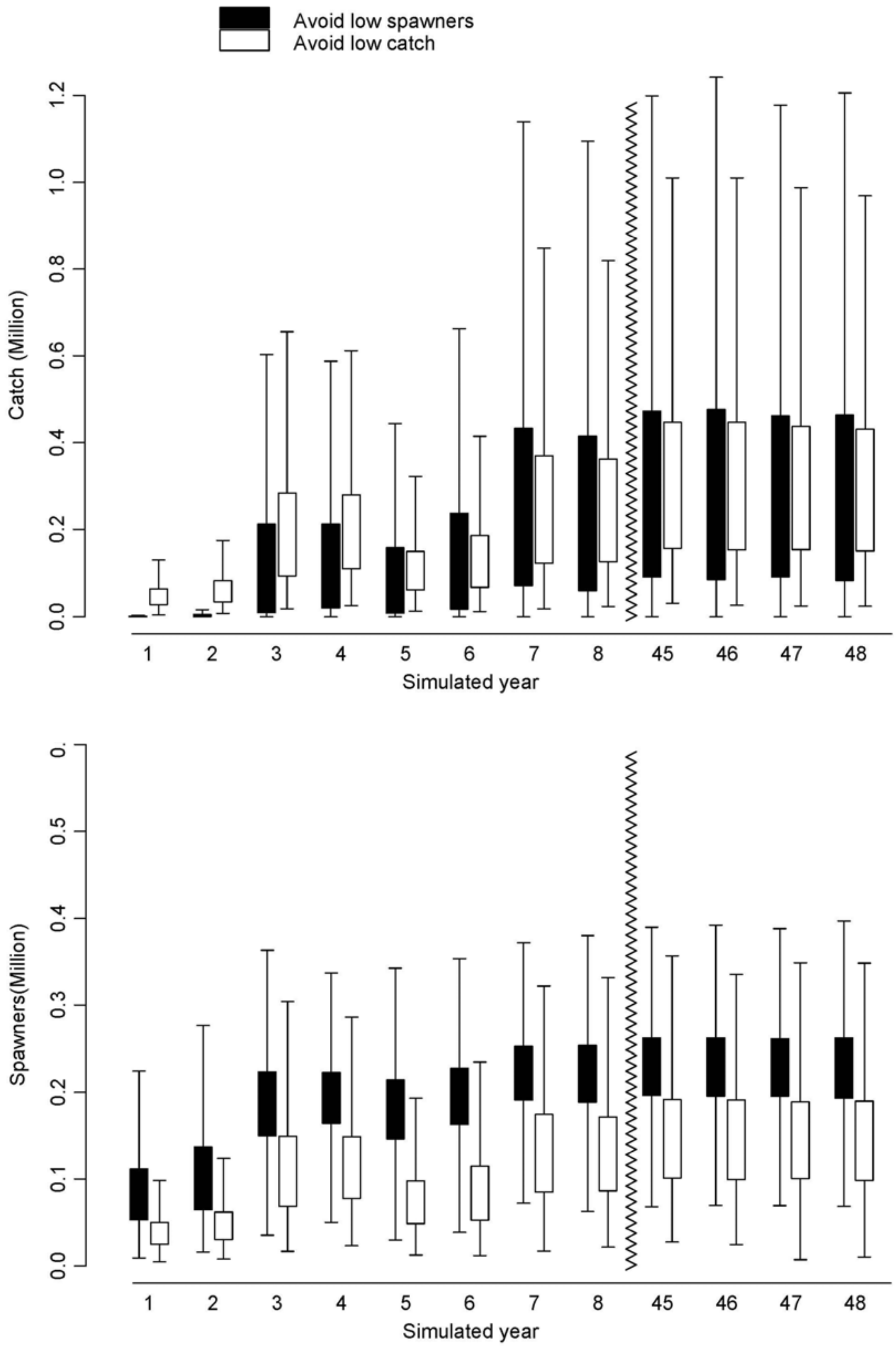


Figure 33: Bowron, Raft, Seymour – Trajectories of catch and escapement for two harvest rules

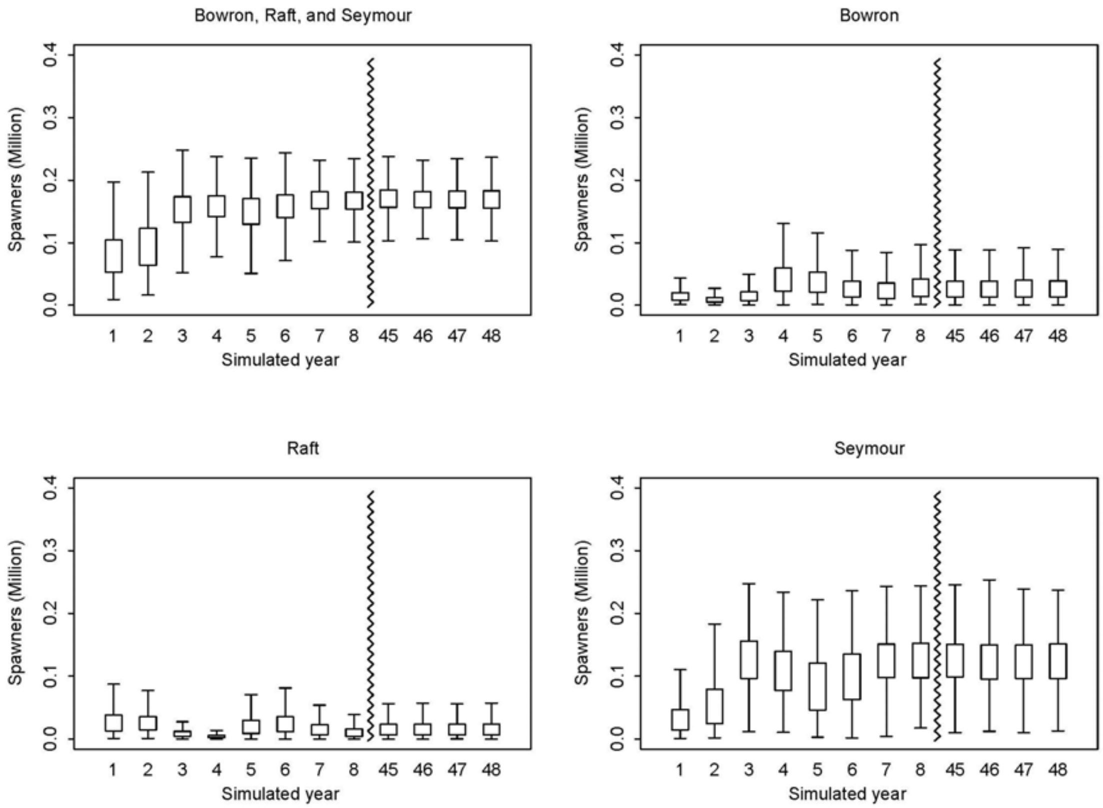


Figure 34: Bowron, Raft, Seymour - Trajectories of escapement for individual stocks, when aggregate is managed to maximize average yearly catch.

Challenge: Extrapolating from Bowron, Raft, and Seymour to the entire Early Summer aggregate

The simulation model used to generate harvest rules only includes stocks for which sufficient spawner-recruit data is available. As a result, harvest rules generated for a given run timing aggregate are only representative of the stocks used to generate the particular harvest rule. For example, the harvest rule for the Early Summer aggregate is based on data for the Bowron, Raft, and Seymour stocks. However, when the harvest rule is applied in-season, the run size is estimated for all of the stocks in the aggregate, not just the Bowron, Raft and Seymour stocks. Therefore the harvest rule needs to be adjusted to account for the other stocks including Fennel, Gates, Nadina, Upper Pitt, Scotch, and other miscellaneous stocks. Estimates of stock composition introduce an additional source of uncertainty.

Stock composition is calculated as the ratio of the abundance of the stocks in the model relative to the total abundance of all stocks in the run timing group. Estimates of stock composition can vary based on the information and time periods used to do the calculation. For the 2004 cycle line and the data from 1980-2001, stock composition calculated based on the pre-season forecast is compared to other calculation methods identified in Table 7. However, results were very similar for calculations using adult spawning escapements or adult returns for each stock. This is quite intuitive given that stocks in the same run group are usually harvested at very similar levels, so proportionally the contribution of modeled stocks will be similar when measured in spawners or returns, as long as there aren't differential en-route losses.

Table 7: Estimated stock composition of the Early Summer aggregate based on three different calculations.

Calculation Method	Contribution of Bowron, Raft, and Seymour
2004 Pre-season Forecast (50% probability level)	16%
Avg. run size (2004 cycle line, 1976-1997 brood years)	23%
Avg. run size (all cycle lines, 1976-1997 brood years)	34%

Also, determining how stock composition, used to calculate escapement targets, can be revised throughout the season will be difficult given the uncertainty in estimates of run composition. The implications of this choice can be substantial. Table 8 shows some examples of the necessary calculations, and illustrates the range of target escapements that results from the different assumption about stock composition. Given the magnitude of that range, the choice of estimate may be as important as the different management objectives.

Table 8: How different estimates of stock composition change the escapement table for the Early Summer aggregate.

The harvest rules shown here correspond to the dotted lines in Figure 31 and Figure 32)

	Strong emphasis on avoiding low catch		**Strong emphasis on avoiding low spawners**	
Run Size for Early Summer aggregate	**1 million**			
Estimated contribution of Bowron, Raft, and Seymour	16%	34%	16 %	34%
Estimated run size for Bowron, Raft, and Seymour	160,000	340,000	160,000	340,000
Target exploitation rate for Bowron, Raft, and Seymour	57.4%	63.0%	6.1%	38.6%
Target exploitation rate for Early Summer aggregate	**57.4%**	**63.0%**	**6.1%**	**38.6%**
Target escapement for Bowron, Raft, and Seymour	68,160	125,800	150,240	208,760
Target escapement for Early Summer aggregate	**426,000**	**370,000**	**93,900**	**614,000**

The choice of which calculation method to use may depend on how quickly the relative contributions of stocks to the total aggregate are changing within an aggregate. If stock contributions are relatively stable over time, then estimates based on average spawners or run size could be used, but if stock contributions are changing rapidly from year to year then some consideration should be given to using estimates based on the pre-season forecast. A very conservative approach could be to calculate stock composition by a number of methods and use the lowest percentage difference. This would result in the lowest run size for Bowron, Raft, and Seymour, and therefore the lowest exploitation rate for a given return of the aggregate (see Table 8). A very low percentage implies that Bowron, Raft, and Seymour represent only a small part of the aggregate.

Implementation challenges introduced by uncertain stock composition:

There are several potential concerns associated with the implementation of harvest rules developed based on a small part of the stocks in an aggregate. In particular, if the calculated stock composition is incorrect, then for a given run size the target exploitation rate applied in-season may be incorrect. There are several conditions that could lead to the use of incorrect estimates of stock composition, and may lead to the application of sub-optimal exploitation rates including:

a) Rapid changes in stock composition within an aggregate may lead to the use of an incorrect estimate of stock composition.

b) If stocks used to determine the aggregate harvest rules represent only a small proportion of all stocks in the aggregate, then making small errors in determining stock composition will have proportionally larger effects on the exploitation rate and target escapement. Even if the estimated stock composition is correct, a sub-optimal exploitation rate may be applied if the stocks used in the model are not representative of the majority of stocks in the aggregate. The harvest rule calculated for a sub-set of stocks is assumed to be optimal for all stocks. This assumption may be problematic if stocks not in the model are smaller, and less productive, than those in the model. This is often the case as smaller, less productive stocks are also poorly assessed and have incomplete or unreliable S-R data.

c) Different methods to calculate the stock composition produce different estimates and thus different escapement targets for a given run size.

It should be noted that these implementation challenges also exist for the current management approach based on escapement targets. The escapement target for an aggregate is a summation of escapement targets for all of the individual stocks in the aggregate. If the escapement target does not include all stocks (as is often the case for miscellaneous small stocks where escapement targets are unknown or not quantified) then the actual escapement for a given run size will be lower than is required (i.e. the exploitation rate will be higher than intended).

Summer run aggregate

The simulation model includes the four main stocks of the Summer aggregate: Late Stuart, Quesnel, Stellako, and Chilko. Of these four, Late Stuart and Quesnel have exhibited 4-year patterns in abundance, and are simulated based on either cyclic or non-cyclic stock dynamics. Stellako and Chilko are modeled as non-cyclic components in an aggregate. In this case either option for the harvest rule is incorrect for half the stocks in the aggregate, which introduces a new element that was not an issue in the previous section covering the results for Early Stuart and Early Summer:

- *How does management based on a cyclic harvest rule affect the non-cyclic components of an aggregate?*
- *How does management based on a non-cyclic harvest rule affect the cyclic components of an aggregate?*

As described earlier, when stocks are modeled in aggregate, all components are subjected to the same exploitation rate, but each component responds to this harvest based on its individual stock dynamics (p. 56). Management objectives relating to catch are evaluated for the aggregate, while objectives relating to spawning escapement are evaluated for each component, and then added together. For example, the objective of avoiding low catch is achieved if the total catch from the aggregate exceeds the benchmark.

Harvest rules for the Summer run aggregate respond to different management objectives just as previously shown for Early Stuart and Early Summer. Sample harvest rules for summer run are included in Chapters 6 and 7.

Figure 35 shows trajectories of escapement for each of the four stocks in the Summer aggregate if they were managed based on a *non-cyclic* harvest rule. This harvest rule attempts to avoid years with low spawner abundance and assumes that the stocks are all *non-cyclic*. Figure 36 shows the same, but for a *cyclic* harvest rule applied to an aggregate of two cyclic and two non-cyclic stocks.

In both cases, spawning escapement remains around current levels for Stellako, and declines for Chilko. Harvest on the aggregate is driven by the more abundant stocks.

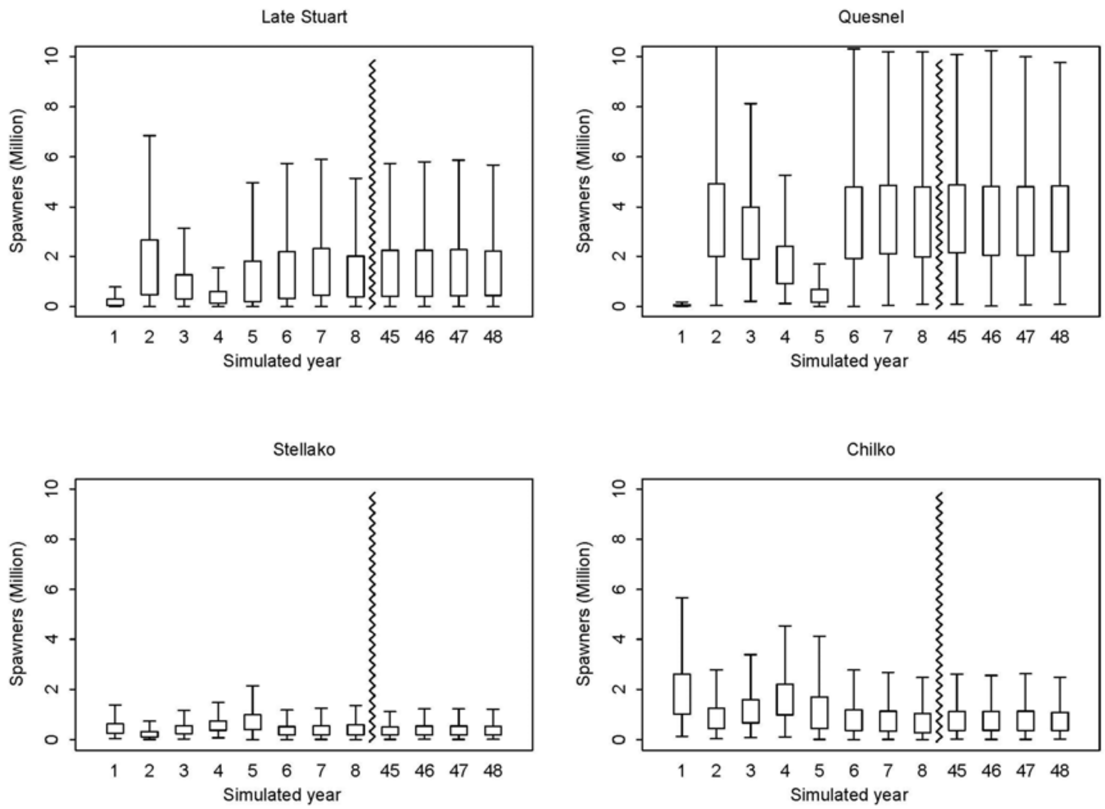


Figure 35: Summer - Trajectories of escapement for individual stocks, when aggregate is managed to avoid low spawner abundance on each stock (*non-cyclic*).

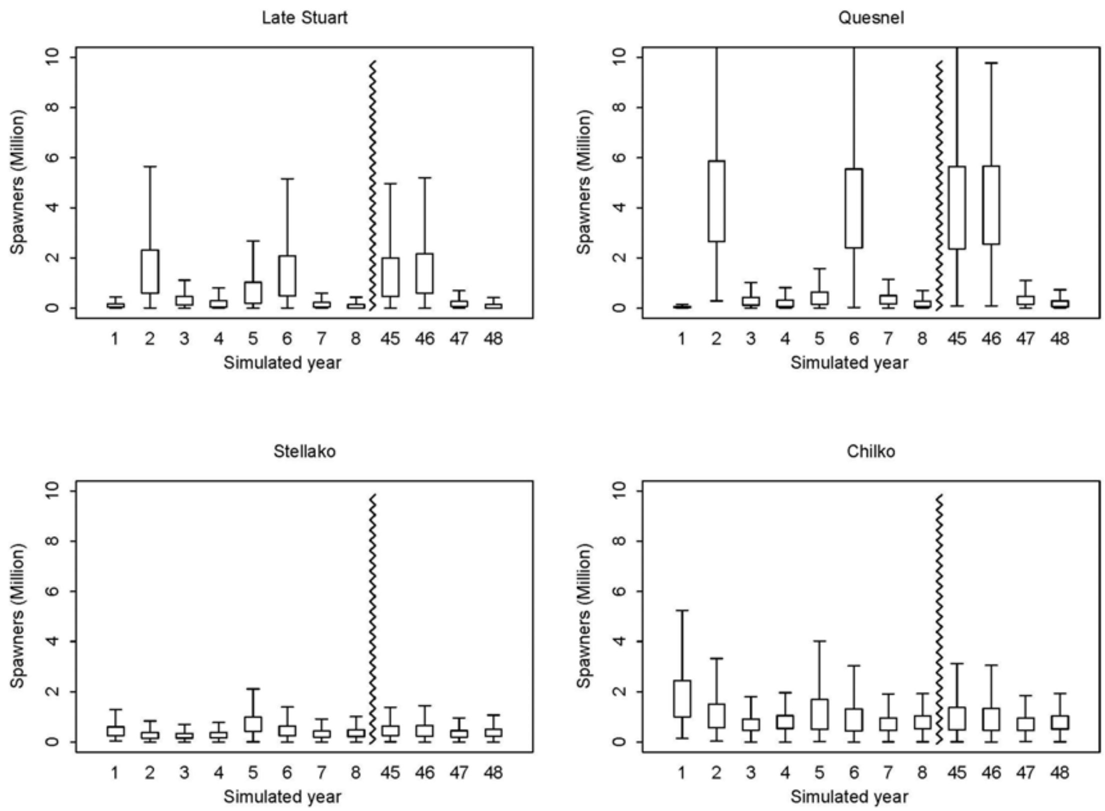


Figure 36: Summer - Trajectories of escapement for individual stocks, when aggregate is managed to avoid low spawner abundance on each stock (*cyclic*).

CHAPTER 6

SIMULATION RESULTS 2: SAMPLE HARVEST RULES FOR 2004

NOTE: This chapter was prepared for the 2004 pre-season planning process, and is retained here to illustrate the evolution of the Spawning Initiative. In particular, this section includes a brief review of harvest plans from 2001 to 2004, and detailed explanations of how to read the harvest rule plots. Chapter 7 was prepared for 2005 pre-season planning, and presents a modified set of harvest rules.

The simulation model developed for this initiative is a tool to explore how the harvest strategy for Fraser River sockeye is shaped by different management objectives and different assumptions about stock dynamics. Chapter 4 described how this model was developed, and how it is used to support the participatory process for this initiative. Chapter 5 provided a description of how the model works. In Chapter 6 we present simulation results for a wide range of scenarios, and we show sample harvest rules used as a comparison during the 2004 season. In Chapter 7 we will discuss the implications of these results for Fraser River sockeye management and make recommendations for the 2005 season.

Test-driving harvest rules

The purpose of the Spawning Initiative is to develop one harvest rule for each of the sockeye management units in order to specify target escapements and target exploitation rates for different run sizes. The participatory process for choosing these harvest rules is described in Appendix 4. One element of benefit in this process is the opportunity to test-drive some of the harvest rules during the 2004 fishing season, without actually implementing a revised approach. The technical team and the Steering Committee closely monitored the actual fishing season, and recorded the considerations that would go into applying a few sample harvest rules. This process has several benefits. First of all, participants were encouraged to consider the practical implications of managing based on exploitation rates. It is expected that differences between harvest rules will be the subject of intense debate which currently goes into developing the escapement tables (next section).

