Optimal harvest policies for Bristol Bay sockeye salmon considering biological and economic returns

Prepared for

Bristol Bay Science and Research Institute
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November 2006

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November 2006

Suggested format for citation:

Bue, B.G., R. Hilborn, and M.R. Link. 2006. Optimal harvest policies for Bristol Bay sockeye salmon considering biological and economic returns. Unpublished report prepared by Bue Consulting LLC, University of Washington, and LGL Alaska Research Associates, Inc., for the Bristol Bay Science and Research Institute, Dillingham, AK, 48 p. + appendices.

Executive summary

We estimated stock-specific biological escapement goals for six Bristol Bay sockeye salmon stocks and determined the optimal management of these systems considering both biological and economic objectives. Our escapement goal analysis was intended to identify fixed escapement goal ranges that could be expected to produce 90 % of the maximum sustained yield (MSY). To examine the biological impacts of alternate harvest policies, we modeled the long-run population dynamics and yield from each stock under a range of escapement levels and harvest rates. The economic analyses were intended to quantify the expected net revenue from each river under different harvest policies and were done by combining the biological model with an economic model that incorporated the declining relationship between salmon price and annual catches, and the costs of processing and harvesting salmon in Bristol Bay.

To estimate these escapement goals we used stock-specific 50-year datasets and two different models to characterize the relationship between spawners and subsequent returns (Ricker and Beverton and Holt spawner-recruit models), accounted for variation in the age structure of the adult return, took into consideration covariation in returns among years (autocorrelation in process errors), and used an alternate statistical approach (Bayesian methods) for estimating model parameters.

While our method of computing escapement goals added a number of factors that have not been considered in past Bristol Bay analyses, the results were generally not qualitatively different from answers obtained using traditional methods. The method did provide a means for estimating the escapement that produces MSY for systems such as Egegik where the traditional method does not work. In general, these more elaborate techniques resulted in wider and higher escapement goal ranges than the escapement goals that are currently in place (see Figure ES-1 below). The broader ranges are partially due to the Bayesian analysis, which takes into account more of the uncertainty in the data.

Based on our results, we speculate that additional and more sophisticated technical analysis of *existing* stock-recruit data will not yield radically different estimates of the escapement level required to produce MSY than the traditional methods. The greatest improvements in estimating the appropriate goals may come from improving the brood tables by better accounting for stock contributions to the catch in all fishing districts. Genetic stock identification is a rapidly evolving tool which shows a great deal of promise for estimating these contributions for both future and historic catches. With additional years' return data, particularly those from higher or lower escapement levels than seen historically, further analysis may yield some new insights into the relationship between escapement and subsequent returns and provide for scientifically justified changes to MSY-based BEGs. Furthermore, in light of the economic state of the fishery and the results presented in this report, it may be beneficial to shift focus from traditional MSY-based analyses to explore and evaluate the biological implications of managing for economic objectives.

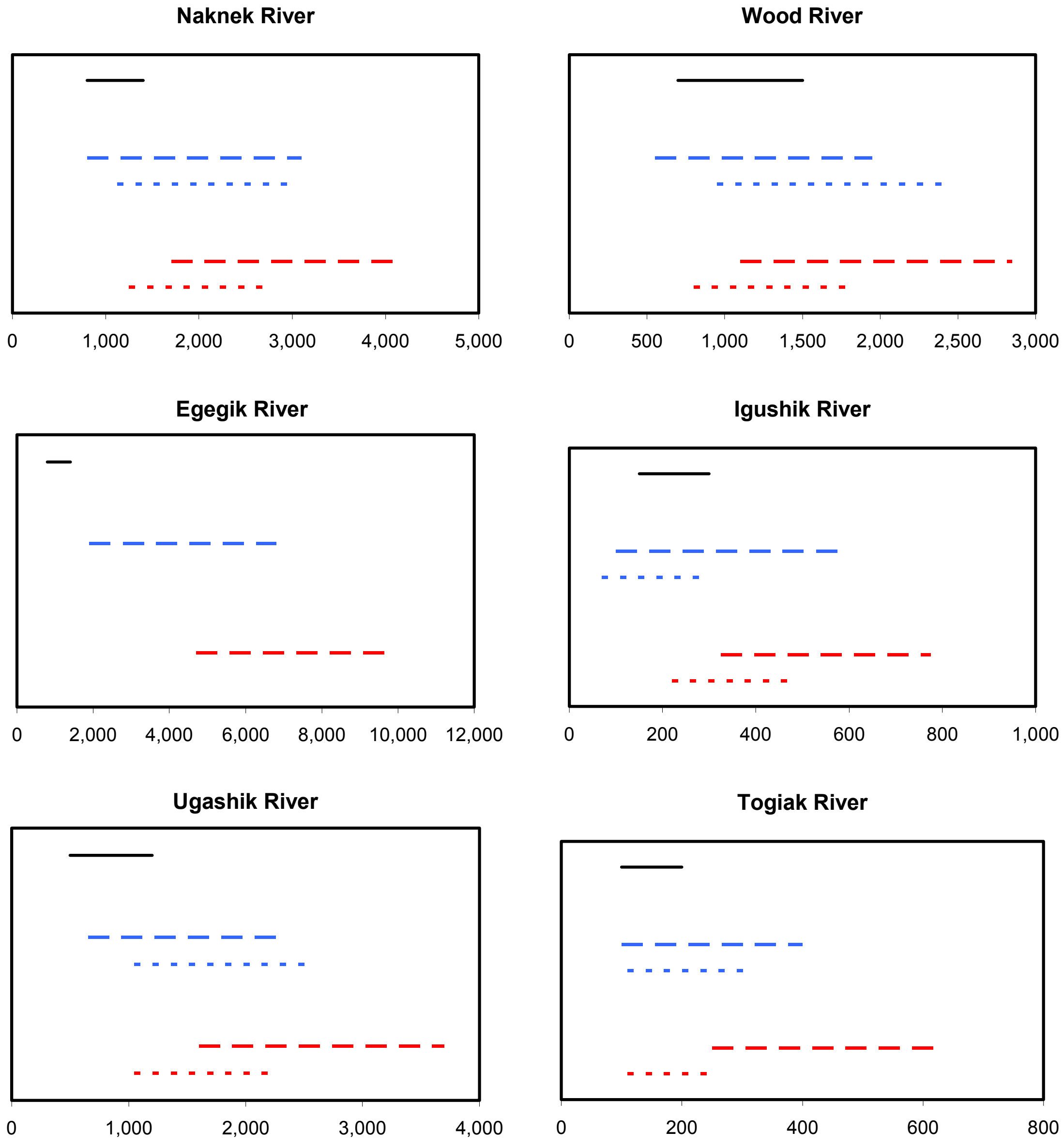

Figure ES-1. Comparison of current escapement goals to the range of escapements that produce 90% or greater of the simulated maximum yield for the Ricker and Beverton Holt models developed here. The solid black line at the top of each plot indicates the range of escapement in the present escapement goal while the blue lines (middle group) indicate Beverton-Holt models and the red lines (bottom group) indicate Ricker models. The long dashed lines indicate the 90% or greater range obtained using the Bayesian method while the short dashed lines indicate the 90% or greater range obtained using the more traditional maximum likelihood method.

It is commonly believed that escapements very near the level of escapement which theoretically produces MSY will yield substantially greater catches in the long run than lower or higher escapement levels. Although Bristol Bay salmon have at least in theory been managed using a fixed-escapement policy, there is a wide range of other harvest policies available. For instance, constant harvest rates and constant catch policies. Constant harvest rates remove a fixed proportion of the adult return each year and let escapement vary with the size of the return whereas constant catch policies remove the same number of fish each year and all the annual variation in run size is reflected in the escapement. An important result from this study was the wide range of harvest policies that produced large, sustained catches similar to the theoretical maximum yield (MSY). This result is counter to the commonly accepted belief that the highest yield from these stocks will occur with fixed escapements within a relatively narrow range.

To quantify the effects of different harvest policies, we used a computer-based simulation model to examine a range of harvest policies that might be considered for a salmon fishery like Bristol Bay. The goal of the exercise was to find the policy or policies that maximized the average annual catch. The model took into account the underlying biological dynamics of each Bristol Bay stock and simulated annual catches under management policies that 1) varied the minimum escapement levels and 2) varied the annual harvest rate on fish above the minimum escapement goal. In the model, each year's return to a district was subjected to a set harvest rate above a minimum escapement goal. The model measured the impact of that harvest policy on the stock's dynamics over a very long term (i.e., 100 years). Returns simulated within the model were a function of the escapement in the previous generation and therefore reflected the impact of the harvest policy over time. Average yields were then calculated for the entire period. The model was run across a range of minimum escapement levels and a range of harvest rates with the same stock-specific biological dynamics.

The results from each harvest policy (a particular minimum escapement level combined with a harvest rate on fish above the minimum goal) are best illustrated by showing how large the average catches were under that policy *relative* to the maximum average catch (theoretical MSY). Figure ES-2 shows the expected performance of a range of minimum escapement goals and annual harvest rate policies for the Wood River stock. The harvest rate is expressed as a proportion, with 0.5 being a harvest of 50% of all the fish above the minimum escapement level and 1.0 representing a harvest of 100% of all the fish above the minimum goal. The contour lines within Figure 2, which are labeled 0.1 through 0.9, represent the corresponding combinations of minimum escapement level and harvest rate that produce from 10 to 90% (0.1 to 0.9) of the maximum average catch (theoretical MSY). The green shaded area inside the 0.9 contour represents all combinations of the minimum escapement goal and harvest rate that produced 90 to 100% of the maximum average catch (theoretical MSY). As can be seen in Figure ES-2, there is a wide range of policy combinations represented by the shaded area that would produce large, sustained yields. For example (and reading from Figure ES-2), we would expect similar average catches (about 90% of the maximum) from a minimum escapement goal of 250,000 fish and a harvest rate of about 62% on all fish above the minimum escapement as would be achieved from a minimum escapement goal of 1.7 million fish (1700 thousand in Figure 2) and harvesting all fish above that escapement (i.e., at a harvest rate of 1.0 or 100%).

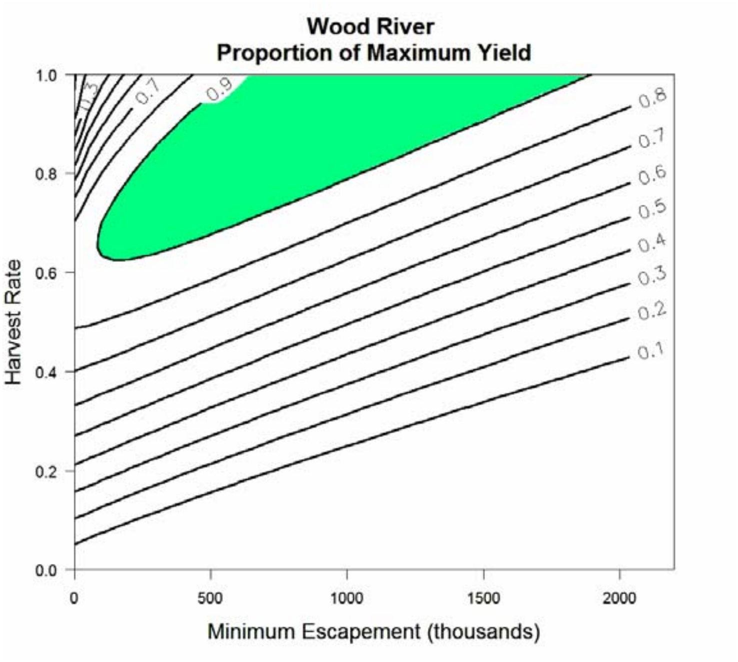

Figure ES-2. Contours of the proportion of maximum yield for a range of harvest policies where the minimum escapement goal and harvest rate for returns in excess of the minimum goal are varied, Wood River, Beverton-Holt spawner-recruit model.

The next step in our analysis was to examine the economic impacts of different harvest policies for each river by combining an economic model of the fish harvesting and processing sectors with the biological model. The economic model incorporated published estimates of the negative relationship between Bristol Bay salmon price and annual catch and published estimates of the cost of processing and harvesting salmon. Similar to the quantifying of the biological impacts of different harvest policies, the economic model, which was combined with the biological model, would keep track of the net revenue in each year over a very long period. Rather than calculating an average economic value by harvest policy (as was done for catch when evaluating biological impacts of harvest policies), the economic model would sum the economic values for the catch over the years. The gross revenue each year was determined by the total catch, weight of the fish, and year-specific price. The price varied as a function of the total catch. The net revenue was determined by taking into account the size of the run and the cost structure for the harvesting and processing sectors in Bristol Bay.

The economic value of each harvest policy was expressed in dollars and was not simply a sum of financial returns across 100 years of harvesting and processing. Instead, the value was expressed as the net present value or NPV. The NPV is calculated by discounting future catches by about 2% per year (7% per salmon generation).

Discounting is a common practice when examining a future stream of income and is done to reflect the fact that the same catch in the future is generally believed to be worth less than it is today. The end result is that catches early in a simulation were given greater weight than those 100 years into the future. More specifically, catches 35 years from the present are discounted by about 50% relative to catches today and catches in 100 years are worth about 2% of the value of fish today. Therefore differences in NPV among harvest policies are heavily dependent on the economic returns from the first two or three decades of the simulation.

First, we used the simulation model to estimate the net present value of catch across a wide range of capacity for both the processing industry and commercial fishermen. We found that the NPV of the catch in each district was heavily influenced by the level of harvesting and processing capacity (Figure ES-3). Although this exercise ignores the Bay-wide dynamics of the fleet and processing capacity, it is useful nonetheless. These plots show that the maximum NPV of Egegik catch for the processors would come from having a capacity for about 9 million fish; for the drift fleet the value is the greatest from a capacity 8 million; for the set net fleet, it would be 1.4 million fish. Note that for the processors, the long-run net value of the catch when they maintain a capacity to process 20 million fish is about 1/3 as much as it would be if they optimized their capacity at 9 million fish ($50 million NPV vs $150 million; Figure ES-3)

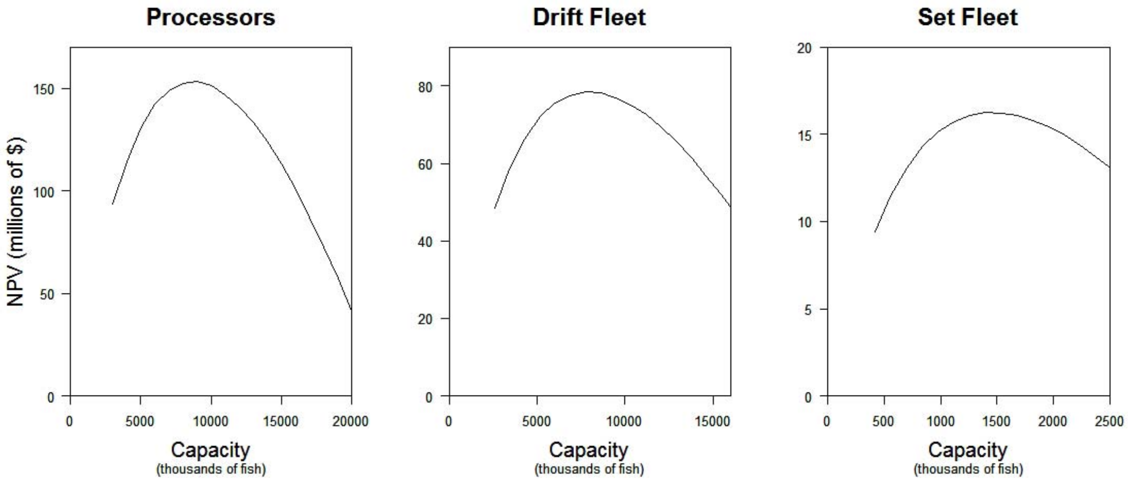

Figure ES-3. Modeled relationship between the long-run value of the catch (NPV) and capacity for the fish processors, drift fleet and set net fleet, Egegik District.

Although these results are interesting and their implications are important, the influence of capacity on the NPV from a fishery isn't surprising. A significant portion of the costs in both the harvesting (boats and gear) and processing (size of processing plants) sectors are fixed costs; they are incurred year in, and year out, whether all the capacity is used or not. These results show that there is an optimum capacity for each sector and that across all sectors there is no economic advantage to maintaining a capacity capable of handling the occasional large harvest possible in Bristol Bay. The costs of maintaining a processor or fishing operation capable of handling very large catches is not made up by the income from that occasional large catch.

Next, we estimated the NPV of catches across the range of harvest policies that we had examined for biological impacts. This time, rather than finding the average catch for each harvest policy, we estimated the NPV of the catch (which was dependent on the annual catches, prices, and harvesting and processing costs). We found that harvest policies that maximize the NPV of the catch are more aggressive harvest policies (lower minimum escapement levels and higher harvest rates) than those required to maintain MSY catches. To illustrate the difference between policies, we plotted two contour lines on a figure similar to Figure ES-2 (see Figure ES-4 below using Egegik as an example). The solid contour line encompasses the harvest policies that produce 90 to 100% of the maximum yield for Egegik while the dashed line represents the area that encompasses 90 to 100% of the maximum long run NPV (net $) to the fish processors. It is the shift of the dashed line to the left in this figure (relative to the solid line) that illustrates the shift to a more aggressive harvest policy to maximize NPV. Our results suggest that the combination of the cost of maintaining capacity and the underlying productivity of the stocks act to make it less profitable over the long run to manage for large minimum escapements.

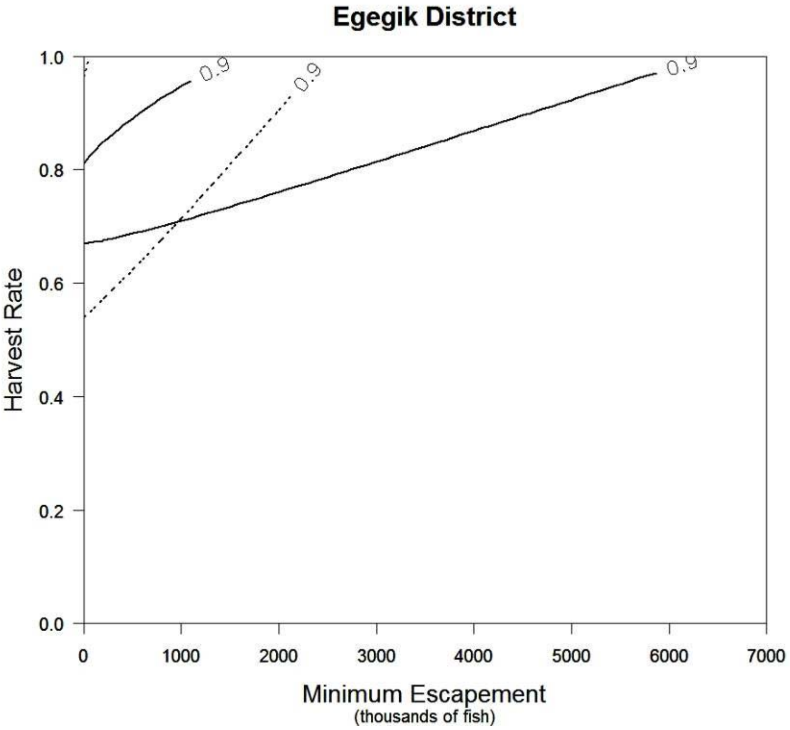

Figure ES-4. Ninety-percent density contours for yield (solid line) and long-run value or NPV to the fish processors (dotted line) Beverton Holt spawner-recruit models, Egegik District.

Clearly what is optimal from a harvest policy perspective is dependent on the management objective. The results from the biological analysis of different harvest policies suggested that large sustained yields were possible across a wide range of harvest policies – from large minimum escapement goals combined with high harvest rates on fish in excess of the escapement goal to low minimum escapement goals combined with modest harvest rates. When you factor in the economic performance from the fishery as an objective, the large minimum escapement goals become less ideal.

The economic results described above were for simplified single-district fisheries. While this approach provides insight into how the biology and economics interact, these models simplify a very dynamic fishery. All of the district fisheries in Bristol Bay interact both biologically and economically with each other. A large catch in one fishing district will have an effect on the price of salmon in a district with a very small catch; similarly, a large smolt population and subsequent adults from one river system will compete for food throughout its life in the marine environment with fish from another river system.

To provide a more accurate assessment of different harvest policies for the Bristol Bay fishery as a whole, we evaluated harvest policies for the entire fishery and searched for the optimal harvest policy for four different management objectives: (1) maximum sustainable yield (MSY), (2) maximum gross value of catch, (3) maximum profit (net income) to the harvesting sector, and (4) maximum profit to the processing sector. To model the biological response to different harvesting strategies we used an aggregate Beverton-Holt spawner-recruit model applied to all Bristol Bay sockeye salmon stocks. We then used stochastic dynamic programming to determine the optimal harvesting policy for each management objective.

The optimal harvest policies differed for the four objectives. To illustrate the differences, we plotted the optimal catch at each level of total return to Bristol Bay (Figure ES-5). We found that when managing for maximum catch (MSY), the optimal approach is to not harvest any fish in years when the return is less than the aggregate escapement goal (a little under 8 million fish) and then harvest all fish in excess of the escapement goal. Theoretically, this is the goal of the existing management program in Bristol Bay. In reality, fleet and processing capacity as well as salmon run timing make it difficult to achieve this goal. The optimal catch for management for the other three objectives was quite different from managing for MSY.

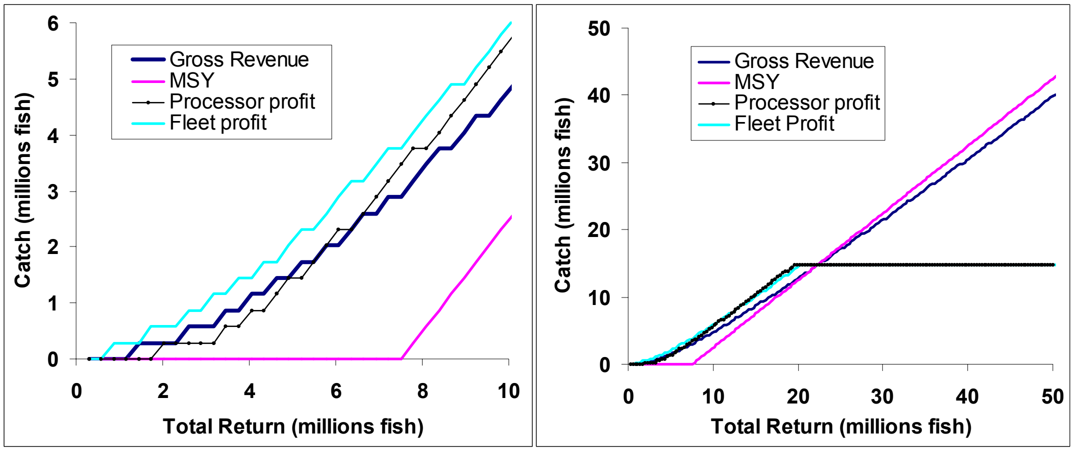

Figure ES-5. Optimal catch at different levels of total return to Bristol Bay for four management objectives. Both plots are for the same results but at different scales; the plot on the left shows the results for returns less than 10 million fish and the plot on the right for returns up to 50 million fish. Note that for the figure on the right the lines for processor and fleet profit follow each other so closely that they appear as the same line.

In contrast to the MSY objective, the three other objectives suggest that some harvest is optimal for Bay-wide returns from 1 to 8 million fish. When economic factors are considered in the management objective, it makes sense to harvest some fish at returns below the MSY escapement goal even though doing so will produce lower average catches. This is consistent with our economic analyses of harvest strategies for single districts. As total returns approach 20 million fish, the optimal harvest level diverges again among the different objectives. At this point, it is optimal to cap the catch (i.e., limit capacity) to near 15 million fish if the objective is to maximize harvester profit or processor profit (Figure ES-5; right).

The impacts of the size of the catch on the price of fish seem to primarily affect the performance of the harvesting policy at low return sizes, where the analysis suggests that the bottom end of the escapement range should be a “soft landing” rather than a hard floor. When returns are low the price is high, and it is economically optimum to allow some harvesting even at low stock sizes. It is important to note that this applies only to Bay-wide catch. If an individual district has a poor return, but other districts have good returns, then the total Bay-wide production will not be low, and the price will not be particularly high. Consequently, there are few price benefits from harvesting below the escapement floor in the individual weak district.

Considering the impacts of catch on the price of fish and the cost structure of fishing and processing provides very different views on what optimal management is compared to MSY-based management. The most striking effect was the importance of capping capacity; it simply does not pay to have large fleets or processing capacity that are only used every few years. It seems worthwhile for the official harvesting policy to recognize that the economic viability of the industry would be enhanced if there was a maximum catch limit for the Bay.

As with all modeling exercises, our results are dependent on the underlying assumptions about the productivity of the stocks and the shape of the relationship between spawners and subsequent recruitment. In addition, we made several economic assumptions about salmon prices, the effect of harvest levels on salmon prices, fixed and variable costs of the harvesting and processing sectors, the allocation between user groups, and the assumed maximum catch level set by the harvest policy. Our results have illustrated some qualitative benefits from changes to escapement goal policy and limiting harvesting and processing capacity. However, more sophisticated analyses that include capturing the inseason dynamics of the fish and the industry are needed to make accurate quantitative assessments of these changes.

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1. Introduction

The theory of optimal harvesting has shown that maximization of biological yield from a fish population is achieved by holding the spawning population at a constant level (Clark 1976). This population size is known as the number of fish that produces maximum sustainable yield or MSY, and is often called the optimal escapement. Policies that hold spawning stock constant are referred to as fixed escapement policies (Hilborn and Walters 1992). The assumptions of this theoretical result are (1) that the underlying average relationship between spawning stock and recruitment is time invariant, (2) that there is perfect knowledge about the underlying production relationship, (3) that there is perfect controllability of spawning stock size, and (4) the objective is to maximize the long-term *average* annual catch.

Among the few commercial fisheries that are theoretically managed on the basis of fixed escapement policies are most of Alaska's terminal salmon fisheries. For these fisheries the annual harvest is regulated in an attempt to hold the spawning stock size within a range of sizes close to that calculated to provide MSY (Minard and Meacham 1987). The typical approach for many Alaskan salmon fisheries, including for Bristol Bay, has four steps in formulating the escapement goal. First is the construction of brood tables from previous annual catches and escapement to determine adult production from historical escapements. Second is fitting of resultant spawner-recruit data using a mathematical model, usually the Ricker curve. Third is the calculation of the spawning stock level that produces the highest long-term average catch (MSY), and finally establishment of a range of escapement targets near the point estimate of the "optimum" spawning stock, generally the range of spawning stock sizes thought to produce 90% of the maximum long-term yield.

These calculations are performed and biologically based escapement goals are determined by the Alaska Department of Fish and Game (ADF&G). The results are presented to the Alaska Board of Fisheries, which usually accepts the recommended escapement range. During the fishing season as the salmon return to their natal streams, the fisheries managers manipulate the number of days or hours fishing is permitted and the size of fishing areas to achieve the escapement goal. If the total return is large, then the catch may be much greater than the escapement, but if the total return is small there may be little if any harvesting permitted.

There have been a number of recent technical developments in the analysis of spawner-recruit data and evaluation of alternative harvest policies that are just now being considered for setting salmon escapement goals. These include the use of Bayesian statistics to evaluate uncertainty (Adkision and Su 2001; Punt and Hilborn 1997), and allowing for autocorrelation of residuals and management implementation error in the evaluation of alternative harvest policies (Hilborn 2001).

Fixed-escapement management has provided the basis for remarkably successful management of salmon in Alaska (Eggers 1992) with record catches since the late 1970s.

However, the economic success of the fisheries in the 1980s and 1990s has evaporated as salmon prices declined dramatically due to competition with farmed salmon (Link et al. 2004, Hilborn 2006). The maximum allowable fishing effort in these fisheries has been managed by a limited entry permit system (Koslow 1982). During the 1980s and 1990s the transferable permits for many of the State's salmon fisheries were valued at hundreds of thousands of dollars, reflecting very high expected economic returns to fishermen from future catches. With the decline in price of salmon the value of permits has collapsed, and fishermen are struggling, with many fishermen unable to operate (Link et al. 2003, Commission 2004). Returns to processors have similarly declined dramatically (Link et al. 2003).

In Bristol Bay, the State's largest sockeye salmon fishery, where there are 1,857 driftnet and 992 setnet permits, the economic hardship is obvious. Whereas average annual economic profit for driftnet vessels from 1982 to 1996 was between $13,000 and $47,000 the fishery now operates at a net loss (CFEC 2004), with average profit negative for all years between 1997 and 2003 except in 1999. Link et al. (2003) report that in 2001 permit holders averaged $4,000 in income after operating costs, but before debt service on permits and vessels. In 2003, only 77% of eligible driftnet permits were active. Given the large number of unused permits in other Alaskan salmon fisheries, and the low market value of limited entry permits, the economic results in Bristol Bay are likely typical of most Alaskan salmon fisheries.

A traditional and prevalent assumption among salmon fishery managers has been that if the resource is managed to produce maximum sustained yield the economics will take care of themselves. Economists have long recognized that the economically optimal harvesting policy is not the same as the policy that maximizes sustainable biological yield (Clark 1976). The general result, derived for a stylized marine fishery in which catch per unit effort is proportional to abundance, is that the optimal stock size is larger than the stock size that produces maximum sustained yield.