The sample harvest rules presented in the next sections were selected for closer consideration based on the results presented in Chapter 5, feedback received from workshop participants. At this time, they should not be interpreted as recommended management options. They simply serve as comparisons throughout the 2004 fishing season.

2004 Escapement plan based on current approach

In recent years, DFO has used a simple table to summarize the escapement strategy for pre-season planning discussions. This *escapement table* basically shows target escapements and target exploitation rates for a few run size reference points. Table 9 shows the escapement table developed prior to the 2004 season. As the season progresses, in-season information is used to update the estimated run size for each of the stock groups identified in the table; Early Stuart, Early Summer, Summers, Birkenhead and Late. As the run size is adjusted in-season by the Fraser River Panel of the Pacific Salmon Commission, escapement targets are adjusted. For example, if the run size for Early Stuart is between 129,000 and 257,000, the spawner escapement target is 90,000. However, if the run size falls below 75,000 the target exploitation rate is set to zero and all fish are intended for the spawning grounds.

Escapement tables can be plotted as harvest rules, just like those shown in Chapter 5 (e.g. Figure 18). In this graphical form, they can be more easily compared and discussed. Figure 37 shows the harvest rules guiding management decisions for Early Stuart, from 2001 to 2004. Escapement targets changed every year based on pre-season forecasts of returning adults, and developing escapement plans proved to be an exhausting yearly process for all involved. For Early Stuart, the harvest rules were very similar for the three most recent years, but drastically different in 2001, the dominant cycle line year.

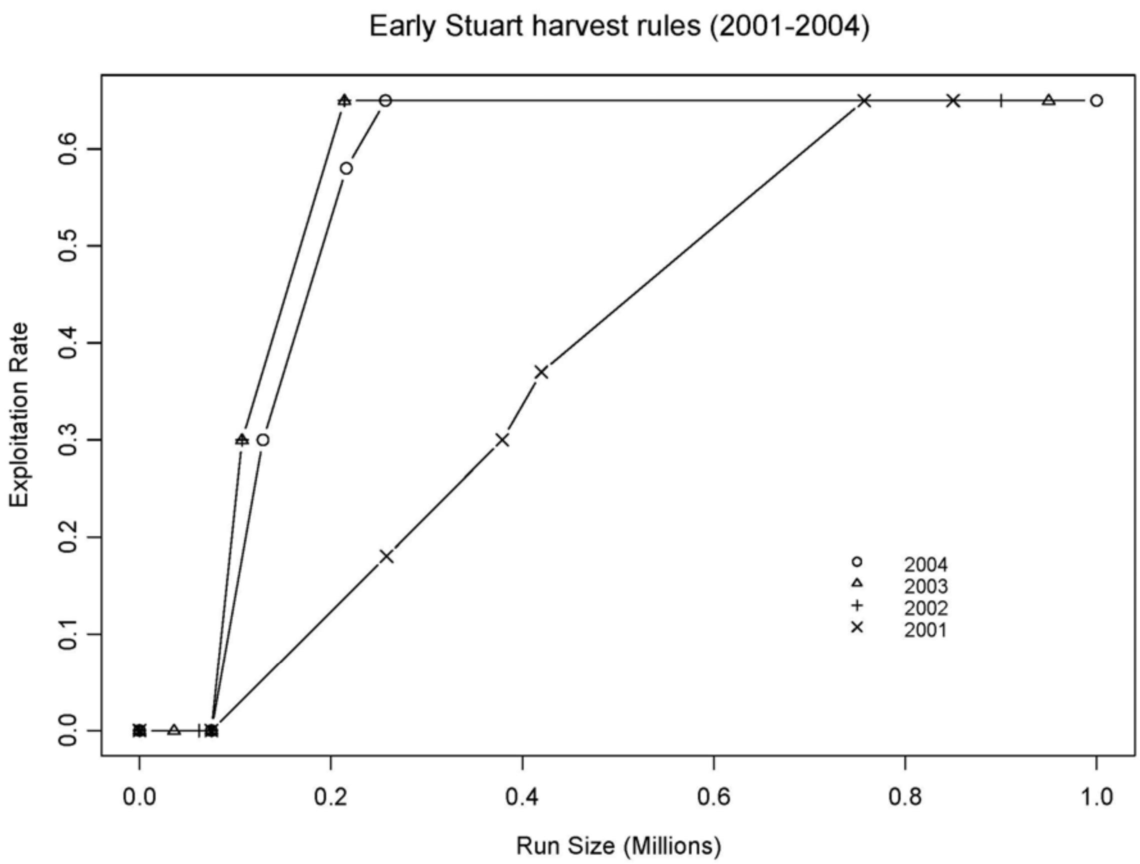


Figure 37: Early Stuart harvest rules 2001-2004

2004 Fraser River sockeye escapement plan using current run size estimates (in thousands of fish). Updated: 03-May-04

50% *Run Size Estimates used in this table!*

Stock Group	Run Size Estimate	Run Size Reference Points (a)		Escapement Target at Run Size	Exploitation Rate Guidelines	Management Adjustment	Exploitation Rate after Mgmt. Adj.	Cycle year adult escapement estimates 1984	1988	1992	1996	2000	Interim Goal
Early Stuart		-	75		0%			48	180	66	88	90	200
		75	129		0 - 30%								
	216	129	257	90	30 - 65%	38	41%						
		257			65 - 65%								
Early Summer		-	235		0 - 15%			125	218	102	363	574	399
		235	571		15 - 65%								
	885	571		310	65 - 65%	105	53%						
Summer		-	2,034		0 - 30%			643	745	635	1,412	1,650	1,424
	3,501	2,034	4,069	1,424	30 - 65%	0	59%						
		4,069			65 - 65%								
Birkenhead		-	104		0 - 15%			40	168	190	60	24	353
(incl. Birk. Type	218	104	253	89	15 - 65%		59%						
Lates)		253			65 - 65%								
true-Late					0 - 15%			69	59	76	139	15	312
(excl. Birk. Type)					15 - 15%								
	100			85	15 - 15%	0	15%						
Sockeye Totals	4,920 *Est. Return*							925	1,370	1,069	2,062	2,353	2,687

a) Reference points based on exploitation rate targets

b) In anticipation of continued high in-river mortality associated with early entry of the Late run into the Fraser River, 15% exploitation rate will reflect measures to protect Late run stocks.

Table 9: 2004 Escapement table based on current management approach

Sample harvest rules for Early Stuart

Four sample harvest rules for Early Stuart are shown here:

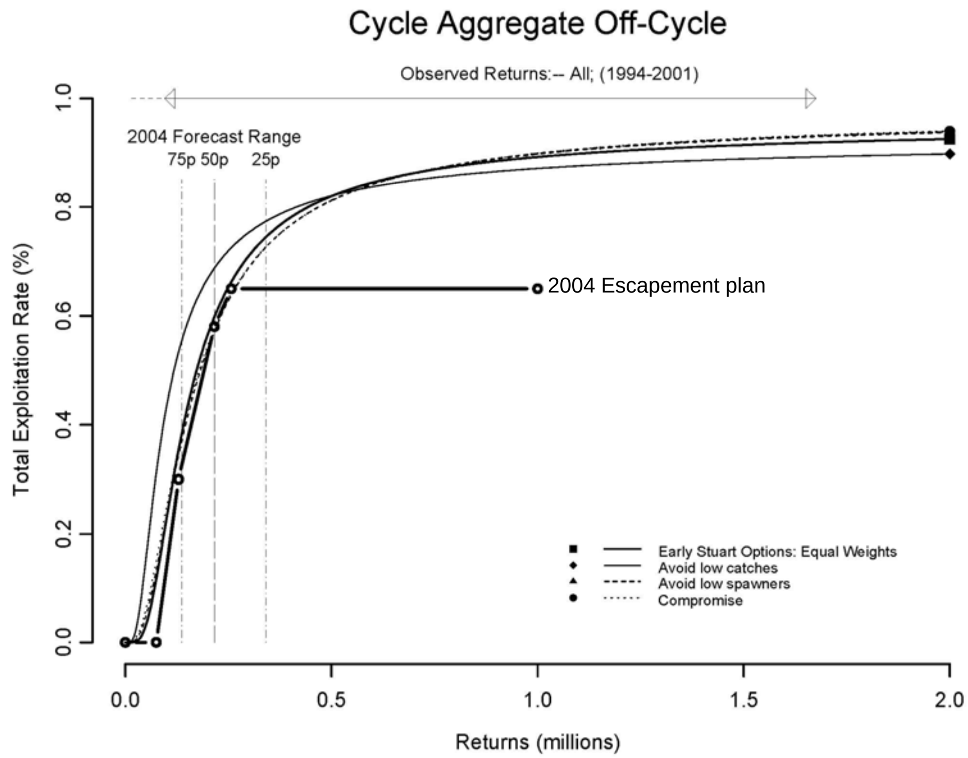
1. Reference scenario, with equal weights on all objectives [1, 1, 1, 1]
2. Moderate emphasis on avoiding low catch [1, 5, 0, 0]
3. Moderate emphasis on avoiding low spawner abundance, with S_{low} benchmark increased to 30% S_{max} [1, 0, 0, 5]
4. Compromise between strong emphasis on avoiding low catch and strong emphasis on avoiding low spawner abundance [1, 10, 0, 10]

Figure 38 shows these four harvest rules for the cyclic stock dynamics. The plot has two panels, showing the harvest rule for off-cycle years on top, and for dominant or subdominant years on the bottom. The 2004 forecast, recent returns, and the 2004 escapement plan are included for reference. Figure 39 shows these harvest rules for the non-cyclic stock dynamics, in which a single harvest rule is applied to all four cycle lines.

As described in Chapter 5 the objective of avoiding years with low catch shifts the harvest rule to the left, prescribing higher exploitation rates. The objective of avoiding low spawner abundance shifts the harvest rule to the right, prescribing lower exploitation rates. For Early Stuart, the compromise between a "*strong emphasis on avoiding low catch*" and a "*strong emphasis on avoiding low spawner abundance*" is quite similar to the reference scenario.

The harvest rules for the off-cycle years are less sensitive to changing management objectives than the non-cyclic and dominant/subdominant harvest rules. These harvest rules most closely match the 2004 escapement plan, with three notable exceptions. First, the harvest rule for the objective of avoiding low catch seems to closely follow the 2004 plan, but the two curves are very steep, so that target exploitation rates actually differ by up to 25%. Second, the harvest rules produced by the model reach exploitation rates of up to 90% at larger run sizes, whereas the 2004 plan is constrained to a maximum exploitation rate of 65%. Third, 2004 plan prescribes 0% exploitation rate for escapements less than 75,000, whereas, some exploitation is allowed by other curves at run sizes below 75,000.

Table 10, Table 11, and Table 12 show three of these harvest rules in tabular form. In-season revisions to run-size estimates are also included.



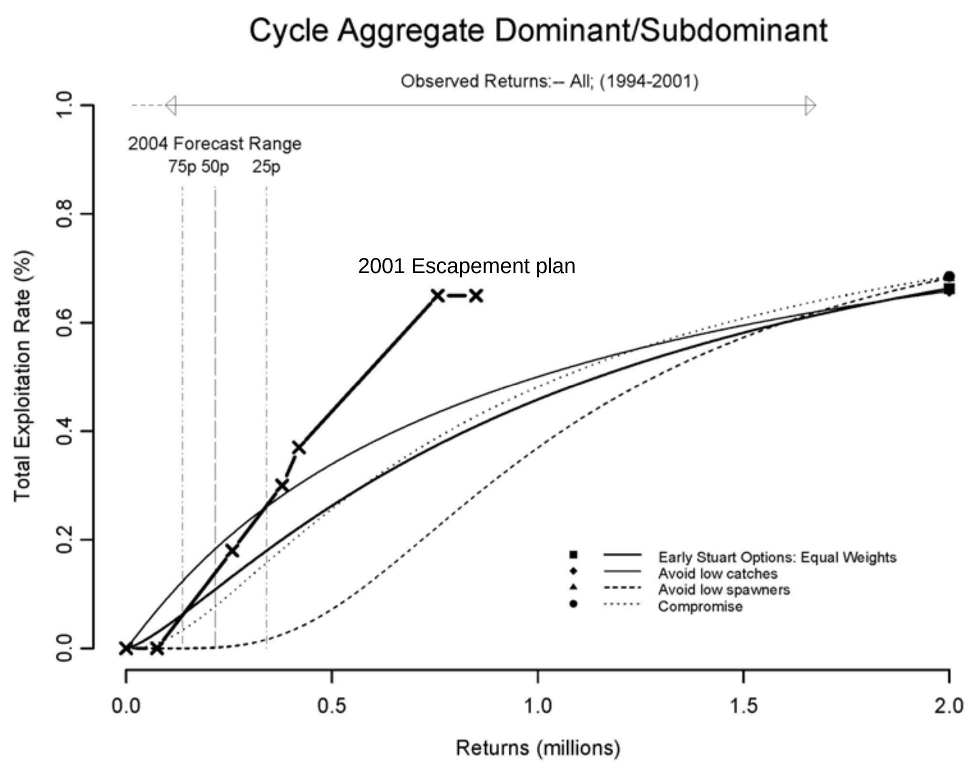


Figure 38: Early Stuart examples (cyclic)

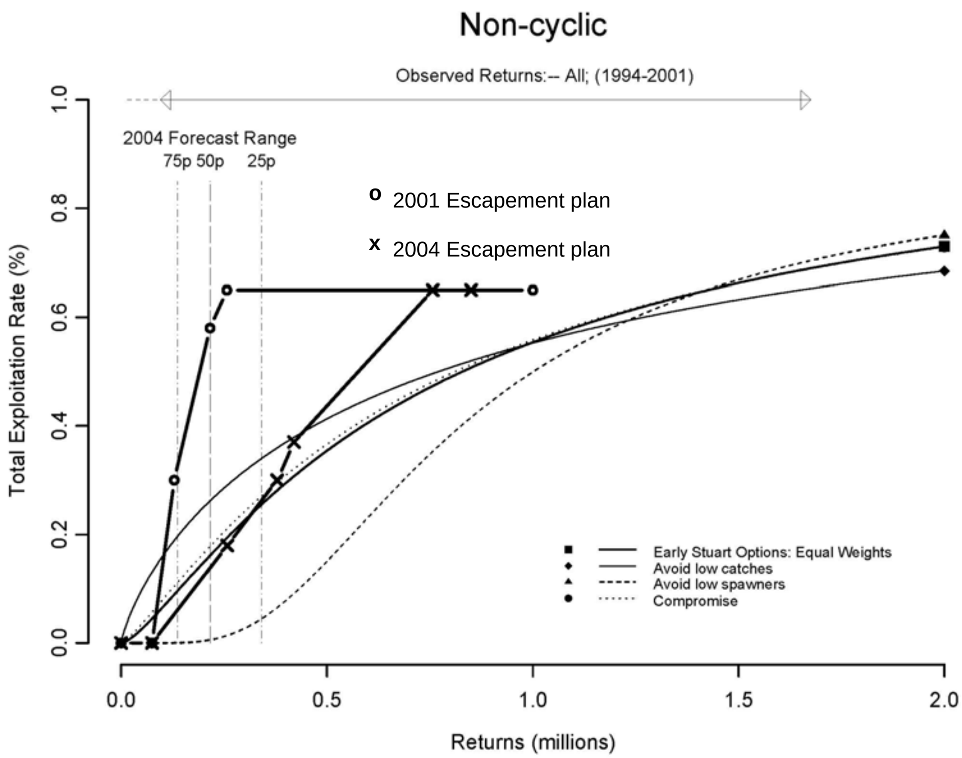


Figure 39: Early Stuart examples (non-cyclic)

	Run Size Reference Point (thousands)	Avoid Low Catch			Avoid Low Spawners			Possible Compromise			2004 Escapement Plan		
		Exploitation rate (%)	Escapement Target at Run Size	Catch Target at Run Size (without mgmt adjustments)	Exploitation rate (%)	Escapement Target at Run Size	Catch Target at Run Size (without mgmt adjustments)	Exploitation rate (%)	Escapement Target at Run Size	Catch Target at Run Size (without mgmt adjustments)	Exploitation rate (%)	Escapement Target at Run Size	Catch Target at Run Size (without mgmt adjustments)
	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	0
	25	2.1	25	1	0.5	25	0	9.9	23	2	0.0	25	0
	50	15.4	42	8	4.9	48	2	32.4	34	16	0.0	50	0
	75	31.1	52	23	13.3	65	10	47.4	40	36	0.0	75	0
	125	52.2	60	65	32.8	84	41	62.4	47	78	27.8	90	35
July 8	**137**	**55.7**	**61**	**77**	**37.2**	**87**	**51**	**64.6**	**49**	**89**	**34.3**	**90**	**47**
July 16	**190**	**65.6**	**66**	**125**	**51.8**	**92**	**99**	**71.0**	**55**	**135**	**52.6**	**90**	**100**
July 21	**200**	**66.9**	**66**	**134**	**54.0**	**92**	**108**	**71.8**	**56**	**144**	**55.0**	**90**	**110**
Pre-season	**216**	**68.7**	**67**	**148**	**57.0**	**93**	**123**	**72.9**	**58**	**157**	**58.3**	**90**	**126**
	250	72.0	70	180	62.8	93	157	75.0	62	188	64.0	90	160
	375	78.7	80	296	75.1	93	282	79.5	77	298	65.0	131	244
	500	82.1	90	411	81.2	94	406	81.8	91	409	65.0	175	325
	750	85.4	110	641	87.1	97	654	84.2	119	632	65.0	263	488
	1,000	87.1	129	872	89.8	102	899	85.5	145	856	65.0	350	650
	1,250	88.2	148	1,100	91.5	107	1,140	86.3	171	1,080	65.0	438	813
	1,500	88.9	167	1,330	92.5	112	1,390	86.9	197	1,300	65.0	525	975
	1,750	89.4	186	1,570	93.3	118	1,630	87.3	223	1,530	65.0	613	1,138
	2,000	89.8	204	1,800	93.8	123	1,880	87.6	248	1,750	65.0	700	1,300
	2,250	90.1	223	2,030	94.3	129	2,120	87.9	273	1,980	65.0	788	1,463

Table 10: Early Stuart escapement table – off-cycle

	Run Size Reference Point (thousands)	Avoid Low Catch			Avoid Low Spawners			Possible Compromise			2004 Escapement Plan		
		Exploitation rate (%)	Escapement Target at Run Size	Catch Target at Run Size (without mgmt adjustments)	Exploitation rate (%)	Escapement Target at Run Size	Catch Target at Run Size (without mgmt adjustments)	Exploitation rate (%)	Escapement Target at Run Size	Catch Target at Run Size (without mgmt adjustments)	Exploitation rate (%)	Escapement Target at Run Size	Catch Target at Run Size (without mgmt adjustments)
	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	0
	25	2.3	24	1	5.8	24	1	2.9	24	1	0.0	25	0
	50	4.7	48	2	9.8	45	5	5.8	47	3	0.0	50	0
	75	7.0	70	5	13.1	65	10	8.4	69	6	0.0	75	0
	125	11.4	111	14	18.6	102	23	13.1	109	16	27.8	90	35
July 8	**137**	**12.4**	**121**	**17**	**19.8**	**110**	**27**	**14.1**	**118**	**19**	**34.3**	**90**	**47**
July 16	**190**	**16.4**	**159**	**31**	**24.3**	**144**	**46**	**18.3**	**155**	**35**	**52.6**	**90**	**100**
July 21	**200**	**17.2**	**166**	**34**	**25.0**	**150**	**50**	**19.1**	**162**	**38**	**55.0**	**90**	**110**
Pre-season	**216**	**18.2**	**176**	**39**	**26.1**	**159**	**56**	**20.1**	**172**	**43**	**58.3**	**90**	**126**
	250	20.6	199	52	28.6	179	72	22.5	194	56	64.0	90	160
	375	27.9	270	105	35.8	241	134	29.9	263	112	65.0	131	244
	500	34.0	331	170	41.3	294	207	35.7	322	179	65.0	175	325
	750	43.2	426	325	49.5	379	371	44.6	416	335	65.0	263	488
	1,000	50.1	500	501	55.3	448	553	51.1	490	511	65.0	350	650
	1,250	55.4	559	693	59.7	504	747	56.0	550	701	65.0	438	813
	1,500	59.6	607	894	63.2	552	949	60.0	601	900	65.0	525	975
	1,750	63.0	648	1,100	66.1	594	1,160	63.2	645	1,110	65.0	613	1,138
	2,000	65.8	684	1,320	68.5	631	1,370	65.9	683	1,320	65.0	700	1,300
	2,250	68.3	715	1,540	70.5	664	1,590	68.2	717	1,530	65.0	788	1,463