There are several factors that can create differences between the optimum biological yield and the optimum economic yield from a salmon stock. For example, because Bristol Bay produces such a large volume of catch on the world market it actually affects the world-wide price. Knapp (2004) estimated that when the Bristol Bay catch is 10 million fish the price would be $0.65 per pound ex-vessel, and if the catch was 30 million fish the price would be $0.36 per pound. This has clear implications on the optimal harvesting where the basic logic of the fixed-escapement policy is that if the expected production of one additional fish in the spawning stock produces one or more fish in the future return then that fish should be added to the spawning stock, whereas if the expected production of one additional fish in the spawning stock is less than one, then that fish should be added to catch now rather than spawning. If the objective is to maximize the value of the catch, and if small catches have a higher value per fish than large catches, then when the run is small and the catch is low, the expected value of the fish produced from the spawning stock in the future will be average. However the value of a fish in the catch now is above average, so the expected number of fish produced for an additional spawner will need to be large enough to offset the expected differential in price. *A priori*, we would expect that an objective of maximizing revenue will suggest some harvesting to levels lower than the traditional optimum “biological-yield” escapement.

The economic profitability of the harvesting sector will depend upon the size of the fishing fleet. Taking into consideration average net income per permit holder, it has been estimated that the optimal number of drift net permits in Bristol Bay is from 800 to 1,200, rather than the current 1,857 (Commission 2004). A considerably smaller fishing fleet would be unable to harvest frequent large catches and a much larger fleet results in undesirably low incomes per permit holder. Charles (1983) has shown for marine fisheries that net revenues are maximized by a choosing a combination of harvesting and investment strategies (rather than basing on only one factor) and that there is a level of harvesting capacity which maximizes net revenue. Similarly there is presumably an optimum processing capacity; the fixed costs in maintaining large processing plants that might only be used for a week every few years would far outweigh the benefits from the fish processed.

Thus, we would expect that a goal of maximizing net revenue will suggest some harvesting at total returns lower than the traditional MSY escapement, and a maximum level of harvest constrained by the fixed costs of harvesting and processing.

In this study we used a new approach to setting escapement goals and determined optimal harvesting policies for Bristol Bay sockeye salmon across a range of objectives: traditional maximum sustained yield, maximum landed value, economic profit to harvesting, and economic profit to processing. In all of these evaluations we consider autocorrelation of residuals, consider both Ricker and Beverton-Holt spawner-recruit relationships, and use Bayesian methods to consider uncertainty.

The impetus for this study came from a combination of recent poor economic conditions in the fishery and ADF&G recommendations in 2003 to increase many of the escapement goals to Bristol Bay river systems. The goal of the study was to characterize and quantify expected trade-offs between maximizing average biological yield and maximizing economic returns from the fishery.

The structure of this report is as follows. First we explore calculation of optimal harvesting policies for strictly biological objectives using recent technical advances in analysis of spawner-recruit data. We present a detailed analysis of alternative harvest policies for a single district (Egegik) and compare them to the current fixed-escapement goal policy (and include in an appendix the analysis for all districts). Then we examine the impact of the economics, and the consequences of alternative harvest policies on the net present value (NPV) of catch to harvesters and processors for each district. Again, in the main body of the report we consider a single district, with detailed results for all districts in an appendix. District-by-district analysis does not, however, adequately consider the implications of the relationship between aggregate Bay-wide catch and price. Therefore, we then conduct an analysis of all districts simultaneously as if they were a single aggregate fishery.

2. Estimating MSY escapement goals and examining alternative harvest policies for achieving similar biological yield

Biological escapement goals (BEGs) have traditionally been defined within ADF&G as the range of spawning escapements expected to produce greater than 90% of the theoretical maximum average annual catch. The traditional approach to spawner-recruit analyses is to find the best-fit relationship between spawners and subsequent recruits using least squares or maximum likelihood, and from the curve, calculate the escapement level that produces the theoretical MSY. In addition, a simple yield analyses is often performed where a smooth curve is fit to the actual yield and escapement data to estimate the escapement level which has provided the greatest average yield in the past. Together these analyses produce a range of escapement levels that are thought to produce the greatest average annual catch from a stock or stock complex. Annual catch and escapement levels are measured with error and this error, combined with high natural (and time varying) variation in the relationship creates uncertainty in estimates of the escapement level that produces MSY. For heavily fished stocks (e.g., most Alaska salmon stocks), there is often little information on stock productivity at high escapement levels and this lack of information introduces additional uncertainty in the estimates of the escapement level expected to produce maximum average yield (i.e., MSY).

The escapement goals used to manage Bristol Bay sockeye salmon fisheries are a product of a formal analyses performed by ADF&G and a formal public process undertaken by the Alaska Board of Fisheries (BOF). An ADF&G escapement goal committee composed of research and management personnel takes into account the theoretical MSY estimate as well as the current escapement goal range in formulating a BEG for the Alaska Board of Fisheries to consider. ADF&G’s Director of Commercial Fisheries formally adopts BEGs. Based on public input, the BOF may modify the recommended BEG to take into account the public’s concerns. A BEG which has been modified by the BOF is called an Optimum Escapement Goal or OEG. Fisheries Managers are then directed to achieve the escapement goal (either BEG or OEG) adopted by the Director or the BOF. Fisheries are managed by “time-and-area” openings to achieve escapement levels within the sanctioned escapement goal range.

In this section of the report we present methods for calculation of BEGs that include the autocorrelation of residuals, Bayesian analysis of uncertainty, and both Ricker and Beverton-Holt spawner recruit curves. To examine the biological yield from alternatives to managing to meet fixed-escapement goals, we developed a model that took into account the underlying dynamics of Bristol Bay salmon populations (and our uncertainty in them) and simulated annual catches under management policies that varied the minimum escapement level and the annual harvest rates.

2.1. Spawner-recruit data

The data used for this project came from the database of catch and escapement data maintained by the Alaska Department of Fish and Game (West 2003, with updates from

Lowell Fair, Personal Communication). Escapement data are collected annually using counting towers while catch numbers come from fish ticket data. Age data are collected from both the catch and escapement. The brood-year data for the traditional eight stock groups in Bristol Bay are in Appendix A.

A longstanding issue in analysis of Bristol Bay BEGs is the range of years to use in data analysis. Many of the stocks showed a significant increase in recruits per spawner after the 1977 regime shift, and analysts always debate whether to use the entire available time series (1956 to present) or to confine the data to the years after the regime shift. We explore both of these options.

While historic returns to the Kvichak River have shown a pronounced 5-year cycle, recent returns indicate the cycle may no longer be occurring. The cycle has greatly complicated interpretation of Kvichak data and hindered traditional spawner-recruit analysis. Attempts have been made to analyze the data by splitting the data set into "peak" years and non-peak years; although this method has also only met with limited success. Since the issue of cycles in Kvichak is unresolved and a successful spawner-recruit analysis has been elusive, we elected to not include Kvichak in this modeling effort.

2.2. Models

2.2.1. Spawner-recruit sub models

Spawner-recruit relationships were used to drive the population dynamics of the modeled sockeye salmon returns for each system. These relationships were estimated from the historical Bristol Bay catch and escapement by age class database maintained by ADF&G. Both the Beverton-Holt

$$(2.1) \quad R_i = \frac{S_i}{\frac{1}{\alpha} + \frac{S_i}{\beta}} \quad ,$$

and Ricker

$$(2.2) \quad R_i = S_i e^{\alpha(1 - S_i/\beta)} \quad ,$$

models were used (Hilborn and Walters 1992, Quinn and Deriso 1999) where S_i and R_i are the spawning stock and subsequent return for brood year *i,* respectively. Autocorrelation in the process error associated with the fit of the models to the historic data was accounted for in both models.

The basic Beverton Holt model with process error can be written as

$$(2.3)\qquad \hat{R}_i = \frac{S_i}{\frac{1}{\alpha}+\frac{S_i}{\beta}}\exp(w_t) \quad ,$$

where $\hat{R}_i$ is the deterministic predicted recruitment from brood year *i* and w_t is the process error. The autocorrelation in the process error can be written as,

$$(2.4)\qquad w_i = zw_{i-1} + \sigma_{w^*} w_i^* \sqrt{1-z^2} \quad ,$$

where w_i^* is the white noise random error at time *i* with mean 0 and standard deviation 1, z is the autocorrelation term, and σ_{w^*} is the standard deviation of the random process error component (Morris and Doak 2002). The value for w_t^* can be found by

$$(2.5)\qquad w_t^* = \frac{w_t - zw_{t-1}}{\sigma_{w^*}\sqrt{1-z^2}} \quad .$$

The Ricker model with process error was written as,

$$(2.6)\qquad \hat{R}_i = S_i e^{\alpha(1-S_i/\beta)} \exp(w_t) \quad ,$$

with likelihood

$$(2.7)\qquad L\{R|\alpha,\beta,\sigma,z\} = \prod_t \frac{1}{\sigma\sqrt{2\pi}} \exp\left(\frac{-\left(\dfrac{w_t - zw_{t-1}}{\sigma_{w^*}\sqrt{1-z^2}}\right)}{2\sigma^2}\right) \quad .$$

This likelihood was also used for the Beverton Holt model.

Parameters were estimated using Bayesian methods and the Metropolis algorithm for Markov chain simulation (MCMC, Gelman et al. 1995, Carlin and Louis 1996). Five hundred samples of the model parameters were collected from a 105,000 sample chain. The first 55,000 samples were discarded to allow the model to stabilize and every 100th sample after the first 55,000 was collected. The priors used for each system reflected our general thoughts for sockeye salmon production in Bristol Bay systems. The standard deviation for the priors was selected to reflect our uncertainty in the model parameters and to allow the MCMC model to search a wide range of possible parameter values. Minimum and maximum limits were used to keep the parameters within a reasonable range. The most often used limitation was for the β parameter, which is not well defined for several systems. For example, we limited the size of the unfished stock (β) for Egegik to 50 million fish or less (Table B-1).

2.2.2. Age-class sub models

Bristol Bay sockeye salmon return at a range of ages with most fish returning between 4 and 6 years after spawning. In evaluating the consequences of any harvest policy, particularly the inter-annual variability in catch or spawning stock, we want to consider the age at return, rather than consider the stock only on a brood-year basis. A river-specific age-class model was estimated for each of the major Bristol Bay sockeye salmon stocks using the methods described in Evans et al. (2000). These models determine how many of the returns generated by the spawner recruit models will mature at each age. The sub model partitions the returns into four age classes, ages 1.2, 1.3, 2.2 and 2.3. Summing across age classes provided annual run sizes for each of the rivers.

Age structure was modeled using the Dirichlet distribution. This is the multivariate form of the beta distribution, sometimes used to model the Bernoulli parameter defining the probability in a success-failure situation. The Dirichlet distribution generalizes the beta in that it can be used to model more than one yes/no parameter at once. Random numbers generated from both the beta and Dirichlet distributions lie between zero and unity, making them suitable for generation of proportions. A Dirichlet distribution was fitted by maximum likelihood to age-class data collected from the major Bristol Bay returns.

The form of the Dirichlet distribution is

$$f(\underline{\theta}|\alpha_1,...,\alpha_K) = \frac{\Gamma(\alpha_1 + ... + \alpha_K)\theta_1^{\alpha_1 - 1} ... \ \theta_K^{\alpha_K - 1}}{\Gamma(\alpha_1)...\Gamma(\alpha_K)} \quad , \tag{2.8}$$

where α_k are parameters of the Dirichlet distribution and θ_k is the proportion of age-class k subject to the constraints $\theta_1,.....,\theta_K \geq 0$ and $\sum_{k=1}^{K} \theta_k = 1$. A Dirichlet distribution was fitted to m years of historical age-class data using maximum likelihood. The log likelihood for m years of observations is

$$\ln(L(\underline{\alpha} \,|\, \{\underline{\theta}_m\}) = \sum_{m=1}^{M} \left[\ln\Gamma(\alpha_o) - \sum_{k=1}^{K} \ln\Gamma(\alpha_k) + \sum_{k=1}^{K} (\alpha_k - 1)\ln(\theta_{km}) \right] \quad ,$$

with

$$\alpha_o = \sum_{k=1}^{K} \alpha_k \quad . \tag{2.9}$$

A multivariate random vector was sampled from the fitted Dirichlet distribution for each brood year in the simulation with the resulting vector defining the age composition for that simulated brood year (Age 1.2, 1.3, 2.2, and 2.3). Fitted and observed means and variances by river system are shown in Table B-2.

2.2.3. Harvest policy sub model

While Bristol Bay salmon have been managed, in theory, by fixed-escapement policies, there is a wider range of harvest policies available. For instance, constant harvest rates and constant catch policies. Constant harvest rates remove a fixed proportion of the adult return each year and let escapement vary with the size of the return. Constant catch policies remove the same number of fish each year and all the annual variation in run size is reflected in the escapement.

From a technical perspective, constant escapement, constant harvest rate, and constant catch are all special cases of a general harvest policy in which catch is a linear function of total return, constrained to be less than the total return and greater than or equal to zero (Hilborn and Walters 1992). A constant harvest rate has an intercept of zero and a slope of the harvest rate. A constant escapement policy has a slope of 1 and an intercept of negative the escapement goal. A constant catch policy has a slope of zero and an intercept of the constant catch. We can further generalize this by capping the catch at a maximum. We call this type of policy a “floor-ceiling model” where the “floor” is the return size at which harvesting begins, the “harvest rate” is the slope of the line, and the “ceiling” is the maximum harvest. Note that the “harvest rate” in this terminology is only the fraction of all returns harvested if the “floor” is zero. It could be more properly called the “marginal harvest rate” that is the fraction of each additional return that would be harvested. This harvest policy model has the potential of identifying the combination of escapement goal, harvest rate, and catch ceiling that has the greatest potential of maximizing parameters such as yield or net present value. The model can be written as,

$$\hat{C}_i = \begin{cases} C_{\max} & \text{if } -E + hr\hat{T}_i \rangle C_{\max} \\ -E + hr\hat{T}_i & \text{if } \hat{T}_i \rangle E \\ 0 & \text{if } \hat{T}_i \langle E \end{cases} \tag{2.10}$$

$$0 \le hr \le 1.0 \tag{2.11}$$

where $\hat{T}_i$ is the estimated total return and $\hat{C}_i$ is the estimated catch for return year i, $C_{\max}$ is the ceiling or maximum allowable catch, E_i is the minimum escapement goal, and hr is the harvest rate.

We can use this generalized harvest policy to identify the combination of E, hr, and $C_{\max}$ that maximizes a desired outcome (catch, profits etc.), but it will be the responsibility fisheries managers to determine how to reach that goal (*E, hr, and C*) through in-season management.

2.3. Results of escapement goal analysis and alternate harvest policies that achieve high sustained yield

2.3.1. Spawner-recruit analysis

The traditional approach in spawner-recruit analysis is to find the best fit relationship using least squares or maximum likelihood, and from that curve calculate the MSY BEG. Figure 2.1 shows these fits for the Wood River system. The parameters estimated are α, β, and σ, and the parameter for autocorrelation z. Generally speaking, the α and σ parameters were well defined while β and at times, the autocorrelation parameter z, were poorly defined. The problems with β are primarily due to the increase in recruits per spawner after 1977. For Egegik and Ugashik in particular this was a period of increasing returns, and increasing escapement, so the overall pattern in spawner-recruit data is increasing escapements "leading" to increasing returns – the curves reflect no sign of density dependence. However, it is widely accepted that this is an artifact of the increase in recruits per spawner due to the change in climatic conditions and for this reason the BEGs are often calculated using only post 1977 data.

Including the uncertainty in parameter estimation via Markov Chain Monte Carlo (MCMC) in many cases provided more reasonable results, especially when the estimation of β was problematic. The most dramatic illustration of this effect can be seen for the estimation of maximum yield for Egegik River (Figure 2.2). The traditional fit suggests that there is no upper bound to the number of fish produced by the Egegik system, in essence the more fish that escape, the more fish that will return. This goes against traditional ecological thought where habitat characteristics such as rearing space or food availability eventually limit population size. The use of the Bayesian technique MCMC allows for the incorporation of prior knowledge. In the case of Egegik, we incorporated our belief that it was highly unlikely that Egegik could sustain a production level of over 50 million fish by constraining β for both the Ricker and Beverton Holt models to 50 million fish through the prior described earlier (Table B-1). The distributions of the collected parameters from the MCMC draws for Egegik are presented in Figure 2.3 and the distributions for the other rivers are presented in Figures B-1 to B-5.

2.3.2. Evaluation of MSY-based escapement goals

Yield curves for both the Ricker and Beverton Holt models were estimated for each river system using brood year data from 1956 to present, and our simulation model which incorporated MCMC methods to account for model variability (Figure 2.4). Yield for a specific level of constant escapement was estimated by setting the harvest policy parameters to a minimum escapement goal and a harvest rate of 1.0 for all returning fish in excess of the goal. Average yield for a wide range of minimum escapements was then estimated for each river using the brood year 1956-1999 data set and a valid spawner recruit model. The range of escapements that produced 90% or more of the maximum yield was then compared to the published BEG range.

The Beverton Holt model estimated all of the Bristol Bay stocks to be more productive at lower escapement levels than did the Ricker model (Figure 2.4). In addition, the range of escapements that produced 90% or greater of the maximum yield was broader for both the Ricker and Beverton Holt models than the published goal (Figure 2.5). The yield curve for the Beverton Holt model was broader than the curve for the Ricker model for all rivers except Ugashik. The published BEG for the Egegik River was lower than the 90% yield curve for either the Ricker or Beverton Holt model while the published goals were narrower and located towards the lower end of the simulated ranges of escapements for the other river systems.

2.3.3. Alternate harvest policies for yield similar to MSY

One of the important outputs of the simulation model was the estimation of the range of harvest policies that produced large, sustained catches similar to the theoretical MSY. Figure 2.6 depicts the average yield or catch for a wide range of minimum escapement goals (or escapement "floors") and harvest rates for fish returning in excess of the minimum escapement goal. For example, a fixed-escapement policy can be viewed as a minimum goal with an exploitation rate of 1.0 for all fish returning in excess of the minimum goal. Likewise, a minimum goal accompanied by a harvest rate of less than 1.0 for all fish returning in excess of the goal will produce an escapement greater than the minimum goal, the magnitude being dependent upon the number of excess fish and the harvest rate.

Biological escapement goals (BEG) in Alaska are often expressed as the range most likely to produce a catch that is 90% or greater of the maximum average catch. Figure 2.6 illustrates a range of escapement and harvest rate policies that will produce 90% or greater of the maximum modeled average catch.

2.4. Discussion – escapement goal analysis and alternate harvest policies to achieve similar yield

Our method of computing MSY adds a number of factors that have not been considered in past Bristol Bay escapement goal analysis. While the estimates of MSY are not qualitatively different from estimates obtained using traditional methods, they do provide a means for obtaining reasonable estimates of MSY for systems such as Egegik where the traditional method was unable to provide an estimate at all.

In general, using more elaborate techniques we estimated that the range of escapements that would emerge under a "90% of MSY" rule would be broader, and in particular go to higher values of escapement than the current escapement goal ranges. The broader ranges are partially due to the Bayesian analysis taking into account more of the variability in the model. This variability provided larger escapements, which tends to produce good average returns over a long simulation because of the log-normal error assumption in the modeled spawner-recruit relationship. The log-normal error provides the possibility for rare but exceptionally large returns from a given escapement. When the model produced a very large escapement in a year of unusually good recruits per spawner, it would produce an exceptionally large return from the escapement, which affects the *average* return considerably. Care should be taken when interpreting these results as this phenomenon translates into higher average returns but also much higher variability in returns and catch (i.e., a periodic or rare very large return “pulls up” an otherwise mediocre average return and increases variation in returns).

Of course, it is the levels of annual catch *and* their associated year-to-year variation that affects the economics of the fishery as much (or more than) the long-term average catch. Sections 3 and 4 of this report set out to address the value of the harvest under different harvest policies and escapement levels.

Contrary to the prevailing salmon management theory, our results suggest that yields very similar to those from fixed-escapement goal management can be achieved by some combinations of fixed harvest rates and escapement “floors” that are lower than current BEG ranges in Bristol Bay. The obvious caveat on these results is our assumption of the general shape of the underlying stock-recruit relationship. The Ricker and Beverton Holt relationships assume that stocks will recover quickly from lower escapement levels and although most Bristol Bay sockeye stocks have demonstrated this dynamic in the past, care should be taken to assume that will be the case in the future. In addition, the Beverton Holt relationship assumes there is no strong negative effect from very high escapement levels, which is an assumption rarely tested with empirical data in Bristol Bay. It makes sense that any dramatic deviation from the fixed-escapement goal management be accompanied by monitoring of the biological responses of the stocks.

We speculate that additional and more sophisticated technical analysis of *existing* stock-recruit data will not yield radically different MSY BEGs than those calculated here or those used in the fishery today. The greatest improvements may be from improving brood tables by better accounting for historical catches from non-terminal districts using genetic stock identification. With additional years’ return data, particularly those from higher or lower escapement levels than seen historically, further analysis may yield some new insights into the relationship between escapement and subsequent returns and provide for scientifically justified changes to MSY-based BEGs. Furthermore, in light of the economic state of the fishery and the results presented in this report, we speculate that it may be beneficial to shift focus from traditional MSY-based analyses to explore and evaluate the biological implications of managing for economic objectives.

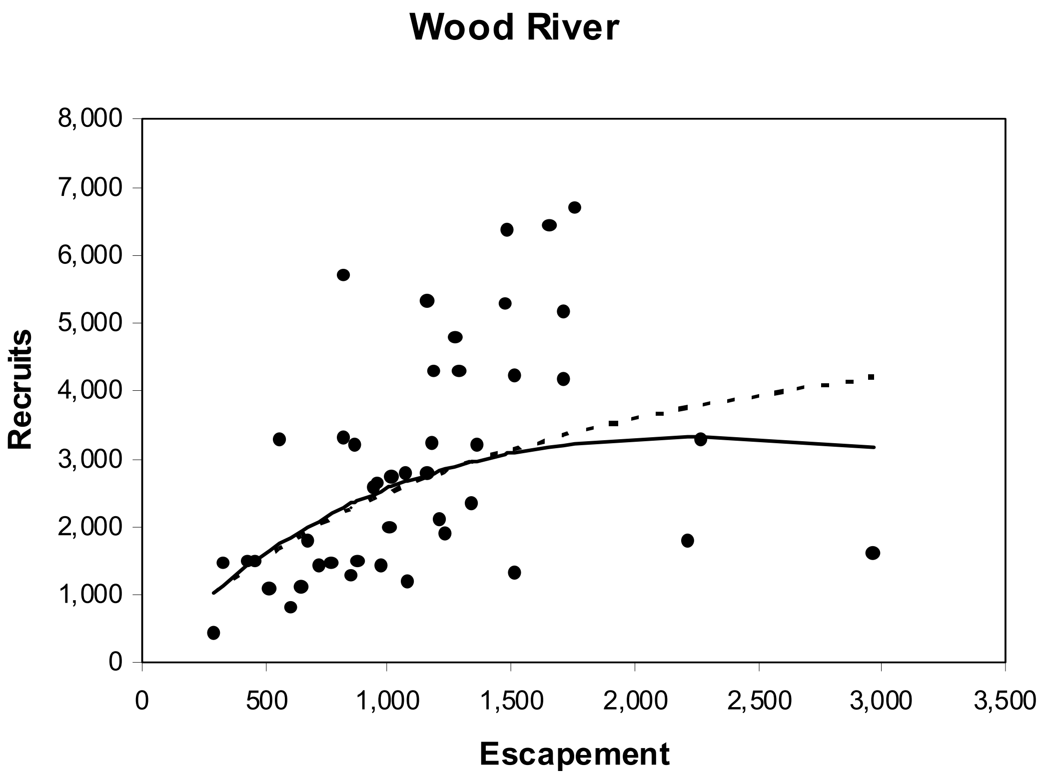


Figure 2.1. Ricker (solid line) and Beverton Holt (dashed line) curves fit using traditional nonlinear methods to the Wood River sockeye salmon data, brood years 1956-1999, in thousands of fish.

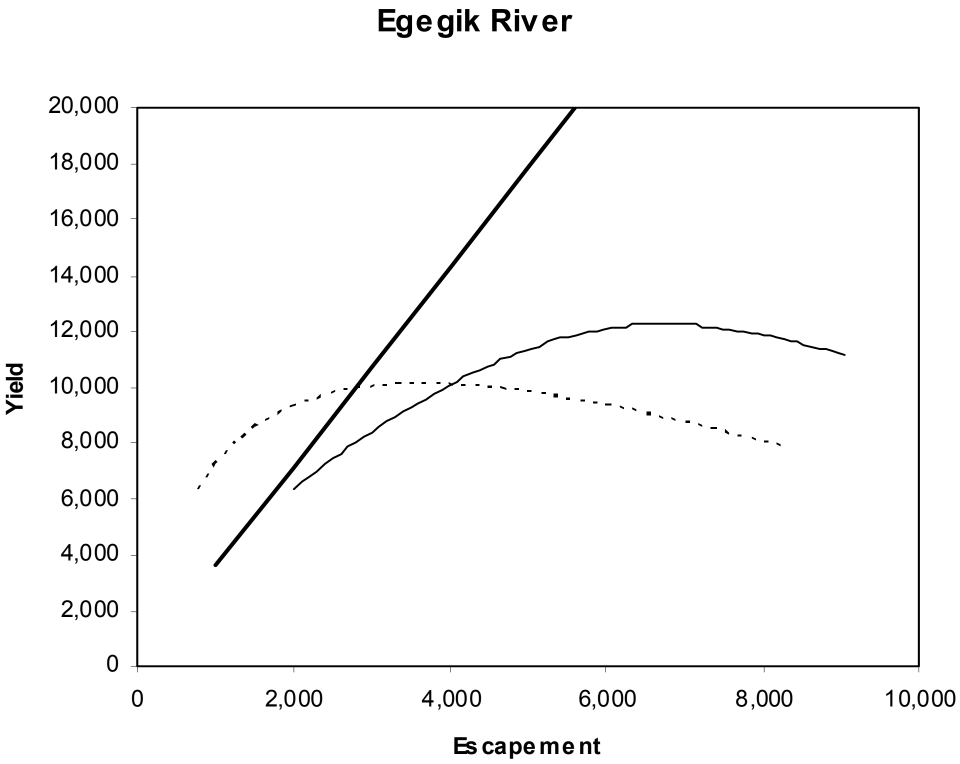
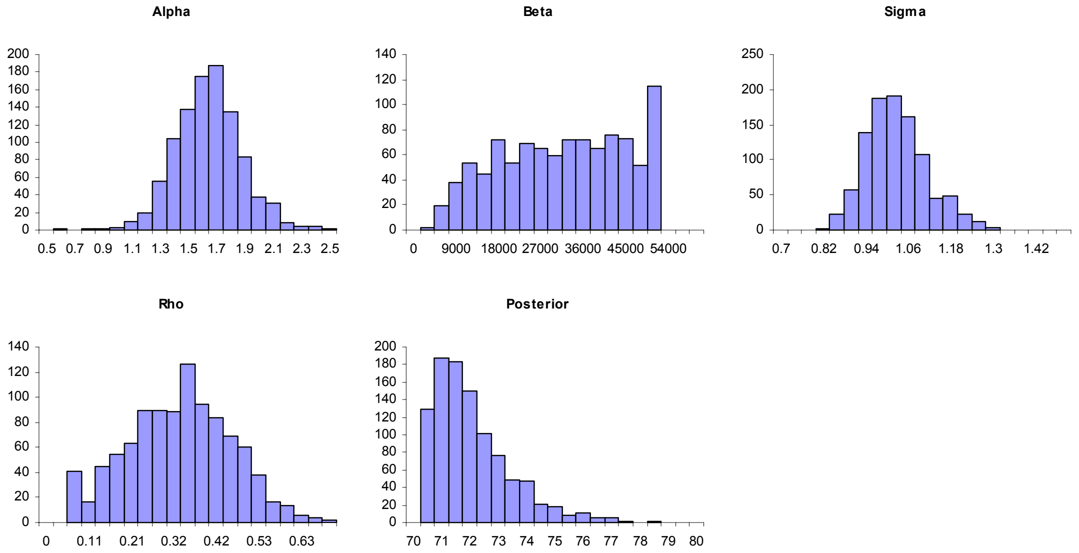


Figure 2.2. Estimated yield for the Egegik River sockeye salmon population in thousands of fish. The heavy solid line indicates the estimated relationship for the traditional nonlinear fit for both the Ricker and Beverton Holt models while the thin solid and dashed lines indicate the results using MCMC to obtain parameter estimates for the Ricker and Beverton Holt models, respectively.