Table 11: Early Stuart escapement table – dominant/subdominant

Run Size Reference Point (thousands)		Avoid Low Catch			Avoid Low Spawners			Possible Compromise			2004 Escapement Plan		
		Exploitation rate (%)	Escapement Target at Run Size	Catch Target at Run Size (without mgmt adjustments)	Exploitation rate (%)	Escapement Target at Run Size	Catch Target at Run Size (without mgmt adjustments)	Exploitation rate (%)	Escapement Target at Run Size	Catch Target at Run Size (without mgmt adjustments)	Exploitation rate (%)	Escapement Target at Run Size	Catch Target at Run Size (without mgmt adjustments)
	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	0
	25	5.8	24	1	0.0	25	0	0.3	25	0	0.0	25	0
	50	9.8	45	5	0.0	50	0	2.7	49	1	0.0	50	0
	75	13.1	65	10	0.0	75	0	6.9	70	5	0.0	75	0
	125	18.6	102	23	0.0	125	0	16.4	105	21	27.8	90	35
July 8	**137**	**19.8**	**110**	**27**	**0.0**	**138**	**0**	**18.7**	**112**	**26**	**34.3**	**90**	**47**
July 16	**190**	**24.3**	**144**	**46**	**0.3**	**190**	**1**	**27.2**	**139**	**52**	**52.6**	**90**	**100**
July 21	**200**	**25.0**	**150**	**50**	**0.4**	**199**	**1**	**28.6**	**143**	**57**	**55.0**	**90**	**110**
Pre-season	**216**	**26.1**	**159**	**56**	**0.6**	**214**	**1**	**30.5**	**149**	**66**	**58.3**	**90**	**126**
	250	28.6	179	72	1.2	247	3	34.7	163	87	64.0	90	160
	375	35.8	241	134	6.3	352	24	45.2	206	170	65.0	131	244
	500	41.3	294	207	15.1	425	76	51.8	241	259	65.0	175	325
	750	49.5	379	371	34.8	489	261	59.6	303	447	65.0	263	488
	1,000	55.3	448	553	50.0	501	500	64.0	360	641	65.0	350	650
	1,250	59.7	504	747	60.1	499	752	66.9	414	838	65.0	438	813
	1,500	63.2	552	949	66.9	497	1,000	69.0	465	1,040	65.0	525	975
	1,750	66.1	594	1,160	71.7	496	1,260	70.6	516	1,240	65.0	613	1,138
	2,000	68.5	631	1,370	75.1	498	1,500	71.8	565	1,440	65.0	700	1,300
	2,250	70.5	664	1,590	77.7	502	1,750	72.8	613	1,640	65.0	788	1,463

Table 12: Early Stuart escapement table – non-cyclic

Sample harvest rules for Early Summer

Figure 40 shows the harvest rules for Early Summer from 2001 to 2004, based on the escapement tables used to guide in-season management. While harvest rules for Early Stuart were very similar for 3 out of the last 4 years, they have changed considerably every year for Early Summer. For a run size of about 500,000, target exploitation ranged from about 30% in 2002 to about 65% for 2001. The harvest rules distributed during annual consultations did not fully describe changes in exploitation rate at low run sizes, and different interpretations are possible. The harvest rules plotted in Figure 40 reflect the assumption that the exploitation rate would be reduced gradually, and that there was no minimum run size at which fishing would seize. The grey-shaded box indicates the range of other possible interpretations, which include either a limit point which would trigger fishing closures, or a minimum exploitation rate to allow fisheries targeting other stocks, This lack of clarity emphasizes the need for more explicit harvest rules covering the full range of possible escapement. The Spawning Initiative is working towards this goal.

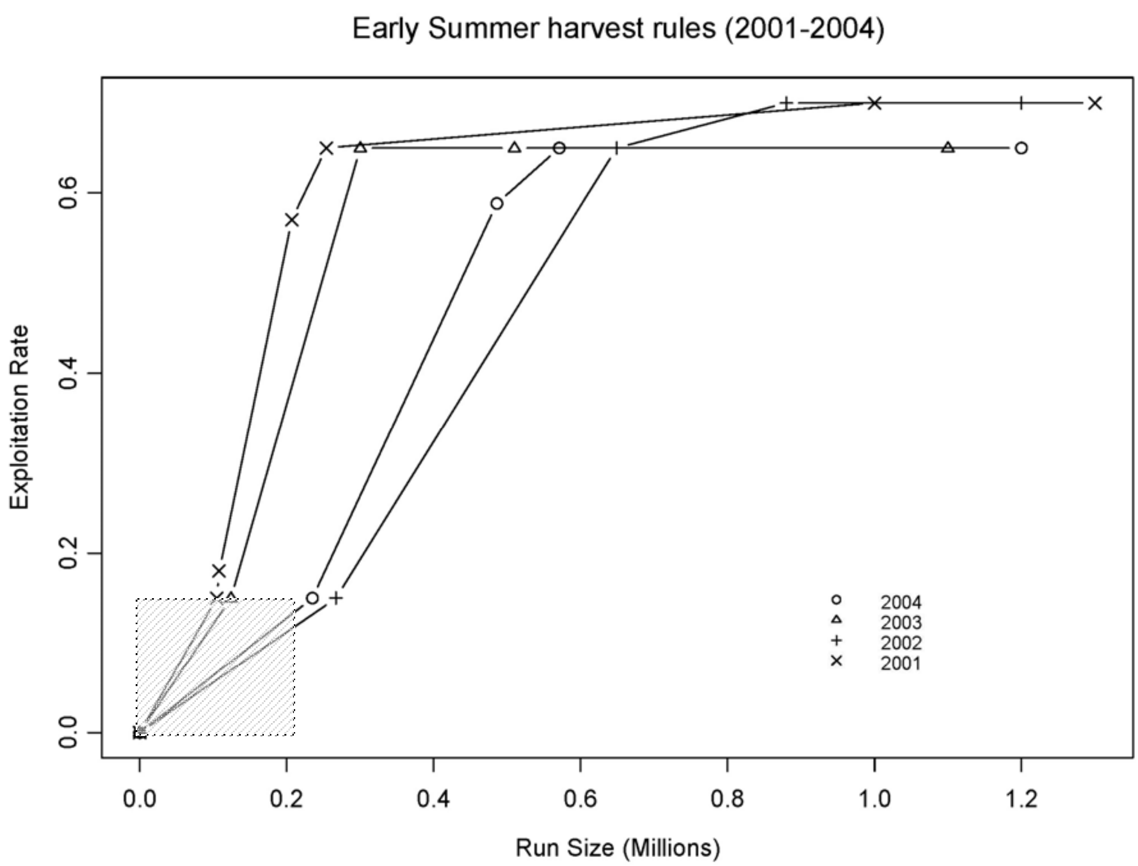


Figure 40: Early Summer harvest rules 2001-2004

Several factors contributed to this fluctuation in harvest rules. Early Summer has been managed towards an interim goal of 399,000 for all four cycle lines, so that fluctuation in returning adults would translate into changing exploitation rate (but relatively fixed escapement). Also, management of Early Summer is constrained by some overlap in run timing with both the Early Stuart and the Summer aggregates, and target exploitation rates for Early Summer are adjusted based on considerations for those other aggregates.

Setting harvest regimes when stocks are at very low abundance is one of the most difficult challenges facing fisheries managers. At very low abundances the details of assumptions become much more important. Assumptions about stock dynamics and the social-economic preferences have a more profound effect and may require more detailed examination than the abstractions of an overall stock recruitment model or the simple preference for avoiding low catch or escapement.

Our understanding and our ability to predict the behavior of these stocks at low abundance is very limited. Factors such as dispensatory mortality or the effect of random events are much more important. Therefore, the application of harvest regimes that have been developed on stock dynamics assumptions that work well for moderate and large stock sizes must be carefully considered if they are to be applied at small stock sizes or low abundance.

Management objectives appear to become more structured at low abundance. Issues about preservation or extinction of stocks come in conflict with sustained fisheries, and the need to preserve fishing fleets and livelihoods. The simple weighted tradeoffs represented in the model may not be adequate to capture the real and conflicted objectives that are present at low stock abundance.

The difficulties with prescribing harvest rules at low abundance has been evidenced in the recent spawning escapement schedules as depicted by the grey/opaque box at the bottom left of Figure 40. Fortunately, the stocks have not ventured into this area recently, at least as stock aggregates. This initiate strives to bring some of the choices of management to the forefront so that everyone with an interest can see, understand and debate the merits of various preferences and stock dynamics assumption. While this initiative has been successful at informing the debate for moderate and large abundance there is still more work needed on characterizing and calculating harvest regimes at low abundance.

Four sample harvest rules for Early Summer are shown here:

1. Reference scenario, with equal weights on all objectives [1, 1, 1, 1]
2. Avoid low catch [1, 5, 0, 0]
3. Avoid low spawner abundance, with S_{low} benchmark increased to 30% S_{max} [1, 0, 0, 5]
4. Compromise between strong emphasis on avoiding low catch and strong emphasis on avoiding low spawner abundance, with S_{low} benchmark increased to 30% S_{max} [1, 10, 0, 10]

Figure 41 shows these four harvest rules, extrapolated from Bowron, Raft, Seymour to the entire

Early Summer aggregate assuming that these three stocks comprise 34% of the total. As shown in Table 8, a percent contribution would shift these four harvest rules further to the right, while the reference information (forecasts, escapement plans) would not shift. For the stock composition used here, thee of the four sample harvest rules resemble the escapement plans used in 2001 and 2004 at low run sizes, but prescribe lower exploitation rates over the range of 300,000 to 1 million.

As described in Chapter 5 the objective of avoiding years with low catch shifts the harvest rule to the left, prescribing higher exploitation rates. The objective of avoiding low spawner abundance shifts the harvest rule to the right, prescribing lower exploitation rates. For Early Summer, the compromise between a "strong emphasis on avoiding low catch" and a "strong emphasis on avoiding low spawner abundance" does not fall between the other two, because the emphasis on both objectives was increased. The harvest rule for this compromise, one of many possible compromises, illustrates that "avoid low catch" has more influence at low run sizes (less than 1 million) , while "avoid low spawners" has more influence at larger run sizes (over 1 million).

For Early Summer, the harvest rule for a possible compromise between avoiding low catches and avoiding low spawners (dotted line) is quite different from the reference scenario, but the two are almost identical for Early Stuart. For Early Summer, the compromise is closer to "avoid low catch" at low run sizes, but shows a considerably reduced exploitation rate on higher run sizes. This is due to the additional element of combining stocks in an aggregate, so that "avoid low catches" applies to the total catch from all component stocks, while "avoid low catches" applies to each individual stock. Given that stocks fluctuate from year to year quite independently of each other (i.e. weak correlation), the exploitation rate for the aggregate is reduced to ensure adequate spawner abundance for each individual stock.

Table 13 shows these harvest rules in tabular form. In-season revisions to run-size estimates are also included.

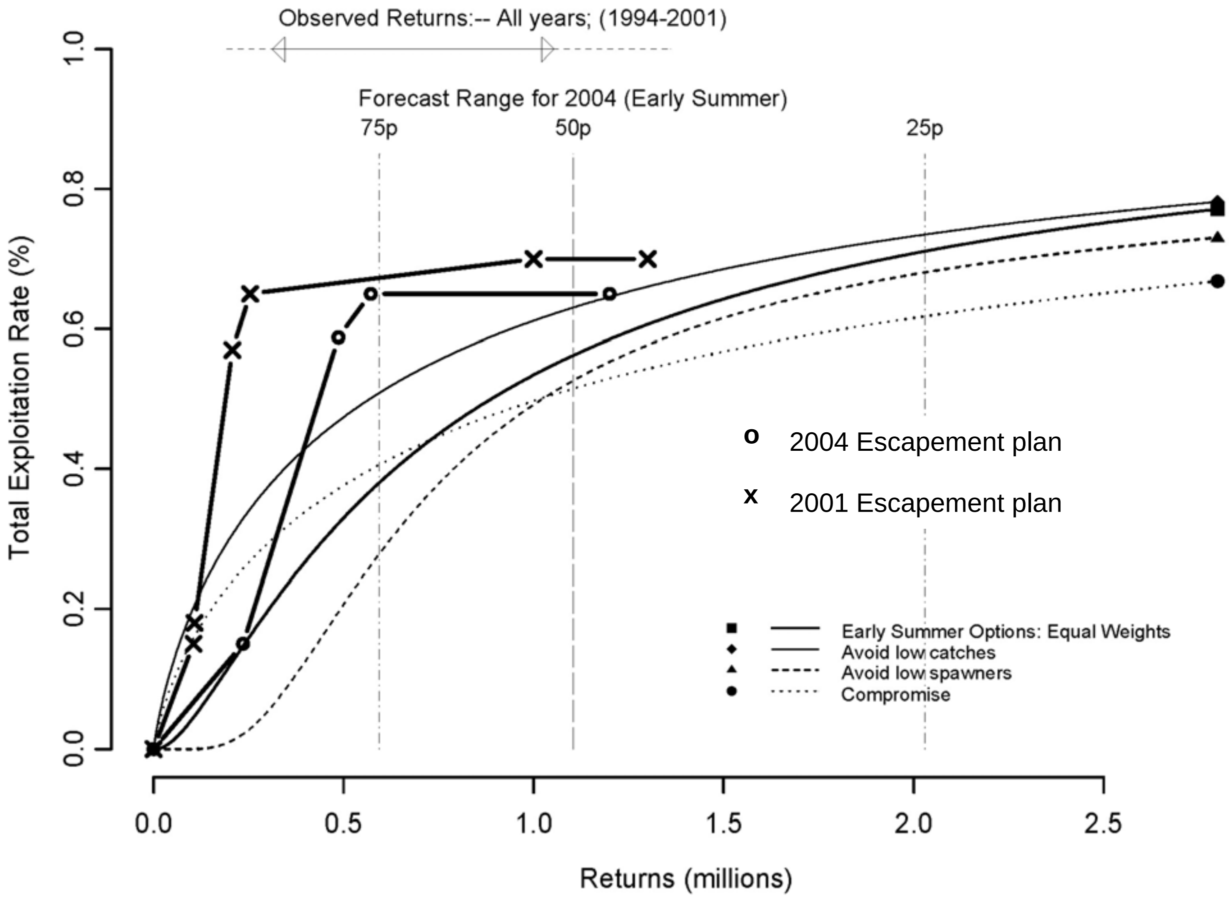


Figure 41: Early Summer examples

EARLY SUMMER OPTIONS (NOTE: Based on the assumption that Bowron, Raft, and Seymour comprise ~34%% of the run)

	Run Size Reference Point (thousands)	Avoid Low Catch: Exploitation rate (%)	Avoid Low Catch: Escapement Target at Run Size	Avoid Low Catch: Catch Target at Run Size (without mgmt adjustments)	Avoid Low Spawners: Exploitation rate (%)	Avoid Low Spawners: Escapement Target at Run Size	Avoid Low Spawners: Catch Target at Run Size (without mgmt adjustments)	Possible Compromise: Exploitation rate (%)	Possible Compromise: Escapement Target at Run Size	Possible Compromise: Catch Target at Run Size (without mgmt adjustments)	2004 Escapement Plan: Exploitation rate (%)	2004 Escapement Plan: Escapement Target at Run Size	2004 Escapement Plan: Catch Target at Run Size (without mgmt adjustments)
	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	0
	50	12.1	44	6	0.0	50	0	9.5	45	5	3.2	48	2
	100	19.6	81	20	0.0	100	0	15.3	85	15	6.4	94	6
	150	25.3	112	38	0.2	150	0	19.8	120	30	9.6	136	14
	250	34.0	165	85	2.7	243	7	26.6	184	67	17.2	207	43
	500	47.4	263	237	20.6	397	103	37.6	312	188	54.4	228	272
	750	55.6	334	417	37.9	466	284	44.7	415	335	65.0	263	488
	1,000	61.2	389	612	49.2	508	493	49.7	503	498	65.0	350	650
Pre-season	**885**	**58.1**	**358**	**498**	**43.3**	**486**	**370**	**47.0**	**454**	**402**	**65.0**	**310**	**575**
27 July	**1,100**	**63.0**	**408**	**693**	**52.5**	**523**	**578**	**51.4**	**535**	**566**	**65.0**	**385**	**715**
31 July	**1,200**	**64.6**	**425**	**776**	**55.3**	**537**	**665**	**52.9**	**565**	**636**	**65.0**	**420**	**780**
7 August	**1,500**	**68.6**	**472**	**1,030**	**61.6**	**577**	**920**	**56.8**	**649**	**849**	**65.0**	**525**	**975**
	1,500	68.6	472	1,030	61.6	577	925	56.8	649	853	65.0	525	975
	2,000	73.3	535	1,470	67.8	644	1,360	61.6	770	1,230	65.0	700	1,300
	2,500	76.6	585	1,920	71.5	713	1,790	65.1	874	1,630	65.0	875	1,625
	3,000	79.1	627	2,380	73.9	783	2,220	67.8	966	2,040	65.0	1,050	1,950
	3,500	81.1	664	2,840	75.6	853	2,650	70.0	1,050	2,450	65.0	1,225	2,275
	4,000	82.6	696	3,310	76.9	924	3,080	71.9	1,130	2,880	65.0	1,400	2,600
	4,500	83.9	724	3,780	77.9	995	3,510	73.4	1,200	3,310	65.0	1,575	2,925

Table 13: Early Summer Run examples

Sample harvest rules for Summer Run

Figure 42 shows the harvest rules for the Summer aggregate from 2001 to 2004, based on the escapement tables used to guide in-season management. While harvest rules for Early Stuart were very similar for 3 out of the last 4 years, they have changed considerably every year for Summer run, just as for Early Summer. For a run size of about 4 million, target exploitation ranged from about 25% in 2004 to about 65% for 2001. The harvest rules distributed during annual consultations did not fully describe changes in exploitation rate at low run sizes, and different interpretations are possible. As for Early Summers, the harvest rules plotted in Figure 42 reflect the assumption that the exploitation rate would be reduced gradually, and that there was no minimum run size at which fishing would seize. The grey-shaded box indicates the range of other possible interpretations, which include either a limit point which would trigger fishing closures, or a minimum exploitation rate to allow fisheries targeting other stocks, This lack of clarity emphasizes the need for more explicit harvest rules covering the full range of possible escapement, and the Spawning Initiative is working towards that goal.

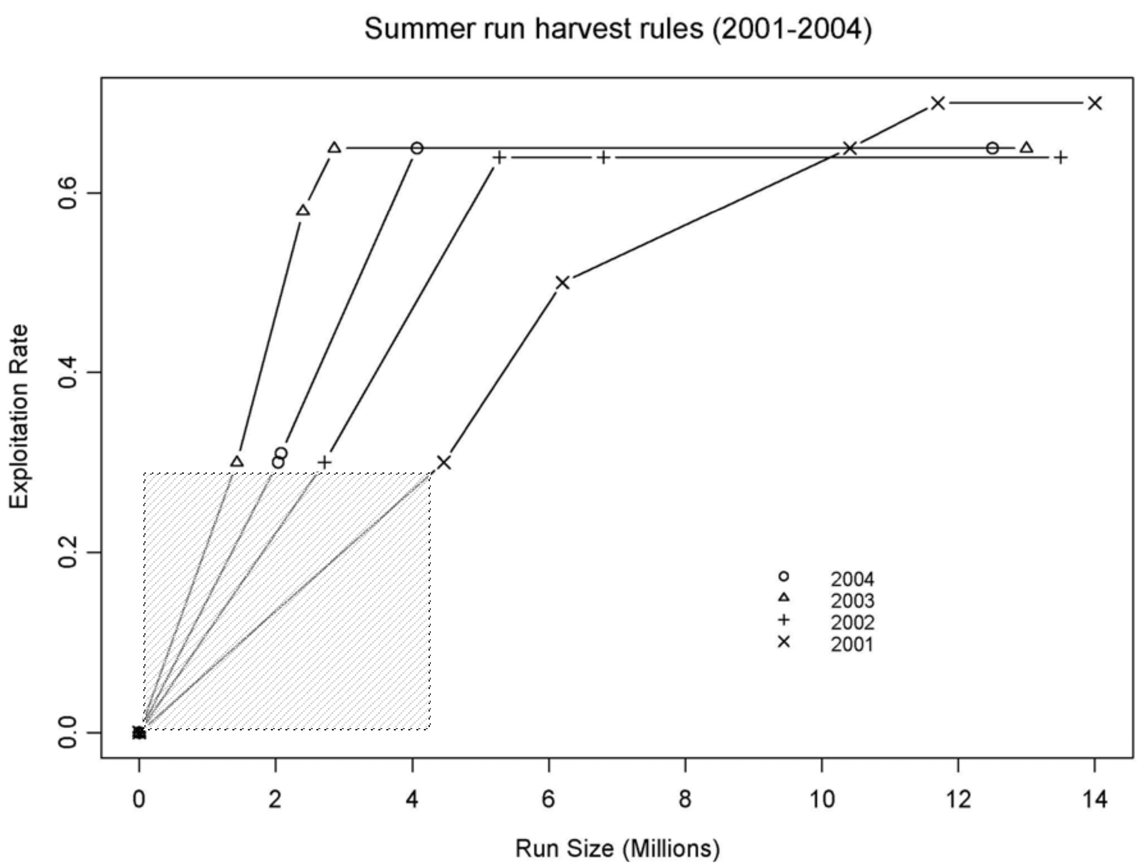


Figure 42: Summer Run harvest rules 2001-2004

Several factors contributed to this fluctuation in harvest rules. The Summer run is the most abundant of the four aggregates, and provides the largest opportunity for harvests. However, the increased overlap in run timing with the Late run stocks (due to their early migration in some recent years) has affected the pattern of exploitation for this aggregate. In addition, two of the four stocks in this aggregate show cyclic patterns in abundance, and interim goals under the rebuilding plan differed for each cycle line (Table 1). Therefore, the year-to-year changes in harvest rules reflect the cyclic pattern in abundance, as well as changing management objectives for mixed-stock fisheries.