Egegik River

Ricker Parameters



Beverton Holt Parameters

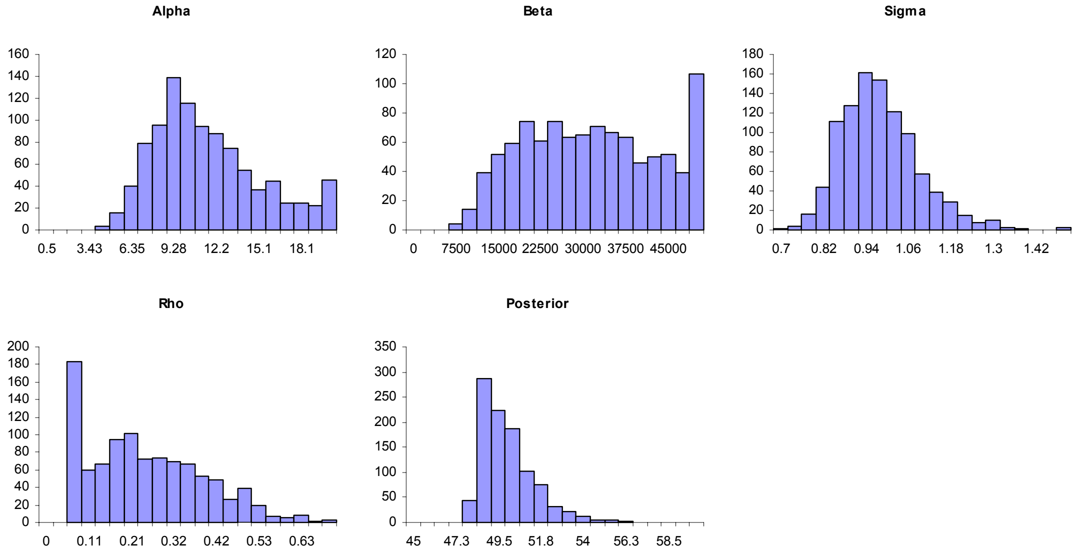


Figure 2.3. Distributions of the parameter estimates obtained from the Markov Chain Monte Carlo (MCMC) for the Ricker and Beverton Holt models for Egegik River.

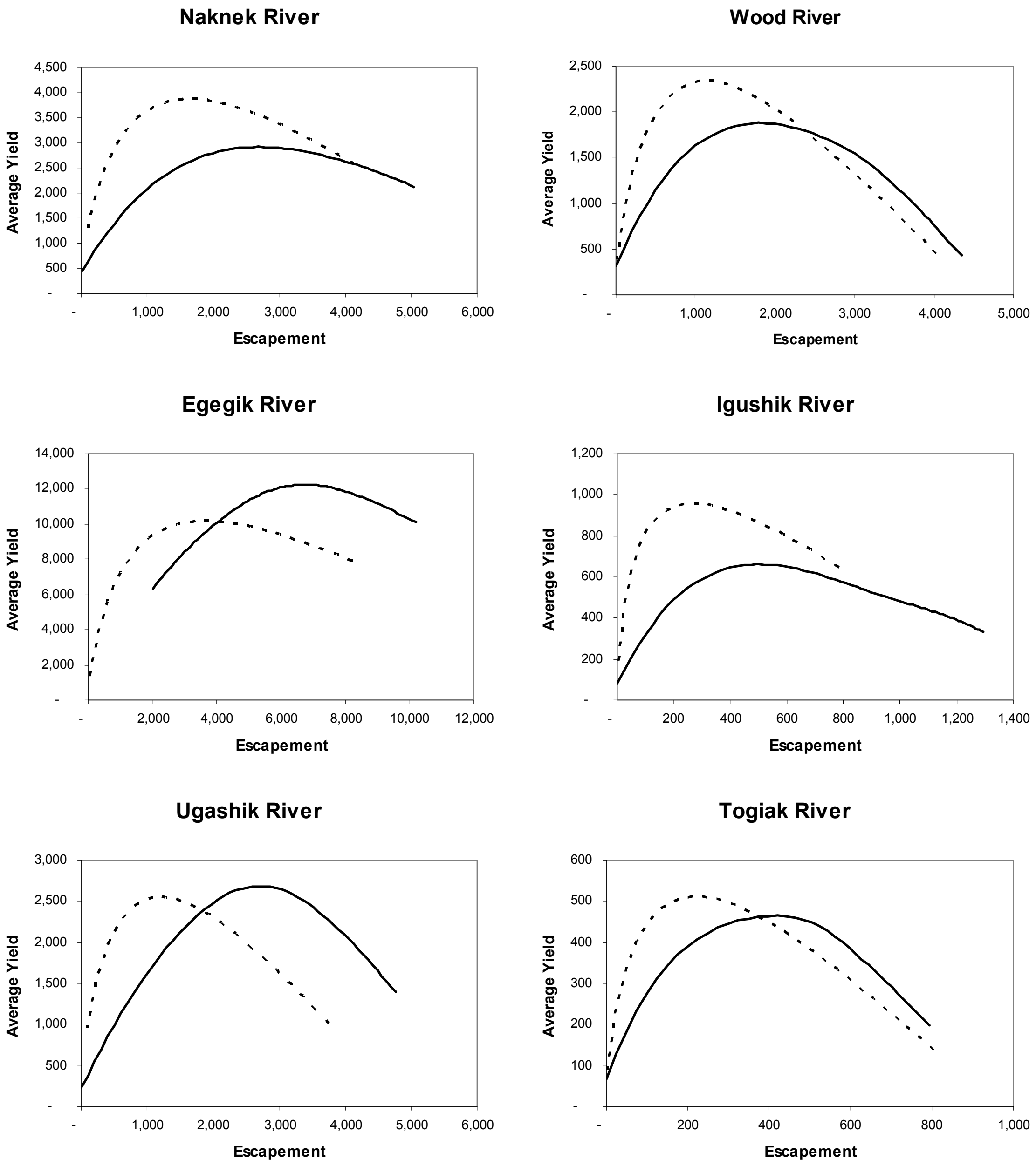


Figure 2.4. Yield curves obtained using Bayesian methods for the major sockeye salmon systems in Bristol Bay. Solid line indicates the results for the Ricker Model while the dashed line indicates the Beverton Holt Model.

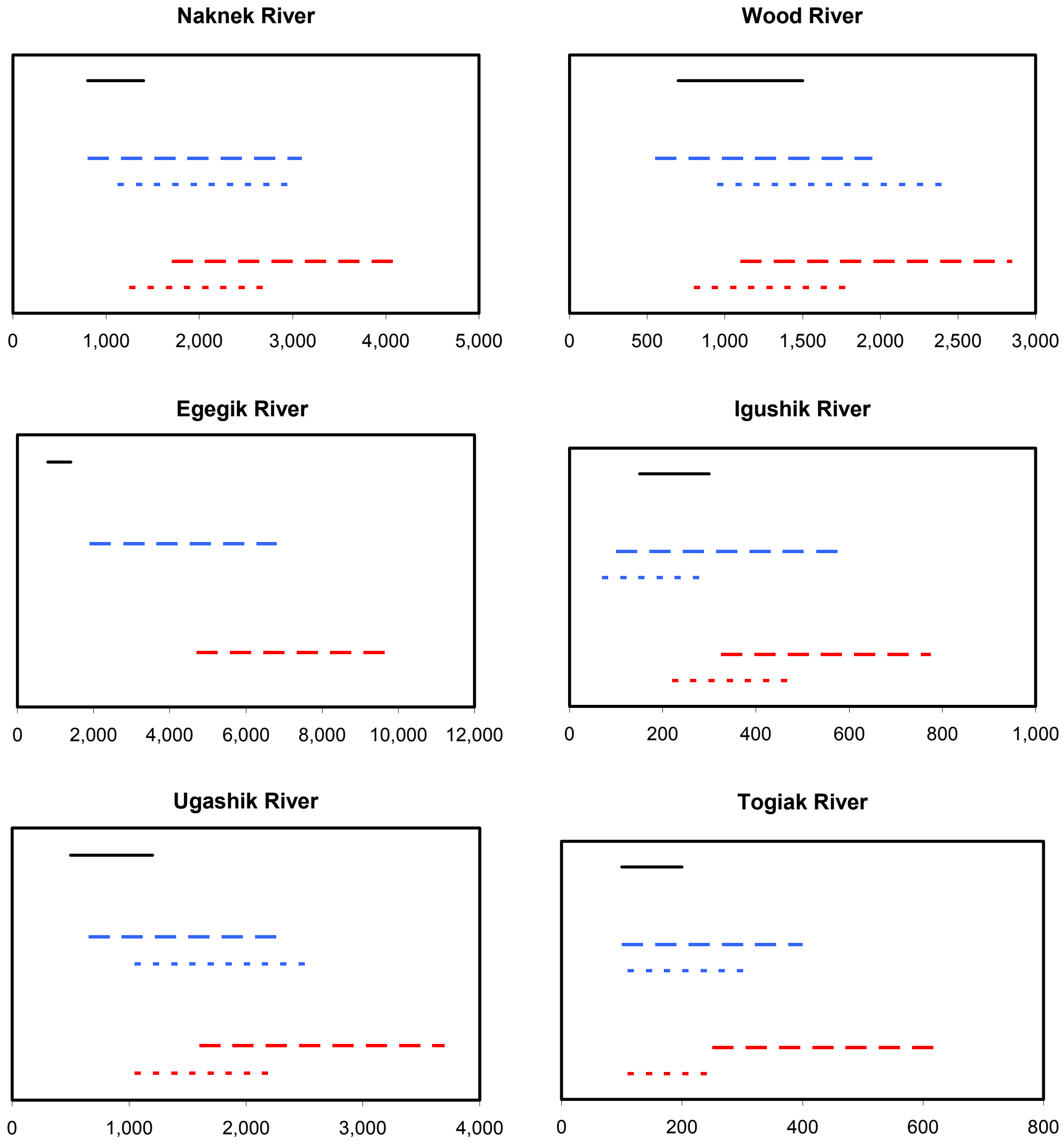


Figure 2.5. Comparison of current escapement goals to the range of escapements that produce 90% of the simulated maximum yield for the Ricker and Beverton Holt models developed here. The solid black line at the top of each plot indicates the range of escapement in the present escapement goal while the blue lines (middle group) indicate Beverton-Holt models and the red lines (bottom group) indicate Ricker models. The long dashed lines indicate the 90% range obtained using the Bayesian method described here while the short dashed lines indicate the more traditional way of fitting the model using maximum likelihood.

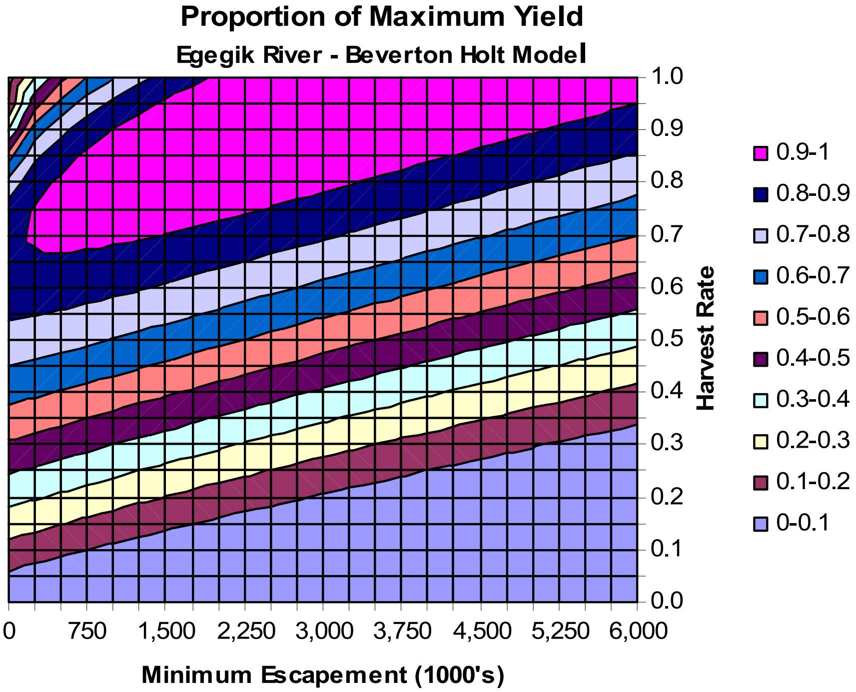


Figure 2.6. Contours of proportion of maximum yield for a range of harvest policies where the minimum escapement goal and harvest rate are varied for Egegik River spawner-recruit data using the Beverton Holt model.

3. Economic value of catch from a single district across a range of harvest policies

In this section we develop an economic model to characterize how the economic value of the catch from a single fishery changes across harvest policy choices. The model combines the previously described salmon production models (spawner-recruit and age-class models) with the harvest policy model to produce theoretical catches over the long run. The wholesale and ex-vessel prices of these catches are then estimated using models based on historic Bristol Bay sockeye salmon prices. The cost of harvesting and processing the catch can be also estimated using other previously developed models. The ability to combine the production, harvest, and economic models into a single simulation allows for the estimation of the long-run value of catch (net present value or NPV) from different harvest policies and ultimately, the harvest policy which is most likely to produce the maximum economic benefit for each sector in the fishery.

3.1. Economic models

3.1.1. Ex-vessel and August Japanese wholesale price sub models

August Japanese wholesale price for sockeye salmon ($P_{whole,y}$) and the magnitude of the harvest was used to estimate revenue to the fish processors. Knapp (2004) concluded that the ex-vessel price for Bristol Bay sockeye salmon was related to the volume of the Bristol Bay sockeye salmon harvested and the wholesale price for farmed coho salmon in Japan ($P_{coho,y}$) for that year. In addition, he implied that the Japanese wholesale price for sockeye salmon was directly related to the ex-vessel price. We developed a relationship to calculate the price that would be paid in year *y* using data presented in Knapp (2004; Table B-3),

$$(3.1) \quad P_{whole,y} = \exp\lfloor 3.91 + (-0.34 * \ln B_y) + (0.96 * \ln P_{coho,y}) + \varepsilon_y \rfloor \ ,$$

where B_y is the biomass of the Bristol Bay sockeye salmon harvest in metric tons in year *y* and ε_y is the process error. Since we had no means of estimating $P_{coho,y}$ for our simulations without developing another model for world-wide farmed coho production, we assumed $P_{coho,y}$ would be the average price paid for the years 2000-2003 ($1.88 per pound) for all years in the simulation. It was also assumed that the average weight of sockeye salmon was 2.68 kg for the conversion of numbers of fish obtained from the harvest policy model into biomass. Process error was simulated by drawing a random normal deviate with a mean of zero and a standard deviation of 0.129, calculated from the variability of the data in Knapp (2004). Revenue to the processors was then calculated by multiplying the harvest volume by the price.

Revenue to both drift gill net and set gill net fishermen was estimated using the ex-vessel price and the magnitude of the harvest. Ex-vessel price in year y ($P_{ex,y}$) was estimated using the historic relationship between August Japanese Wholesale price and Ex-vessel price for the years 1991-2003 (data from Knapp 2004),

$$P_{ex,y} = 0.25 + 0.35P_{whole,y} + \varepsilon_{ex,y} \tag{3.2}$$

Process error was assumed to be normally distributed and was simulated by drawing a random normal deviate with a mean of zero and a standard deviation of 0.099 estimated from the data (Figure 3.1). Again, the average weight of sockeye salmon was assumed to be 2.68 kg (5.9 lbs) and revenue to the fishermen was calculated by multiplying the harvest volume by the ex-vessel price.

3.1.2. Processor and fisherman cost sub models

The cost sub models for the fish processors and both the drift and set gillnet fisheries were developed directly from Appendix F of *An Analysis of Options to Restructure the Bristol Bay Salmon Fishery* (Link et al. 2003). Both fixed and variable costs were estimated and incorporated into the economic models for processing and harvesting Bristol Bay salmon.

For their analysis, Link et al. (2003) developed hypothetical processing plants, both shore-based and floating, using information gathered through interviews with plant managers and owners. While neither of the hypothetical processors depicts an actual Bristol Bay processor, it was felt that a representative processing operation was described. The fixed or overhead cost for the hypothetical floating processor described by Link et al. (2003) was for an operation that processed crab and Pacific cod as well as salmon. Because of this we felt it inappropriate to charge all of the overhead cost to the salmon fishery and subsequently made the assumption that half of the total annual overhead cost would be charged to the Bristol Bay salmon fishery. All other costs for processing salmon described by Link et al. (2003) were included in our model (Table B-4). An option was added to the simulation model that allows the user to select the percentage of the catch that would be processed by shore-based processors.

The operating parameters for the drift and set gillnet fleets were also estimated by Link et al. (2003) using information acquired by the State of Alaska Commercial Fisheries Entry Commission for a study designed to determine the optimum number of permits holders for Bristol Bay (Commission 2004). This information was divided into three groups based on residency (1) residents of the immediate Bristol Bay area, (2) other Alaskan residents, and (3) non-Alaskan residents. Each residency group was further divided into three sub groups based on revenue rankings. We simplified our model by averaging the costs for each revenue group within a residency group, while maintaining the residency stratification (Tables B-5 and B-6). An option was included in the simulation where the user could select the residency makeup of either gillnet fleet. For the purpose of simplicity, we elected to use the average residencies by gear group presented by Link et al. (2003). Process error was not included in the cost sub model.

3.1.3. Combining sub models to estimate net present value

Net Present Value (*NPV*) was estimated for the fish processors as well as the drift and set gillnet fishery using output from the previously described sub models. An average sockeye salmon weight of 5.9 pounds per fish was used to convert the number of fish estimated in the spawner-recruit, age-class, and harvesting sub models of the simulation into pounds of fish, the unit of measure required for the economic segment of the simulation. An option was incorporated into the simulation that allowed the user to specify a discount rate.

The estimation of *NPV* for all three user groups (fish processors, drift gill-netters, and set gill-netters) was similar. A time series of user-specified duration of recruitment, catch, and economic factors was generated for each MCMC draw. Average NPV for a particular harvest policy was then estimated by averaging across the number of MCMC draws.

<u>*NPV* for Fish Processors</u>. Gross revenue to the fish processors in year y ($I_{proc,y}$) is a function of the magnitude of the catch (C_y), the August Japanese wholesale price ($P_{whole,y}$), and the recovery rate or percentage of the catch converted to marketable product (r),

$$I_{proc,y} = C_y P_{whole,y} r \quad . \tag{3.3}$$

Total cost to process the catch for a year ($H_{proc,y}$) is a function of the magnitude of the catch and, the variable ($V_{proc,y}$) and fixed costs ($F_{proc,y}$) of processing which differ between shore based ($V_{shore,y}$; $F_{shore,y}$) and floating processors ($V_{float,y}$; $F_{float,y}$). Variable cost for processing the catch for year *y* was estimated by,

$$V_{proc,y} = B_y\left(V_{shore,y} p_s + V_{float,y}(1 - p_s)\right) \quad , \tag{3.4}$$

where p_s is the proportion of the catch processed by shore based plants. Fixed cost for year *y* was estimated by,

$$F_{proc,y} = G\left(F_{shore,y} p_s + F_{float,y}(1 - p_s)\right) \tag{3.5}$$

where *G* is the total processing capacity. The total cost to process the catch was then,

$$H_{proc,y} = V_{proc,y} C_y + F_{proc} \quad . \tag{3.6}$$

Net Present Value (NPV_{proc}) to the fish processors for a time period *n* years in length is,

$$NPV_{proc} = \sum_{y}^{n} \frac{I_{proc,y} - H_{proc,y}}{(1 + d)^y} \tag{3.7}$$

where *d* is the discount rate.

Net Present Value to Drift and Setnet Fishermen. The calculation of net present value to the drift (NPV_{drift}) and setnet (NPV_{set}) fishermen was similar to the calculations for the fish processors. The differences were (1) the use of ex-vessel price in the place of August Japanese Wholesale price in the calculation of gross revenue, (2) the determination of both variable and fixed costs using the proportions of local residents, other Alaskan residents, and non-Alaskans rather than the proportion of catch processed by shore based operations, (3) the inclusion of an average annual capacity estimate for each drift and setnet permit in place of processing capacity, and (4) an accounting for the allocation of catch between drift and setnet fisheries.

3.2. Results – district-by-district economic value to harvester and processor sectors

The *net* economic value of the catch (or NPV) was heavily influenced by the level of available harvesting and processing capacity. Available capacity influences the net value of the catch because a significant portion of the costs in both sectors are fixed costs. In addition, the underlying productivity of the stocks as we have described by either a Ricker or Beverton Holt relationship becomes more variable as the size of the run increases.

A maximum for net present value was found for the processors, drifters, and set netters for all systems examined for both the Ricker and Beverton Holt models (Figures 3.2 to 3.7). These dome-shaped relationships show how there is insufficient processing and fishing capacity to deal with the stock's surplus catch for the ascending portion of the plot while there is excess capacity for the descending limb. The peak of the dome reflects the optimum capacity that strikes a balance between fleet and processing capacity and the gross value of the harvest.

An interesting product of these results is that the optimum number of processors or fishing permits for a district can be estimated from these plots by taking the catch where NPV is maximized, convert it into pounds of fish and then divide by the average annual capacity (in pounds). For example for the Naknek district (Figure 3.2), NPV for the drifters is maximized at 2.75 million fish or 16.23 million pounds; 16.23 million pounds divided by 150 thousand pounds per permit equals 108 permits. A similar exercise for Egegik provides an estimate of about 350 permits.

The presently used allocations between the drift and set net fleets for each of the fishing districts are being applied to the modeled catches. These allocations heavily influence the capacity which maximizes NPV for the fishing sectors. The maximum capacity will be different for each of the fishing groups with different allocations. For example the allocations used for Ugashik are 0.90 drift and 0.10 set net (Table B-7). If the modeled catch to the set net fleet is going to be increased by 100,000 fish, the total catch to the district will be increased by 1,000,000 fish resulting in a great deal of more variability in the salmon production model. Increasing the set net allocation will move the capacity at maximum NPV to a larger value while decreasing the capacity at maximum NPV for the drift fleet.

While the results of the economic analysis are interesting, care should be taken when interpreting these results. The models developed here are quite complex and a number of assumptions have been made. Two notable assumptions are (1) the data for the revenue and cost portions of the model are the same for each river system; a situation which in reality is most likely not true; it costs more to operate in Ugashik than it does Naknek. (2) there are questions as to how sensitive the model is to the capacity assumptions we made for the drift and set net fisheries using very little information other than personal observation. Obviously more data would help to validate or strengthen our assumptions.

3.2.1. Sensitivity to the selection of the spawner-recruit model

The sensitivity of the NPV estimates due to the assumed spawner recruit relationship was evaluated by varying the spawner recruit model for otherwise identical simulations. No definite pattern emerged. The peak in NPV for the fish processors, drifters and set nets was higher for the Ricker model for both the Naknek and Egegik systems. In addition, the peaks for both models occurred at approximately the same Maximum Catch in the Naknek and Egegik system (Figures 3.2 and 3.3). The Beverton Holt model generally produced larger estimates of NPV with the peaks occurring at a higher maximum catch for the Ugashik, Wood, Igushik, and Togiak systems (Figures 3.4 through 3.7). Because there was no definitive evidence that pointed to one model being superior over the other for representing the spawner recruit relationship for the various river systems, the harvest policies were evaluated under both the Ricker and Beverton Holt models.

3.2.2. Sensitivity to the proportion of catch processed by shore-based processors

Sensitivity of the NPV estimates to the assumed proportion of the catch processed by shore-based facilities was evaluated by running identical simulation models for the Egegik fishery and varying the proportion of the catch processed by shore-based processors. Shore-based percentages of 50%, 75% and 100% were examined. Net present value increased with decreasing percentage of shore-based processing (Figure 3.8). In addition, NPV peaked at larger Maximum Catches with decreased shore-based proportion. A shore-based percentage of 75% was used for the evaluation of harvest policies.

3.2.3. Sensitivity to the average annual capacity by permit for the drift and set net fishery

The sensitivity of the NPV estimates to the assumed average annual capacity by permit for both the drift and set net fishery was briefly examined. The simulations used to compare the various harvest policies for this project were run at drift and set net capacities of 150,000 and 60,000 pounds per permit. The effect of under and over estimating these capacities was examined by running identical simulation models for the levels 100,000, 150,000, and 200,000 pounds per permit for the drift fleet, and 40,000, 60,000, and 80,000 pounds per permit for the set net fleet while keeping all fixed costs the same. As may be expected, NPV increased with increasing capacity (Figure 3.9) implying that the more economically efficient the permit holder, the greater profit to be made. While this analysis does provide a graphical illustration of how the simulation outcome can be affected by the selection of values for permit capacity, it does have practical limitations. In most real world situations it is extremely difficult to increase average annual permit capacity without increasing costs through adding additional crewmembers or upgrading fishing equipment.

3.2.4. Relationship of NPV to yield

The traditional method of determining the range of escapements that will produce 90 to 100% of maximum yield is based on the examination of a range of fixed escapements. Our approach expands upon the traditional approach by examining a wide range of minimum escapements and harvest rates for total returns in excess of a minimum goal. As an example, Table 3.1 presents the percent of the maximum catch observed for a range of minimum escapements and harvest rates for the Egegik River using the Beverton Holt spawner recruit model. The range of minimum escapements and harvest rates that produce 90% or greater of the maximum catch is encompassed by a polygon. As can be seen there are numerous combinations of minimum escapement goals and harvest rates that will produce high yields. An examination of the average escapements that produced these yields (Table 3.2) demonstrates that the escapements that provide high yield fall within a range. Escapements below the range don't produce enough fish to provide high yield while larger average escapements are typically the result of low harvest rates, which also don't produce large catches.

A similar approach can be taken to determine the harvest policy that produces 90% or greater of the maximum net present value for the processors, drifters, and set netters. Table 3.3 presents the percent of the maximum net present value for the processors for the same range of minimum escapements and harvest rates for the Egegik River using the Beverton Holt model.

Overlaying the 90% contours for the various NPV curves over the yield curve for a river system provides insight into how the harvest policies for maximizing NPV and yield vary. In general, for the economic parameters used in our simulation, NPV was maximized for the lower portion of the range of escapements that produced maximum yield (Figure 3.10, Figure C-1 through C-5).

3.3. Discussion - district-by-district economic value to harvester and processor sectors

In this section, we demonstrated that net economic benefit (NPV) is maximized by capping utilization by the various user groups. The cost of maintaining a processor or fishing operation capable of handling very large catches is not made up by the value of that occasional large catch. This result is not surprising but demonstrates the importance of fixed costs in determining the optimal harvest levels from a fishery.

Our models also suggest that NPV was maximized at more aggressive harvest policies (lower minimum escapement levels and higher harvest rates) than those required to maintain maximum sustained yield (Figure 3.10 and Figures C-1 through C-5). This was largely due to the fact that the Ricker and Beverton-Holt spawner-recruit models become more variable or produce an increasingly wider range of returns as the level of escapement increases.

NPV for each district fishery is dependent on the underlying assumptions about the productivity of the stock and the shape of the relationship between stock and recruitment. In addition, NPV is also heavily dependent on the underlying economic assumptions including salmon prices, fixed and variable costs, the allocation between user groups, and the assumed maximum catch level set by the harvest policy. These results are interesting and can be used to infer qualitative benefits to net income from limiting capacity but better data are needed to make useful quantitative estimates of district-specific maximum catch limits.

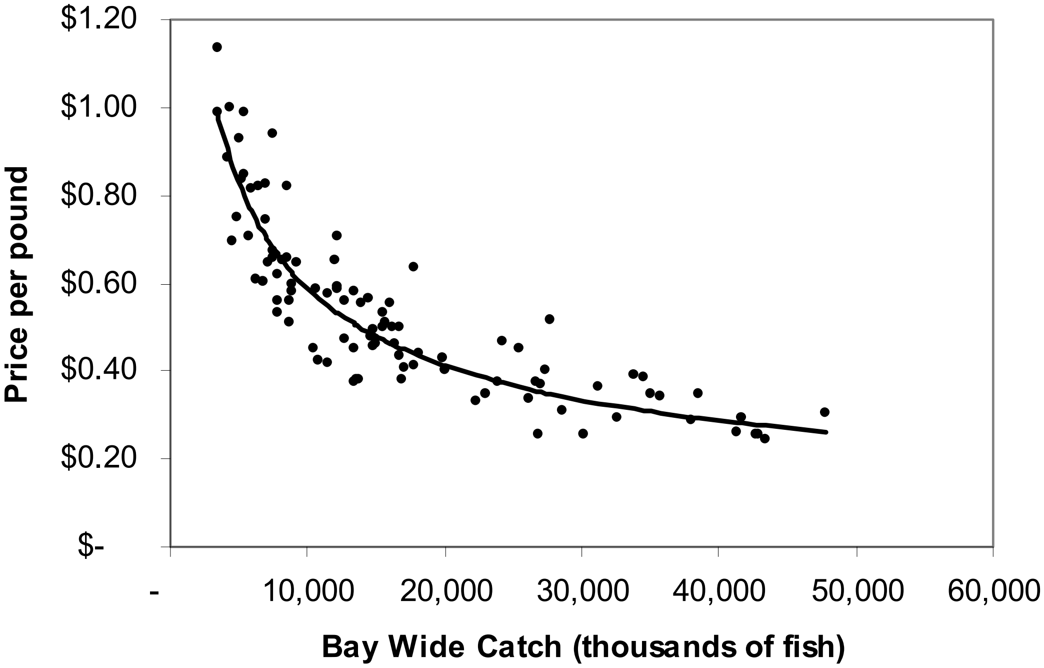
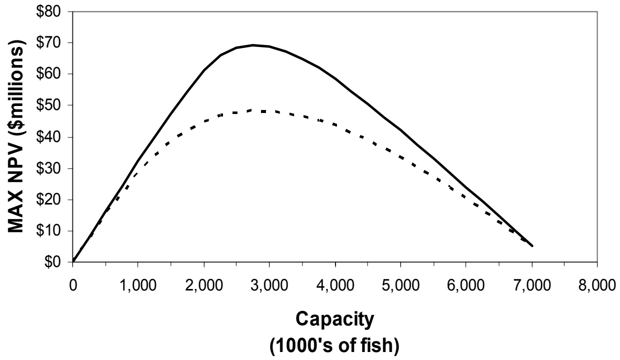
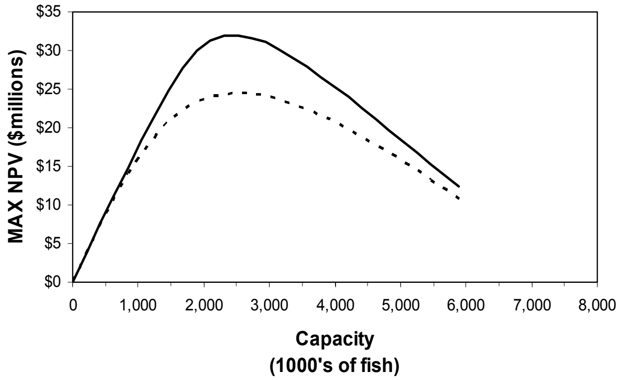


Figure 3.1. Modeled ex-vessel price function and corresponding process error (approach from Knapp 2004).

Naknek - NPV to Fish Processors



Naknek - NPV to Drift Gillnet Fishery



Naknek - NPV to Set Gill Nets

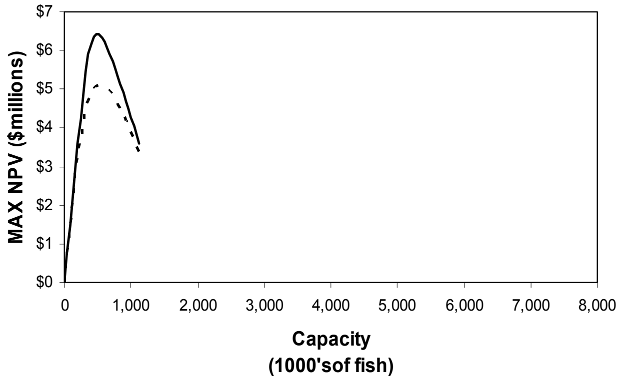
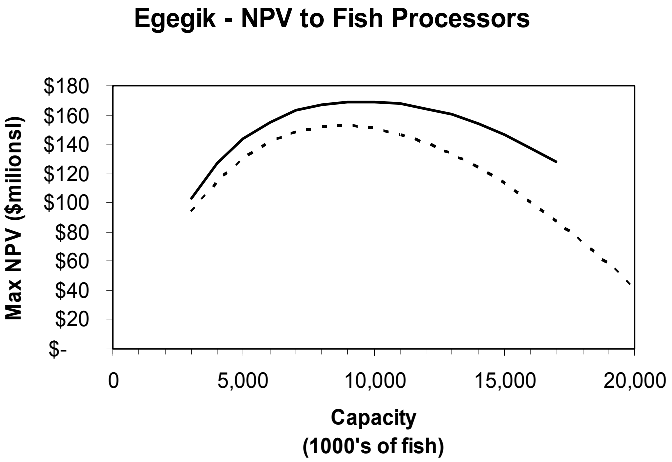
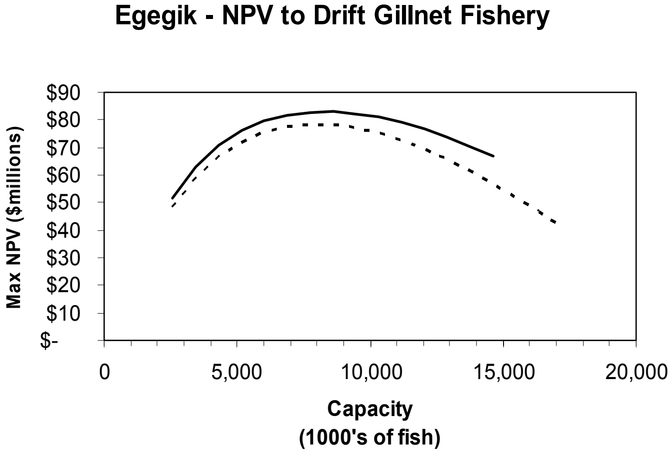


Figure 3.2. Maximum net present value (NPV) to the processors, drift, and set net fisheries for a 100-year simulation of the Naknek River sockeye salmon fishery. The models examined both the Ricker (solid line) and Beverton Holt (dashed line) production models and restricted the number of Processors, Drift, and Set net fishermen in the fishery based on the maximum catch.





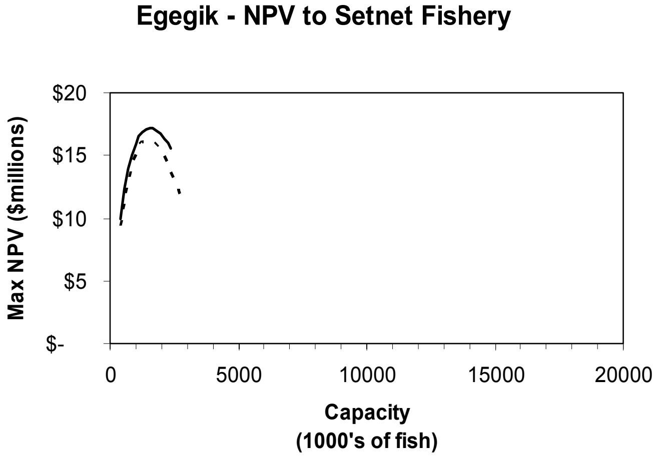
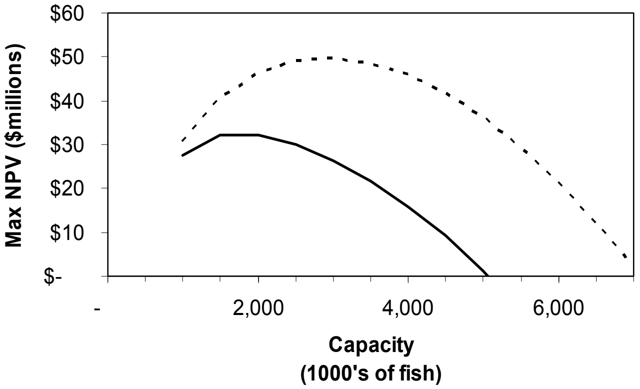
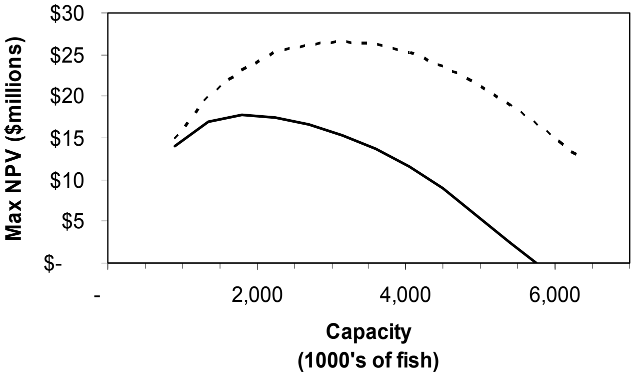


Figure 3.3. Maximum net present value (NPV) to the processors, drift, and set net fisheries for a 100-year simulation of the Egegik River sockeye salmon fishery. The models examined both the Ricker (solid line) and Beverton Holt (dashed line) production models and restricted the number of Processors, Drift, and Set net fishermen in the fishery based on the maximum catch.

Ugashik - NPV to Fish Processors



Ugashik - NPV to Drift Gillnet Fishery



Ugashik - NPV to Setnet Fishery

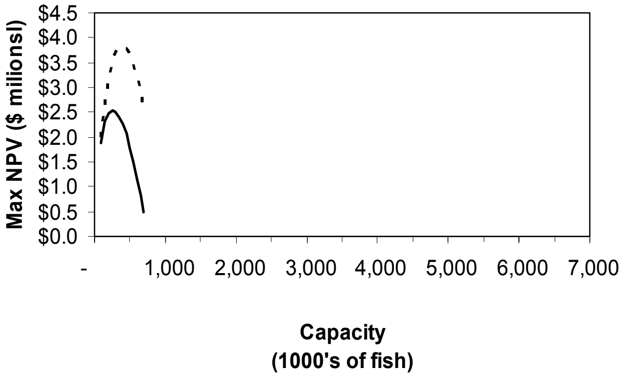
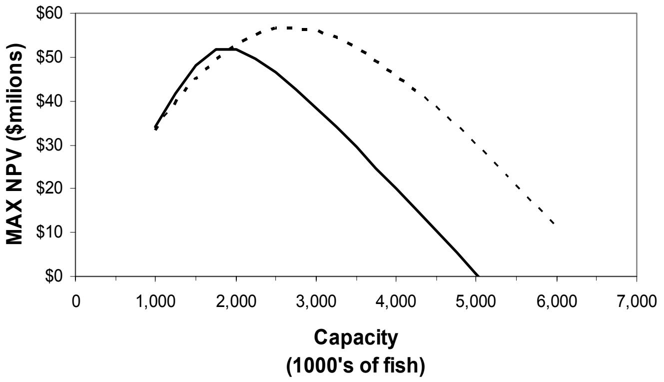
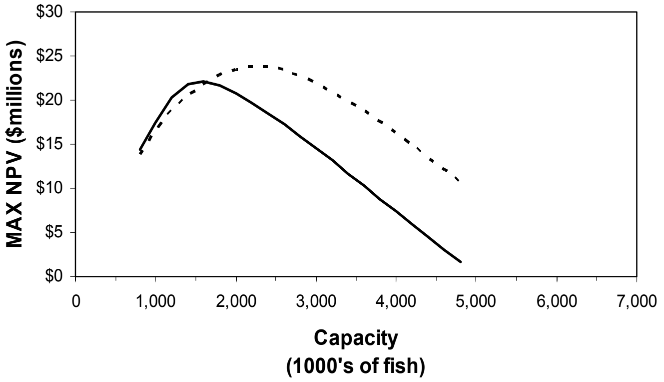


Figure 3.4. Maximum net present value (NPV) to the processors, drift, and set net fisheries for a 100-year simulation of the Ugashik River sockeye salmon fishery. The models examined both the Ricker (solid line) and Beverton Holt (dashed line) production models and restricted the number of Processors, Drift, and Set net fishermen in the fishery based on the maximum catch.

Wood - NPV to Fish Processors



Wood - NPV to Drift Gillnet Fishery



Wood - NPV to Set Gill Nets

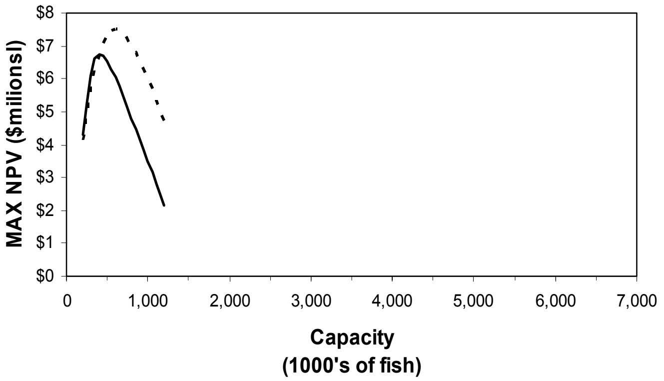
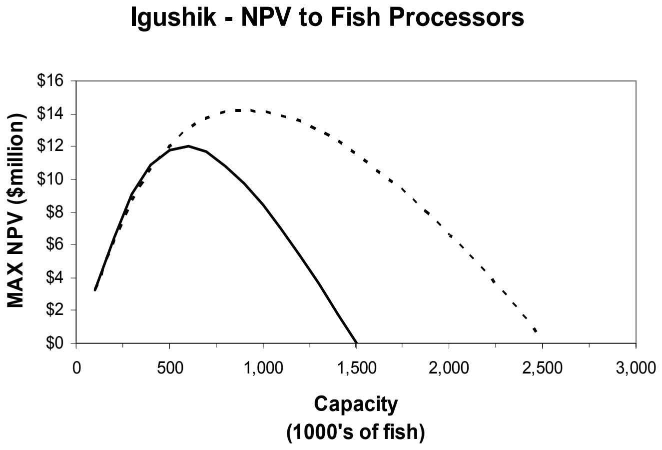
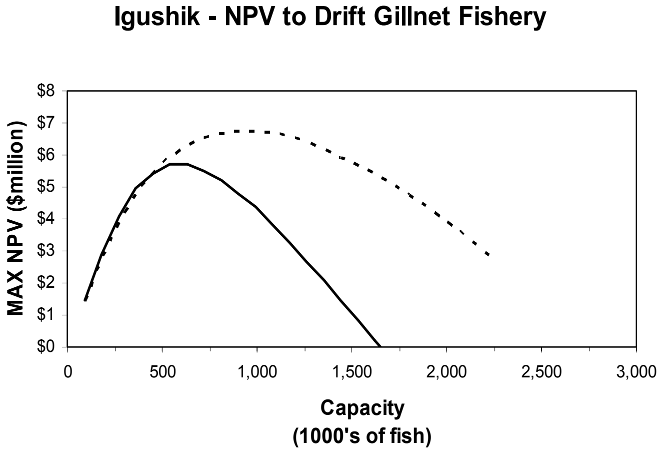


Figure 3.5. Maximum net present value (NPV) to the processors, drift, and set net fisheries for a 100-year simulation of the Wood River sockeye salmon fishery. The models examined both the Ricker (solid line) and Beverton Holt (dashed line) production models and restricted the number of Processors, Drift, and Set net fishermen in the fishery based on the maximum catch.





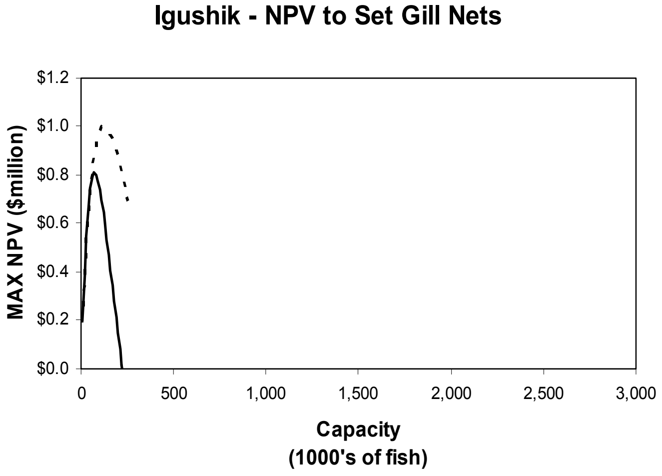


Figure 3.6. Maximum net present value (NPV) to the processors, drift, and set net fisheries for a 100-year simulation of the Igushik River sockeye salmon fishery. The models examined both the Ricker (solid line) and Beverton Holt (dashed line) production models and restricted the number of Processors, Drift, and Set net fishermen in the fishery based on the maximum catch.

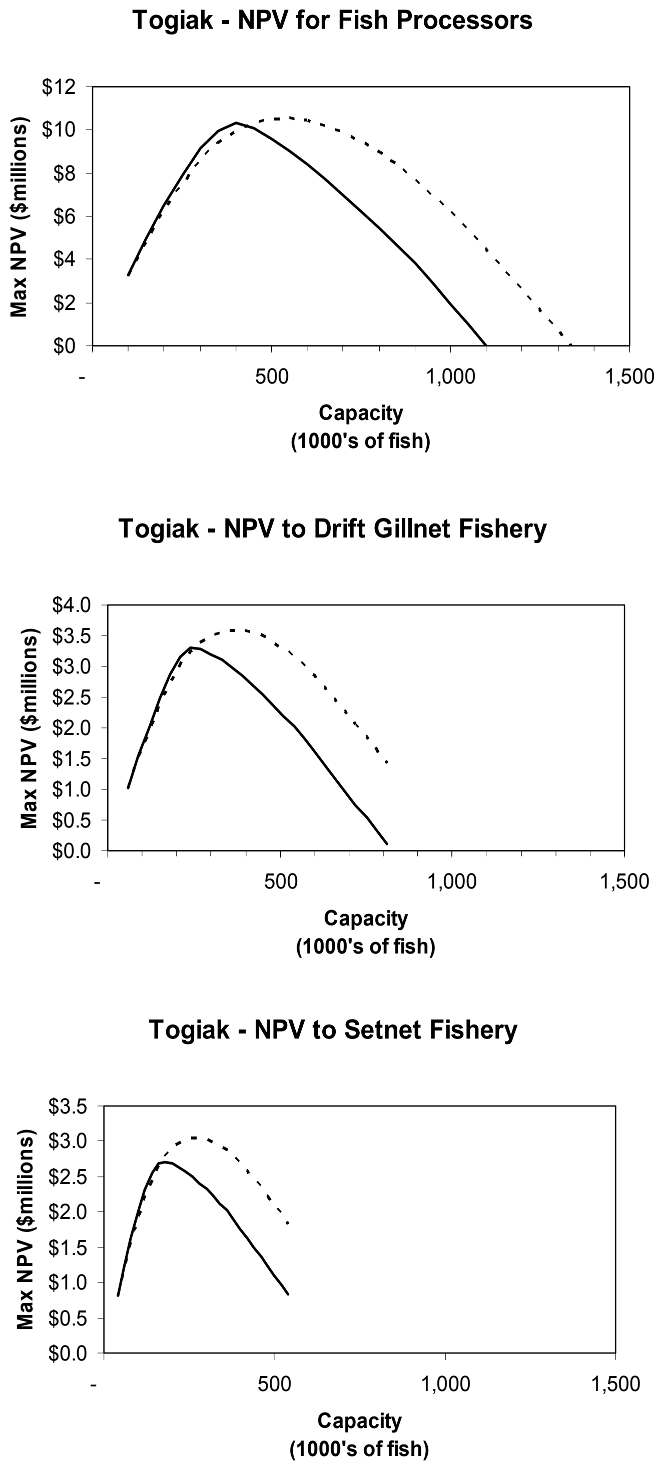


Figure 3.7. Average net present value (NPV) to the processors, drift, and set net fisheries for a 100-year simulation of the Togiak River sockeye salmon fishery. The models examined both the Ricker (solid line) and Beverton Holt (dashed line) production models and restricted the number of Processors, Drift, and Set net fishermen in the fishery based on the maximum catch.

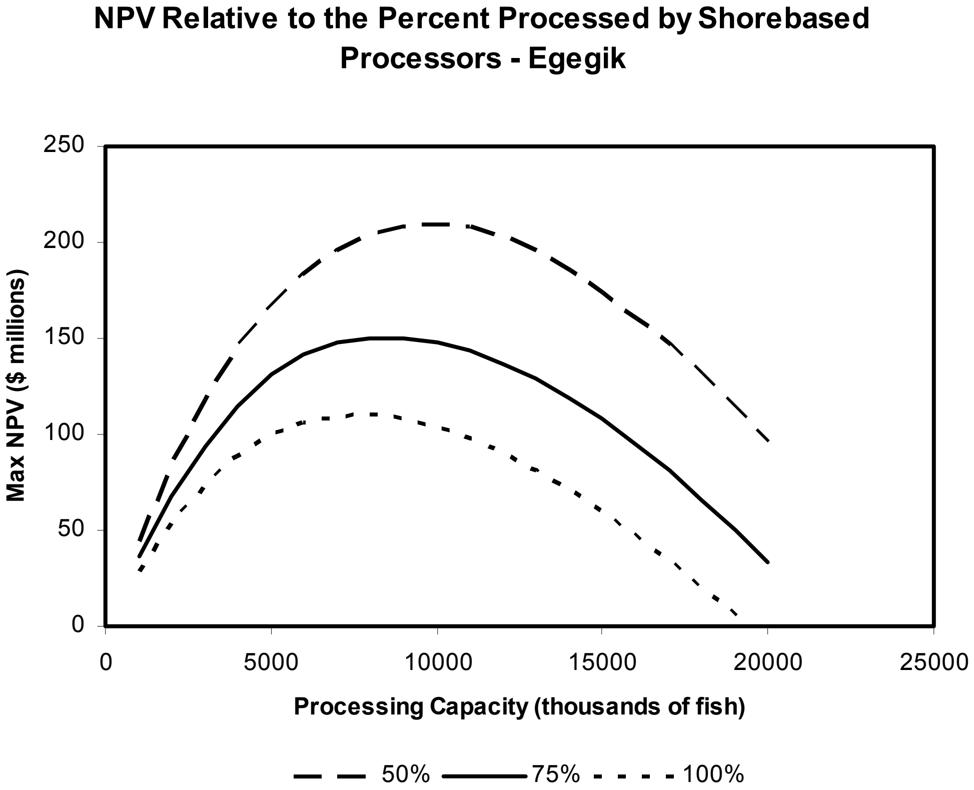


Figure 3.8. Results of a sensitivity analysis to examine the effect of changing the percent of the catch processed by shore-based facilities.

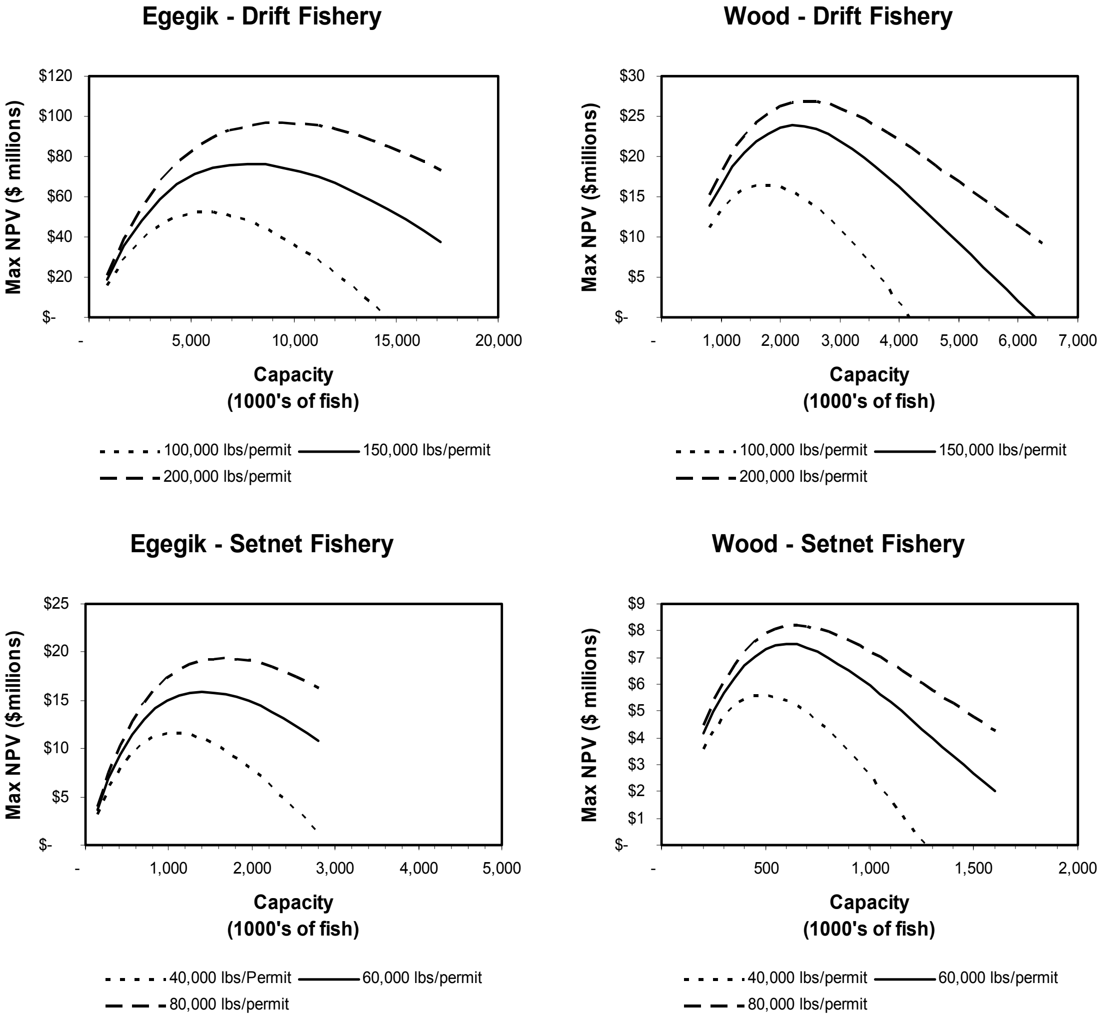
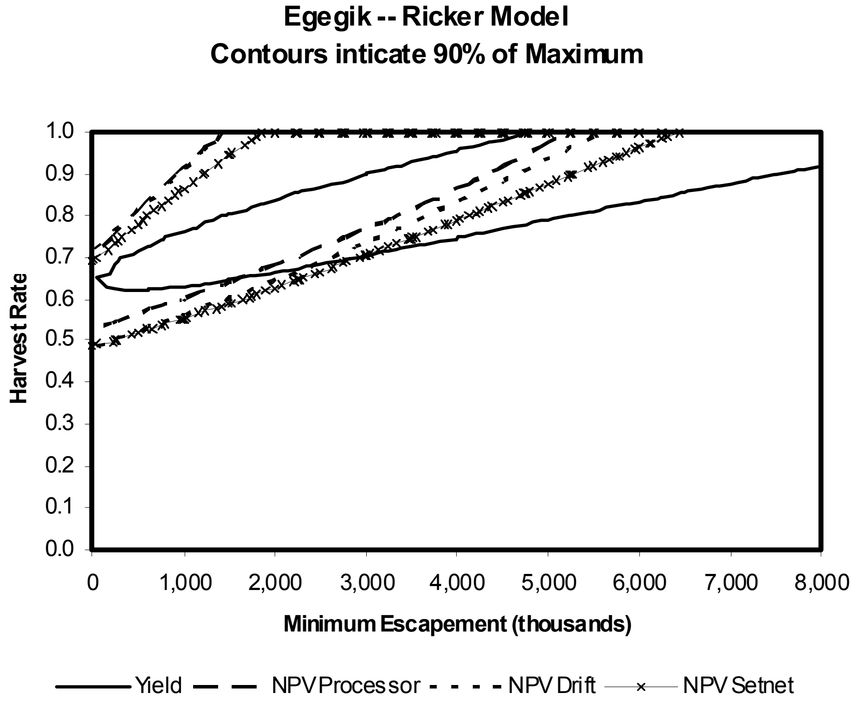


Figure 3.9. Results of a sensitivity analysis to examine the effect of changing the average capacity per permit for the drift and set net fisheries for Egegik and Wood Rivers.



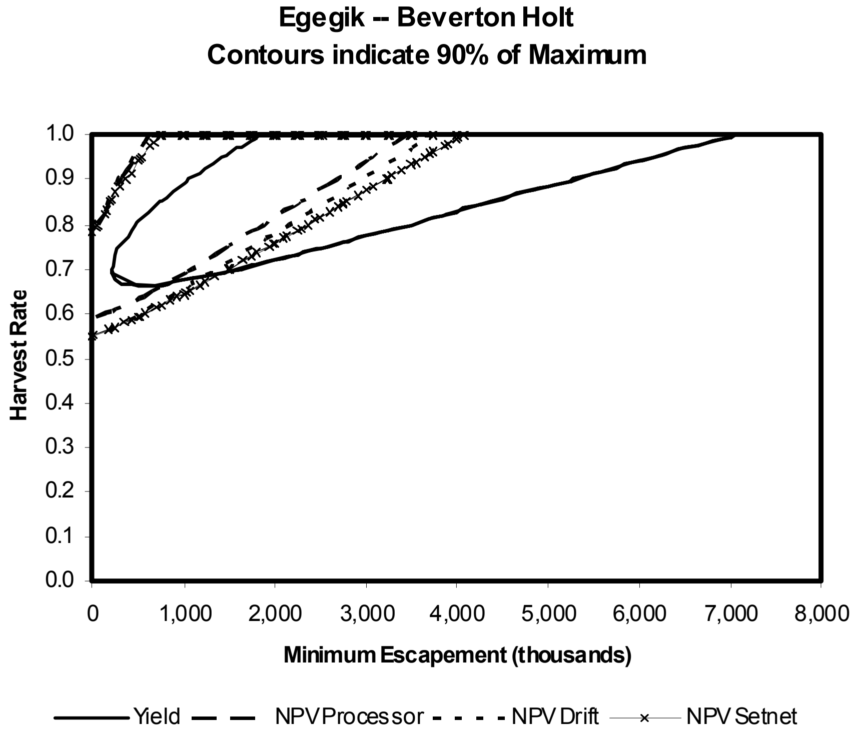


Figure 3.10. Ninety-percent density contours for yield and NPV to the fish processors, drifters, and set netters for the Ricker and Beverton Holt spawner-recruit models, Egegik River.

Table 3.1. Proportion of maximum catch for an array of minimum escapement goals and harvest rates for returns in excess of the minimum escapement, Egegik River, Beverton Holt spawner-recruit relationship. The area inside the polygon indicates the harvest policies that produce yields or average catch that are 90% or greater of the maximum catch.