Four sample harvest rules for Summer Run are shown here:

1. Reference scenario (equal weights on all objectives)
2. Avoid low catch
3. Avoid low spawner abundance (benchmark increased to 30% S_{max})
4. Compromise between strong emphasis on avoiding low catch and strong emphasis on avoiding low spawner abundance, with S_{low} increased to 30% S_{max} [1, 10, 0, 10]

Figure 43 shows these four harvest rules. The plot has two panels, showing the harvest rule for off-cycle years on top, and for dominant or subdominant years on the bottom. The off-cycle harvest rules would be applied to the aggregate when both Late Stuart and Quesnel are in off years, while the dominant/subdominant harvest rule would be used if Late Stuart and Quesnel are in dominant/subdominant years. Chilko and Stellako are modeled as non-cyclic in both cases.

The 2004 forecast, recent returns, and the 2004 escapement plan are included for reference. Figure 44 shows these harvest rules for the non-cyclic stock dynamics, in which a single harvest rule is applied to all four cycle lines. Just as for Early Summer, the objective of “avoid low catch” applies to the aggregate, while “avoid low spawners” applies to each of the four individual stocks, measured relative to a stock-specific benchmark.

As described for Early Stuart and Early Summer, the objective of avoiding years with low catch tends to shift the harvest rule to the left, prescribing higher exploitation rates. The objective of avoiding low spawner abundance shifts the harvest rule to the right, prescribing lower exploitation rates. Due to the mix of cyclic and non-cyclic stocks in an aggregate, the effect combining the different objectives (reference scenario, compromise) is more complex than for either Early Stuart or Early Summer.

The harvest rules for the off-cycle years are less sensitive to changing management objectives than the non-cyclic and dominant/subdominant harvest rules. These off-cycle harvest rules match the 2003 escapement plan very closely, with one notable exception: the harvest rules produced by the model reach exploitation rates over 90% at larger run sizes, whereas the 2003 and 2004 plans are constrained to a maximum exploitation rate of 65%.

Harvest rules for the dominant/subdominant cycle years fall to either side of the 2001 plan. For the objective of avoiding low catch, target exploitation rates exceed the 2001 plan for run sizes up to about 10 million. The reference scenario (equal weights) prescribes a lower exploitation rate than the 2001 plan for run sizes up to about 6 million, but the two match closely at larger run sizes. As for the Early Summer aggregate, the objective of avoiding low spawners (with the benchmark raised to 30% of S_{low}), decreases the target exploitation rate at larger run sizes.

Similarly, the non-cyclic harvest rules also fall to either side of the 2001 plan. In fact, the harvest rules for dominant/subdominant cycle lines and the non-cyclic harvest rule are quite similar, much more so than for Early Stuart.

Table 14, Table 15, and Table 16 show three of these harvest rules in tabular form, for easier use during the discussions. In-season revisions to run-size estimates are also included.

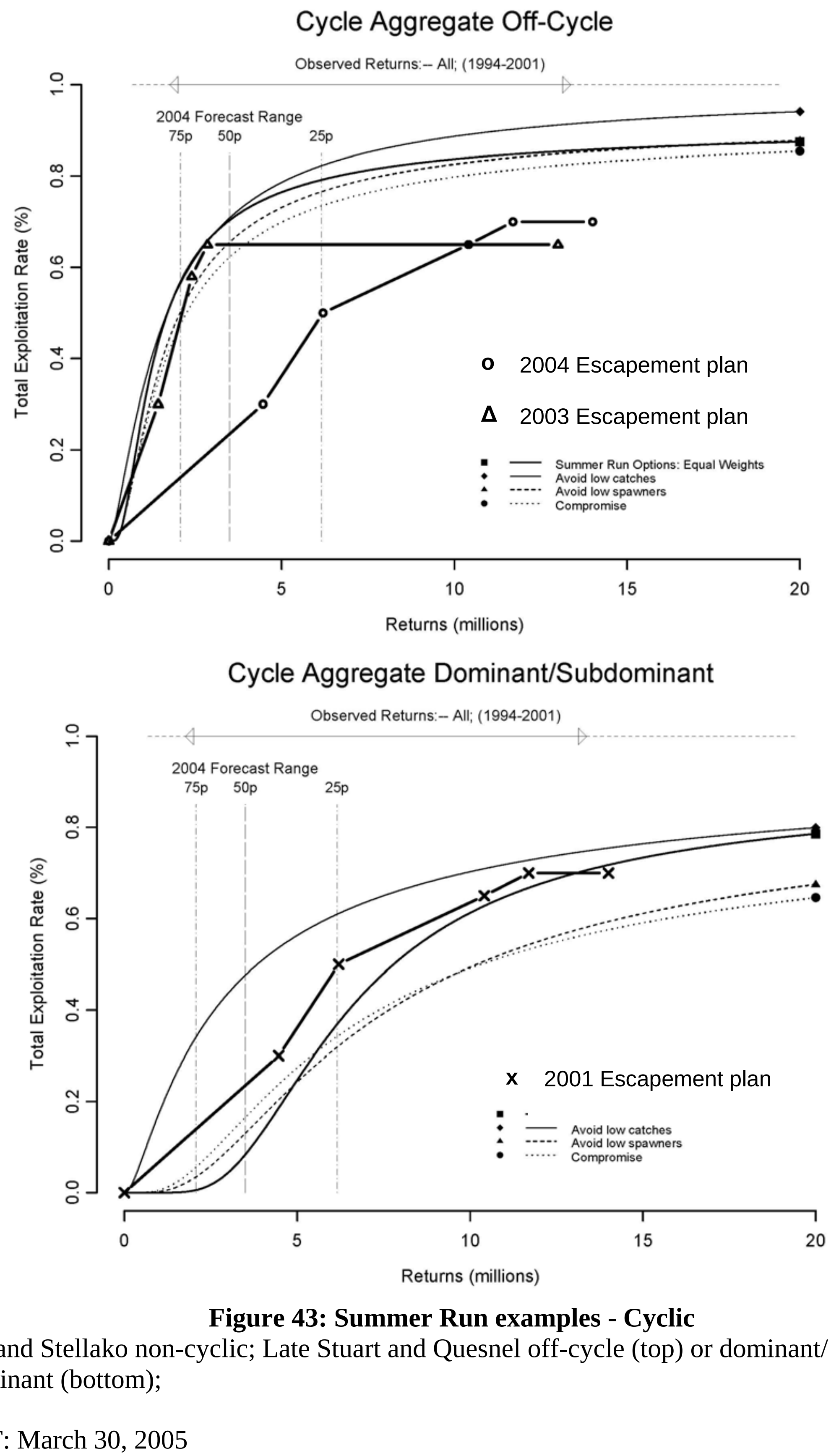


Figure 43: Summer Run examples - Cyclic

Chilko and Stellako non-cyclic; Late Stuart and Quesnel off-cycle (top) or dominant/ subdominant (bottom);

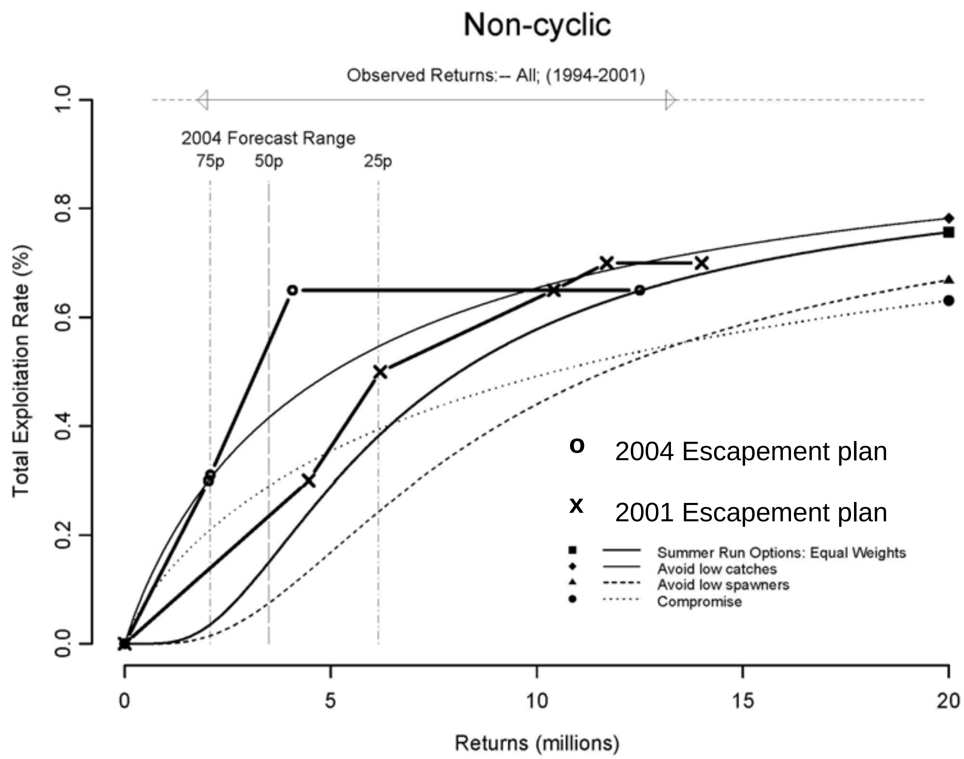


Figure 44: Summer Run examples – All stocks non-cyclic

	Run Size Reference Point (thousands)	Avoid Low Catch			Avoid Low Spawners			One Possible Compromise			2004 Escapement Plan		
		Exploitation rate (%)	Escapement Target at Run Size	Catch Target at Run Size (without mgmt adjustments)	Exploitation rate (%)	Escapement Target at Run Size	Catch Target at Run Size (without mgmt adjustments)	Exploitation rate (%)	Escapement Target at Run Size	Catch Target at Run Size (without mgmt adjustments)	Exploitation rate (%)	Escapement Target at Run Size	Catch Target at Run Size (without mgmt adjustments)
	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	0
	100	1.6	99	2	0.0	100	0	0.0	100	0	1.5	99	1
	200	4.8	191	10	0.5	199	1	0.5	199	1	2.9	194	6
	300	8.5	275	26	1.7	295	5	1.9	295	6	4.4	287	13
	400	12.4	351	50	3.9	385	16	4.0	384	16	5.9	376	24
	500	16.4	419	82	6.7	467	34	6.8	466	34	7.4	463	37
	600	20.2	479	121	10.0	540	60	9.9	541	60	8.8	547	53
	700	23.9	533	167	13.6	606	95	13.2	608	93	10.3	628	72
	800	27.4	582	219	17.2	663	137	16.6	668	133	11.8	706	94
	900	30.6	625	276	20.7	714	187	19.9	722	179	13.3	781	119
	1,000	33.7	664	337	24.2	759	242	23.1	770	231	14.7	853	147
	1,500	46.3	806	695	38.7	920	582	36.6	952	549	22.1	1,168	332
	2,000	55.3	894	1,110	49.0	1,020	982	46.2	1,080	926	29.5	1,410	590
	2,500	62.0	952	1,550	56.3	1,090	1,410	53.2	1,170	1,330	38.0	1,550	950
	3,000	67.0	991	2,010	61.6	1,150	1,850	58.3	1,250	1,750	46.6	1,602	1,398
Pre-season(50p)	**3,500**	**70.9**	**1,020**	**2,480**	**65.5**	**1,210**	**2,300**	**62.3**	**1,320**	**2,180**	**55.2**	**1,568**	**1,932**
August 6	**4,000**	**74.0**	**1,040**	**2,960**	**68.6**	**1,260**	**2,750**	**65.3**	**1,390**	**2,620**	**63.8**	**1,447**	**2,553**
August 13	**3,500**	**70.9**	**1,020**	**2,480**	**65.5**	**1,210**	**2,300**	**62.3**	**1,320**	**2,180**	**55.2**	**1,568**	**1,932**
August 20	**3,200**	**68.7**	**1,000**	**2,200**	**63.3**	**1,180**	**2,030**	**60.0**	**1,280**	**1,920**	**50.1**	**1,597**	**1,603**
	4,000	74.0	1,040	2,960	68.6	1,260	2,750	65.3	1,390	2,620	63.8	1,448	2,552
	4,500	76.5	1,060	3,450	71.1	1,300	3,200	67.8	1,450	3,060	65.0	1,575	2,925
	5,000	78.6	1,070	3,930	73.1	1,350	3,660	69.9	1,510	3,500	65.0	1,750	3,250
	5,500	80.4	1,080	4,420	74.8	1,390	4,120	71.6	1,560	3,940	65.0	1,925	3,575
	6,000	81.9	1,090	4,920	76.2	1,430	4,580	73.0	1,620	4,390	65.0	2,100	3,900
	7,000	84.3	1,100	5,900	78.4	1,510	5,500	75.4	1,720	5,280	65.0	2,450	4,550
	8,000	86.1	1,110	6,890	80.2	1,590	6,420	77.2	1,830	6,180	65.0	2,800	5,200
	9,000	87.5	1,120	7,890	81.5	1,670	7,340	78.6	1,930	7,080	65.0	3,150	5,850
	10,000	88.7	1,130	8,880	82.6	1,740	8,270	79.8	2,020	7,990	65.0	3,500	6,500
	11,000	89.7	1,140	9,870	83.5	1,820	9,190	80.8	2,120	8,890	65.0	3,850	7,150
	12,000	90.5	1,140	10,900	84.3	1,890	10,100	81.6	2,210	9,800	65.0	4,200	7,800
	14,000	91.8	1,150	12,900	85.5	2,030	12,000	82.9	2,390	11,600	65.0	4,900	9,100
	16,000	92.7	1,160	14,900	86.4	2,170	13,800	84.0	2,570	13,400	65.0	5,600	10,400
	18,000	93.5	1,170	16,800	87.2	2,310	15,700	84.8	2,740	15,300	65.0	6,300	11,700
	20,000	94.1	1,180	18,800	87.8	2,450	17,600	85.4	2,910	17,100	65.0	7,000	13,000

Table 14: Summer Run examples - Late Stuart and Quesnel off-cycle; Chilko and Stellako non-cyclic

	Run Size Reference Point (thousands)	Avoid Low Catch			Avoid Low Spawners			One Possible Compromise			2004 Escapement Plan		
		Exploitation rate (%)	Escapement Target at Run Size	Catch Target at Run Size (without mgmt adjustments)	Exploitation rate (%)	Escapement Target at Run Size	Catch Target at Run Size (without mgmt adjustments)	Exploitation rate (%)	Escapement Target at Run Size	Catch Target at Run Size (without mgmt adjustments)	Exploitation rate (%)	Escapement Target at Run Size	Catch Target at Run Size (without mgmt adjustments)
	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	0
	100	0.4	100	0	0.0	100	0	0.0	100	0	1.5	99	1
	200	1.6	197	3	0.0	200	0	0.0	200	0	2.9	194	6
	300	3.3	290	10	0.0	300	0	0.0	300	0	4.4	287	13
	400	5.2	380	21	0.0	400	0	0.0	400	0	5.9	376	24
	500	7.2	464	36	0.0	500	0	0.0	500	0	7.4	463	37
	600	9.3	545	56	0.0	601	0	0.1	600	0	8.8	547	53
	700	11.4	621	80	0.0	700	0	0.1	700	1	10.3	628	72
	800	13.5	693	108	0.1	800	1	0.2	799	2	11.8	706	94
	900	15.5	761	139	0.1	900	1	0.3	898	3	13.3	781	119
	1,000	17.4	827	174	0.2	999	2	0.5	996	5	14.7	853	147
	1,500	26.1	1,110	393	1.2	1,480	17	2.2	1,470	33	22.1	1,168	332
	2,000	33.2	1,340	665	3.1	1,940	62	5.1	1,900	101	29.5	1,410	590
	2,500	39.0	1,530	975	5.9	2,360	147	8.7	2,290	216	38.0	1,550	950
	3,000	43.7	1,690	1,310	9.3	2,720	279	12.6	2,630	377	46.6	1,602	1,398
Pre-season(50p)	**3,500**	**47.7**	**1,830**	**1,670**	**13.0**	**3,050**	**456**	**16.5**	**2,920**	**580**	**55.2**	**1,568**	**1,932**
August 6	**4,000**	**51.0**	**1,960**	**2,040**	**16.9**	**3,330**	**675**	**20.4**	**3,190**	**817**	**63.8**	**1,447**	**2,553**
August 13	**3,500**	**47.7**	**1,830**	**1,670**	**13.0**	**3,050**	**456**	**16.5**	**2,920**	**580**	**55.2**	**1,568**	**1,932**
August 20	**3,200**	**45.4**	**1,750**	**1,450**	**10.8**	**2,860**	**345**	**14.2**	**2,750**	**454**	**50.1**	**1,597**	**1,603**
	4,000	51.0	1,960	2,040	16.9	3,330	675	20.4	3,190	817	63.8	1,448	2,552
	4,500	53.9	2,080	2,430	20.6	3,570	930	24.0	3,420	1,080	65.0	1,575	2,925
	5,000	56.3	2,190	2,820	24.3	3,790	1,220	27.4	3,630	1,370	65.0	1,750	3,250
	5,500	58.5	2,280	3,220	27.8	3,980	1,530	30.5	3,820	1,680	65.0	1,925	3,575
	6,000	60.4	2,380	3,630	31.0	4,150	1,860	33.4	4,000	2,010	65.0	2,100	3,900
	7,000	63.7	2,550	4,460	36.8	4,430	2,570	38.4	4,320	2,690	65.0	2,450	4,550
	8,000	66.3	2,700	5,310	41.7	4,670	3,340	42.6	4,600	3,410	65.0	2,800	5,200
	9,000	68.5	2,840	6,170	45.8	4,880	4,130	46.1	4,850	4,160	65.0	3,150	5,850
	10,000	70.3	2,970	7,040	49.4	5,070	4,940	49.1	5,090	4,920	65.0	3,500	6,500
	11,000	71.9	3,100	7,910	52.4	5,240	5,770	51.7	5,320	5,690	65.0	3,850	7,150
	12,000	73.2	3,220	8,800	55.1	5,400	6,610	53.9	5,540	6,480	65.0	4,200	7,800
	14,000	75.5	3,440	10,600	59.4	5,700	8,320	57.6	5,950	8,070	65.0	4,900	9,100
	16,000	77.3	3,640	12,400	62.7	5,980	10,000	60.4	6,340	9,680	65.0	5,600	10,400
	18,000	78.7	3,830	14,200	65.3	6,240	11,800	62.7	6,720	11,300	65.0	6,300	11,700
	20,000	79.9	4,010	16,000	67.5	6,500	13,500	64.6	7,080	12,900	65.0	7,000	13,000

Table 15: Summer run examples - Late Stuart and Quesnel dominant/subdominant; Chilko and Stellako non-cyclic