Harvest Rate	Minimum Escapement (thousands of fish)																						
	0	250	500	750	1000	1250	1500	1750	2000	2250	2500	2750	3000	3250	3500	3750	4000	4250	4500	4750	5000	5250	5500
1.00	0.064	0.298	0.469	0.596	0.694	0.769	0.828	0.874	0.910	0.937	0.959	0.974	0.986	0.993	0.998	1.000	1.000	0.997	0.994	0.988	0.982	0.974	0.965
0.95	0.111	0.456	0.626	0.737	0.815	0.871	0.911	0.941	0.963	0.978	0.988	0.995	0.998	0.998	0.996	0.992	0.986	0.979	0.971	0.961	0.951	0.940	0.928
0.90	0.300	0.632	0.765	0.845	0.898	0.933	0.957	0.973	0.984	0.990	0.992	0.991	0.987	0.982	0.975	0.966	0.956	0.946	0.934	0.922	0.909	0.896	0.882
0.85	0.547	0.773	0.860	0.911	0.942	0.961	0.973	0.979	0.981	0.979	0.974	0.968	0.960	0.950	0.939	0.928	0.915	0.902	0.888	0.873	0.859	0.844	0.828
0.80	0.735	0.860	0.912	0.940	0.955	0.963	0.965	0.963	0.958	0.951	0.942	0.932	0.920	0.907	0.894	0.879	0.865	0.849	0.834	0.818	0.802	0.785	0.769
0.75	0.836	0.901	0.928	0.941	0.945	0.944	0.939	0.932	0.922	0.911	0.898	0.885	0.871	0.856	0.840	0.824	0.807	0.791	0.774	0.757	0.740	0.722	0.705
0.70	0.876	0.908	0.918	0.920	0.917	0.910	0.900	0.888	0.875	0.861	0.846	0.830	0.814	0.797	0.780	0.762	0.745	0.727	0.709	0.692	0.674	0.656	0.638
0.65	0.878	0.890	0.890	0.884	0.875	0.864	0.850	0.836	0.820	0.804	0.787	0.769	0.751	0.733	0.715	0.697	0.678	0.660	0.642	0.623	0.605	0.587	0.568
0.60	0.855	0.855	0.847	0.837	0.824	0.809	0.793	0.776	0.758	0.740	0.722	0.703	0.685	0.666	0.647	0.628	0.609	0.590	0.571	0.552	0.534	0.516	0.497
0.55	0.815	0.807	0.795	0.781	0.765	0.747	0.729	0.711	0.692	0.673	0.653	0.634	0.614	0.595	0.575	0.556	0.537	0.518	0.499	0.480	0.461	0.443	0.425
0.50	0.763	0.750	0.735	0.718	0.699	0.681	0.661	0.642	0.622	0.602	0.582	0.562	0.542	0.522	0.502	0.482	0.463	0.444	0.425	0.407	0.388	0.370	0.353
0.45	0.702	0.686	0.669	0.650	0.630	0.610	0.589	0.569	0.548	0.528	0.507	0.487	0.467	0.447	0.427	0.408	0.388	0.370	0.351	0.333	0.315	0.298	0.280
0.40	0.636	0.618	0.598	0.578	0.557	0.536	0.515	0.494	0.473	0.452	0.431	0.411	0.391	0.371	0.351	0.332	0.313	0.295	0.277	0.260	0.243	0.226	0.210
0.35	0.565	0.545	0.524	0.503	0.481	0.459	0.438	0.416	0.395	0.374	0.354	0.333	0.314	0.294	0.275	0.257	0.239	0.221	0.205	0.188	0.172	0.157	0.142
0.30	0.491	0.469	0.447	0.425	0.403	0.381	0.359	0.338	0.317	0.296	0.276	0.256	0.237	0.218	0.200	0.183	0.166	0.150	0.135	0.120	0.106	0.092	0.080
0.25	0.414	0.391	0.368	0.346	0.323	0.301	0.279	0.258	0.237	0.217	0.198	0.180	0.162	0.145	0.128	0.113	0.098	0.084	0.071	0.058	0.047	0.037	0.028
0.20	0.334	0.311	0.288	0.265	0.242	0.220	0.199	0.179	0.159	0.140	0.123	0.106	0.090	0.076	0.062	0.049	0.038	0.028	0.019	0.011	0.005	0.000	0.000
0.15	0.253	0.229	0.205	0.182	0.160	0.139	0.120	0.101	0.084	0.068	0.053	0.040	0.028	0.019	0.010	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.10	0.170	0.145	0.122	0.100	0.080	0.062	0.045	0.031	0.019	0.010	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.05	0.085	0.061	0.040	0.023	0.009	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 3.2. Average escapement for an array of minimum escapement goals and harvest rates for returns in excess of the minimum escapement, Egegik River, Beverton Holt spawner-recruit relationship. The outlined polygon corresponds with the same polygon in Table 3.1, which defines the harvest policies that produce 90% or greater of the maximum yield.

Harvest	Minimum Escapement (thousands of fish)																						
Rate	0	250	500	750	1000	1250	1500	1750	2000	2250	2500	2750	3000	3250	3500	3750	4000	4250	4500	4750	5000	5250	5500
1.00	13	253	498	745	993	1,239	1,485	1,730	1,974	2,217	2,458	2,699	2,938	3,175	3,412	3,647	3,880	4,112	4,343	4,573	4,801	5,027	5,252
0.95	58	503	856	1,176	1,478	1,768	2,049	2,323	2,591	2,854	3,114	3,370	3,623	3,873	4,121	4,365	4,607	4,847	5,084	5,320	5,553	5,784	6,013
0.90	335	983	1,408	1,774	2,109	2,423	2,724	3,014	3,297	3,573	3,844	4,109	4,370	4,627	4,880	5,130	5,377	5,621	5,862	6,101	6,337	6,570	6,801
0.85	969	1,664	2,112	2,494	2,842	3,167	3,478	3,777	4,067	4,349	4,625	4,895	5,160	5,420	5,677	5,930	6,179	6,425	6,667	6,907	7,144	7,378	7,609
0.80	1,844	2,472	2,913	3,295	3,644	3,973	4,286	4,588	4,880	5,164	5,442	5,714	5,981	6,242	6,500	6,753	7,003	7,249	7,491	7,731	7,967	8,200	8,430
0.75	2,799	3,349	3,772	4,146	4,492	4,818	5,131	5,432	5,724	6,008	6,286	6,558	6,824	7,085	7,342	7,594	7,843	8,088	8,329	8,567	8,801	9,033	9,261
0.70	3,771	4,263	4,665	5,029	5,369	5,691	6,000	6,299	6,589	6,872	7,148	7,418	7,682	7,942	8,197	8,447	8,694	8,937	9,176	9,412	9,644	9,872	10,097
0.65	4,749	5,194	5,579	5,932	6,264	6,582	6,887	7,183	7,470	7,750	8,023	8,290	8,552	8,809	9,061	9,309	9,553	9,793	10,029	10,261	10,490	10,714	10,935
0.60	5,722	6,136	6,504	6,848	7,173	7,485	7,786	8,077	8,361	8,637	8,907	9,171	9,429	9,683	9,932	10,176	10,417	10,653	10,884	11,112	11,335	11,555	11,771
0.55	6,691	7,081	7,437	7,772	8,090	8,396	8,692	8,979	9,259	9,531	9,797	10,057	10,311	10,561	10,806	11,046	11,281	11,512	11,739	11,960	12,178	12,391	12,599
0.50	7,656	8,029	8,374	8,700	9,012	9,313	9,604	9,887	10,161	10,429	10,690	10,946	11,196	11,441	11,680	11,914	12,144	12,368	12,587	12,802	13,011	13,216	13,417
0.45	8,619	8,978	9,314	9,633	9,939	10,235	10,520	10,798	11,067	11,330	11,586	11,835	12,079	12,318	12,550	12,778	12,999	13,215	13,426	13,631	13,832	14,026	14,216
0.40	9,580	9,928	10,256	10,569	10,869	11,159	11,439	11,710	11,973	12,229	12,479	12,722	12,958	13,189	13,413	13,631	13,842	14,048	14,248	14,442	14,630	14,812	14,988
0.35	10,539	10,878	11,199	11,506	11,800	12,083	12,357	12,621	12,877	13,126	13,367	13,601	13,828	14,048	14,261	14,467	14,666	14,858	15,043	15,222	15,395	15,560	15,720
0.30	11,497	11,829	12,143	12,444	12,731	13,007	13,272	13,528	13,775	14,014	14,245	14,467	14,681	14,887	15,085	15,275	15,457	15,631	15,798	15,957	16,110	16,256	16,392
0.25	12,454	12,779	13,088	13,381	13,660	13,926	14,182	14,427	14,662	14,888	15,103	15,309	15,505	15,691	15,868	16,036	16,195	16,346	16,487	16,616	16,734	16,841	16,937
0.20	13,411	13,730	14,031	14,315	14,583	14,838	15,080	15,309	15,526	15,731	15,924	16,105	16,274	16,432	16,580	16,714	16,834	16,939	17,032	17,113	17,184	17,233	17,233
0.15	14,367	14,681	14,972	15,243	15,495	15,731	15,951	16,154	16,341	16,513	16,670	16,811	16,933	17,037	17,124	17,196	17,233	17,233	17,233	17,233	17,233	17,233	17,233
0.10	15,322	15,629	15,904	16,153	16,377	16,577	16,752	16,906	17,033	17,132	17,209	17,233	17,233	17,233	17,233	17,233	17,233	17,233	17,233	17,233	17,233	17,233	17,233
0.05	16,278	16,568	16,804	16,992	17,133	17,221	17,233	17,233	17,233	17,233	17,233	17,233	17,233	17,233	17,233	17,233	17,233	17,233	17,233	17,233	17,233	17,233	17,233
0.00	17,233	17,233	17,233	17,233	17,233	17,233	17,233	17,233	17,233	17,233	17,233	17,233	17,233	17,233	17,233	17,233	17,233	17,233	17,233	17,233	17,233	17,233	17,233

Table 3.3. Proportion of maximum net present value for the processors, for an array of minimum escapement goals and harvest rates for returns in excess of the minimum escapement, Egegik River, Beverton Holt spawner-recruit relationship. The area inside the polygon indicates the harvest policies that produce net present values that are 90% or greater of the maximum net present value.

Harvest	Minimum Escapement (thousands of fish)																						
Rate	0	250	500	750	1000	1250	1500	1750	2000	2250	2500	2750	3000	3250	3500	3750	4000	4250	4500	4750	5000	5250	5500
1.00	0.63	0.77	0.87	0.92	0.96	0.99	1.00	1.00	1.00	0.99	0.98	0.96	0.94	0.92	0.89	0.87	0.85	0.82	0.80	0.77	0.74	0.72	0.69
0.95	0.66	0.83	0.91	0.96	0.99	1.00	1.00	1.00	0.98	0.97	0.95	0.93	0.91	0.88	0.86	0.83	0.80	0.78	0.75	0.72	0.69	0.67	0.64
0.90	0.74	0.88	0.94	0.98	0.99	0.99	0.99	0.98	0.96	0.94	0.92	0.89	0.87	0.84	0.81	0.78	0.75	0.73	0.70	0.67	0.64	0.61	0.59
0.85	0.82	0.93	0.97	0.99	0.99	0.98	0.97	0.95	0.93	0.90	0.88	0.85	0.82	0.79	0.76	0.73	0.70	0.67	0.64	0.62	0.59	0.56	0.53
0.80	0.88	0.95	0.98	0.98	0.97	0.96	0.94	0.91	0.89	0.86	0.83	0.80	0.77	0.74	0.71	0.68	0.65	0.62	0.59	0.56	0.53	0.50	0.47
0.75	0.92	0.96	0.97	0.96	0.95	0.92	0.90	0.87	0.84	0.81	0.78	0.75	0.71	0.68	0.65	0.62	0.59	0.56	0.53	0.50	0.47	0.44	0.41
0.70	0.94	0.95	0.95	0.93	0.91	0.88	0.85	0.82	0.79	0.75	0.72	0.69	0.65	0.62	0.59	0.56	0.53	0.50	0.47	0.44	0.41	0.38	0.35
0.65	0.93	0.93	0.92	0.89	0.86	0.83	0.80	0.76	0.73	0.69	0.66	0.63	0.59	0.56	0.53	0.49	0.46	0.43	0.40	0.37	0.35	0.32	0.29
0.60	0.91	0.89	0.87	0.84	0.81	0.77	0.74	0.70	0.67	0.63	0.60	0.56	0.52	0.49	0.46	0.43	0.40	0.37	0.34	0.31	0.28	0.26	0.24
0.55	0.87	0.85	0.82	0.79	0.75	0.71	0.68	0.64	0.60	0.56	0.53	0.49	0.46	0.42	0.39	0.36	0.33	0.30	0.27	0.25	0.22	0.20	0.18
0.50	0.83	0.80	0.76	0.73	0.69	0.65	0.61	0.57	0.53	0.49	0.45	0.42	0.39	0.35	0.32	0.29	0.26	0.24	0.21	0.19	0.17	0.15	0.13
0.45	0.77	0.74	0.70	0.66	0.62	0.58	0.53	0.49	0.45	0.42	0.38	0.35	0.31	0.28	0.25	0.23	0.20	0.17	0.15	0.13	0.12	0.10	0.08
0.40	0.71	0.67	0.63	0.58	0.54	0.50	0.46	0.42	0.38	0.34	0.31	0.27	0.24	0.21	0.18	0.16	0.14	0.12	0.10	0.08	0.07	0.06	0.04
0.35	0.64	0.60	0.55	0.51	0.46	0.42	0.38	0.34	0.30	0.27	0.23	0.20	0.17	0.15	0.12	0.10	0.08	0.07	0.05	0.04	0.03	0.02	0.01
0.30	0.57	0.52	0.47	0.43	0.38	0.34	0.29	0.26	0.22	0.19	0.16	0.13	0.11	0.09	0.07	0.05	0.04	0.03	0.02	0.01	0.00	-0.01	-0.02
0.25	0.49	0.44	0.39	0.33	0.29	0.25	0.21	0.17	0.14	0.12	0.09	0.07	0.05	0.04	0.03	0.02	0.00	-0.01	-0.02	-0.04	-0.05	-0.06	-0.06
0.20	0.40	0.35	0.30	0.25	0.20	0.16	0.13	0.10	0.07	0.05	0.04	0.02	0.01	-0.01	-0.02	-0.04	-0.05	-0.06	-0.09	-0.10	-0.12	-0.13	-0.13
0.15	0.30	0.25	0.20	0.16	0.11	0.08	0.06	0.04	0.02	0.00	-0.02	-0.04	-0.06	-0.09	-0.11	-0.12	-0.13	-0.13	-0.13	-0.13	-0.13	-0.13	-0.13
0.10	0.21	0.14	0.10	0.07	0.04	0.01	-0.02	-0.05	-0.08	-0.11	-0.12	-0.13	-0.13	-0.13	-0.13	-0.13	-0.13	-0.13	-0.13	-0.13	-0.13	-0.13	-0.13
0.05	0.11	0.04	-0.02	-0.07	-0.11	-0.13	-0.13	-0.13	-0.13	-0.13	-0.13	-0.13	-0.13	-0.13	-0.13	-0.13	-0.13	-0.13	-0.13	-0.13	-0.13	-0.13	-0.13
0.00	-0.13	-0.13	-0.13	-0.13	-0.13	-0.13	-0.13	-0.13	-0.13	-0.13	-0.13	-0.13	-0.13	-0.13	-0.13	-0.13	-0.13	-0.13	-0.13	-0.13	-0.13	-0.13	-0.13

4. Harvest policies for optimal economic returns from a single aggregate fishery

Alaska’s salmon fisheries are managed for sustained yield with several stocks being managed for maximum sustained yield (MSY). Since adequate escapements are critical to maintaining sustainable salmon fisheries, the Alaska Board of Fisheries (BOF) has developed the Sustainable Salmon Fishery Policy (SSFP, 5 AAC 39.222) and the Policy for Statewide Salmon Escapement Goals (EGP, 5 AAC 39.223) to guide the development of escapement goals.

While Biological Escapement Goals (BEGs) are expected to produce MSY, Sustainable Escapement Goals (SEG) are used in situations where BEGs can not be estimated due to inadequate stock-specific data, and represent escapement levels (or indices of escapement) known to provide sustained yield over a 5-to-10-year period. It is the duty of the Alaska Department of Fish and Game to recommend escapement goals, either BEG or SEG for each of the major stocks of salmon. The Alaska Board of Fisheries can adopt as part of management plans if desired, an Optimum Escapement Goal or OEG, which diverges from the BEG or SEG goal. Typically this occurs when strict adherence to a recommended BEG or SEG causes unreasonable economic hardship to the industry or prevents reaching minimum escapement levels for a stock of concern as designated by the Alaska Board of Fisheries. Two recent examples of Optimum Escapement Goals implemented in Bristol Bay stem from mixed-stock fishery concerns. The Nushagak River OEG (no less than 235,000 fish) deviated below the recommended BEG (340,000 to 760,000 fish) to allow for the prosecution of a more effective fishery on Wood River fish in the Nushagak District. The Naknek River OEG (800,000 to 2,000,000 million fish) diverges above the BEG (800,000 to 1,400,000 fish) and was done to provide managers the ability to adequately protect depressed Kvichak River stocks in the Naknek-Kvichak District. In the case of the Nushagak OEG, the Alaska Board of Fisheries took into consideration economic factors in the setting of the OEG. In both the Nushagak and the Naknek Rivers, the Alaska Board of Fisheries was attempting to meet an objective other than a stock-specific goal.

A harvest policy designed to achieve the BEG goal will not have a fishery when the total return is less than the low point of the BEG range and will harvest all fish in excess of the upper point in the BEG range. In such a situation, the objective to “maximize average catch” would be met, escapement levels vary little, and the catch varies with the size of the return. Other possible harvest policies would attempt to achieve objectives other than maximizing average catch and could result in more or less fish in the escapement than when operating under BEG management. Therefore, an “optimal harvest policy” is defined by the management objective it attempts to address.

In this section, we modeled an aggregate of Bristol Bay salmon stocks to illustrate how the optimal harvest policy for the fishery as a whole differs when different management objectives are considered. We explored four objectives: maximum sustainable yield, maximum gross value of the catch, maximum profit to the harvesting sector, and maximum profit to the processing sector.

To determine the harvest policy that maximized a given objective we modeled the underlying year-to-year dynamics of catch and escapement of an aggregate of Bristol Bay stocks and evaluated the yield and value of harvest from these stocks across a range of harvest policies. Specifically, the steps in this analysis were:

1. define the spawner-recruit relationship;
2. define the alternative objective functions;
3. use stochastic dynamic programming to calculate the harvest policy that maximizes the value of the objective function.

4.1. Defining the spawner-recruit relationship

The data for all the major Bristol Bay river systems less Kvichak and Nushagak were combined into a single spawner-recruit data set. Kvichak was excluded because it dominated Bristol Bay production until the mid 1990's while in recent years has not been a significant contributor to catch. Within the foreseeable future it seems unlikely that yield from he Kvichak will be a major contributor to the Bristol Bay fishery, yet when the data from Kvichak are included in the data set it dominates, thereby reducing the utility of this exercise to reflect current conditions. Nushagak was eliminated because the data were only available for more recent years. For this example we confined the data to brood years 1975 to 1999 the period of high productivity that has generally been ascribed to good ocean conditions and the pacific decadal oscillation. The Beverton-Holt model was then fit using simple sum of squares.

$$\begin{aligned} R &= \frac{S}{\frac{1}{\alpha}+\frac{S}{\beta}}\exp(w) \\ w &\approx N\left(0,\sigma^2\right) \end{aligned} \tag{4.1}$$

The three parameters are α, the initial slope, β the asymptote, and σ the standard deviation of the log recruitment deviates.

The best-fit estimate of the initial slope of this relationship is very high (α=23) and it is clear from the graph (Figure 4.1) that there is high uncertainty in the fit to the data. This is an unrealistically high α and suggests an extremely productive stock that would be very robust to intensive harvesting and is atypical of most salmon populations. Therefore we used a value of α of 4.0 to impose a more realistic model of sockeye salmon biology on our analysis.

4.2. Definition of alternative objective functions

4.2.1. Maximum sustainable yield

The MSY objective was defined as maximizing the average annual catch in numbers of fish. While there is a tendency for Bristol Bay fish to be smaller in years of large returns, we have ignored this consideration assumed each fish to be of equal value regardless of the magnitude of catch.

4.2.2. Maximum landed gross value of fish caught

The landed gross value of catch was calculated using the average weight of fish times the price per pound. Price per pound was estimated using the historical relationship between annual sockeye salmon ex-vessel price, total Bristol Bay salmon production, and the price of farmed coho salmon (from Knapp 2004, method described in section 3.1 of this report).

4.2.3. Maximum profit to harvesting sector

We defined profit to the harvesting sector as ex-vessel value, less fixed costs and variable costs. Fixed costs were estimated to be $12,787 per vessel and variable costs were 0.24 of the landed value. The impact of different fleet sizes was evaluated in the optimization process, and we were able to determine the fleet size that maximized the total profit to the fishery.

4.2.4. Maximum profit to processing sector

We defined profit to the processing sector as wholesale price of fish, less fixed costs and variable costs. Fixed costs were estimated to be $1.8 million per capacity to process 1 million fish in shore-based plants, and $1.2 million per capacity to process 1 million fish in floating processors. We assumed an equal capacity of shore based and floating processors yielding an average fixed cost of $1.5 million per capacity to process 1 million fish. The variable costs were estimated to be $0.72 per pound of fish processed (Link et al. 2003), plus the ex-vessel price. The wholesale price of fish was estimated by Knapp (2004) to be $1.53 + 2.2 * ex-vessel price.

4.3. Calculation of optimal harvest policies

The method of stochastic dynamic programming (DP) has now become standard in calculation of optimal harvest policies (Walters 1975, Hilborn 1976). The DP method is used to determine an optimum policy among many potential policies for complex dynamics occurring over time when there are variable (stochastic) processes at work. The method is ideal for determining an optimal harvest policy for a salmon population or aggregate of salmon populations because it allows for a search across a wide range of modeled “natural” variation in the relationship between spawners and subsequent recruitment while holding a harvest policy constant. The DP then searches over a range of harvest policies to identify the one that maximizes a given objective.

We will not describe the full stochastic program methodology here, but will comment on implementation details relevant to our analysis and to facilitate peer review. We used 200 alternative levels of spawning stock size and 200 alternative levels of catch, a very fine grid. We initially calculated a transition matrix giving the probability that each discrete spawning stock size would produce a discrete level of total return (the 200 x 200 matrix). Calculation of this matrix used the standard deviation of the stochastic process. Then in the backwards iteration process of dynamic programming the alternative catch levels were evaluated for each alternative stock size.

The normal practice for DP is to specify a discount rate, and then run the dynamic programming algorithm backwards until the value vector converges. The converged vector corresponds to the net present value of a population of each size. The discount rate to use is a subject of considerable discussion; it is known that the discount rate itself will affect the optimal harvest solution, particularly for unproductive populations. We used a rate of 7% per sockeye salmon generation (we are solving a generation-to-generation model), which corresponds to approximately 2% discount rate.

For the objectives of maximum harvester or processor profit, the harvesting or processing capacity is an additional control variable, but one that we assume is not changing from year to year. This is a considerable simplification but given the nature of the limited entry policy within Alaska it seems reasonable for the harvesting sector. The number of permits is fixed, and while there is discussion about a buy-back or other forms of license reduction, it is hard to imagine at this time that there would be any form of annual adjustment in the number of permits. For the processing industry the situation is more complex because processors having some flexibility by bringing in additional floating processors in years of anticipated high catches, and by their ability to ship fish from Bristol Bay to processing plants elsewhere. For simplicity we are considered the capacity of the processing sector as fixed over all years.

When calculating the optimal harvesting policy for the two “profit” objectives, we ran the DP over a range of different capacities to determine how the net present value changes with different capacities.

4.4. Results for optimal economic returns from an aggregate fishery

Figure 4.2 shows the optimum harvest level across a range of total return given the optimal fleet and processing capacity discussed later. When MSY is the objective, then we obtain the traditional fixed-escapement management result, with no harvest below the escapement goal of a little below 8 million. In addition, there is no catch up to a total return of about 8 million, then the catch increases directly with return (all fish above the escapement goal are taken as catch), and the escapement remains at 8 million. However, when the objective is any of the other options we examined, then the harvest policy is considerably different from the fixed-escapement policy. In all other cases, there is no harvest at very low stock sizes, but they all provide for harvest at almost all stock sizes. For example, at a return of 6 million, rather than no harvest as would occur in MSY fixed-escapement management, the harvest would be about 2 million. Figure 4.3 shows the optimal catch over a broader range of total returns.

At the lower stock sizes, the optimal harvest is for more catch if the objective is revenue, processor profit or harvester profit, with the revenue policy becoming very similar to MSY at about 20 million total return, whereas the optimal policy for profits to both harvesters and processors caps at a catch of 15 million fish, optimal for both harvesting and processing.

The two primary differences between the optimal policies for the different objectives are the capping of catch when runs are large for a processor or harvester profit objective, and the exploitation rates when the stock is less than 8 million for the maximum revenue and maximum profit objectives. Neither of these results is surprising. As soon as one considers fixed costs associated with harvesting and processing, there is going to be a maximum harvesting capacity. The exact level of the optimal harvest capacity will depend on a wide range of factors including the spawner-recruit curve, revenue, and costs.

Under a MSY policy the optimum escapement occurs when the slope of the spawner-recruit curve = 1, that is when putting one additional fish in the escapement will produce exactly one additional fish in the future catch. However, when we consider the fact that revenue depends on volume, there will be a reason to harvest at lower stock sizes because the fish will be worth more if harvested because the price will be high because catch will be very small. The offspring of this fish will be worth relatively less in the future because the expected harvest off of an escapement of 6-8 million will be about 20 million fish, commanding a much lower price per fish than when the harvest is only a few million.

Optimum capacity was calculated for the harvesting and processing industries by running the DP optimization over values of capacity from 10 to 30 million fish in 1 million fish intervals and examining the net present value. The net present value depends on the current population size; more fish now are always better, as well as on the fleet capacity. This is shown in Figure 4.4 for 3 different levels of current stock size. We see that more fish is always better, but when fleet capacity is small, the difference between 20 and 30 million fish at present is very small because there isn't the capacity to harvest them now, and the future value of the differences in runs is small because of the asymptotic nature of the spawner-recruit curve (those extra 10 million fish won't make much difference in the next generation).

This example demonstrates that the MSY-based policy is not economically optimal and provides us with qualitative ideas about the impact of considering fixed costs and the impact of volume of harvest on price. We examined at how much was due to price as opposed to the fixed costs. The price effect causes the harvesting at low stock sizes, the fixed costs move the optimum escapement down.

4.5. Discussion – policies for optimal economic returns from an aggregate fishery

The economic perspective from the harvesting and processing sectors provides a very different view on what "optimal" management is compared to traditional MSY-based management. The most striking effect was the importance of capping capacity; it simply does not pay to have large fleets or processing capacity that are only used every few years.

This has been recognized by the Commercial Fisheries Entry Commission in its recommendations for a much smaller fleet and by the processing industry who on its own has reduced its capacity in recent years. It would seem appropriate for the official harvesting policy to recognize that the economic viability of the industry would be enhanced if there was a maximum catch limit for the Bay.

Capping maximum catch implies that in years of large return there will be some particularly large escapements. While the Kvichak has had escapements in excess of 20 million fish, there are certainly some concerns that an escapement of 3-10 million fish in Egegik, Naknek, Wood or Ugashik would have major impacts on spawning success and juvenile fish growth. Traditionally there was concern about "overescapement" reducing future production, but there are certainly no data from Bristol Bay that indicate lower production at high escapements, and indeed such data are almost unknown for sockeye salmon. The recent very large escapements in the Alagnak will provide useful information, and before formally adopting harvest policies that have maximum catch built in, a biological evaluation of the risks of high escapement to production in comparison to the benefits of high escapements to other ecosystem components should be considered

The impacts of volume on price seem to primarily affect the harvesting policy at low return sizes, where the analysis suggests that the bottom end of the escapement range should be a "soft landing" rather than a hard floor. When returns are low the price is high, and it is economically optimum to allow some harvesting even at low stock sizes. It is important to note that this applies only to Bay-wide catch, if an individual district has a poor return, but other districts have good returns, then the total Bay-wide production will not be low, and the price will not be particularly high, thus there are few price benefits from some harvesting below the escapement floor in the individual weak district.

While all of our analyses are built on the assumption of a single annual harvest decision, in practice these stocks are managed in-season, and the harvesting and processing capacities are daily or two-day limits rather than annual limits. It would be useful to evaluate the in-season implementation of harvest policies to determine if there are ways to provide for more early-season harvest, which would improve the economics by making a fixed capacity in both harvesting and processing able to handle more fish through a single season. Bristol Bay managers are traditionally reluctant to provide much fishing opportunity until they have some confidence they will reach their minimum escapement goals. The results of the economic analysis suggest that some harvesting below traditional escapement floors is economically optimal – thus the economic performance of the fishery may be enhanced by more aggressive fishing early in the season.