	Run Size Reference Point (thousands)	Avoid Low Catch			Avoid Low Spawners			One Possible Compromise			2004 Escapement Plan		
		Exploitation rate (%)	Escapement Target at Run Size	Catch Target at Run Size (without mgmt adjustments)	Exploitation rate (%)	Escapement Target at Run Size	Catch Target at Run Size (without mgmt adjustments)	Exploitation rate (%)	Escapement Target at Run Size	Catch Target at Run Size (without mgmt adjustments)	Exploitation rate (%)	Escapement Target at Run Size	Catch Target at Run Size (without mgmt adjustments)
	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	0
	100	2.4	98	2	0.0	100	0	2.2	98	2	1.5	99	1
	200	4.5	191	9	0.0	200	0	3.7	193	8	2.9	194	6
	300	6.5	281	20	0.0	300	0	5.2	285	16	4.4	287	13
	400	8.4	367	34	0.0	400	0	6.4	375	26	5.9	376	24
	500	10.2	450	51	0.0	500	0	7.6	462	38	7.4	463	37
	600	11.9	529	71	0.0	601	0	8.8	548	53	8.8	547	53
	700	13.5	606	95	0.0	701	0	9.8	632	69	10.3	628	72
	800	15.1	680	121	0.0	801	0	10.8	714	87	11.8	706	94
	900	16.5	752	149	0.0	901	0	11.8	795	106	13.3	781	119
	1,000	18.0	821	180	0.1	1,000	1	12.7	874	127	14.7	853	147
	1,500	24.3	1,140	365	0.4	1,500	6	16.9	1,250	254	22.1	1,168	332
	2,000	29.6	1,410	593	1.3	1,980	25	20.5	1,590	411	29.5	1,410	590
	2,500	34.2	1,650	856	2.8	2,430	70	23.7	1,910	592	38.0	1,550	950
	3,000	38.1	1,860	1,150	4.9	2,860	147	26.5	2,210	795	46.6	1,602	1,398
Pre-season(50p)	**3,500**	**41.6**	**2,050**	**1,460**	**7.5**	**3,240**	**262**	**29.0**	**2,490**	**1,020**	**55.2**	**1,568**	**1,932**
August 6	**4,000**	**44.6**	**2,220**	**1,790**	**10.4**	**3,590**	**417**	**31.3**	**2,750**	**1,250**	**63.8**	**1,447**	**2,553**
August 13	**3,500**	**41.6**	**2,050**	**1,460**	**7.5**	**3,240**	**262**	**29.0**	**2,490**	**1,020**	**55.2**	**1,568**	**1,932**
August 20	**3,200**	**39.6**	**1,940**	**1,270**	**5.9**	**3,020**	**188**	**27.5**	**2,320**	**881**	**50.1**	**1,597**	**1,603**
	4,000	44.6	2,220	1,790	10.4	3,590	417	31.3	2,750	1,250	63.8	1,448	2,552
	4,500	47.4	2,370	2,130	13.6	3,890	612	33.4	3,000	1,510	65.0	1,575	2,925
	5,000	49.8	2,510	2,490	16.8	4,160	843	35.4	3,230	1,770	65.0	1,750	3,250
	5,500	52.1	2,640	2,870	20.1	4,400	1,110	37.2	3,460	2,050	65.0	1,925	3,575
	6,000	54.1	2,760	3,250	23.3	4,610	1,400	38.9	3,670	2,340	65.0	2,100	3,900
	7,000	57.6	2,970	4,040	29.4	4,950	2,060	41.9	4,070	2,940	65.0	2,450	4,550
	8,000	60.6	3,150	4,850	34.9	5,210	2,790	44.6	4,430	3,570	65.0	2,800	5,200
	9,000	63.2	3,320	5,690	39.8	5,430	3,580	47.0	4,770	4,240	65.0	3,150	5,850
	10,000	65.4	3,460	6,550	44.0	5,600	4,410	49.2	5,090	4,920	65.0	3,500	6,500
	11,000	67.4	3,590	7,420	47.8	5,750	5,260	51.1	5,380	5,630	65.0	3,850	7,150
	12,000	69.1	3,710	8,300	51.1	5,880	6,140	52.9	5,660	6,360	65.0	4,200	7,800
	14,000	72.1	3,910	10,100	56.5	6,100	7,920	56.1	6,160	7,860	65.0	4,900	9,100
	16,000	74.5	4,080	11,900	60.7	6,290	9,730	58.7	6,610	9,410	65.0	5,600	10,400
	18,000	76.5	4,230	13,800	64.1	6,460	11,600	61.1	7,020	11,000	65.0	6,300	11,700
	20,000	78.2	4,360	15,600	66.9	6,630	13,400	63.1	7,380	12,600	65.0	7,000	13,000

Table 16: Summer run examples – All stocks non-cyclic

CHAPTER 7

RECOMMENDATIONS FOR 2005

Suggested escapement plan for 2005

Attached is an escapement target plan for Fraser River sockeye stock management units (MUs) in 2005. In past years, recommendations have been based on a rebuilding strategy used since 1989. To deal with some of the shortcomings of the rebuilding strategy, additional options resulting from the Fraser River Sockeye Spawning Initiative were considered for setting the escapement targets for each MU on a trial basis in 2005.

1989 Rebuilding Strategy

Under the rebuilding strategy, interim spawning escapement goals were specified for each management unit to rebuild spawner abundance and maximize productive potential. In any given year, escapement targets have generally been set to maintain the brood year escapement (or interim goals if these have been achieved) and limit maximum exploitation rates to 65% or less; however, other considerations have resulted in deviations from these general guidelines.

The rebuilding strategy did not specify rates of rebuilding for each management unit rather it envisioned a passive rebuilding approach where brood year abundance is maintained and good returns further contributed to escapement producing a positive feedback loop for spawner abundance. A major shortcoming of this strategy is that it does not accommodate contingencies to deal with issues like poor survival that led to decreases in escapement relative to the previous brood year. Setting the escapement target based on brood year escapement under the latter scenario could result in a negative feedback loop where spawner abundance declines over time; a situation that should be avoided to ensure rebuilding over time.

The Spawning Initiative

In addition to the escapement targets and harvest rules based on the approach used in recent years, we have also included a series of harvest rules based on the work from the Spawning Initiative for consideration.

To find a balance between harvest objectives and catch objectives, the Spawning Initiative model allows us to weigh the relative importance of three specific objectives:

1. Keeping spawner abundance above a minimum level each year
2. Keeping total catch (all areas and sectors) above a minimum level each year
   Maximizing the average catch over 50 years

The three harvest rules shown in each of Figure 47, Figure 49, and Figure 51 correspond to the following objectives:

- *Avoid low spawner:* Strong emphasis on keeping spawner abundance above a minimum level each year, with a small emphasis on maximizing the average catch over 50 years. Disregard years with catch below minimum level.

- *Avoid low catch:* Strong emphasis on keeping catch above a minimum level each year, with a small emphasis on maximizing the average catch over 50 years. Disregard years with spawner abundance below minimum level.
- *Compromise:* Very strong emphasis on keeping spawner abundance above a minimum level each year **and** a very strong emphasis on keeping catch above a minimum level each year, with a small emphasis on maximizing the average catch over 50 years.

To evaluate the long-term performance of these harvest rules, the model allows us to simulate the stocks forward into the future while applying the harvest rule each year and including both natural variability and uncertainty in the stock's population dynamics. For the harvest rules shown here, we used the following assumptions:

- *Early Stuart* is modeled as single stock with cyclic patterns in recruitment using independent Ricker curves for dominant/sub-dominant cycles and off-cycles. The harvest rule applied in 2005 is for the dominant/subdominant cycle.
- *Early Summer* is modeled as an aggregate of non-cyclic stocks using Ricker curves for each stock. Due to data limitations, only Bowron, Raft, and Seymour are directly modeled, and the harvest rule is adjusted to account for the expected contribution of these stocks to the full Early Summer aggregate.
- *Summer* is modeled as an aggregate of four stocks, with Late Stuart and Quesnel assumed to have cyclic patterns of recruitment and with 2005 as the dominant/subdominant cycle line while Chilko and Stellako are assumed to be non-cyclic.

The Wild Salmon Policy

In addition, the draft Wild Salmon Policy (WSP) requires the Department to maintain diversity by protecting conservation units (CUs). For Fraser sockeye, the WSP envisions management based on 4 major run timing aggregates (Early Stuart, Early Summer, Summer and Late) or management units (MUs), each group containing a variable number of CUs. Recently, the Late group has been further split into the Birkenhead group and Late group (i.e. Late stocks excluding Birkenhead and some Harrison Lake tributaries) to refine management actions on the Late run which has experienced high migration mortality. While CUs have not been explicitly defined yet, each CU will likely correspond to distinct populations rearing in major lakes, with some further divisions possible (e.g. for run timing groups within lakes). *However, managers will need to be aware of the CUs contributing to each run timing group, and fisheries will be evaluated, in part, in terms of the status of these CUs.* The stock status section provides a snapshot of the current status for some of the key "stocks" within each MU. These stocks will likely be CUs once the determinations are made and some other stocks in the miscellaneous groups may also be identified as CUs (e.g. Chilliwack Lake sockeye in the Early Summer group)

Status of Fraser River sockeye salmon

There has not been a recent review to assess the status of Fraser River sockeye salmon stocks, apart from Cultus Lake sockeye. Table 3 provided earlier is a summary of historical adult spawner abundance and recent trends for each stock.

The recent trend is based on International Union for the Conservation of Nature (IUCN) decline criteria and provides an indication of the relative rate of change of the adult spawner abundance for each stock over the last 3 population cycles (e.g. 12 years). Guidelines for the criteria specify that declines greater than 30% are consistent with *threatened* and greater than 50% are consistent with *endangered* where the reduction or its causes may not have ceased OR may not be understood OR may not be reversible. The decline criteria gives an early warning of deteriorating stock status, however, a more thorough review of other stock status indicators (e.g. freshwater and marine survival, exploitation rates, pre-spawn mortality, etc…) in conjunction with an analysis of the reasons for the decline are required to make status determinations for each stock. Stock status determinations are made by Committee on the Status of Endangered Wildlife in Canada (COSEWIC).

Based on recent trends, spawner abundance in 3 out of 4 MUs is increasing. (Note: large positive percentage changes in the miscellaneous other stock groups may reflect increases in some populations but may also reflect the inclusion of estimates for previously unassessed populations.) However, within each MU there are stocks that have experienced declines greater than 30% including:

- *Early Stuart (-79%)*;
- Early Summer stocks entering the North Thompson system: *Fennell (-46%)* and *Seymour (-43%);*
- *Late Stuart (-69%)* in the Summer group*;* and.
- Late run stocks including: *Cultus (-59%), Portage (-47%)* and *Weaver (-37%).*

The exact mechanisms for the declines in these stocks are unknown. However, Early and Late Stuart sockeye have declined despite different migration timing suggesting that their long freshwater migration, poor freshwater survival, or exposure to fisheries along the length of their migration routes may have contributed. Fennell and Seymour have declined despite recent large increases in the Raft stock, even though all enter marine areas at a similar time and migrate to spawn in the North Thompson system. Despite lower exploitation rates in recent years, most Late run stocks continue to decline likely as a result of high migration mortality in the Fraser River, with the notable exception of the Late Shuswap which has reversed its decline with some improved escapements in the last few years.

Escapement Target Plan Options

For each MU (except Late), the Department recommends an escapement target plan option based on a comparison of options for a **modified status quo approach** and the **spawning initiative approach.** Escapement targets are based on run size forecasts at the 50% probability level for each MU (Table 18). Interim rebuilding goals and cycle line spawner abundance are shown in Figure 46, Figure 48, Figure 50, and Figure 52. Each option considered is also shown as a relationship of exploitation rate as a function of run size (i.e. *harvest rule*) for each MU (Figure 47, Figure 49, and Figure 51).

In the discussion of escapement targets or harvest rules, the term *target exploitation rate* represents the acceptable fishing impacts on a stock that would allow the escapement target to be achieved *in the absence of environmental management adjustments (EMAs).* If an EMA is adopted to account for adverse migration conditions (e.g. warm water), then the exploitation rate would need to be reduced to ensure the escapement target is met. For example, at a run size of 100,000 and an escapement target of 65,000 the *target exploitation rate* would be 35%, but if an

EMA of 10,000 is adopted then the then the exploitation rate after EMA would be reduced to 25% (e.g. 1 – (65K+10K)/100K).

Environmental Management Adjustments (EMAs)
In recent years, substantial environmental management adjustments (EMAs) that further restrict harvest opportunities have been made for some management units (run timing groups) In the 2005 escapement plan options, EMAs have been added to the escapement targets to correct for the historical observed differences between Mission and upstream abundance estimates over all years. This approach makes no prior assumption about environmental conditions in 2005 because we don't yet know whether conditions will be favourable or unfavourable. We expect that the EMAs will be revised to take into account an outlook of environmental conditions before the start of the fishing season (e.g. May 2005).

Early Stuart Management Unit

Issues
2005 is the dominant cycle line for Early Stuart sockeye and has provided harvest opportunities in the past. The 50% p-level forecast of 258,000 on this cycle is well below the historical average run size of 893,000 due to below average fry survival and a decline in spawner abundance in the Driftwood system {e.g. adult spawner abundance for last 3 generations: 430K(1993), 31K (1997), and 16K (2001)} that has been a major production driver in the past. In addition, escapement targets have only been reached or exceeded in 3 of the last 16 years (Figure 45) and the abundance of spawners has declined by 79% over the last 12 years. Further, when the run size has been less than 500,000 (13 of the last 16 years), on average only 55% of the spawner escapement target has been achieved. This is the current situation for 2005 with a forecast return of 258,000 (Table 18).

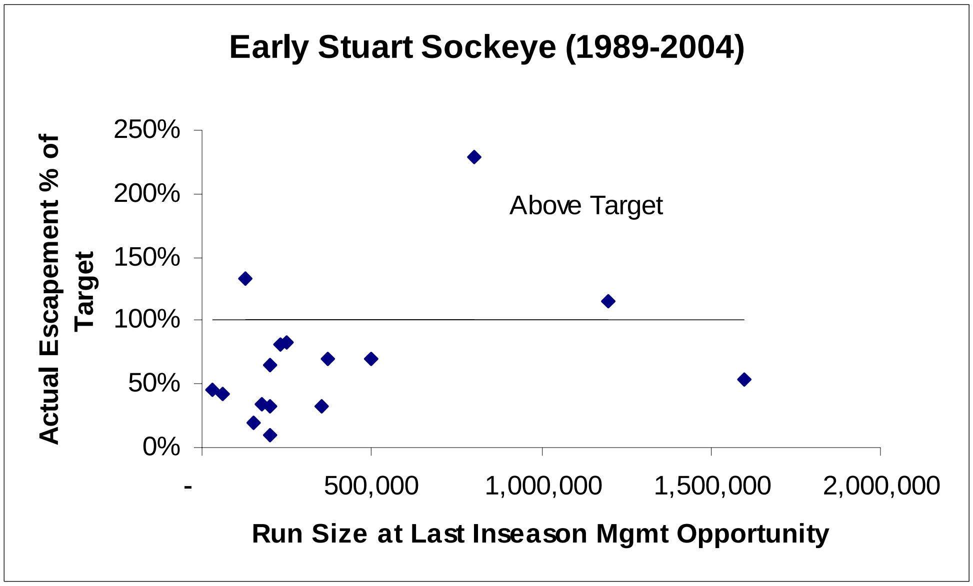


Figure 45: Observed implementation error.
Relationship between the run size where in season management actions can be taken to adjust fisheries and final escapement relative to the target for Early Stuart sockeye from 1989-2004. Solid line indicates achievement of the escapement target; data points below the line indicate actual escapement is less than the target.

The brood year adult escapement of 171,000 was the lowest escapement for this cycle line in the last 5 generations and well below the interim rebuilding goal of 500,000 (Figure 46). Substantial EMAs have also restricted Early Stuart harvest opportunities in recent years. Based on historical differences between Mission and upstream abundance estimates, the mean EMA proportion for Early Stuart sockeye is 54% of the escapement target (e.g. the EMA is 0.54 × escapement target). It should be noted that if the escapement target is adjusted with run size changes, then the EMA will also change as well.

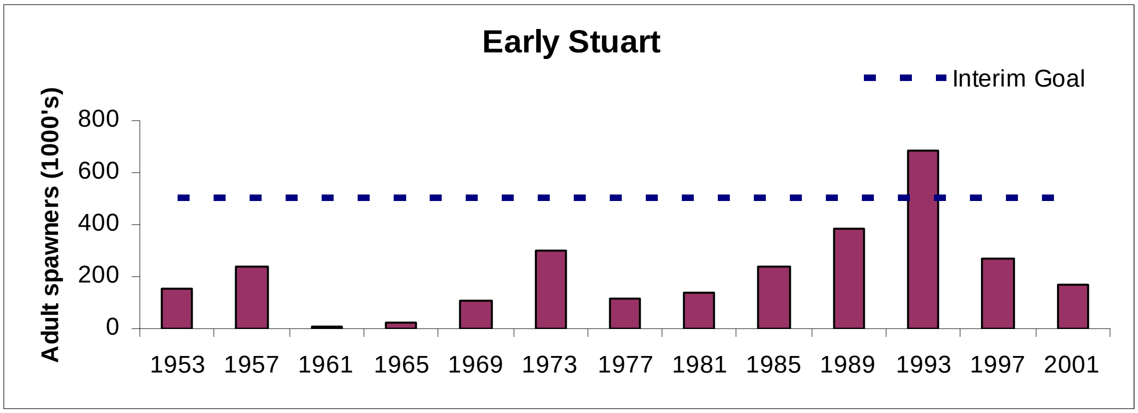


Figure 46: Early Stuart cycle-line adult spawner abundance and interim rebuilding goal.

Escapement Target Options:
There were 2 options developed based on a modified status quo approach and a spawning initiative approach (Table 19). Figure 47 shows the harvest rules for both options below as well as some other options that were explored but not considered further.

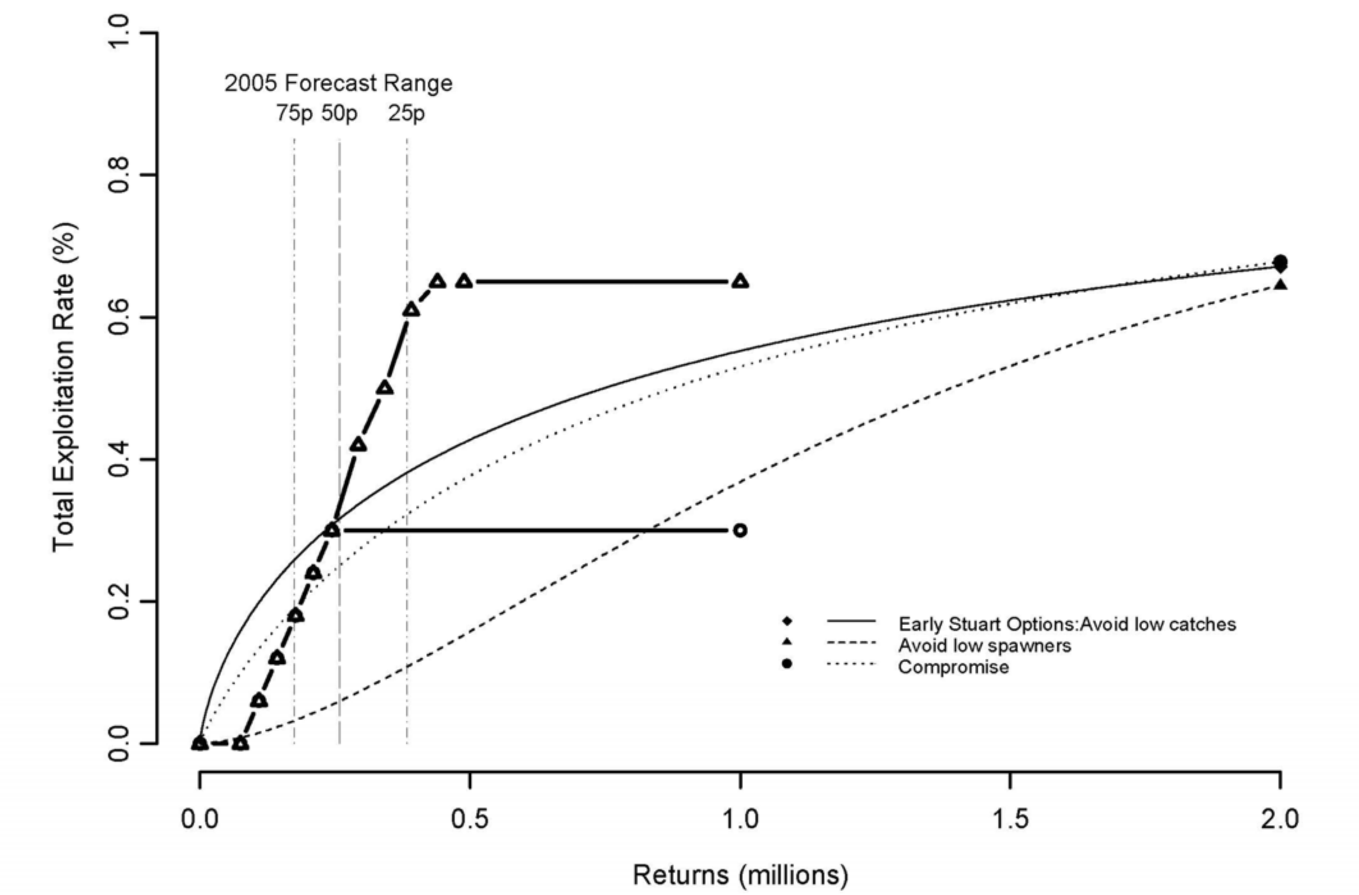


Figure 47: Early Stuart Harvest Rules.
Early Stuart MU exploitation rates (not including EMA adjustments) over a range of run sizes for status quo (open triangles), modified status quo (open circles), and a spawning initiative approach with a strong preference for avoiding low catches (solid diamonds) or low spawners (solid triangles) or a compromise with equal preference for avoiding low catch/low spawners (solid circles). Harvest rules shown are for cyclic dynamics for the dominant/subdominant Early Stuart cycle lines (off-cycle harvest rules will be developed in future years).