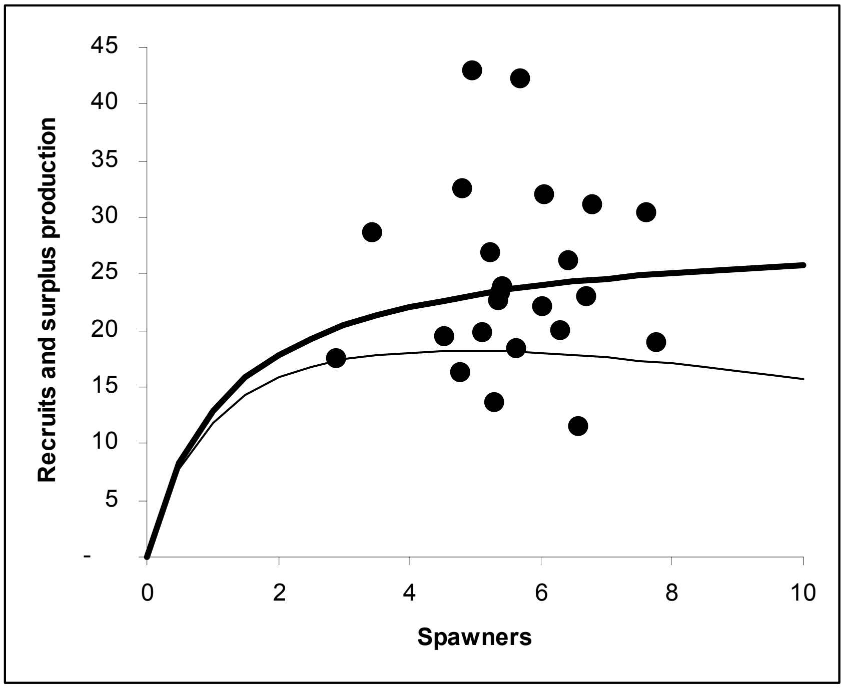


Figure 4.1. Spawner-recruit curve for Bristol Bay, brood years 1975-1999, all major river systems combined except Kvichak and Nushagak. Solid dots are spawner-recruit data, solid thick line is the best fit curve, and the thin line is the surplus production across the range of spawning stock sizes.

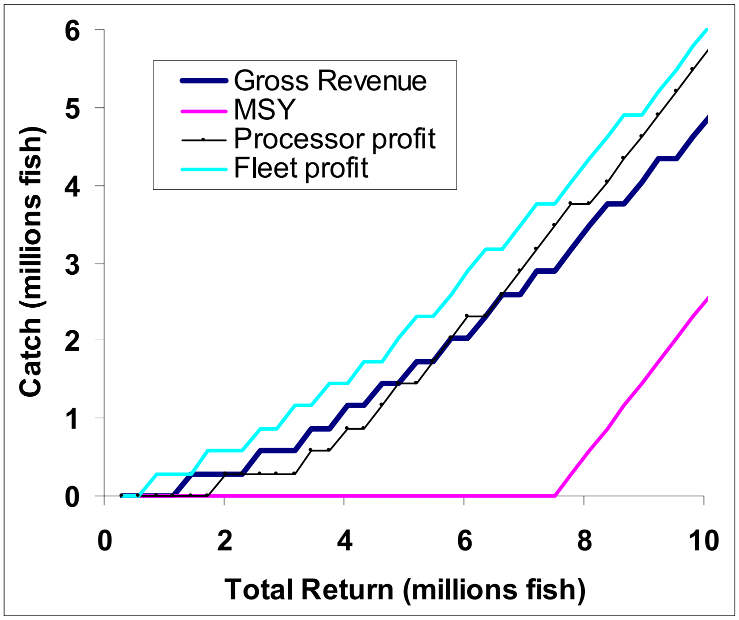


Figure 4.2. Optimal catch as a function of total return for four management objectives at a range of returns from 0 to 10 million fish.

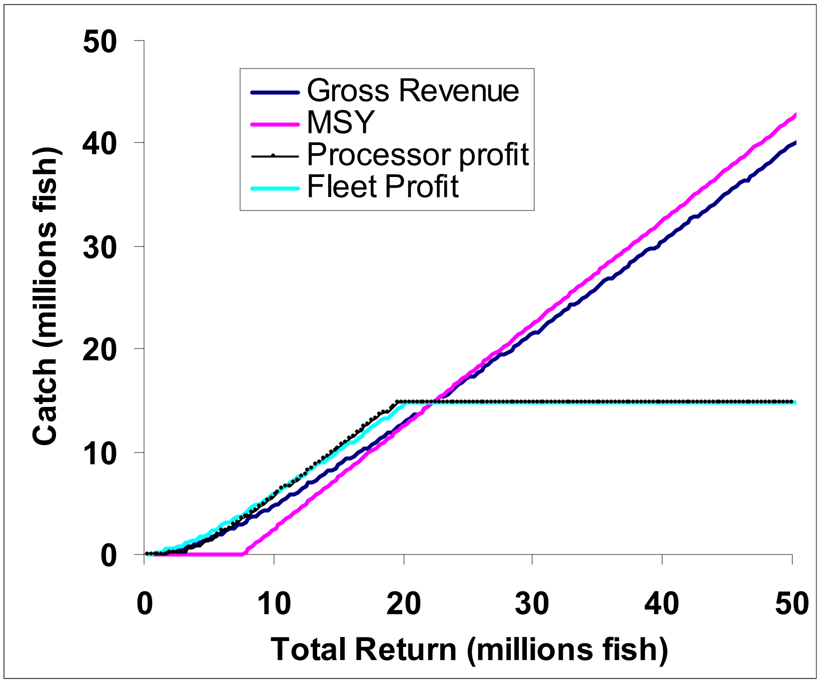


Figure 4.3. Optimal catch as a function of total return for four management objectives at a range of returns from 0 to 50 million fish.

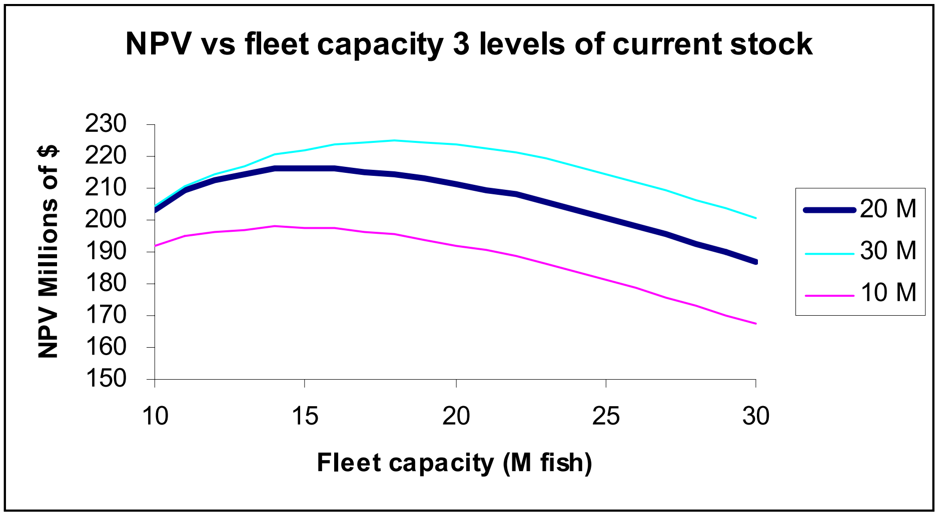


Figure 4.4. Net present value versus fleet capacity for 3 different levels of current stock size, 10, 20 and 30 million fish.

5. Conclusions

5.1. Estimating BEGs

Formally taking into account more uncertainty in the relationship between spawners and subsequent recruitment than has been done in the past generally leads to estimates of higher levels and wider ranges for MSY BEGs than those developed by current approaches. Broader ranges for BEGs are a result taking uncertainty into account but care should be taken in interpreting the value of these higher ranges, which can be expected to result in more variability in annual catches than current BEG ranges.

5.2. Alternative harvest policies to achieve 90% of MSY yield

Long-term average yields very similar to those from current fixed-escapement goal policy can be achieved by many different combinations of escapement level and harvest rate. Contrary to the prevailing salmon management approach, our results suggest that yields very similar to those from fixed-escapement goal management can be achieved by many combinations of fixed harvest rates and escapement “floors” that are lower than current BEG ranges in Bristol Bay.

5.3. District-specific economic yield

The net income or NPV of harvests is heavily dependent on the assumed maximum catch level set by the harvest policy (as well as the productivity and dynamics of the stock). The existence of fixed costs in the harvesting and processing sectors results in a maximum catch level that optimizes the net income from a fishery. Using average harvesting and processing capacity, the maximum catch level can be translated into the number of processors and harvesters that maximizes the net income from a specific fishery.

5.4. Policies for optimal economic returns from an aggregate fishery

Considering the economics of the price of fish and the cost structure of fishing and processing, harvesting and processing sectors provide very different views on what “optimal” management is compared to MSY-based management. The most striking effect was the importance of capping capacity; it simply does not pay to have large fleets or processing capacity that are only used every few years. It seems appropriate for the official harvesting policy to recognize that the economic viability of the industry would be enhanced if there was a maximum catch limit for the Bay.

The impacts of volume on fish price seem to primarily affect the harvesting policy at low return sizes, where the analysis suggests that the bottom end of the escapement range should be a “soft landing” rather than a hard floor. When returns are low the price is high, and it is economically optimum to allow some harvesting even at low stock sizes. It is important to note that this applies only to Bay-wide catch, if an individual district has a poor return, but other districts have good returns, then the total Bay-wide production will not be low, and the price will not be particularly high, thus there are few price benefits from some harvesting below the escapement floor in the individual weak district.

6. Future work

We see several avenues for further work on harvest policies. We have shown that the optimal harvest policy with economic objectives can differ significantly from the BEG. We used published economic data, but we suspect that building on what we have done, some economic analysis and critique of our models would be appropriate. The integration of the annual harvest policy with the reality of in-season management is a high priority and was discussed in an earlier paragraph. A major limitation of the methods used here is the use of brood tables to summarize the life history of the fish. The real biology of many of these stocks has shown great changes in survival over different life history stages, and it seems likely that an analysis based on a more realistic life history model, including explicitly freshwater and marine survival, would provide a better way to understand the role of density dependence in these stocks, and indeed in almost all salmon.

While harvest policies have traditionally been conducted on a district-by-district basis, the harvesting and processing capacity, and the price impacts are Bay-wide phenomena, and it would be very useful to calculate the optimal policies simultaneously for all fishing districts. This would involve looking at the total returns for each district simultaneously. This is now possible with modern computational methods and should be pursued.

Finally, with an increase in interest and some progress toward addressing economic objectives for the fishery (e.g., Naknek and Nushagak OEGs, the implementation of a “general district” in 2004) we should expect more fluctuation in escapement levels in the future than has been observed historically. Further work should be done to design and evaluate monitoring programs that can assess the biological implications of deviations from the recent historical escapement levels.

7. Acknowledgements

We would like to thank the members of the Board of Directors of the Bristol Bay Science and Research Institute for providing the impetus and support to this project. Together these Directors (Hattie Albecker, Ted Angasan, Robert Heyano, Moses Kritz, Hazel Nelson, Robin Samuelsen, Victor Seybert, Moses Tuyakuk) have fished over 250 seasons in Bristol Bay and they have long appreciated the difference between maximizing biological yield and maximizing net income from the fishery. Data were provided by Fred West and Lowell Fair. Lowell Fair and Doug Eggers (ADF&G) reviewed earlier versions and provided helpful suggestions that improved the report.

8. References

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Appendix A. Brood tables for eight Bristol Bay sockeye salmon stocks groups, 1950-2004.

Table A-1. Egegik River sockeye salmon escapement and return by brood year including estimated interception catch (in thousands), 1949 - 2004.

		Return by Age Class																
Brood Year	Escapement	0.2	1.1	0.3	1.2	2.1	0.4	1.3	2.2	3.1	1.4	2.3	3.2	1.5	2.4	3.3	3.4	Total
1950	0 [b]	0 [c]	0 [c]	0 [c]	0 [c]	0 [c]	0	0	0	0	0	274	70	0	4	23	0	371 [d]
1951	0 [b]	0 [c]	0 [c]	0	0	0	0	325	1,018	0	1	1,301	2	0	0	6	0	2,653 [d]
1952	0 [b]	0	0	0	623	0	0	446	241	0	1	295	19	0	2	5	0	1,632
1953	0 [b]	0	0	0	26	0	0	39	435	2	0	337	254	0	0	12	0	1,105
1954	0 [b]	0	0	0	11	4	0	13	1,190	0	0	641	87	0	0	46	0	1,992
1955	0 [b]	0	1	0	20	0	0	163	672	0	0	396	6	0	1	6	0	1,265
1956	1,104	0	6	0	2,025	0	0	3,190	925	0	2	685	1	0	0	12	0	6,846
1957	391	0	0	0	37	0	0	43	1,096	0	0	927	70	0	0	62	0	2,235
1958	246	0	0	0	42	2	0	73	817	0	0	308	16	0	0	3	0	1,261
1959	1,053	0	0	0	73	2	0	164	1,037	0	0	467	14	0	0	24	0	1,781
1960	1,799	8	0	0	447	21	0	328	4,447	0	1	2,560	49	0	0	50	0	7,911
1961	702	0	0	3	82	0	0	229	446	0	1	791	28	0	0	10	0	1,590
1962	1,027	0	0	0	22	0	0	69	950	0	0	375	28	0	0	30	0	1,474
1963	998	0	0	1	16	2	0	112	538	1	1	506	74	0	0	7	0	1,258
1964	850	0	1	0	126	6	0	69	1,454	1	0	242	73	0	0	12	0	1,983
1965	1,445	0	0	0	104	35	0	72	2,016	0	4	845	6	0	2	20	0	3,104
1966	804	0	0	1	249	0	0	752	600	0	2	890	7	0	0	10	0	2,511
1967	637	0	0	2	60	2	0	257	665	0	0	622	1	0	1	2	0	1,612
1968	339	0	0	0	41	0	0	56	87	0	0	258	3	0	5	9	0	459
1969	1,016	0	0	0	12	1	0	111	1,096	0	0	1,141	279	0	2	113	0	2,755
1970	920	0	0	0	59	0	0	89	796	0	1	175	95	0	0	25	0	1,240
1971	634	0	0	0	45	2	0	109	1,477	0	0	970	74	0	1	55	0	2,733
1972	546	0	0	1	57	2	0	61	1,508	0	0	1,264	48	0	0	18	0	2,959
1973	329	0	0	0	76	0	0	135	578	0	0	851	35	0	0	4	0	1,679
1974	1,276	0	0	0	131	18	0	99	2,224	0	0	496	54	0	0	3	0	3,025
1975	1,174	0	0	0	148	9	0	241	2,449	2	0	797	14	0	2	1	0	3,664
1976	509	1	1	2	612	59	0	789	3,003	0	4	846	0	0	0	0	0	5,317
1977	693	0	2	0	823	1	0	1,969	688	0	14	655	52	0	0	13	0	4,217
1978	896	0	0	2	398	6	0	510	6,071	0	0	2,184	25	0	4	8	0	9,208
1979	1,032	0	3	0	712	9	3	520	3,036	0	4	1,659	0	0	0	0	0	5,947
1980	1,061	0	1	13	803	26	0	2,225	4,576	0	6	917	7	0	0	0	0	8,575
1981	695	0	0	6	544	64	0	953	3,284	0	11	1,438	9	0	0	7	0	6,316
1982	1,035	2	2	4	988	12	0	1,874	1,796	0	9	1,638	11	0	2	2	0	6,339
1983	792	0	3	0	1,748	7	1	2,763	3,235	0	7	2,822	21	0	23	16	0	10,646
1984	1,165	0	1	8	608	85	0	978	6,539	3	10	5,029	215	0	13	39	0	13,528
1985	1,095	4	0	9	567	32	0	1,404	4,358	0	9	1,262	8	0	0	18	0	7,671
1986	1,152	0	2	14	1,850	10	0	3,733	3,912	0	92	4,515	86	0	83	34	0	14,331
1987	1,274	2	0	9	886	66	0	4,561	8,863	3	101	11,239	133	0	31	57	0	25,951
1988	1,599	0	1	0	413	62	0	1,278	11,061	0	4	5,650	261	0	3	152	0	18,885
1989	1,612	1	0	6	513	34	0	456	6,063	1	6	3,979	170	0	1	31	0	11,261
1990	2,192	0	0	2	403	66	0	867	9,598	1	3	4,721	21	0	28	30	0	15,739
1991	2,787	4	1	3	1,397	20	2	3,939	3,113	0	47	2,607	19	0	2	9	0	11,163
1992	1,946	5	0	32	335	54	3	1,117	4,963	2	4	3,099	53	0	16	17	0	9,701
1993	1,517	0	2	10	497	31	0	573	880	0	11	992	6	0	0	1	0	3,002
1994	1,898	1	8	0	368	65	0	982	4,228	0	0	3,071	11	0	15	9	0	8,758
1995	1,267	0	7	0	3,151	4	0	3,175	1,644	0	16	1,455	10	0	11	12	0	9,485
1996	1,076	0	1	0	497	5	0	1,791	515	3	40	1,727	28	0	4	7	0 [e]	4,617 [e]
1997	1,104	0	0	0	34	19	0	322	3,572	9	3	1,971	246	0 [e]	7 [e]	39 [e]	0 [d]	6,678
1998	1,111	0	0	0	104	13	0	206	602	1	2 [e]	672 [e]	20 [e]	0 [d]	0 [d]	0 [d]	0 [d]	1,631
1999	1,728	1	0	0	249	213	0 [e]	659 [e]	9,685 [e]	0 [e]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	15,918
2000	1,032	0	2	0 [e]	1,745 [e]	28 [e]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	
2001	969	0 [e]	0 [e]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	
2002	1,036	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	
2003	1,152	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	
2004	1,290	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	

[a] R/S = return per spawner.

[b] Escapement not available.

[c] Younger age groups not available.

[d] Incomplete returns from brood year escapement.

[e] Estimate from 2004 preliminary return numbers.

Table A-2. Kvichak River sockeye salmon escapement and return by brood year including estimated interception catch (in thousands), 1950 – 2004.

		Return by Age Class																
Brood Year	Escapement	0.2	1.1	0.3	1.2	2.1	0.4	1.3	2.2	3.1	1.4	2.3	3.2	1.5	2.4	3.3	3.4	Total
1950	0[b]	0[c]	0[c]	0[c]	0[c]	0[c]	0[c]	0[c]	0[c]	0[c]	0	248	0	0	0	0	0	248[d]
1951	0[b]	0[c]	0[c]	0[c]	0[c]	0[c]	0	221	3,377	0	0	983	0	0	1	0	0	4,582[d]
1952	0[b]	0[c]	0[c]	0	9,954	0	0	6,681	2,956	0	0	654	1	0	0	1	0	20,247[d]
1953	0[b]	0	0	0	91	0	0	62	365	0	0	60	0	0	0	0	16	594
1954	0[b]	0	0	0	81	17	0	29	638	0	0	0	0	0	0	29	0	794
1955	0[b]	0	0	0	249	14	0	100	588	0	0	531	20	0	0	0	0	1,502
1956	9,443	0	14	0	24,246	0	0	6,968	6,472	0	0	1,308	0	0	0	0	0	39,008
1957	2,843	8	0	0	243	0	0	244	3,333	0	2	259	0	0	0	2	0	4,091
1958	535	0	0	0	76	0	0	48	135	0	0	26	0	0	0	3	0	288
1959	674	0	0	0	212	1	0	117	206	0	0	11	0	0	0	0	0	547
1960	14,602	0	0	1	1,314	134	0	563	46,746	0	0	6,472	10	0	0	6	0	55,246
1961	3,706	1	0	0	334	0	0	190	2,287	0	0	679	5	0	0	0	0	3,496
1962	2,581	0	0	0	104	2	0	152	4,675	0	0	408	12	0	0	4	0	5,357
1963	339	0	0	0	49	3	0	50	639	0	0	366	3	0	0	9	0	1,119
1964	957	0	8	0	2,232	105	0	407	2,341	0	0	647	8	0	0	3	0	5,751
1965	24,326	0	25	0	9,853	484	0	471	32,951	0	0	1,239	2	0	0	1	0	45,026
1966	3,755	4	11	6	497	11	0	1,086	4,262	0	0	385	0	0	1	0	0	6,263
1967	3,216	0	0	5	349	2	0	272	812	0	0	86	0	0	0	0	0	1,526
1968	2,557	0	0	0	293	0	0	34	77	0	5	132	0	0	0	2	0	543
1969	8,394	0	0	1	129	7	0	321	4,221	0	0	595	19	0	0	11	0	5,304
1970	13,935	0	1	0	43	40	0	13	14,463	6	0	848	412	0	0	7	0	15,832
1971	2,387	0	0	0	244	18	0	93	2,169	0	0	303	2	0	0	0	0	2,829
1972	1,010	0	0	0	255	1	0	159	1,206	0	22	297	0	0	0	0	0	1,940
1973	227	0	0	2	576	2	2	1,028	274	0	3	543	28	0	0	0	0	2,458
1974	4,434	0	9	1	6,328	309	0	2,009	16,725	0	8	763	23	0	0	5	0	26,180
1975	13,140	0	5	0	5,683	302	0	1,232	30,263	0	0	599	2	0	0	0	0	38,087
1976	1,965	0	5	11	5,298	43	0	826	4,115	0	4	273	0	0	0	0	0	10,575
1977	1,341	11	43	6	1,934	2	0	935	208	0	0	99	0	0	0	0	0	3,239
1978	4,149	0	0	0	1,835	16	0	1,157	1,318	0	0	817	11	0	0	6	0	5,160
1979	11,218	1	57	3	18,331	73	0	2,234	17,931	0	0	3,512	0	0	0	0	0	42,142
1980	17,505[e]	0	2	5	2,889	20	0	1,641	8,076	0	2	413	0	0	0	0	0	13,048
1981	1,754	0	0	12	789	0	0	231	931	0	0	167	0	0	0	0	0	2,130
1982	1,135	25	0	2	445	1	0	544	524	0	6	139	0	0	0	0	0	1,686
1983	3,570	0	1	5	8,596	3	0	3,010	1,195	0	5	573	0	0	2	1	0	13,391
1984	10,491	0	0	4	2,532	44	1	1,924	16,952	0	0	2,483	8	0	0	2	0	23,950
1985	7,211	4	7	30	1,024	29	0	1,282	13,465	0	2	1,560	1	0	15	2	0	17,421
1986	1,179	10	0	27	688	0	1	1,079	1,390	0	25	1,332	2	0	0	4	0	4,558
1987	6,066	29	4	69	4,179	31	4	2,519	4,499	0	5	700	4	0	0	2	0	12,045
1988	4,065	11	5	19	2,503	19	1	2,470	4,385	0	5	557	11	0	0	6	0	9,991
1989	8,318	29	2	54	2,147	117	2	1,679	18,841	0	2	3,316	13	0	1	0	0	26,203
1990	6,970	6	8	11	1,542	83	0	1,192	21,105	0	0	1,162	0	0	1	0	0	25,110
1991	4,223	0	1	4	2,688	2	0	1,232	699	0	6	170	0	0	0	0	0	4,802
1992	4,726	2	0	13	429	2	0	226	567	0	0	175	0	0	0	6	0	1,420
1993	4,025	0	1	1	852	1	4	890	624	0	8	574	0	0	0	0	0	2,955
1994	8,356	0	3	0	1,811	29	0	1,204	3,777	0	1	250	1	0	0	0	0	7,076
1995	10,039	0	17	0	7,736	0	0	1,810	600	0	5	76	0	0	0	0	0	10,244
1996	1,451	4	0	0	369	0	0	1,202	19	0	9	16	0	0	0	0	0[f]	1,619[f]
1997	1,504	0	0	4	130	0	1	107	263	0	0	75	0	0[f]	5[f]	0[f]	0[d]	**585**
1998	2,296	0	0	2	323	1	4	278	245	0	6[f]	56[f]	0[f]	0[d]	0[d]	0[d]	0[d]	**917**
1999	6,197	4	1	0	1,070	78	0[f]	232[f]	5,712[f]	0[f]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	**7,677**
2000	1,828	0	0	12[f]	1,736[f]	0[f]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	
2001	1,095	0[f]	0[f]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	
2002	704	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	
2003	1,687	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	
2004	5,500	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	

[a] R/S = return per spawner.

[b] Escapement not available.

[c] Younger age groups not available.

[d] Incomplete returns from brood year escapement.

[e] The 1980 brood year escapement of 22.5 million was reduced to 17.5 million in the brood table to reflect the estimated 5 million sockeye salmon that did not spawn successfully because of the extreme velocity barrier at the falls on the Newhalen River .

[f] Estimate from 2004 preliminary return numbers.

Table A-3. Naknek River sockeye salmon escapement and return by brood year including estimated interception catch (in thousands), 1950 – 2004.

		Return by Age Class																
Brood Year	Escapement	0.2	1.1	0.3	1.2	2.1	0.4	1.3	2.2	3.1	1.4	2.3	3.2	1.5	2.4	3.3	3.4	Total
1950	0[b]	0[c]	0[c]	0[c]	0[c]	0[c]	0[c]	0[c]	0[c]	0[c]	0	1,093	0	0	2	5	0	1,100[d]
1951	0[b]	0[c]	0[c]	0[c]	0[c]	0[c]	0	1,295	688	0	0	1,250	0	0	1	0	0	3,234[d]
1952	0[b]	0[c]	0[c]	0	79	0	0	1,199	108	0	7	176	1	0	0	2	0	1,572[d]
1953	0[b]	0	0	0	24	0	0	135	177	3	0	206	42	0	0	1	1	589
1954	0[b]	0	0	0	85	19	0	302	2,129	0	0	587	0	0	13	3	0	3,138
1955	0[b]	0	0	0	720	1	0	820	214	0	0	88	2	0	4	2	0	1,851
1956	1,773	0	1	0	473	0	0	1,701	3	0	17	304	0	0	0	0	0	2,499
1957	635	0	0	0	53	2	0	329	505	0	1	674	5	0	0	3	0	1,572
1958	278	0	0	0	112	4	0	211	539	0	0	168	3	0	0	2	0	1,039
1959	2,232	0	0	0	349	7	0	351	742	0	0	705	0	0	0	0	0	2,154
1960	828	0	1	1	1,408	9	0	625	696	0	0	1,278	1	0	1	2	0	4,022
1961	351	0	0	0	239	3	0	744	315	0	3	640	0	0	0	8	0	1,952
1962	723	0	0	0	76	4	0	230	351	0	2	397	13	0	0	1	0	1,074
1963	905	0	0	0	136	8	0	390	833	0	0	627	7	0	0	1	0	2,002
1964	1,350	0	1	0	447	24	0	264	1,135	0	0	177	11	0	0	1	0	2,060
1965	718	0	5	0	540	44	0	360	732	0	0	437	1	0	0	1	0	2,120
1966	1,016	1	4	0	728	2	0	2,304	167	0	1	630	0	0	1	0	0	3,839
1967	756	0	0	2	326	6	0	625	401	0	0	356	0	0	1	0	0	1,717
1968	1,023	0	3	0	152	0	0	234	83	0	0	269	2	0	0	2	0	745
1969	1,331	0	0	0	47	3	0	307	976	0	0	1,211	5	0	0	3	0	2,552
1970	733	0	1	0	154	19	0	318	1,845	0	0	370	12	0	0	0	0	2,718
1971	936	0	1	0	397	24	0	559	1,428	0	0	1,844	3	0	9	8	0	4,273
1972	587	0	3	0	245	3	0	241	161	0	3	599	9	0	0	1	0	1,264
1973	357	0	0	0	494	0	0	618	524	0	0	598	0	0	0	0	0	2,234
1974	1,241	0	2	0	232	3	0	228	1,026	0	1	783	5	0	0	5	0	2,284
1975	2,027	0	1	0	425	11	0	1,746	1,393	0	0	1,641	1	0	8	0	0	5,226
1976	1,321	0	4	0	1,084	3	0	4,048	1,575	0	21	1,491	0	0	28	1	0	8,255
1977	1,086	2	10	7	635	0	0	2,272	95	0	64	401	0	0	1	5	0	3,492
1978	813	0	1	0	331	4	0	1,695	1,121	0	11	530	2	0	0	0	0	3,695
1979	925	0	4	1	2,438	4	0	973	792	0	9	408	4	0	0	3	0	4,636
1980	2,645	0	1	1	723	14	0	1,505	1,192	0	9	828	0	0	2	0	0	4,275
1981	1,796	0	4	0	782	9	0	2,568	473	0	12	937	0	0	3	0	0	4,789
1982	1,156	0	3	3	185	0	0	1,172	191	0	23	457	0	0	9	0	0	2,043
1983	888	0	0	1	163	7	0	484	336	0	5	480	0	0	0	1	0	1,477
1984	1,242	0	1	0	469	23	0	911	1,214	0	21	1,828	5	0	1	4	0	4,477
1985	1,850	0	2	6	656	20	1	3,533	1,293	0	44	1,441	0	0	28	10	0	7,034
1986	1,978	0	3	6	1,981	6	1	7,167	1,276	0	367	2,817	1	0	38	2	0	13,665
1987	1,062	3	0	12	336	4	1	1,251	565	0	95	3,225	2	0	12	0	0	5,506
1988	1,038	0	0	0	273	13	0	796	516	0	37	544	2	0	2	1	0	2,184
1989	1,162	0	1	0	226	5	0	930	1,154	0	0	566	4	0	0	1	0	2,887
1990	2,093	0	0	0	405	46	0	1,236	1,345	0	12	1,316	3	0	12	0	0	4,375
1991	3,579	1	13	0	546	1	0	5,209	250	0	45	343	0	0	1	0	0	6,408
1992	1,607	0	0	16	268	1	0	552	250	1	10	379	5	0	2	0	0	1,484
1993	1,536	0	0	2	293	12	0	1,390	473	0	23	692	0	0	0	0	0	2,885
1994	991	0	6	0	503	15	0	631	553	0	7	526	4	0	7	0	0	2,251
1995	1,111	0	9	0	2,067	1	1	3,896	156	0	65	280	0	0	5	0	0	6,479
1996	1,078	1	1	0	345	0	0	6,117	83	0	109	354	1	0	2	0	0[e]	7,013[e]
1997	1,026	0	0	2	119	9	0	854	824	0	19	1,596	5	0[e]	7[e]	0[e]	0[d]	3,435
1998	1,202	0	1	0	625	3	0	2,099	598	0	11[e]	709[e]	0[e]	0[d]	0[d]	0[d]	0[d]	4,053
1999	1,625	0	0	0	854	7	0[e]	1,355[e]	718[e]	0[e]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	3,818
2000	1,375	0	3	1[e]	1,197[e]	0[e]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	
2001	1,830	0[e]	0[e]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	
2002	1,264	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	
2003	1,831	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	
2004	1,939	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	

[a] R/S = return per spawner.