1. **Modified Status Quo Approach**– Under the rebuilding strategy, the Early Stuart stock is the only MU that has a defined lower reference point of 75,000 below which fisheries impacts will be managed as close to zero as possible. Under the status quo, the escapement target would usually be set at brood year escapement level of 171,000 and the exploitation rate could increase as high as 65% (without an EMA) (Figure 47). There is considerable potential for this approach to worsen the decline in this stock given the failure to achieve the spawning escapement target in past years. To ensure the brood year escapement is exceeded and help reverse the decline in this stock, a modified approach is proposed. Above the 75,000 lower reference point the escapement target would be set at 70% of the run size allowing for up to a 30% target exploitation rate. The 30% exploitation rate ceiling is a reduction by over ½ from the 65% ceiling used in previous years to compensate for the tendency to achieve only 55% of spawner targets in years when the run size is less than 500,000. At the 50% p-level run size forecast of 258,000 (Table 18) the escapement target would be 181,000, with an EMA of 98,000 (e.g. .54 × 181,000) resulting in a 0% exploitation rate after EMA (Table 19). Given current information there would be no directed harvest of Early Stuart

sockeye possible unless run size increased in season or the EMA was lowered due to favourable migration conditions.

2. **Spawning Initiative Approach-** Harvest rules are presented that encompasses a range of management objectives for the dominant and subdominant cycle lines (Figure 47). The *avoid low catch* objective has the highest target exploitation rates over all run sizes, but would provide for the least rebuilding potential. Conversely, the *avoid low spawners* objective provides the best rebuilding potential, but very little harvest over a wide range of forecast returns. We recommend the *compromise* harvest rule for further comparison because it represents an equal weighting on avoiding low catches and avoiding low spawners and is most similar to the modified status quo approach at run sizes less than 258,000. At the 50% p-level run size forecast of 258,000 (Table 18) the escapement target would be 194,000, with an EMA of 105,000 (e.g. .54 × 194,000) resulting in a 0% exploitation rate after EMA (Table 19). There would be no directed harvest of Early Stuart sockeye possible given current information.

Recommendation
At a run size of 258,000, both options do not provide for directed harvest opportunities given the large EMA required to achieve spawner targets. At run sizes below 75,000, option 2 could provide the potential for some harvest in the unlikely event the EMA was zero. Both options should provide the opportunity to achieve a spawning escapement above the brood year levels that would help to reverse the stock decline. The key difference is that option 2 would provide higher exploitation rates at run sizes above the 50% p-level subject to EMA and reduced rebuilding. Option 2 is recommended for the escapement target on a trial basis in 2005 as it should provide opportunity for rebuilding at the 50% p-level forecast and may provide for some harvest at larger run sizes subject to any EMA (Table 17).

Early Summer Management Unit

Issues
This MU is composed of a diverse group of smaller stocks that spawn throughout the Fraser watershed. The 50% p-level forecast of 718,000 on this cycle is more than double the historical average run size of 316,000 and was largely due to a window closure to protect these stocks from harvest in 2001. Strong rebuilding has occurred for some stocks, but there are stocks of concern that have declined recently including Fennell, Scotch and Seymour, all of which spawn in the Thompson system. Recent constraints on harvesting Late run sockeye have resulted in increased pressure to plan fisheries earlier in the season resulting in the potential for higher harvest impacts on later timed stocks such as Scotch and Seymour within the MU. In season management actions to reduce harvest impacts in 2001 resulted in a record spawner abundance of 213,000 for the aggregate (Figure 48). Note: the brood year spawning escapement is based on the 2001 spawner abundance for all stocks except Pitt where the 2000 brood year was used because the majority of Pitt spawners are 5 years of age. The 213,000 spawners were more than double the previous 4 cycles which were all below 90,000 spawners, but is still below the 599,000 interim rebuilding goal (includes a 200,000 interim goal for Upper Adams on all cycle lines). As with

Early Stuart sockeye substantial EMAs have restricted harvest opportunities in recent years. The mean EMA for Early Summer sockeye is 39% of the escapement target (e.g. the EMA shown in the tables is 0.39 × escapement target minus the Pitt contribution that is not included in the EMA). Note if the escapement target changes then the EMA will also change.

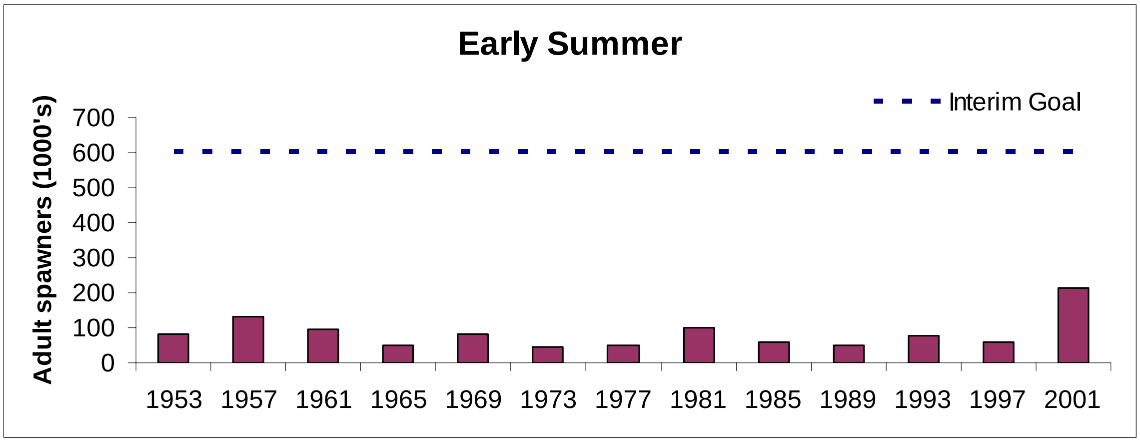


Figure 48: Early Summer cycle-line adult spawner abundance and interim rebuilding goal

Escapement Target Options:
There were 2 options developed based on a modified status quo approach and a spawning initiative approach. Figure 49 shows the *harvest rules* for both options below as well as some other options that were explored but not considered further.

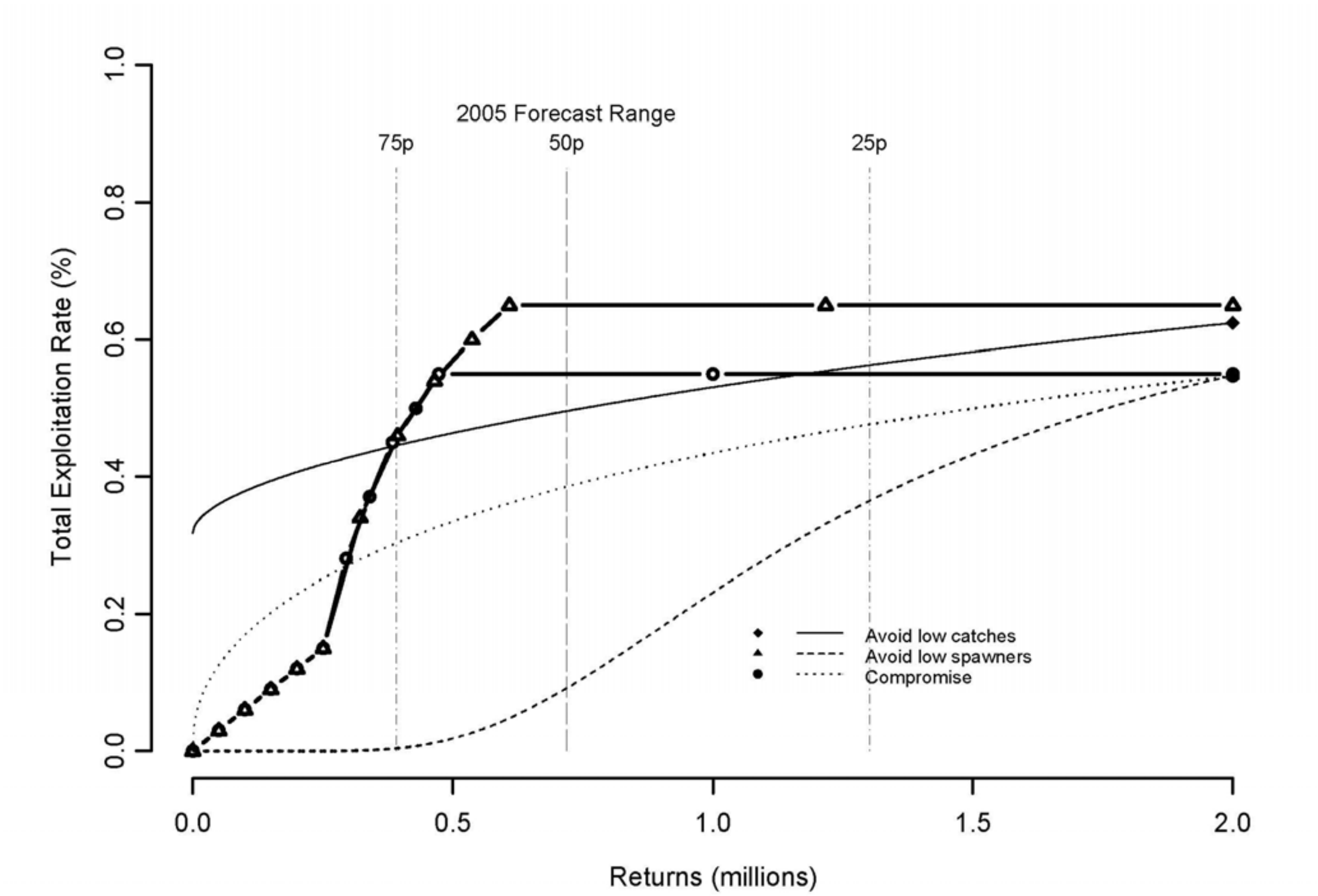


Figure 49: Early Summer Harvest Rules.
Early Summer MU exploitation rates (not including EMA adjustments) over a range of run sizes for status quo (open triangles), modified status quo (open circles), and a spawning initiative approach with a strong preference for avoiding low catches (solid diamonds) or low spawners (solid triangles) or a compromise with equal preference for avoiding low catch/low spawners (solid circles). Harvest rules shown are for all cycle lines as there is little evidence of cyclic patterns in Early Summer stocks.

1. **Modified Status Quo (with 10% Reduction in Exploitation Rate Ceiling)** - The escapement target would be set at the brood year level of 213,000 with a reduction of the maximum exploitation rate ceiling from 65% to 55%. Given the narrow window of opportunity expected for harvesting the abundant Summer MU there is potential for higher exploitation rates on later timed Early Summer stocks (e.g. Scotch and Seymour). The reduced exploitation rate ceiling is intended to protect later timed Early Summer stocks that may be exposed to higher fishing effort. Based on a 718,000 run size (Table 18) and the exploitation rate being constrained to 55%, results in an escapement target of 323,000 (Table 19). An EMA of 111,000 {e.g. 0.39× (323,000 escapement target minus the 43,000 Pitt contribution that is not included in the EMA)} would result in a 40% exploitation rate after EMA or potential catch of 284,000.

2. **Spawning Initiative Approach-** Harvest rules are presented that encompass a range of management objectives for all cycle lines (Figure 49). At a run size of 718,000, all of the management objectives prescribe lower target exploitation rates than the modified status quo. We recommend the *avoid low catch* harvest rule for further comparison because it most closely represents the status quo type rules used in recent years. Based on a 718,000 run size (Table 18) the escapement target would be 362,000, with an EMA of 124,000 {e.g. 0.39× (323,000 escapement target minus the 43,000 Pitt contribution that is not included in the EMA)} resulting in a 32% exploitation rate after EMA and potential catch of 232,000 (Table 19). This approach would provide additional opportunity for rebuilding declining stocks relative to option 1.

Recommendation

Overall, the escapement target for this MU is still well below the interim goal and some stocks returning to the North Thompson have been declining. Exploitation rates at the 50% p-level forecast considered in Option 2 for all of the management objectives are lower than the modified status quo approach in Option 1. Previous analyses (*see report*) done for the spawning initiative approach suggests that there are substantial benefits to rebuilding the stocks in this MU over a wide range of objectives, including avoid low catches. Although option 2 contemplates lower exploitation rates than a modified status quo approach (Figure 49), catches should be at least double the 90,000 catch that resulted from the window closure in 2001. Option 2 also provides a clear strategy for setting escapement targets for this MU in future years compared with the status quo approach. Option 2 is recommended for the escapement target on a trial basis in 2005 (Table 17).

Summer Management Unit

Issues

In 2005, the Summer MU will be the primary target of harvest for all fisheries based on a forecast run size of 11,048,000 that is slightly below the historical average of 11,873,000 (Table 18). These are the dominant cycle lines for Quesnel and Late Stuart stocks. However, there is a concern about the Late Stuart stock due to a 69% decline in spawner abundance. There is also considerable uncertainty about the Quesnel run size forecast (e.g. 1 in 2 chance the run size will fall between 5,076,000 and 9,510,000; Table 18) because the record brood year escapement of over 3.5 million spawners produced a large number, but smaller than average fry (fry weight of 2.6g is 20% less than previous smallest fry on this cycle) and is outside the range of previous observations. The small fry size is a qualitative signal that survival may be less that average and that the 50% forecast may overestimate actual returns. Given the uncertainty associated with the forecast, cautious management planning is warranted so fisheries plans can respond to lower than expected run sizes. Given the later timing of the Quesnel stocks and expected Late run constraints, it is likely that fisheries will be targeted on the earlier components of the Summer run resulting in higher exploitation rates on Late Stuart sockeye which have an earlier run timing. The brood year spawner abundance of 4,683,000 for this MU exceeded the interim goal of 3,124,000; an outcome that has occurred on the last 3 cycles (Figure 50). The mean EMA for Summer sockeye is -3% of the escapement target suggesting an EMA is usually not required to achieve spawning targets. Although EMAs for this MU are not common, record warm temperatures in the Fraser River resulted in large EMAs in 2004.

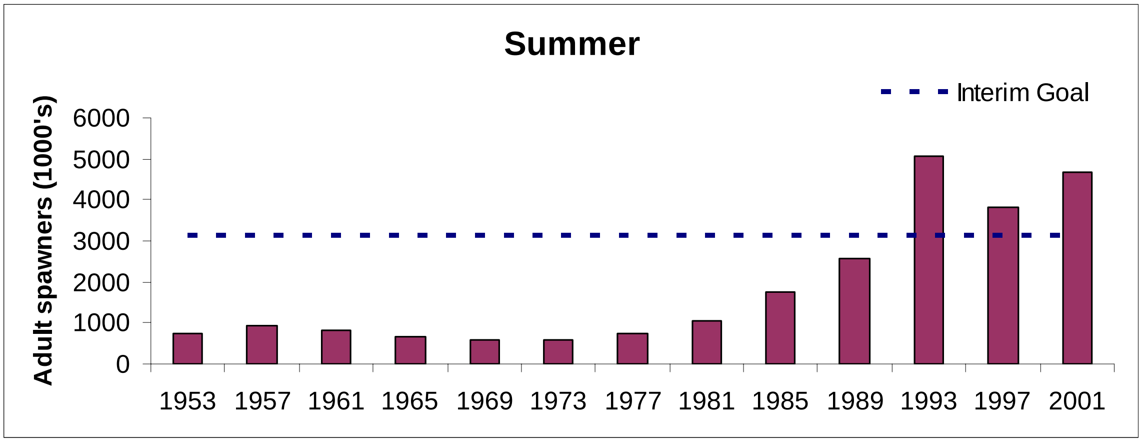


Figure 50: Summer cycle-line adult spawner abundance and interim rebuilding goal.

Escapement Target Options:
There were 2 options developed based on a modified status quo approach and a spawning initiative approach. Figure 51 shows the exploitation rates over a range of run sizes (called *harvest rules*) for both options below, as well other options were explored but not considered further.

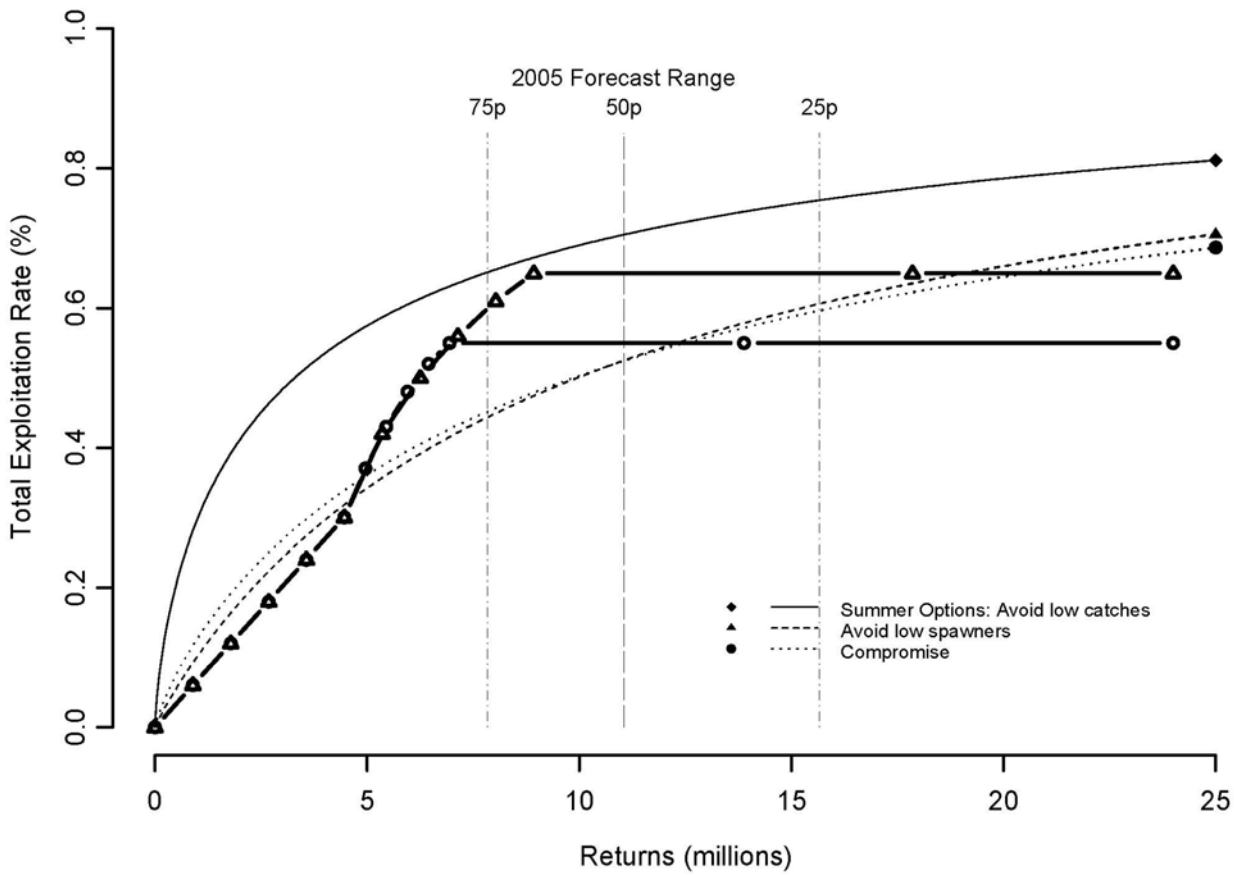


Figure 51: Summer Harvest Rules.
Summer MU exploitation rates (not including EMA adjustments) over a range of run sizes for status quo (open triangles), modified status quo (open circles), and a spawning initiative approach with a strong preference for avoiding low catches (solid diamonds) or low spawners (solid triangles) or a compromise with equal preference for avoiding low catch/low spawners (solid circles). Harvest rules shown are based on cyclic dynamics for the dominant/subdominant Late Stuart and Quesnel cycle lines and non-cyclic dynamics for all Chilko and Stellako cycle lines.

1. **Modified Status Quo (with 10% Reduction in Exploitation Rate Ceiling)** - The escapement target would be set at the interim goal of 3,124,000 with a maximum 55% exploitation rate for the aggregate to protect the Late Stuart stock and later timed Early Summer stocks (e.g. Scotch and Seymour) which have declined recently. This also will provide a buffer against some of the uncertainty in the Quesnel forecast. At the 11,048,000 run size (Table 18), the exploitation rate target would be limited to 55% with a 4,972,000 spawning escapement target and potential maximum catch of 6,076,000 (Table 19). While this option allows for a substantial potential catch, harvest opportunities could be further restricted in the event of a large EMA. In addition, it is unlikely that all of this catch could be taken in traditional mixed stock fishing areas without compromising Early Summer or Late run objectives, given the expected run timing overlaps of these groups with the Summer run.

3. **Spawning Initiative Approach-** Harvest rules are presented that encompass a range of management objectives for the dominant/subdominant Quesnel and Late Stuart cycle lines and non-cyclic dynamics for all Chilko and Stellako cycle lines (Figure 51). As with other MUs, the "*avoid low catch*" objective has the highest exploitation rates over all run sizes compared with other objectives and the modified status quo approach. The "avoid low spawners" and the "compromise" objectives produce similar harvest rules, because the harvest rules for this aggregate of cyclic and non-cyclic stocks are much more sensitive to "avoid low spawners" than to "avoiding low catch". While "avoid low catch" is given the same weight, "avoid low spawners" has more influence. We recommend the *compromise* harvest rule for further comparison because it represents an equal weighting on avoiding low catches and avoiding low spawners and is similar to the modified status quo approach at a run size of 11,048,000. At a run size of 11,048,000 (Table 18) the escapement target would be 5,262,000 resulting in a 52% exploitation rate with a potential catch of 5,786,000 (Table 19). Exploitation rates would increase slightly above the 50% p-level forecast compared with the modified status quo approach.