[b] Escapement not available.

[c] Younger age groups not available.

[d] Incomplete returns from brood year escapement.

[e] Estimate from 2004 preliminary return numbers.

Table A-4. Ugashik River sockeye salmon escapement and return by brood year including estimated interception catch (in thousands), 1950 – 2004.

		Return by Age Class																
Brood Year	Escapement	0.2	1.1	0.3	1.2	2.1	0.4	1.3	2.2	3.1	1.4	2.3	3.2	1.5	2.4	3.3	3.4	Total
1950	0[b]	0[c]	0[c]	0[c]	0[c]	0[c]	0	0	0	0	1	45	0	0	0	3	0	49[d]
1951	0[b]	0[c]	0[c]	0	0	0	1	47	174	0	2	118	1	0	0	0	0	343[d]
1952	0[b]	0	0	1	508	0	0	391	209	0	0	78	2	0	0	0	0	1,189
1953	0[b]	0	0	0	216	0	0	249	420	0	0	216	7	0	0	0	0	1,108
1954	0[b]	0	0	0	24	3	0	28	395	0	0	61	0	0	0	0	0	511
1955	0[b]	0	0	1	17	1	0	33	118	0	0	7	0	0	0	0	0	178
1956	425	1	12	0	3,165	0	0	837	80	0	2	35	0	0	0	0	0	4,132
1957	215	0	0	1	35	0	0	105	354	0	2	100	4	0	0	2	0	603
1958	280	0	0	0	63	0	0	105	444	0	0	66	0	0	0	0	0	678
1959	219	0	0	0	18	0	0	38	310	0	0	132	0	0	0	1	0	499
1960	2,304	0	0	0	674	11	0	296	1,563	0	0	487	0	0	0	0	0	3,031
1961	349	0	0	3	240	2	0	500	247	0	1	120	0	0	0	0	0	1,114
1962	255	0	0	2	77	2	0	130	185	0	0	27	0	0	0	0	0	423
1963	388	0	0	0	13	0	0	21	91	0	0	23	0	0	0	0	0	148
1964	473	0	0	0	31	9	0	16	245	0	0	18	0	0	0	2	0	322
1965	997	0	0	0	86	2	0	38	249	0	1	162	1	0	0	0	0	539
1966	704	1	0	2	723	0	0	1,478	90	0	0	21	0	0	0	0	0	2,315
1967	239	0	0	0	56	0	0	50	44	0	0	34	0	0	0	0	0	184
1968	71	0	0	0	14	0	0	7	15	0	0	3	0	0	0	0	0	39
1969	160	0	0	0	4	0	0	5	53	0	0	26	2	0	0	2	0	92
1970	735	0	0	0	4	1	0	2	256	0	1	28	2	0	0	1	0	295
1971	530	0	0	0	178	0	0	236	290	0	0	130	0	0	0	1	0	835
1972	79	0	0	0	35	0	0	58	119	0	0	41	2	0	0	3	0	258
1973	39	0	0	1	16	0	0	8	17	0	0	46	4	0	0	0	0	92
1974	62	0	0	0	13	10	0	15	602	0	0	83	2	0	0	0	0	725
1975	429	0	3	0	1,484	4	0	575	1,721	0	0	325	2	0	1	0	0	4,116
1976	356	0	0	2	2,027	58	0	1,527	1,248	0	7	437	0	0	0	3	0	5,309
1977	202	0	2	18	585	0	0	1,614	266	0	10	186	6	0	1	4	0	2,692
1978	82	0	0	5	247	7	0	413	863	0	6	523	1	0	0	0	0	2,065
1979	1,707	0	20	0	3,076	8	0	851	1,471	0	14	562	0	0	5	0	0	6,006
1980	3,335	0	1	13	1,183	39	0	2,309	3,371	0	10	850	3	0	2	0	0	7,781
1981	1,328	0	2	10	1,603	4	0	2,632	2,278	0	4	933	1	0	1	0	0	7,468
1982	1,186	0	1	15	423	1	1	713	606	0	9	737	0	0	2	0	0	2,508
1983	1,001	0	0	10	650	6	1	342	632	0	3	319	1	0	1	0	0	1,965
1984	1,270	0	0	5	472	55	0	568	3,635	0	13	709	3	0	0	4	0	5,464
1985	1,006	2	1	6	508	2	0	721	978	0	4	469	0	0	5	0	0	2,695
1986	1,016	5	1	46	503	1	0	2,427	1,874	0	71	1,750	4	0	15	0	0	6,696
1987	687	7	1	9	828	11	0	1,626	1,875	0	25	2,310	10	0	20	24	0	6,745
1988	654	1	2	1	463	27	0	692	2,144	0	37	2,252	22	0	3	7	0	5,650
1989	1,713	3	7	7	694	14	0	391	2,479	0	12	955	6	0	1	4	0	4,573
1990	749	0	1	13	345	15	2	709	2,302	0	2	1,218	2	0	2	0	0	4,611
1991	2,482	1	6	0	2,034	1	0	3,167	597	0	14	326	0	0	4	0	0	6,151
1992	2,195	6	3	49	191	4	1	597	1,013	0	1	827	0	0	10	1	0	2,703
1993	1,413	1	2	2	265	7	0	352	241	0	17	198	0	0	0	1	0	1,086
1994	1,095	0	12	4	333	12	0	327	689	0	6	274	1	0	2	0	0	1,660
1995	1,321	3	18	7	2,808	1	0	1,562	185	0	19	82	0	0	1	0	0	4,686
1996	692	0	0	40	231	0	3	978	36	0	16	81	1	0	1	1	0[e]	1,388[e]
1997	657	1	0	2	234	0	0	701	1,553	0	11	534	23	0[e]	0[e]	2[e]	0[d]	3,061
1998	925	0	1	0	204	1	0	292	603	0	4[e]	230[e]	2[e]	0[d]	0[d]	0[d]	0[d]	1,339
1999	1,662	0	6	3	1,088	25	0[e]	767[e]	1,420[e]	0[e]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	3,929
2000	638	0	3	2[e]	1,719[e]	0[e]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	
2001	866	1[e]	2[e]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	
2002	892	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	
2003	790	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	
2004	815	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	

[a] R/S = return per spawner.
[b] Escapement not available.
[c] Younger age groups not available.
[d] Incomplete returns from brood year escapement.
[e] Estimate from 2004 preliminary return numbers.

Table A-5. Wood River sockeye salmon escapement and return by brood year including estimated interception catch (in thousands), 1950 – 2004.

		Return by Age Class																
Brood Year	Escapement	0.2	1.1	0.3	1.2	2.1	0.4	1.3	2.2	3.1	1.4	2.3	3.2	1.5	2.4	3.3	3.4	Total
1950	0[b]	0[c]	0[c]	0[c]	0[c]	0[c]	0[c]	0[c]	0[c]	0[c]	1	57	0	0	0	0	0	58[d]
1951	0[b]	0[c]	0[c]	0[c]	0[c]	0[c]	0	456	290	0	3	54	0	0	0	1	0	804[d]
1952	0[b]	0[c]	0[c]	0	690	0	0	558	29	0	2	34	0	0	0	0	0	1,313[d]
1953	0[b]	0	0	0	301	0	0	331	139	0	2	34	0	0	0	1	0	808
1954	0[b]	0	0	0	1,237	0	0	140	1,085	0	1	66	0	0	0	0	0	2,529
1955	0[b]	0	0	0	2,407	0	0	833	401	0	5	143	0	0	0	0	0	3,789
1956	773	0	0	48	774	0	0	627	24	0	0	0	0	0	0	0	0	1,473
1957	289	0	0	21	136	0	0	257	35	0	0	0	0	0	0	0	0	449
1958	960	0	1	0	2,145	1	0	389	75	0	0	32	0	0	0	0	0	2,643
1959	2,209	0	0	1	979	10	0	398	359	0	1	55	0	0	0	2	0	1,805
1960	1,016	0	6	0	1,474	0	0	1,039	106	0	2	105	1	0	0	0	0	2,734
1961	461	0	0	10	255	0	0	1,183	24	0	2	20	0	0	1	1	0	1,496
1962	874	1	2	0	992	1	2	340	116	0	6	43	0	0	0	0	0	1,503
1963	721	0	0	0	536	1	0	769	76	0	0	46	0	0	0	0	0	1,428
1964	1,076	0	1	6	452	0	0	347	338	0	0	74	0	0	0	2	0	1,220
1965	675	2	1	8	472	1	0	999	90	0	0	213	0	0	0	1	0	1,786
1966	1,209	0	7	29	974	0	0	988	46	0	7	69	0	0	0	1	0	2,121
1967	516	0	3	21	642	0	0	269	75	0	2	80	0	0	0	0	0	1,092
1968	649	0	1	0	514	0	0	565	5	0	4	19	0	0	0	0	0	1,108
1969	604	0	0	4	57	0	0	445	201	0	10	116	0	0	0	0	0	833
1970	1,162	0	2	0	1,539	0	0	1,002	231	0	0	26	0	0	0	0	0	2,800
1971	851	3	0	18	456	0	0	576	198	0	1	49	0	0	0	0	0	1,301
1972	431	2	1	22	779	0	0	631	32	0	20	27	0	0	0	0	0	1,514
1973	330	1	1	0	213	0	0	1,148	74	0	3	44	0	0	0	0	0	1,484
1974	1,709	0	3	6	2,956	4	0	1,698	421	0	5	71	0	0	0	0	0	5,164
1975	1,270	13	47	12	1,592	2	0	1,977	406	0	2	734	0	0	0	0	0	4,785
1976	817	0	3	0	2,278	3	0	2,589	572	0	10	265	0	0	0	0	0	5,720
1977	562	0	20	0	1,029	0	0	2,173	40	0	0	26	2	0	0	0	0	3,290
1978	2,267	0	0	0	1,364	3	0	1,029	784	0	12	96	0	0	0	0	0	3,288
1979	1,706	0	10	0	2,643	0	0	1,491	24	0	1	13	0	0	0	0	0	4,182
1980	2,969	0	0	0	453	0	0	978	72	0	1	101	0	0	0	0	0	1,605
1981	1,233	0	0	0	626	0	0	1,137	60	0	0	86	0	0	0	0	0	1,909
1982	976	0	4	0	522	0	0	765	121	0	12	14	0	0	0	0	0	1,438
1983	1,361	0	1	5	1,940	0	2	1,154	15	0	2	75	0	0	0	0	0	3,194
1984	1,003	0	0	0	586	0	2	1,340	32	0	15	23	0	0	0	0	0	1,998
1985	939	8	3	15	1,127	0	1	1,390	29	0	2	12	0	0	1	0	0	2,588
1986	819	7	2	25	1,179	0	1	1,970	70	0	12	64	0	0	0	0	0	3,330
1987	1,337	25	0	30	1,334	0	14	756	98	0	8	92	0	0	1	0	0	2,358
1988	867	4	1	8	1,613	0	3	1,425	90	0	15	34	0	0	0	0	0	3,193
1989	1,186	1	4	16	2,293	0	0	1,922	13	0	2	39	0	0	0	0	0	4,290
1990	1,069	10	1	10	1,104	1	3	1,208	286	0	2	169	0	0	0	0	0	2,794
1991	1,160	0	12	9	2,633	0	0	2,466	54	0	65	71	0	0	0	0	0	5,310
1992	1,286	10	1	57	2,398	0	2	1,674	90	0	0	49	0	0	0	1	0	4,282
1993	1,176	14	0	3	1,715	0	9	1,161	129	0	3	191	0	0	0	0	0	3,225
1994	1,472	0	10	0	2,747	1	0	1,993	448	0	2	91	0	0	0	0	0	5,292
1995	1,482	1	5	0	3,524	0	0	2,594	149	0	61	35	0	0	0	0	0	6,369
1996	1,650	0	0	0	2,705	0	0	3,675	3	0	58	13	0	0	0	0	0[e]	6,454[e]
1997	1,512	4	0	63	174	0	4	675	164	0	25	203	0	0[e]	0[e]	0[e]	0[d]	1,312
1998	1,756	0	3	11	2,910	1	0	3,516	176	0	5[e]	96[e]	0[e]	0[d]	0[d]	0[d]	0[d]	6,717
1999	1,512	4	2	42	1,778	1	0[e]	1,896[e]	403[e]	0[e]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	4,245
2000	1,300	0	3	2[e]	3,218[e]	0[e]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	
2001	1,459	6[e]	0[e]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	
2002	1,284	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	
2003	1,460	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	
2004	1,543	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	

[a] R/S = return per spawner.

[b] Escapement not available.

[c] Younger age groups not available.

[d] Incomplete returns from brood year escapement.

[e] Estimate from 2004 preliminary return numbers.

Table A-6. Igushik River sockeye salmon escapement and return by brood year including estimated interception catch (in thousands), 1950 – 2004.

		Return by Age Class																
Brood Year	Escapement	0.2	1.1	0.3	1.2	2.1	0.4	1.3	2.2	3.1	1.4	2.3	3.2	1.5	2.4	3.3	3.4	Total
1950	0[b]	0[c]	0[c]	0[c]	0[c]	0[c]	0[c]	0[c]	0[c]	0[c]	1	78	0	0	0	0	0	79[d]
1951	0[b]	0[c]	0[c]	0[c]	0[c]	0[c]	0	615	62	0	1	29	0	0	0	2	0	709[d]
1952	0[b]	0[c]	0[c]	0	147	0	0	303	9	0	5	73	0	0	0	0	0	537[d]
1953	0[b]	0	0	0	98	0	0	1	20	0	3	65	0	0	0	1	0	188
1954	0[b]	0	0	0	175	0	0	269	204	0	0	113	0	0	1	0	0	762
1955	0[b]	0	0	0	454	0	0	781	113	0	0	94	0	0	0	0	0	1,442
1956	400	0	0	0	169	0	0	523	12	0	3	36	0	0	0	0	0	743
1957	130	0	0	0	2	0	0	35	19	0	0	20	0	0	0	0	0	76
1958	107	0	0	0	14	0	0	71	20	0	0	28	0	0	0	0	0	133
1959	644	0	0	0	101	0	0	155	93	0	0	22	0	0	0	0	0	371
1960	495	0	0	1	61	0	0	310	44	0	0	57	0	0	0	0	0	473
1961	294	0	0	1	33	0	1	364	20	0	0	17	0	0	0	0	0	436
1962	16	0	0	8	20	0	0	280	9	0	0	9	0	0	0	0	0	326
1963	92	0	0	3	254	0	0	190	36	0	0	25	0	0	0	0	0	508
1964	129	0	0	1	162	0	0	585	133	0	0	49	0	0	0	0	0	930
1965	181	0	0	0	371	0	0	436	203	0	0	80	0	0	0	0	0	1,090
1966	206	0	0	0	66	0	0	383	6	0	0	15	0	0	0	0	0	470
1967	282	0	0	3	57	0	0	90	13	0	0	12	0	0	0	0	0	175
1968	195	0	0	0	43	0	0	120	0	0	2	10	0	0	0	0	0	175
1969	512	0	0	0	1	0	0	131	301	0	2	103	0	0	0	0	0	538
1970	371	0	0	1	26	0	0	170	41	0	0	71	0	0	0	0	0	309
1971	211	0	0	1	48	0	0	164	60	0	0	30	0	0	0	0	0	303
1972	60	0	0	4	89	0	0	109	6	0	8	13	0	0	0	0	0	229
1973	60	0	0	0	19	0	0	650	25	0	2	29	0	0	0	0	0	725
1974	359	0	0	7	441	1	0	750	346	0	4	25	0	0	0	0	0	1,574
1975	241	0	0	0	783	0	0	2,556	137	0	2	503	0	0	0	0	0	3,981
1976	186	0	0	0	551	3	0	1,411	194	0	20	215	0	0	0	0	0	2,394
1977	96	0	0	6	294	0	0	1,689	9	0	8	9	0	0	0	0	0	2,015
1978	536	0	0	0	96	0	0	330	84	0	1	15	0	0	0	0	0	526
1979	860	0	0	0	422	0	0	406	13	0	0	5	0	0	0	0	0	846
1980	1,988	0	0	0	20	0	0	271	25	0	0	56	0	0	0	0	0	372
1981	591	0	0	0	188	0	0	779	8	0	1	49	0	0	0	0	0	1,025
1982	424	0	0	7	57	0	0	434	9	0	2	10	0	0	0	0	0	519
1983	180	1	0	0	151	0	0	353	8	0	2	29	0	0	0	0	0	544
1984	185	0	0	0	41	0	0	641	56	0	5	36	0	0	1	0	0	780
1985	212	0	0	7	515	0	0	938	86	0	7	79	0	0	1	0	0	1,633
1986	308	3	0	14	236	0	1	2,231	27	0	15	30	0	0	0	0	0	2,557
1987	169	2	0	11	158	0	0	587	7	0	12	29	0	0	0	0	0	806
1988	170	0	0	1	189	0	1	1,056	41	0	3	36	0	0	0	0	0	1,327
1989	462	0	0	15	508	0	0	1,119	59	0	7	53	0	0	0	0	0	1,761
1990	366	1	0	3	159	0	0	1,429	183	0	4	146	0	0	0	0	0	1,925
1991	756	0	0	1	318	0	0	1,314	3	0	5	20	0	0	0	0	0	1,661
1992	305	0	0	3	44	0	0	148	8	0	0	26	0	0	0	0	0	229
1993	406	0	0	1	132	0	2	316	20	0	0	35	0	0	0	0	0	506
1994	446	0	0	0	238	0	0	846	92	0	1	26	0	0	0	0	0	1,203
1995	473	0	0	0	653	0	0	1,599	15	0	21	13	0	0	0	0	0	2,301
1996	401	0	0	0	171	0	0	1,237	1	0	4	4	0	0	0	0	0[e]	1,417[e]
1997	128	0	0	19	34	0	0	52	10	0	5	58	0	0[e]	0[e]	0[e]	0[d]	178
1998	216	0	0	0	143	0	0	732	28	0	8[e]	37[e]	0[e]	0[d]	0[d]	0[d]	0[d]	948
1999	446	0	0	7	206	0	0[e]	376[e]	67[e]	0[e]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	692
2000	413	0	0	0[e]	102[e]	0[e]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	
2001	410	0[e]	0[e]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	
2002	123	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	
2003	194	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	
2004	110	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	

[a] R/S = return per spawner.

[b] Escapement not available.

[c] Younger age groups not available.

[d] Incomplete returns from brood year escapement.

[e] Estimate from 2004 preliminary return numbers.

Table A-7. Nushagak River sockeye salmon escapement and return by brood year including estimated interception catch (in thousands), 1950 – 2004.

		Return by Age Class																
Brood Year	Escapement [a]	0.2	1.1	0.3	1.2	2.1	0.4	1.3	2.2	3.1	1.4	2.3	3.2	1.5	2.4	3.3	3.4	Total
1974	185	[c]	[c]	[c]	[c]	[c]	[c]	[c]	[c]	[c]	[c]	[c]	[c]	[c]	[c]	[c]	0	
1975	752	[c]	[c]	[c]	[c]	[c]	[c]	[c]	[c]	[c]	[c]	[c]	[c]	0	1	0	0	1 [d]
1976	470	[c]	[c]	[c]	[c]	[c]	[c]	[c]	[c]	[c]	38	281	0	0	0	0	0	319 [d]
1977	553	[c]	[c]	[c]	[c]	[c]	67	1,946	3	0	134	11	1	0	0	0	0	2,162 [d]
1978	664	[c]	[c]	436	100	0	149	779	20	0	1	6	0	0	1	0	0	1,491
1979	499	18	1	466	494	0	16	854	6	0	42	5	0	0	0	0	0	1,902
1980	3,317	19	0	447	84	0	67	344	162	0	4	156	0	0	0	0	0	1,284
1981	1,012	9	0	137	170	0	14	1,476	2	0	86	32	0	0	0	0	0	1,926
1982	601	35	0	351	164	0	49	894	2	0	62	7	0	0	0	0	0	1,563
1983	404	100	0	608	114	0	122	553	6	0	16	3	0	0	0	0	0	1,521
1984	593	10	0	226	51	0	32	566	2	0	20	6	0	0	0	0	0	912
1985	498	68	0	510	64	0	62	612	6	0	13	16	0	0	1	0	0	1,351
1986	990	68	0	837	114	0	58	676	0	0	182	64	0	0	0	0	0	1,999
1987	388	140	0	933	36	0	253	535	36	0	101	10	0	0	1	0	0	2,047
1988	483	68	0	546	214	0	120	1,426	12	0	62	8	0	0	0	0	0	2,457
1989	513	68	0	483	124	0	35	703	1	0	18	4	0	0	0	0	0	1,436
1990	680	53	0	761	36	0	104	253	18	0	11	7	0	0	4	0	0	1,247
1991	493	10	1	137	172	0	6	1,010	3	0	131	19	0	0	0	0	0	1,491
1992	695	85	0	496	228	0	11	650	9	0	63	11	0	0	0	0	0	1,551
1993	715	43	0	43	63	0	2	803	1	0	119	49	0	0	0	0	0	1,124
1994	509	0	0	55	81	0	2	665	6	0	9	53	0	0	0	0	0	872
1995	281	5	1	8	143	0	0	923	34	0	106	15	0	0	0	0	0	1,236
1996	504	0	0	6	502	0	5	1,795	3	0	58	5	0	0	0	0	0 [e]	2,374 [e]
1997	373	0	0	129	71	0	6	254	14	0	19	86	0	3 [e]	1 [e]	0 [e]	0 [d]	583
1998	459	2	0	10	312	0	3	1,633	64	0	190 [e]	82 [e]	0 [e]	0 [d]	0 [d]	0 [d]	0 [d]	2,296
1999	312	4	0	40	421	0	5 [e]	1,793 [e]	24 [e]	0 [e]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	2,382
2000	404	7	0	88 [e]	234 [e]	0 [e]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	
2001	811	13 [e]	0 [e]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	
2002	316	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	
2003	581	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	
2004	492	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	0 [d]	

[a] Escapement for brood years 1974 - 1983 and 1985 - 1986 based on Nuyakuk tower plus aerial survey estimates. Escapement for brood years 1984 and 1987 - present based on Nushagak sonar estimates.

[b] R/S = return per spawner.

[c] Escapement not available.

[d] Younger age groups not available.

[e] Incomplete returns from brood year escapement.

[f] Estimate from 2004 preliminary return numbers.

Table A-8. Togiak River sockeye salmon escapement and return by brood year including estimated interception catch (in thousands), 1950 – 2004.

Brood Year	Escapement	Return by Age Class 0.2	1.1	0.3	1.2	2.1	0.4	1.3	2.2	3.1	1.4	2.3	3.2	1.5	2.4	3.3	3.4	Total
1950	0[b]	0[c]	0[c]	0[c]	0[c]	0[c]	0[c]	0[c]	0[c]	0[c]	0	28	0	0	0	0	0	28[d]
1951	0[b]	0[c]	0[c]	0[c]	0[c]	0[c]	0	98	53	0	0	9	0	0	0	0	0	160[d]
1952	0[b]	0[c]	0[c]	0	152	0	0	58	9	0	0	6	0	0	0	0	0	225[d]
1953	0[b]	0	0	1	31	0	0	84	8	0	0	16	0	0	0	0	0	140
1954	0[b]	0	0	0	20	0	0	146	12	0	0	17	2	0	0	0	0	197
1955	0[b]	0	0	0	136	0	0	190	9	0	1	38	0	0	0	0	0	374
1956	225	0	0	4	114	0	0	306	22	0	1	13	0	0	0	0	0	460
1957	25	2	0	5	48	0	0	70	20	0	0	36	1	0	0	0	0	182
1958	72	0	1	2	68	0	0	115	59	0	0	25	0	0	0	0	0	270
1959	210	0	0	0	141	0	0	92	56	0	0	7	0	0	0	0	0	296
1960	163	0	0	2	191	0	0	274	22	0	0	52	0	0	0	0	0	541
1961	122	1	0	3	85	0	0	216	15	0	1	19	0	0	0	0	0	340
1962	62	0	0	7	48	0	0	102	4	0	0	8	0	0	0	0	0	169
1963	116	0	0	2	43	0	0	65	18	0	0	24	0	0	0	0	0	152
1964	105	0	0	1	43	0	0	84	41	0	0	6	0	0	0	0	0	175
1965	96	0	0	2	154	0	0	181	31	0	0	37	0	0	0	0	0	405
1966	104	1	0	6	200	0	0	419	4	0	1	9	0	0	0	0	0	640
1967	81	1	0	6	18	0	0	99	16	0	1	40	0	0	0	0	0	181
1968	50	0	0	1	49	0	0	190	6	0	3	13	0	0	0	0	0	262
1969	117	0	0	5	28	0	0	142	25	0	3	13	0	0	0	0	0	216
1970	203	0	0	1	54	0	0	226	55	0	1	70	0	0	0	0	0	407
1971	200	0	0	4	106	0	0	317	62	0	1	68	0	0	0	0	0	558
1972	79	0	0	2	93	0	0	150	21	0	2	34	0	0	0	0	0	302
1973	107	1	0	10	151	0	0	442	18	0	1	31	0	0	0	0	0	654
1974	104	0	0	2	271	0	0	307	73	0	3	45	0	0	1	0	0	702
1975	181	1	0	7	195	0	0	848	87	0	2	59	0	0	0	0	0	1,199
1976	189	0	0	1	189	0	0	558	142	0	4	175	0	0	0	0	0	1,069
1977	163	0	0	5	232	0	0	617	14	0	4	14	0	0	0	0	0	886
1978	306	0	0	12	149	0	0	430	65	0	1	25	0	0	0	0	0	682
1979	198	1	0	1	270	0	0	293	12	0	2	5	0	0	0	0	0	584
1980	527	0	0	5	45	0	1	224	10	0	0	19	0	0	0	0	0	304
1981	307	2	0	11	53	0	0	245	15	0	1	16	0	0	0	0	0	343
1982	289	0	0	16	109	0	0	255	14	0	5	26	0	0	0	0	0	425
1983	213	1	0	3	285	0	2	924	9	0	2	21	0	0	0	0	0	1,247
1984	151	0	0	14	21	0	0	109	4	0	1	17	0	0	0	0	0	166
1985	153	0	0	7	35	0	0	194	35	0	1	77	0	0	1	0	0	350
1986	203	0	0	18	77	0	1	445	83	0	14	121	0	0	0	0	0	759
1987	278	0	0	7	190	0	1	575	31	0	7	81	0	0	0	0	0	892
1988	309	1	0	9	111	0	3	403	34	0	3	53	0	0	0	0	0	617
1989	104	0	0	36	132	0	1	328	7	0	1	41	0	0	0	0	0	546
1990	166	1	0	23	101	0	1	460	75	0	5	37	0	0	0	0	0	703
1991	254	1	3	3	189	0	1	429	28	0	8	29	0	0	0	0	0	691
1992	210	1	0	35	50	0	1	124	33	0	1	30	0	0	0	0	0	275
1993	189	0	0	4	64	0	0	229	6	0	4	15	0	0	0	0	0	322
1994	174	1	0	3	43	0	0	167	31	0	1	8	0	0	0	0	0	254
1995	211	0	1	6	341	0	1	1,010	11	0	5	66	0	0	0	0	0	1,441
1996	187	1	0	9	87	0	0	987	4	0	8	21	1	0	0	0	0[e]	1,444[e]
1997	152	0	0	5	43	0	0	305	16	0	5	87	0	0[e]	2[e]	0[e]	0[d]	463
1998	175	0	0	1	54	0	0	633	24	0	5[e]	92[e]	0[e]	0[d]	0[d]	0[d]	0[d]	809
1999	196	0	0	11	137	0	0[e]	290[e]	29[e]	0[e]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	505
2000	352	0	0	4[e]	87[e]	0[e]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	
2001	303	0[e]	0[e]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	
2002	162	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	
2003	232	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	
2004	136	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]	

[a] R/S = return per spawner.