Recommendation
Options 1 and 2 provide for a similar exploitation rate at the 50% p-level forecast, but Option 2 provides for slightly higher exploitation rates as run sizes increase. Both options prescribe lower exploitation rates if run sizes are less than the 50% p-level, however slightly lower exploitation rates for Option 2 will provide a greater potential for rebuilding Late Stuart sockeye. Option 2 also provides a clear strategy for setting escapement targets for this MU on this cycle line in future years compared with the status quo approach. Option 2 is recommended for the escapement target on a trial basis in 2005 (Table 17).

Birkenhead Group

Includes: Birkenhead, Big Silver, Cogburn, Poole, Samson, Railroad, Green R., Douglas

Issues
This stock group has not been actively managed in the past. However, it has been split from the Late group for management purposes because these stocks have not experienced the high prespawn mortality characteristic of other Late stocks. The Late run forecast of 524,000 (Table 18) was divided into the Birkenhead group and Late MU (excluding Birkenhead group) by removing the adding the portion of the Misc. non-Shuswap stocks entering the Harrison Lake tributaries and to the Birkenhead forecast (209,000, Table 18). The Misc. non-Shuswap forecast (159,000, Table 18) was split based on brood year effective females in Harrison Lake tributaries (e.g. 42.7% of effective spawners) resulting in 68,000 being assigned to the Birkenhead group. This produced a total run size for the Birkenhead group of 277,000. Run timing of the Birkenhead group is overlapped with the tail end of the Summer group and, as a result, is exposed to higher exploitation rates than Late stocks but lower than the Summer stocks.

Escapement Target Options

No options were considered for this group as it is passively managed. The escapement target for the Birkenhead group (Table 17) was calculated by applying the recommended Summer run exploitation rate of 52% to the Birkenhead group forecast. Actual exploitation rates will likely be lower.

Late Management Unit (excluding Birkenhead Group)

Issues

The continuation of the Late run early upstream migration behaviour and associated high en route and pre-spawning mortalities will continue to be a primary driver of management actions in 2005. The Late run forecast is 247,000 (Table 18), excluding the Birkenhead group (277,000), and should be dominated by a return of 108,000 Weaver sockeye. Recent declines in spawner abundance of the Weaver, Portage and *endangered* Cultus stocks continue to pose concerns for this MU. Cultus sockeye are expected to have a very poor return <500 adults (*a preseason forecast may be developed based on the 2004 PSARC methodology*), that will not meet Objective 1 in the National Recovery Strategy which states: *Ensure the genetic integrity of the population by exceeding a four-year arithmetic mean of 1,000 successful spawners with no fewer than 500 successful adult spawners on any one cycle.* It is anticipated that measures to protect Cultus sockeye will be similar to the 10 to 12% exploitation rate ceiling as in 2004.

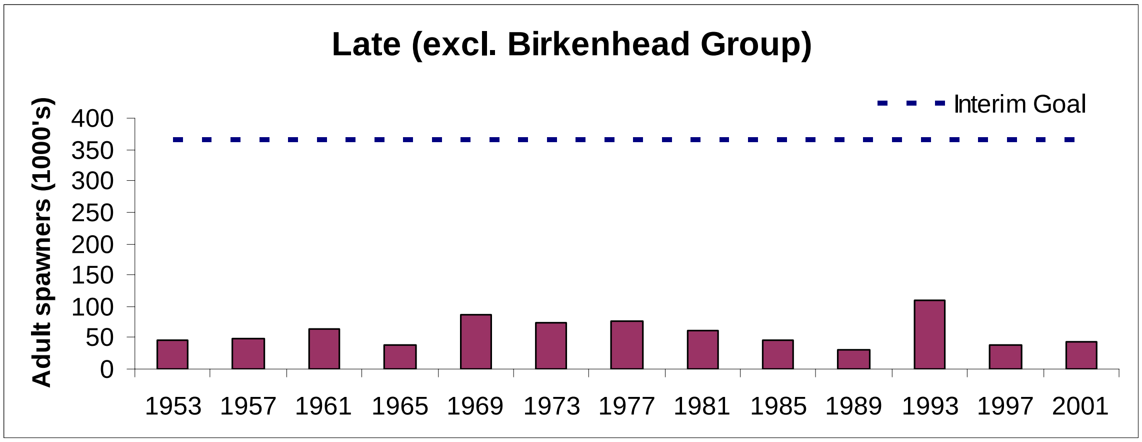


Figure 52: Late (excluding Birkenhead Group) cycle-line adult spawner abundance and interim rebuilding goal.

Recommended escapement target:

The brood year spawner abundance of 44,000 for this MU was a slight increase over the previous year on this cycle, but is still well below the interim goal of 364,000 (Figure 52).

1. **15% Exploitation Rate Ceiling-** A 15% exploitation rate ceiling was adopted for this MU in 2004 to protect Late stocks and allow for some by catch in fisheries targeting abundant Summer stocks. It is likely that a similar plan will be adopted in 2005 given the poor expected return. As in 2004, it is likely that Cultus sockeye constraints may restrict harvest of Late runs in areas seaward of the Fraser / Vedder confluence.

RECOMMENDATION SUMMARY

Management Unit	Option	Forecast Abundance at 50% probability level	Escapement Target at recommended forecast abundance	EMA*	Exploitation Rate after EMA	Maximum Potential Catch
Early Stuart	**2**	258	194	105	0%	0
Early Summer	**2**	718	362	124	32%	232
Summer	**2**	11,048	5,262	0	52%	5,786
Birkenhead group	Passive mgmt.	277	133	n/a	52%	144
Lates (excl. Birk)	**1**	247	210	n/a	15%	37
TOTAL		12,548	6,161	229	49%	6,199
Pink	Status quo	16,318	6,000	n/a	63%	10,318

Table 17: Key variables recommended for development of the 2005 escapement plan for Fraser River sockeye and pink salmon (Numbers of fish in thousands).

**EMA required for the escapement target may exceed the available run size. If this is the case, then the exploitation rate after EMA is zero.*

The full escapement plan based on the recommended options is attached (Table 19).

General Constraints

The recommended escapement targets represent the number of adult spawners required in terminal spawning areas. The difference between the run size and the escapement target represents the potential maximum catch, or total mortality if expressed as fraction of the available run. Other considerations may result in decreases in available catch to compensate for:

- Implementation errors associated with achieving escapement targets
- Revised environmental management adjustments to compensate for poor environmental conditions that are expected to lead to high migration mortalities.
- Differing management objectives for MUs (e.g. Early Summer vs. Summer vs. Late) resulting in foregone catch in mixed stock fishery areas.
- Conservation concerns for other stocks or species (e.g. Sakinaw sockeye, Cultus sockeye, Interior Fraser coho) that limit mixed stock fishery opportunities.

Sockeye stock/timing group	Forecast model[b]	Meanc Run Size[c]		Probability of Achieving Specified Run Sizes[a]				
		all cycles	2005 cycle	0.25	0.5	0.75	0.8	0.9
Early Stuart	Fry	**348,000**	**893,000**	**383,000**	**258,000**	**175,000**	**158,000**	**120,000**
Early Summer		**489,000**	**316,000**	**1,301,000**	**718,000**	**391,000**	**338,000**	**224,000**
Fennell	Ricker	28,000	18,000	74,000	40,000	22,000	19,000	13,000
Bowron	Power	23,000	14,000	44,000	28,000	18,000	16,000	12,000
Raft	Power	25,000	20,000	182,000	106,000	62,000	54,000	38,000
Gates	R/S	68,000	51,000	103,000	57,000	31,000	27,000	18,000
Nadina	Fry	75,000	76,000	194,000	106,000	58,000	50,000	33,000
Pitt	Power	57,000	81,000	152,000	88,000	51,000	45,000	31,000
Seymour	Cmean	156,000	27,000	37,000	20,000	11,000	9,000	6,000
Scotch	Power	57,000	29,000	28,000	12,000	5,000	4,000	2,000
Misc[d]	R/S	-	-	487,000	261,000	133,000	114,000	71,000
Summer		**5,800,000**	**11,873,000**	**15,658,000**	**11,048,000**	**7,834,000**	**7,196,000**	**5,747,000**
Chilko	Pooled	1,887,000	1,520,000	2,870,000	2,087,000	1,518,000	1,402,000	1,135,000
Quesnel	Ricker	2,536,000	7,402,000	9,510,000	6,948,000	5,076,000	4,694,000	3,813,000
Stellako	Ricker	532,000	343,000	843,000	562,000	375,000	339,000	259,000
Late Stuart	Cmean	845,000	2,608,000	2,435,000	1,451,000	865,000	761,000	540,000
Late		**3,378,000**	**1,070,000**	**974,000**	**524,000**	**279,000**	**239,000**	**156,000**
Birkenhead	Power	522,000	527,000	375,000	209,000	117,000	101,000	69,000
Late Shuswap	Ricker	2,316,000	92,000	33,000	18,000	9,000	8,000	5,000
Cultus	Power	21,000	4,000	<500	<500	<500	<500	<500
Portage	Power	63,000	87,000	47,000	23,000	11,000	9,000	6,000
Weaver	R/S	456,000	360,000	207,000	108,000	57,000	48,000	31,000
Misc Shuswap[e]	R/S	-	-	14,000	7,000	4,000	3,000	2,000
Misc. non-Shuswap[f]	R/S	-	-	298,000	159,000	81,000	70,000	43,000
TOTAL		**10,015,000**	**14,152,000**	**18,316,000**	**12,548,000**	**8,679,000**	**7,931,000**	**6,247,000**
Pink	Fry, Salinity		**11,520,000**	**22,761,000**	**16,318,000**	**11,698,000**	**10,734,000**	**8,450,000**

Table 18: 2005 Fraser River sockeye salmon forecasts at specified probability levels of achieving different run sizes.
a probability that the actual run size will exceed the specified projection **b** see citation in footnote 2 for details **c** 1980-2002 mean
d unforecasted miscellaneous Early Summer stocks **e** unforecasted miscellaneous Late stocks **f** based on multiple regression using fry and salinity (July-Aug; see citation in footnote 1 for details)

Table 19: Escapement plan based on recommended options for 2005.

Stock Group	Run Size Estimate	Run Size Reference Points (a)		Option 1: Modified Status Quo Escapement Target at Run Size	Exploitation Rate Guidelines	Environmental Management Adjustment (c)	Exploitation Rate after EMA	Option 2: Spawning Initiative Escapement Target at Run Size	Exploitation Rate Guidelines	Environmental Management Adjustment (c)	Exploitation Rate after EMA	Cycle year adult escapement estimates 1985	1989	1993	1997	2001	Interim Goal
Early Stuart		-	75		0%				0 - 10%			238	385	688	266	171	500
		75	244		0 - 30%				10 - 24%								
		244	244		30 - 30%				24%								
	258	244	2,000	181	30 - 30%	98	0%	194	24 - 68%	105	0%						
Early Summer		-	251		0 - 15%				0 - 42%			59	51	76	59	213	599
		251	473		15 - 55%				42 - 46%								(b)
	718	473	2,331	323	55 - 55%	111	40%	362	46 - 65%	124	32%						
Summer		-	4,463		0 - 30%				0 - 34%			1,738	2,557	5,072	3,807	4,683	3,124
		4,463	6,942		30 - 55%				34 -43 %								
	11,048	6,942	25,000	4,972	55 - 55%	0	55%	5,262	43 - 69%	0	52%						
Birkenhead		-	147		0 - 15%							12	29	246	52	57	342
(incl. Birk. Type	277	147	277	125	15 - 55%	0	55%	133		0	52%						
Lates)		277			55 - 55%												
true-Late		-	-		0 - 15%							47	30	110	38	44	322
(excl. Birk. Type)		0	-		15 - 15%												
(d)	247	0		210	15 - 15%	0	15%	210		-	15%						
Sockeye Totals	12,548 *Est. Return*			5,810		208		6,161		229		2,094	3,052	6,192	4,222	5,168	4,887
												1995	1997	1999	2001	2003	
Pink		-	7,059		0 - 15%							7,291	2,890	3,453	19,930	24,283	6,000
	16,318	7,059	17,143	6,000	15 - 65%		63%										
		17,143			65 - 70%												

a) Reference points based on exploitation rate targets
b) Interim goal includes previous amount of 399K plus 200K for Upper Adams from the 1988 Rebuilding Strategy.
c) Environmental management adjustments (EMAs) are added to the escapement targets to correct for the actual differences between Mission and upstream abundance estimates over all years. This approach makes no prior assumption about environmental conditions because we don't yet know whether conditions will be favourable or unfavourable in 2005. We expect that the EMAs will be revised to take into account an outlook of environmental conditions sometime in May.
d) In anticipation of continued high in-river mortality associated with early entry of the Late run into the Fraser River, 15% exploitation rate will reflect measures to protect Late run stocks.

Implementation 2005

Following the consultations during the Fall and winter of 2004/05, the Spawning Initiative will move into the implementation phase. The simulation results and recommendations included in this report will be used to guide the development of the Integrated Fisheries Management Plans (IFMP), and more specifically, the escapement plan for the 2005 fishing season. We are proposing that two escapement plans will be developed for 2005.

- One plan will be developed based upon the 1987 rebuilding program.
- The second plan will be developed based upon the Spawning Initiative.

We propose that both of these plans will be distributed for consultation with First Nations and stakeholders, with the intent to design a 2005 escapement plan for Fraser River sockeye. It is expected that more then one year will be required to complete full implementation of the Spawning Initiative process and the development of an escapement plan for Fraser River sockeye. Consideration should also be given to implementing an escapement plan for one or more of the Fraser River sockeye aggregate groups based upon the Spawning Initiative process. The *Spawning Initiative* plan will need to incorporate at a minimum a lower benchmark below which immediate actions will be implemented to protect the fish, increase their abundance and reduce the risk for any further loss. The *Spawning Initiative* plan will also include a higher benchmark. This higher benchmark will be determined based upon consultation with First Nations and other interested parties. Here social and economic factors will be paramount. There is no one definition for the higher benchmark; it will depend upon the type of information available. The higher benchmark may be the amount that on average maximizes catch or alternatively a higher benchmark that avoids low catch.

Review Performance

The Spawning Initiative requires the development of a review strategy in order to determine what is working and what requires adjustment. In this way a continuous learning environment will be fostered. It is proposed that on an annual basis a post-season review be conducted in order to determine whether the spawning plan as developed via the Spawning Initiative was implemented as designed. For example, if run-size is adjusted as a result of new information was the escapement plan adjusted according to the agreed spawning escapement plan. Secondly, did the annual escapement plan reach the stated objectives or operational targets that were intended? For example, there may be different operational exploitation rates for two or more of the aggregate groups that overlap in time of migration through various fisheries. We would want to know if we met those targets and if not why were they not achieved. The outcome of these annual performance reviews will lead to recommended adjustments to the next season.

Naturally, the results of the annual reviews will feed into long term reviews and possible adjustments to the strategic approach. It is this last stage that will review the overall strategic plan. This stage will not be conducted on an annually, but be conducted on a much more infrequent basis. The outcome from this review stage will lead to recommendations for improvements to the overall Spawning Initiative objectives and ensure that these objectives are consistent with Departmental policies like the WSP.

APPENDIX 1: SPAWNER-RECRUIT PARAMTERS

Stock dynamics of Fraser sockeye are simulated based on assumptions about the spawner-recruit relationships. These assumptions are defined by two parameters, the spawner abundance (*S**) and exploitation rate (*h**) associated with maximum sustainable yield. These two parameters are estimated from the available data using assumptions about the plausible range of values and about the cyclic patterns in abundance. In this initiative, the simulations are repeated for 250 pairs (*h**, *S**) sampled from the posterior distribution to capture the inherent uncertainty. Average values are reported in the table below. For more detail about stock dynamics refer to *Chapter 3: Status of Fraser River Sockeye* and *Appendix 4: How the model works*).

Note: S* is S at MSY, S_{max} is S at maximum recruits

		S* Prior constrained to maximum observed Spawners		S* Prior constrained to **double** of maximum observed Spawners	
		Productivity Parameter	Capacity Parameter S* (1000s)	Productivity Parameter	Capacity Parameter S* (1000s)
Early Stuart	Non-cyclic	0.60	473	0.59	737
	Cycle-Aggregate Off-years	0.72	95	0.71	85
	Cycle-Aggregate Dom/Subdom years	0.56	563	0.55	962
Bowron	Non-cyclic	0.69	22	0.68	27
Raft	Non-cyclic	0.64	15	0.62	24
Seymour	Non-cyclic	0.64	126	0.63	188
Late Stuart	Non-cyclic	0.71	918	0.70	1,610
	Cycle-Aggregate Off-years	0.78	53	0.78	53
	Cycle-Aggregate Dom/Subdom years	0.66	925	0.67	983
Quesnel	Non-cyclic	0.72	2,320	0.71	3,815
	Cycle-Aggregate Off-years	0.69	150	0.70	167
	Cycle-Aggregate Dom/Subdom years	0.74	2,145	0.73	3,391
Stellako	Non-cyclic	0.70	268	0.69	357
Chilko	Non-cyclic	0.71	550	0.74	503
Birkenhead	Non-cyclic	0.74	162	0.74	162
Late Shuswap	Non-cyclic	0.66	2,191	0.64	3,406
	Cycle-Aggregate Off-years	0.80	7	0.81	6
	Cycle-Aggregate Dom/Subdom years	0.64	2,288	0.62	3,475
Cultus	Non-cyclic	0.55	33	0.54	52
	Cycle-Aggregate Off-years	0.59	37	0.55	24
	Cycle-Aggregate Dom/Subdom years	0.50	103	0.56	58
Weaver	Non-cyclic	0.78	133	0.75	224

APPENDIX 2: STOCK-SPECIFIC BENCHMARKS

It is necessary to describe different management objectives in a quantitative form that can be used in the model. Benchmarks are used to quantify objectives such as “avoid low escapement” or “avoid low catch”.

- “Avoid low escapement” is achieved if spawner abundance exceeds S_{low}.
- “Avoid low catch” is achieved if catch exceeds C_{low}.
- “Maintain maximum sustainable catch” is achieved if catch exceeds C_{high}.

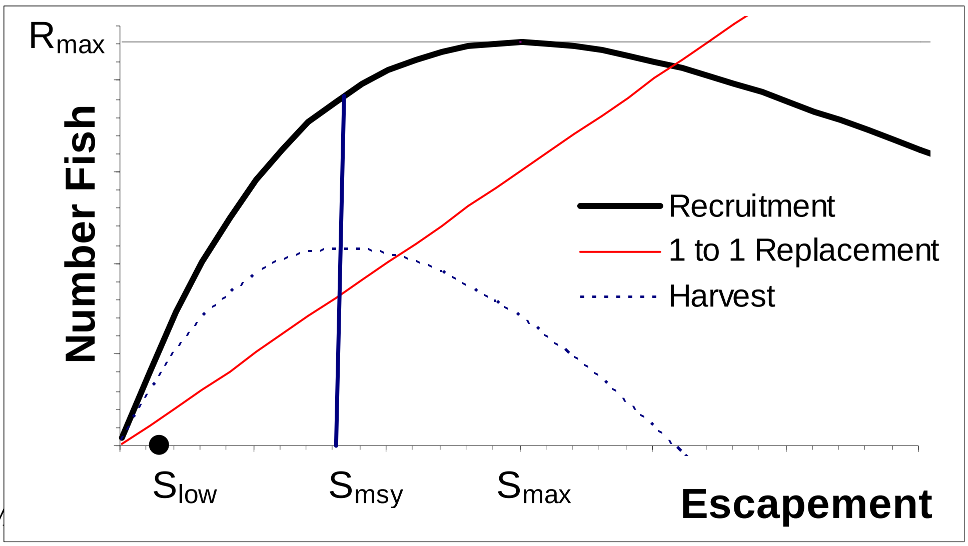
We use stock-specific reference points to describe these concepts:

S_{low} = Spawner abundance that allows rebuilding to S_{msy} within 1 generation **or**
10% of spawners that produce maximum recruits (S_{max}) **or**
30% of spawners that produce maximum recruits (S_{max})
C_{low} = 10% of catch at maximum sustainable yield (C_{MSY})
C_{high} = 100% of catch at maximum sustainable yield (C_{MSY})

S_{low} is intended to describe a spawner level which keeps the stock away from critically low escapements. The approach of using 10% or 30% of S_{max} as a reference point has its origins in the concept of wise resource usage. This approach has gained increasing support within DFO, and a similar tactic is being applied to Skeena River sockeye. An alternative has been suggested during the fifth workshop for this initiative in September 2004: Choose stock-specific values of S_{low} such that the stocks can rebuild to S_{msy} within 1 generation in the absence of fishing. The results presented in Chapters 5 and 6 are based on this new definition of S_{low}, which is intended to better reflect the reproductive capacity at low run sizes and the time horizon for rebuilding.

These benchmarks are calculated based on the modelled population dynamics, and are therefore affected by assumptions about cyclic patterns and capacity. Stock-specific values are tabulated on the next page, showing the three alternatives for defining S_{low}.

The graph below shows the relationship between S_{low}, S_{max}, and S_{msy}. C_{high} is achieved on average from the adult returns produced by a spawner abundance of S_{msy}



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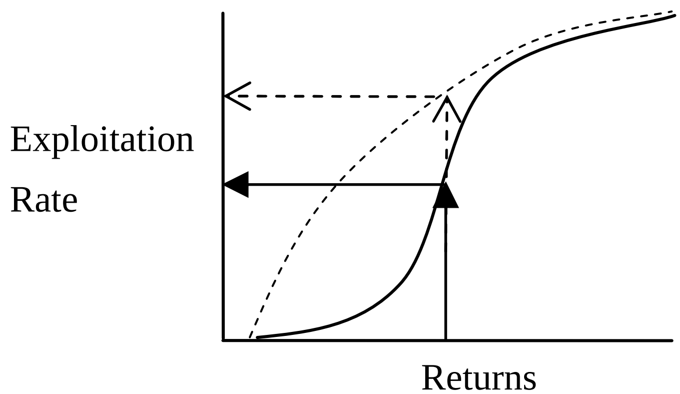
		S* Prior constrained to maximum observed Spawners					S* Prior constrained to **double** of maximum observed Spawners				
		S_{low}			C_{low}	C_{hi}	S_{low}			C_{low}	C_{hi}
		10% S_{max} (1000s)	30% S_{max} (1000s)	Rebuild to S_{msy} (1000s)	(1000s)	(1000s)	10% S_{max} (1000s)	30% S_{max} (1000s)	Rebuild to S_{msy}	(1000s)	(1000s)
Early Stuart	*Non-cyclic*	30.0	98.3	120.1	71.7	717.2	47.5	155.5	194.0	107.2	1,072.0
Cycle-Aggregate Off-years		5.0	16.4	14.4	24.3	243.3	4.6	15.0	13.7	20.5	204.6
CA Dom/Subdom years		38.2	125.0	165.1	72.6	726.2	67.4	220.5	300.4	115.5	1,154.7
Early Summer	*Non-cyclic*				29.8	297.8				41.6	416.3
Bowron	*Non-cyclic*	1.2	4.0	3.9			1.5	5.1	5.1		
Raft	*Non-cyclic*	0.9	2.8	3.2			1.5	4.8	5.6		
Seymour	*Non-cyclic*	7.5	24.6	27.6			11.4	37.3	42.7		
Summer Run	*Non-cyclic*				1,012.8	10,127.8				1,533.8	15,338.3
Cycle-Aggregate Off-years					248.3	2,483.0				279.1	2,790.5
CA Dom/Subdom years					995.2	9,951.8				1,362.4	13,624.3
Late Stuart	*Non-cyclic*	49.5	162.0	147.6			88.3	289.1	274.2		
Cycle-Aggregate Off-years		2.6	8.5	5.8			2.6	8.5	5.8		
CA Dom/Subdom years		53.6	175.2	185.4			56.0	183.4	188.4		
Quesnel	*Non-cyclic*	123.3	403.6	354.6			204.9	670.4	604.0		
Cycle-Aggregate Off-years		8.3	27.1	26.1			9.2	30.0	28.6		
CA Dom/Subdom years		110.4	361.2	290.2			176.4	577.1	478.1		
Stellako	*Non-cyclic*	14.7	48.0	45.2			19.7	64.6	62.3		
Chilko	*Non-cyclic*	29.7	97.0	88.3			26.0	85.0	69.3		
Birkenhead	*Non-cyclic*	8.3	27.2	21.8	47.0	469.6	8.3	27.3	21.9	47.0	469.6

APPENDIX 3: HOW TO INTERPRET PLOTS AND TABLES

Harvest rules

The harvest rules calculated in the first step of the simulation model can be illustrated in a variety of forms, but all show essentially the same information. The harvest rules specify a target exploitation rate over a range of run sizes, which can also be converted into a target escapement or a target catch.

Plots of harvest rules are very useful for assessing the effect of different assumptions, because subtle differences are clearly visible. To read these plots, choose a particular number of returning adults on the horizontal axis, and then consider the corresponding exploitation rate, as indicated by the arrows in the diagram below. Changing management objectives may shift the harvest rule, resulting in a different target exploitation rate for the same run size, as indicated by the dashed lines. Similar plots show target escapement or target catch.



Harvest rules can also be described in tables, which show catches and escapement in actual numbers. However, comparisons between harvest rules are difficult in this format.

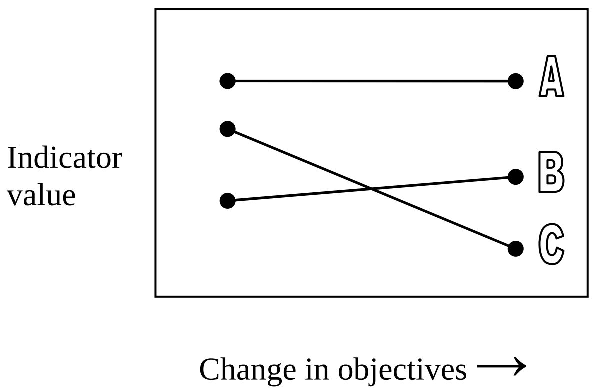
Adult Returns	Total Exploitation Rate	Catch	Escapement
100	10%	10	90
200	25%	50	150
300	40%	120	180

Trade-off plots

To evaluate the effect of changing management objectives, we need to also consider changes in performance. Trade-off plots contain a lot of information and allow for comparisons between options to be easily be made, by illustrating what you have to give up on one performance measure as you improve another.

The diagram below illustrates this for three performance indicators (A,B,C). As management objectives change moving from left to right, A stays the same, B increases slightly, and C decreases considerably.

With plots like this, we can then consider whether the observed improvement in one indicator is worth the degradation in another. For example, is a 10% increase in average catch over 50 years worth a 30% increase in fluctuation of spawner abundance? Each trade-off plot needs to be carefully interpreted, because for some indicators, an increase is good, (e.g. average catch), while for some an increase is bad (variability in catch),



Due to the uncertainty about population dynamics, we need to look at these trade-off plots under four different eventualities.

Top left: Cyclic stocks managed using a cyclic harvest rule (Correct assumption)	**Top right:** Cyclic stocks managed using a non-cyclic harvest rule (Incorrect assumption)
Bottom left: Non-cyclic stocks managed using a cyclic harvest rule (Incorrect assumption)	**Bottom right:** Non-cyclic stocks managed using a non-cyclic harvest rule (Correct assumption)

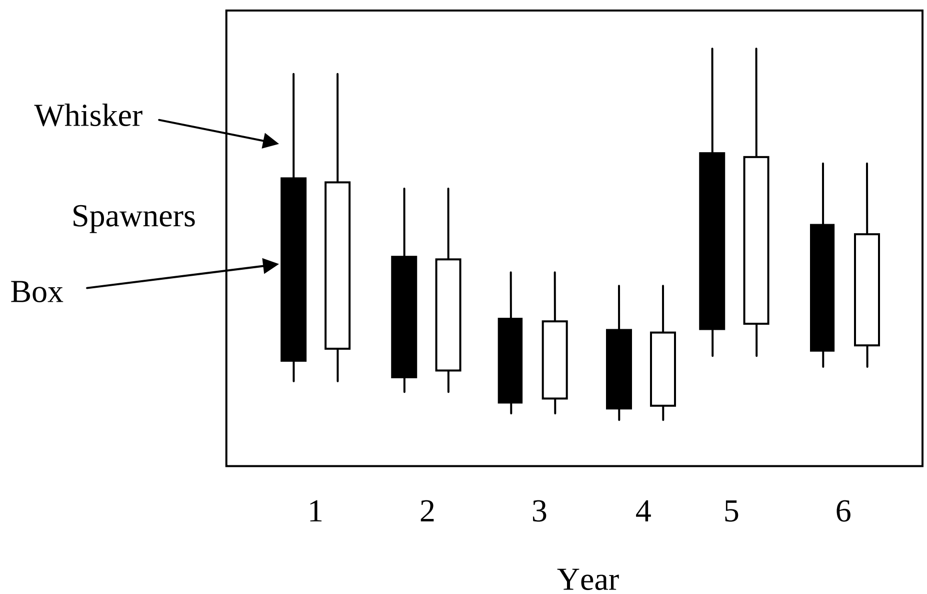
Trajectories of boxplots

Boxplots show the distribution of many observations. Each vertical box shows the range of values which captures half the observations, and the whiskers span 90% of the observations. Plotting the distribution of observations illustrates the uncertainty associated with estimated performance of different harvest strategies, which may influence the choice.

Time trajectories show how the distribution of observations changes over time.

We overlay two trajectories, identified by empty and solid boxes, to emphasize the differences between two harvest rules.

In this format, we can display catches, spawner abundance, and returns for either stock aggregates or individual stocks.

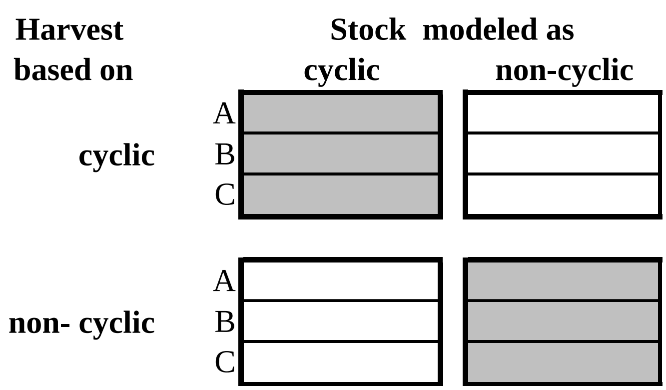


Decision table

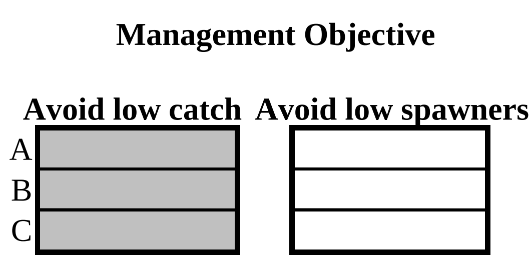
The final step is to compare the simulation results in decision tables, which show the numerical results for some scenarios that were chosen for closer consideration. These tables provide decision makers a score sheet with which to assess the alternative options. Decision tables can provide information for two types of choices:

- Technical choices, such as assumptions about stock dynamics
- Policy choices, such as preferences for different management objectives

<u>Technical choice</u>
Decision tables for technical choices need to reflect not only what happens under two different assumptions, but also what happens if the stocks are managed based on incorrect assumptions. These are the same four eventualities considered in the trade-off plots above. The two darkened boxes provide results for the two different assumptions, if they are correct. The light boxes provide results for the two different assumptions, if they are incorrect. For example, the bottom left-hand box shows the result for a cyclic stock that is managed based on a non-cyclic harvest rule.



<u>Policy choice</u>
For policy choices, there are no correct or incorrect assumptions, just different preferences. In this case, the decision tables compare the results when applying harvest rules developed for two different management objectives, under the same assumption about stock dynamics. For example, the table below could compare the performance of harvest rules for "Avoid low catch" and "Avoid low spawners", under the assumption that the stocks are cyclic.



Appendix 4: DEVELOPING THE MODEL: THE PARTICIPATORY PROCESS

In this initiative, we use a simulation model to develop and evaluate harvest strategies. Chapters 1 to 3 provided background information about Fraser River sockeye management, the fisheries, and the stocks. In this appendix we briefly describe how this model is used in a participatory process to develop alternative harvest strategies for future seasons.

The Spawning initiative: A process and a model, linked to other processes

The simulation model provides a framework for exploring the effect of different policy choices (e.g. management objective is to avoid years with low catch) and technical choices (e.g. assume that stock dynamics are cyclic). The Spawning Initiative is the participatory process for reviewing the management objectives and assumptions that are modeled.

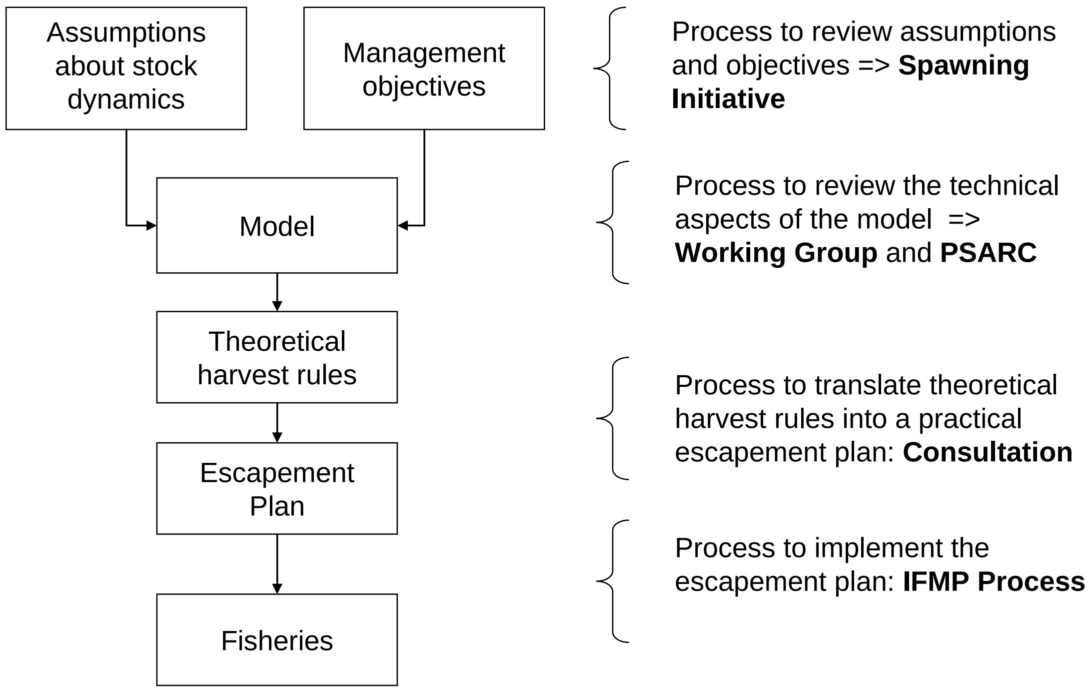


Figure 53: The Spawning Initiative is linked to other processes

To capture the reproductive dynamics of Fraser River sockeye stocks, and the uncertainty in estimates of productivity and capacity, the model has become quite complex. The technical details have been reviewed through the Pacific Scientific Advice Review Committee (PSARC), and are available on-line at www.dfo-mpo.gc.ca/csas/ under > English > Publications > Research Documents > Report Number 2004/25. Continuing refinements of the model are being developed in a working group with external experts.
The harvest rules produced by the model are theoretical, and are intended as guidelines for the actual process of choosing a harvest rule (or escapement table). This particularly relates to the larger than 65% exploitation rates that some of the harvest rules indicate at higher run sizes.

Implementation challenges may prevent us from applying those types of harvests in mixed-stock fisheries, and we did not model the benefits and costs of fishing in different areas or with different gears. Broad consultation will be necessary to translate the theoretical harvest rules into practical guidelines for setting escapement targets. As a result of these consultations, a maximum exploitation rate of 65% may be set.

The final step in planning future fisheries for Fraser River sockeye is the annual development of Integrated Fisheries Management Plans (IFMP). During IFMP consultations, DFO seeks feedback on conservation measures, First Nations objectives, allocations between harvest sectors, and gear- and area-specific fisheries.

Levels of participation in the Spawning Initiative

Under the Pacific Salmon Treaty, Fisheries and Oceans Canada (DFO) is responsible for setting escapement targets and harvest guidelines for Fraser River sockeye salmon. These targets and guidelines affect many people directly or indirectly that are associated with the fishery. Any changes in the management approach require consultation with First Nations, commercial and recreational harvesters, environmental and other non-governmental organizations, and a number of management agencies including the Pacific Salmon Commission. To encourage broad participation in the Fraser River Sockeye Spawning Initiative, DFO has adopted an open and transparent process with several levels of involvement:

1) A *working group* of fisheries managers and analysts performs the analyses;
2) A *steering committee* of senior representatives from stakeholder organizations and DFO guides the working group and ensures participation by their respective organizations;
3) *Workshops* where representatives from participating groups review intermediate results;
4) Technical *peer-review* of methods through the Pacific Scientific Advice Review Committee (PSARC);
5) *In-season evaluation* of example harvest rules during the 2004 season, and comparison to current management approach;
6) *Consultation* on the resulting recommendations through established processes.

Each of these stages is more fully described in the following sections.

Working group

The working group initially developed a computer model to help identify the most appropriate harvest policies and escapement targets for Fraser sockeye stocks. The model takes into account the biology of individual stocks, historical patterns of ocean productivity, and the priorities and values of all interested parties. This model, described in more detail in Chapter 5, provides a tool for consistently evaluating alternative assumptions about population dynamics and different management objectives. With this tool as a starting point, the focus of the working group shifted to eliciting feedback from stakeholders, revising the model accordingly, and communicating results to other participants.

Steering committee

A steering committee was formed to keep the process moving, ensure consistent involvement by technical staff and provide clear direction to the working group. This committee is composed of senior representatives from DFO, First Nations, commercial harvesters, recreational harvesters, and environmental non-governmental organizations. Steering committee members are not necessarily involved in technical details, but they ensure that the technical work addresses the issues that form the basis for recommendations taken into general consultation. Steering committee members were also expected to support this initiative among the groups they represent and to endorse the resulting recommendations.

Workshops

DFO organized facilitated workshops to elicit feedback on both the conceptual approach and the technical details of the decision framework. Workshop participants were expected to comment constructively on the intermediate results and to review the resulting recommendations prior to broad consultation. Participants' feedback helped DFO refine the proposed approach for managing spawning escapements prior to taking this initiative into broader consultation.

Workshop participants have clearly stated that they were involved purely as individuals with an interest in shaping the content of materials taken into consultation at some future point, that they were not attending as official representatives of stakeholder organizations. First Nations also stated that the workshops did not qualify as consultation. More effort has been dedicated to small group meetings with participants, and additional analyses has been done to address specific questions and concerns raised at the four workshops held over the last two years. Concerns expressed by some participants about the transparency of the process have also been addressed through increased communication efforts, of which this report is one element.

External technical review

To capture the reproductive dynamics of Fraser River sockeye stocks, and the uncertainty in estimates of productivity and capacity, the model has become quite complex. The technical details have been reviewed through the Pacific Scientific Advice Review Committee (PSARC), and accepted as scientifically sound. The revisions made to the model based on technical review include:

- refinement of the optimizer
- additional aspects of value functions.
- additional explanations included in text

The PSARC paper is available on-line at www.dfo-mpo.gc.ca/csas/ under > English > Publications > Research Documents > 2004/25. Continuing refinements of the model are being developed in a working group with external experts.

In-season evaluation of examples

During the 2004 fishing season the Steering Committee and working group compared the actual in-season management to some possible alternative harvest rules. These examples were developed using the simulation model, and discussions focused on differences and similarities between the examples and the current management strategy.

General consultation through established processes

During the Fall of 2004, feedback from the broader stakeholder community will be sought through established advisory processes. For First Nations groups these processes include bilateral meetings with individual bands, tribal councils, watershed processes (e.g. FRAFS) and other established organizations. The recreational fishing community will provide feedback through the Main Board of the Sport Fishing Advisory Board (SFAB) as well as the appropriate sub-committees. For the commercial fishing sector the Commercial Salmon Advisory Board (CSAB) and gear-specific advisory processes will be provided an opportunity to submit comments and suggestions. Representatives of non-harvest interests, such as researchers, environmental organizations, and other government agencies will contribute through their established interactions with DFO managers. All interested parties can provide comments directly to the working group through the contacts listed on page 2.

Depending on the status and progress toward implementation of the Improved Decision Making policy, other approaches may also be taken. For additional information about Improved Decision Making and consultation, refer to:
www-comm.pac.dfo-mpo.gc.ca/english/database/Consult.htm
www-comm.pac.dfo-mpo.gc.ca/english/consult/decision.htm

Advice received and DFO responses

Steering Committee members and workshop participants have provided valuable feedback. In response to comments received from the Steering Committee, external working group members and workshop participants, the spawning initiative has evolved as follows:

- The timeline for the initiative was extended to allow for additional technical analyses, further refinement of the consultation packages, and additional work on on-going policy development (e.g. Wild Salmon Policy);
- More effort was dedicated to on-going communication with invited participants, to ensure productive participation;
- The technical analyses were scientifically reviewed through the PSARC process;
- Additional analyses were performed to address specific questions and concerns raised at the workshops.

From the very beginning, the team has recognized the challenges associated with involving stakeholders in the development phase of technical work, but the evolution of the model shows the clear benefits of this strategy. Initial stakeholder involvement focused on obtaining feedback for the technical working group regarding additional analyses and communication of results. The present report is based on feedback from the four workshops and forms the basis for broad consultation in the fall of 2004. Implementation of components of the initiative initially planned for 2004 will now await the outcome of these consultations.