[b] Escapement not available.

[c] Younger age groups not available.

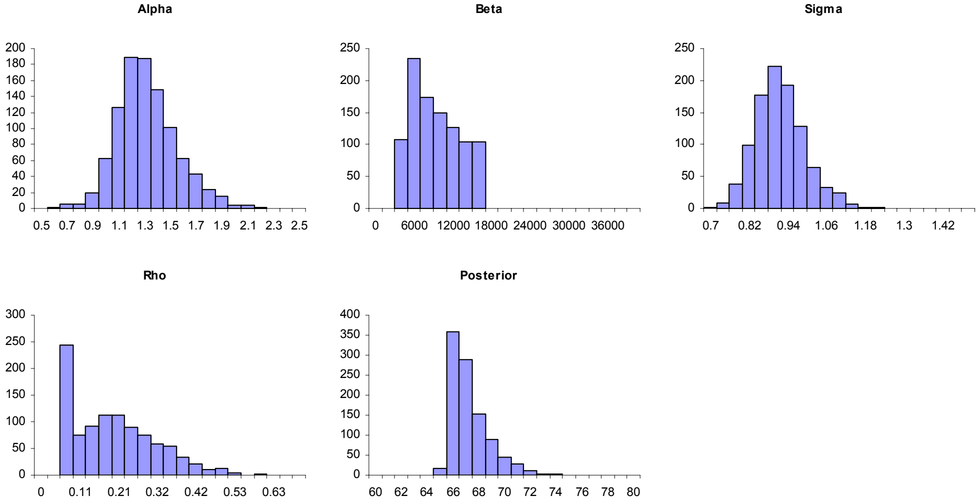
[d] Incomplete returns from brood year escapement.

[e] Estimate from 2004 preliminary return numbers.

Appendix B. Distributions of parameter estimates obtained from the Markov Chain Monte Carlo (MCMC) and the biological and economic parameters used in the modeling effort

Naknek River

Ricker Parameters



Beverton Holt Parameters

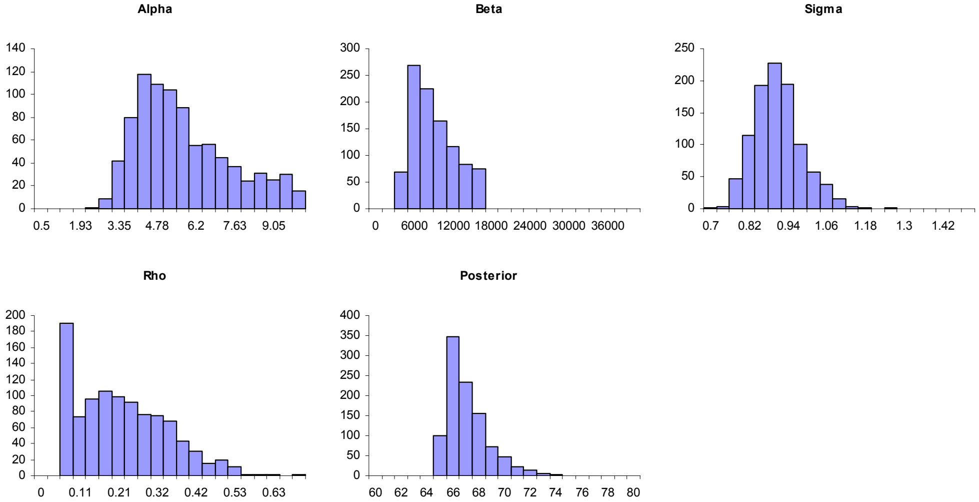
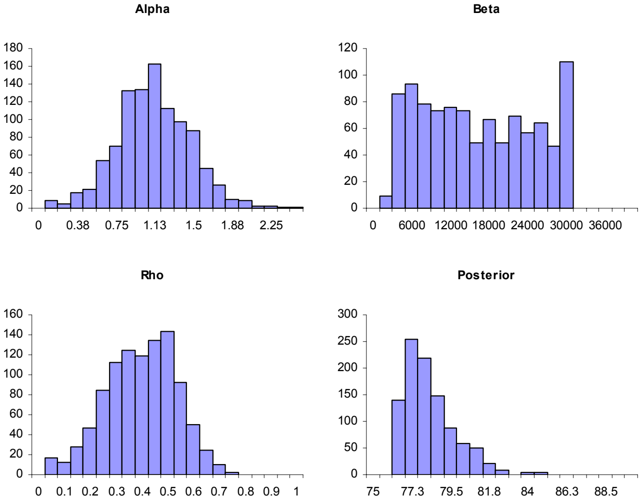


Figure B-1. Distributions of the parameter estimates obtained from the Markov Chain Monte Carlo (MCMC) for the Ricker and Beverton Holt models for Naknek River.

Ugashik River

Ricker Parameters



Beverton Holt Parameters

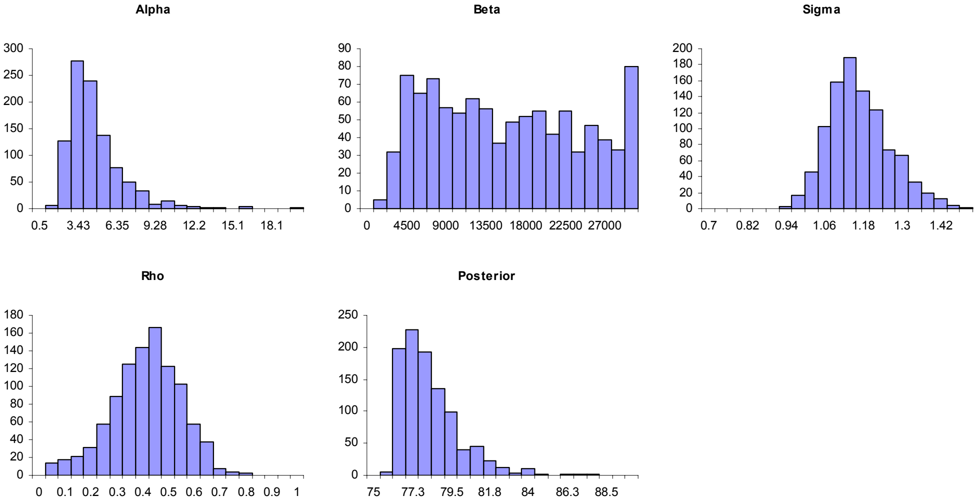
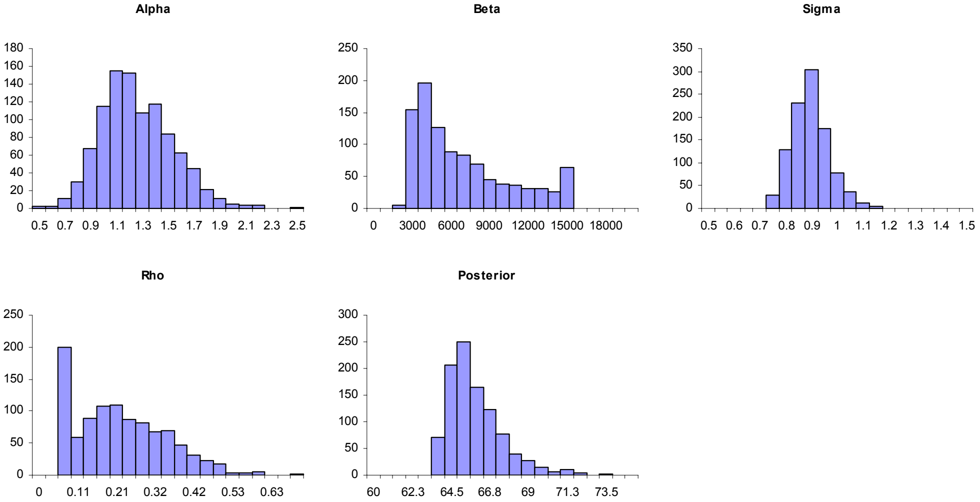


Figure B-2. Distributions of the parameter estimates obtained from the Markov Chain Monte Carlo (MCMC) for the Ricker and Beverton Holt models for Ugashik River.

Wood River

Ricker Parameters



Beverton Holt Parameters

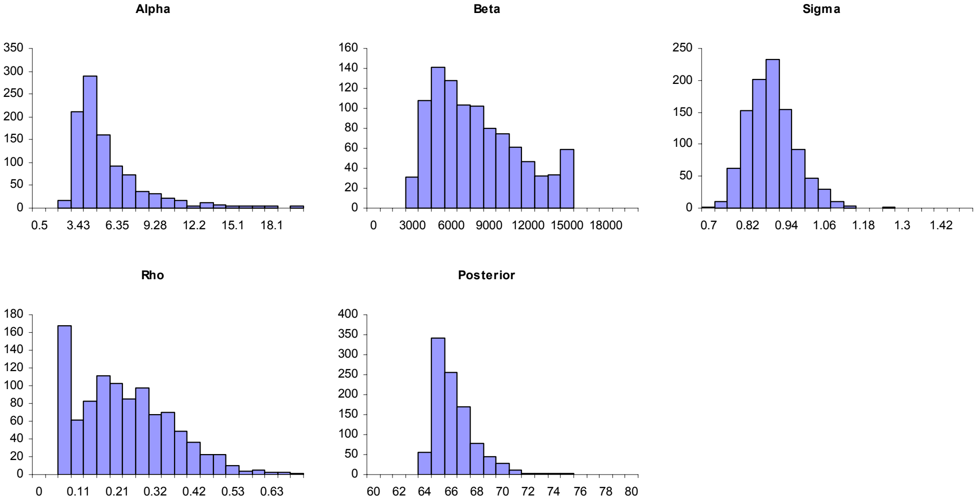
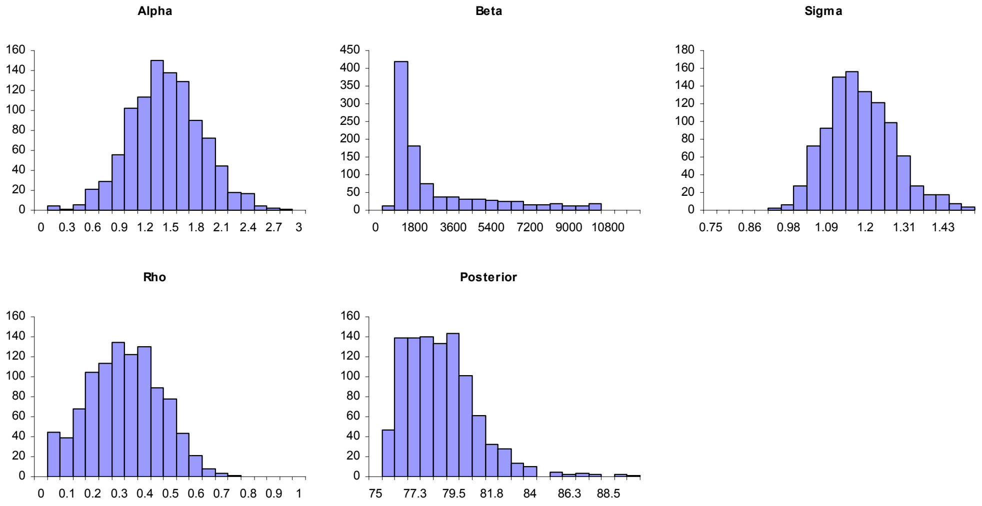


Figure B-3. Distributions of the parameter estimates obtained from the Markov Chain Monte Carlo (MCMC) for the Ricker and Beverton Holt models for Wood River.

Igushik River

Ricker Parameters



Beverton Holt Parameters

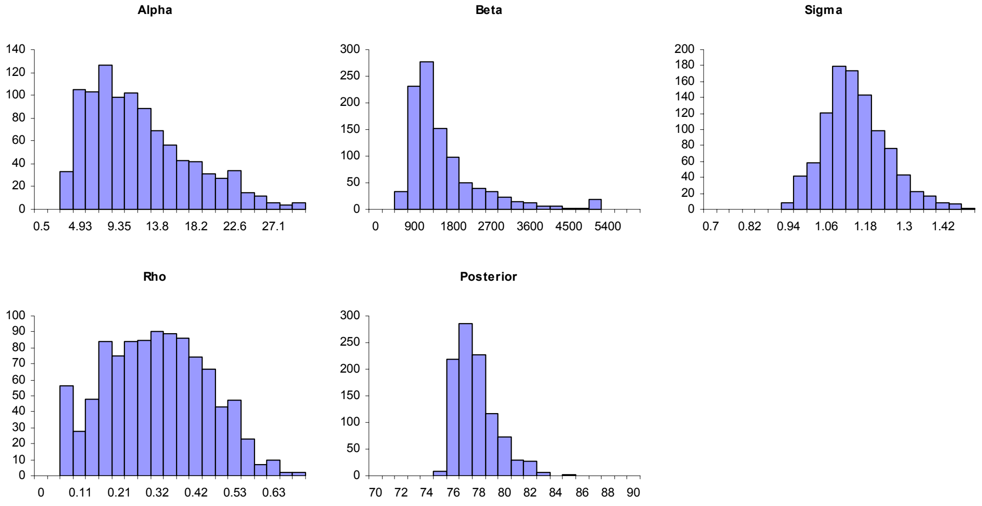
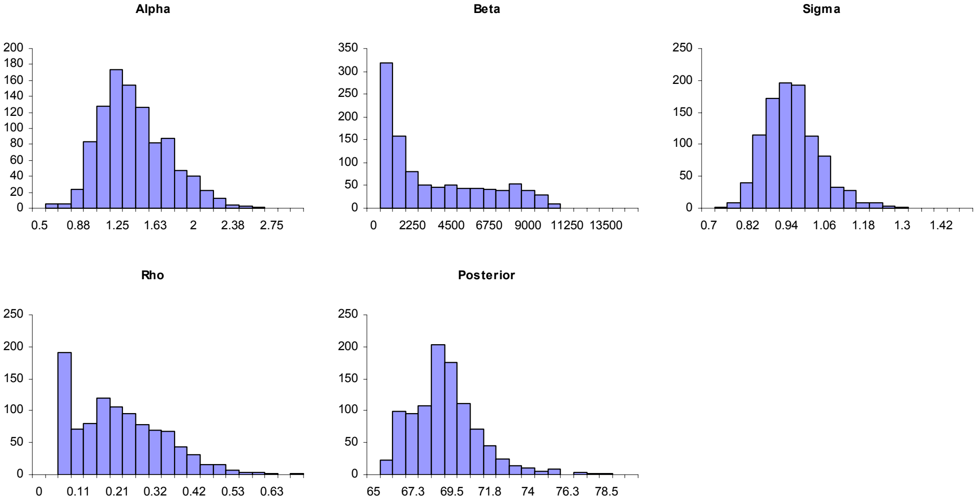


Figure B-4. Distributions of the parameter estimates obtained from the Markov Chain Monte Carlo (MCMC) for the Ricker and Beverton Holt models for Igushik River.

Togiak River

Ricker Parameters



Beverton Holt Parameters

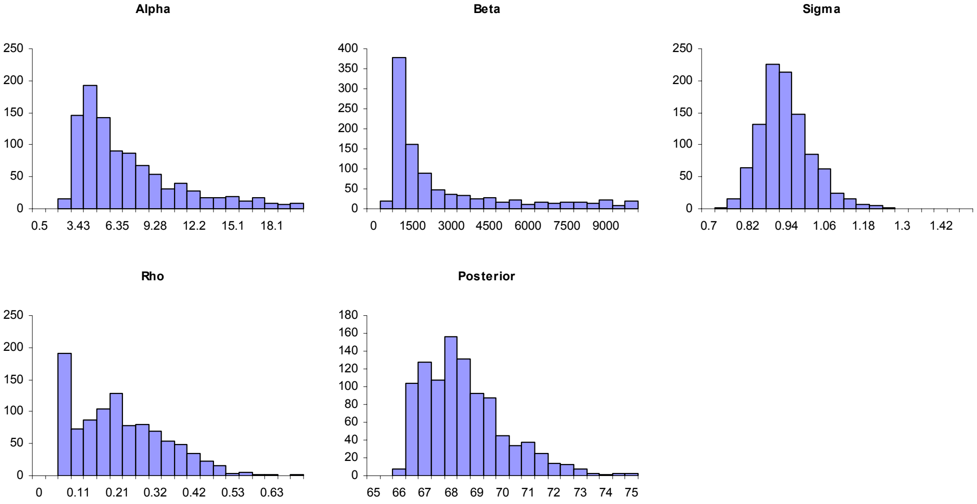


Figure B-5. Distributions of the parameter estimates obtained from the Markov Chain Monte Carlo (MCMC) for the Ricker and Beverton Holt models for Togiak River.

Table B-1. Priors used to initialize and constrain the Markov Chain Monte Carlo used to estimate the Ricker and Beverton Holt spawner recruit models.

	α			β [1]			σ			z		
	Prior	Prior σ^{α}	Min/Max	Prior	Prior σ^{β}	Min/Max	Prior	Prior σ^{σ}	Min/Max	Prior	Prior σ^{z}	Min/Max
Naknek	4.0	10.0	0.1/20.0	10,000	50,000	1,000/15,000	1.0	10.0	0.0/2.0	0.20	10.0	0.05/0.90
Egegik	4.0	10.0	0.1/20.0	30,000	50,000	2,000/50,000	1.0	10.0	0.0/2.0	0.20	10.0	0.05/0.90
Ugahsik	4.0	10.0	0.1/20.0	20,000	50,000	1,000/30,000	1.0	10.0	0.0/2.0	0.20	10.0	0.05/0.90
Wood	4.0	10.0	0.1/20.0	10,000	50,000	1,000/15,000	1.0	10.0	0.0/2.0	0.20	10.0	0.05/0.90
Nushagak	4.0	10.0	0.1/20.0	10,000	50,000	1,000/15,000	1.0	10.0	0.0/2.0	0.20	10.0	0.05/0.90
Igushik	4.0	10.0	0.1/20.0	2,000	50,000	200/10,000	1.0	10.0	0.0/2.0	0.20	10.0	0.05/0.90
Togiak	4.0	10.0	0.1/20.0	2,000	50,000	100/10,000	1.0	10.0	0.0/2.0	0.20	10.0	0.05/0.90

[1] β is in terms of thousands of fish.

Table B-2. Statistics reflecting the fit of the Dirichlet distribution to the age composition data for the major sockeye salmon producing systems.

	Age Classes			
	1.2	1.3	2.2	2.3
Kvichak				
Obs Mean	0.260	0.150	0.488	0.093
Theor Mean	0.246	0.174	0.435	0.145
Obs Variance	0.0388	0.0189	0.0704	0.0059
Theor Variance	0.0324	0.0250	0.0429	0.0216
Naknek				
Obs Mean	0.147	0.353	0.236	0.252
Theor Mean	0.176	0.347	0.212	0.265
Obs Variance	0.0090	0.0389	0.0242	0.0161
Theor Variance	0.0171	0.0268	0.0198	0.0230
Egegik				
Obs Mean	0.078	0.147	0.454	0.295
Theor Mean	0.099	0.147	0.444	0.310
Obs Variance	0.0052	0.0156	0.0306	0.0129
Theor Variance	0.0089	0.0125	0.0246	0.0214
Ugashik				
Obs Mean	0.203	0.234	0.383	0.165
Theor Mean	0.217	0.240	0.351	0.192
Obs Variance	0.0249	0.0268	0.0466	0.0120
Theor Variance	0.0254	0.0273	0.0341	0.0232
Wood				
Obs Mean	0.442	0.452	0.063	0.033
Theor Mean	0.433	0.452	0.068	0.046
Obs Variance	0.0220	0.0205	0.0047	0.0013
Theor Variance	0.0194	0.0196	0.0050	0.0035
Nushagak				
Obs Mean	0.085	0.529	0.013	0.021
Theor Mean	0.213	0.586	0.088	0.113
Obs Variance	0.0021	0.0380	0.0009	0.0009
Theor Variance	0.0504	0.0730	0.0242	0.0302
Igushik				
Obs Mean	0.192	0.652	0.082	0.067
Theor Mean	0.189	0.651	0.072	0.088
Obs Variance	0.0140	0.0249	0.0109	0.0040
Theor Variance	0.0157	0.0233	0.0069	0.0082
Togiak				
Obs Mean	0.227	0.591	0.073	0.079
Theor Mean	0.236	0.595	0.079	0.090
Obs Variance	0.0088	0.0117	0.0033	0.0033
Theor Variance	0.0122	0.0163	0.0049	0.0055

Table B-3. Data used for the development of the ex-vessel and August Japanese wholesale price sub models.

	Bristol Bay Sockeye salmon				Wholesale Price	
Year	Ex-Vessel[a] Price	Harvest[b] (metric tons)	Average Weight (Kg)	Number[c] Of Fish	Sockeye[d]	Farmed[e] Coho
1980	$1.08	60,264			$4.93	
1981	$1.35	71,991			$4.76	
1982	$1.14	43,806			$4.42	
1983	$1.05	96,029	2.57	37,372,031	$3.38	
1984	$1.04	63,238	2.56	24,710,306	$3.86	
1985	$1.28	61,758	2.61	23,702,883	$4.54	
1986	$2.15	43,223	2.74	15,776,056	$5.20	
1987	$2.10	43,465	2.71	16,068,775	$5.35	
1988	$3.15	39,821	2.85	13,989,757	$7.91	
1989	$1.82	74,370	2.59	28,735,306	$5.50	
1990	$1.50	87,223	2.60	33,523,127	$4.64	
1991	$0.99	67,818	2.63	25,821,180	$3.39	$3.62
1992	$1.42	82,810	2.60	31,879,696	$4.33	$4.36
1993	$0.83	110,476	2.73	40,462,124	$3.33	$4.46
1994	$1.19	88,660	2.52	35,224,050	$4.64	$3.86
1995	$0.93	110,299	2.49	44,266,217	$3.14	$3.33
1996	$0.92	84,349	2.85	29,588,297	$3.40	$3.01
1997	$1.05	32,989	2.71	12,158,777	$3.67	$2.72
1998	$1.32	26,175	2.61	10,035,574	$4.09	$2.52
1999	$0.92	61,572	2.40	25,657,889	$3.16	$3.11
2000	$0.72	56,962	2.78	20,457,452	$2.49	$2.44
2001	$0.44	43,380	3.06	14,178,605	$2.07	$1.59
2002	$0.50	29,473	2.76	10,676,320	$2.31	$1.51
2003	$0.50	42,362	2.87	14,742,456	$2.14	$1.96
Average	$1.22	63,438	2.68	24,239,375	$4.03	$2.96
Minimum	$0.44	26,175	2.40	10,035,574	$2.07	$1.51
Maximum	$3.15	110,476	3.06	44,266,217	$7.91	$4.46

[a] Bristol Bay ex-vessel price in 2003 dollars per pound

[b] Bristol Bay sockeye salmon commercial harvest in metric tons(CFEC data)

[c] Bristol Bay sockeye salmon commercial harvest in fish (ADFG 2004)

[d] August Japanese wholesale price in 2003 dollars per pound

[e] Average Japanese wholesale price for frozen farmed Chilean coho salmon in 2003 dollars per pound

Table B-4. Parameters used to simulate processor operating costs. From Link et al. (2003).

	Processor Type	
	Shorebased	Floating
Operating Parameters		
Processor Capacity in fish	1,600,000	800,000
Product Recovery Rate	0.77	0.80
Facility Overhead (Fixed Costs)	$1,900,000	$1,500,000
Processing Variable Costs		
Cost per pound purchased for labor	$0.20	$0.21
Cost per pound purchased for packaging	$0.10	$0.05
Cost per pound purchased for miscellaneous	$0.01	$0.01
Cost per pound purchased for utilities (fuel, water, etc.)	$0.04	$0.08
Carrying cost	$0.01	
FOB Freight	$0.04	
Raw Fish Costs		
Tendering costs per lb	$0.48	$0.13
Fish Taxes per lb	$0.02	$0.03
Total Variable costs per pound purchased	$0.90	$0.51

Table B-5. Parameters used to simulate drift gillnet operating cost. From Link et al. (2003).

	Residency of Permit Holder		
	Local	Other Alaskan	Non-Alaskan
Crew Parameters			
Average No. of Paid Crew	1.4	1.7	1.7
Average Crew Share (prop of gross)	0.14	0.13	0.13
Variable Costs			
Total Crew Share (prop of gross)	0.196	0.221	0.221
Raw Fish Tax (prop of gross)	0.020	0.029	0.030
Total Variable Costs (Prop pf gross)	0.216	0.250	0.251
Fixed Costs			
Fuel, Oil, Lubricants	$1,451.00	$1,192.00	$1,325.00
Maintenance	$2,360.00	$1,944.00	$2,008.00
Nets	$1,474.00	$1,218.00	$1,205.00
Miscellaneous gear and supplies	$600.00	$634.00	$586.00
Administrative Services	$408.00	$537.00	$734.00
Transportation	$1,054.00	$1,423.00	$2,296.00
Food	$1,383.00	$1,009.00	$1,259.00
Insurance	$1,608.00	$1,643.00	$1,802.00
Moorage, Gear storage, Haulout	$652.00	$1,478.00	$1,477.00
Property Tax	$369.00	$568.00	$515.00
Vessel License fees	$48.00	$47.00	$48.00
Permit renewal fees	$188.00	$202.00	$572.00
Total Fixed Costs	$11,595.00	$11,895.00	$13,829.00

Table B-6. Parameters used to simulate set gillnet operating costs. From Link et al. (2003).

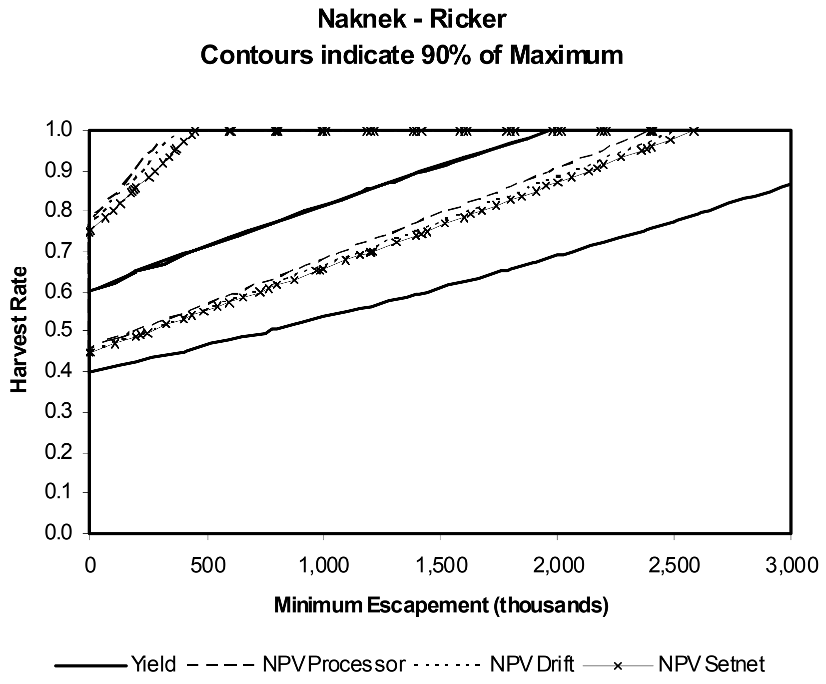
	Residency of Permit Holder		
	Local	Other Alaskan	Non-Alaskan
Crew Parameters			
Average No. of Paid Crew	2	2	2
Average Crew Share (prop of gross)	0.05	0.05	0.05
Variable Costs			
Total Crew Share (prop of gross)	0.10	0.10	0.10
Raw Fish Tax (prop of gross)	0.05	0.05	0.05
Total Variable Costs (Prop of gross)	0.15	0.15	0.15
Fixed Costs			
Fuel, Oil, Lubricants	$346.00	$328.00	$291.00
Maintenance	$838.00	$824.00	$796.00
Nets	$573.00	$563.00	$545.00
Miscellaneous gear and supplies	$1,092.00	$1,074.00	$1,038.00
Administrative Services	$179.00	$170.00	$151.00
Transportation	$0,00	$501.00	$1,000.00
Food	$626.00	$621.00	$613.00
Insurance	$175.00	$174.00	$171.00
Moorage, Gear storage, Haulout	$165.00	$160.00	$150.00
Vessel License fees	$100.00	$100.00	$100.00
Permit renewal fees	$312.00	$312.00	$312.00
Total Fixed Costs	$4,406.00	$4,827.00	$5,167.00

Table B-7. Additional model inputs for the estimation of net present value (NPV).

River System	Catch to Other Districts	Average Capacity per Permit [1]		Proportion Shore based	Drift Allocation	Discount Factor
		Drift	Set net			
Naknek	22,000,000	150,000	60,000	0.75	0.84	0.07
Egegik	16,000,000	150,000	60,000	0.75	0.86	0.07
Ugashik	21,700,000	150,000	60,000	0.75	0.90	0.07
Wood	21,800,000	150,000	60,000	0.75	0.80	0.07
Igushik	26,000,000	150,000	60,000	0.75	0.90	0.07
Togiak	24,000,000	150,000	60,000	0.75	0.60	0.07

[1] Average Maximum Catch per permit is the average capacity for a drift boat on an annual basis in pounds.

Appendix C. Results from economic analysis for all districts.



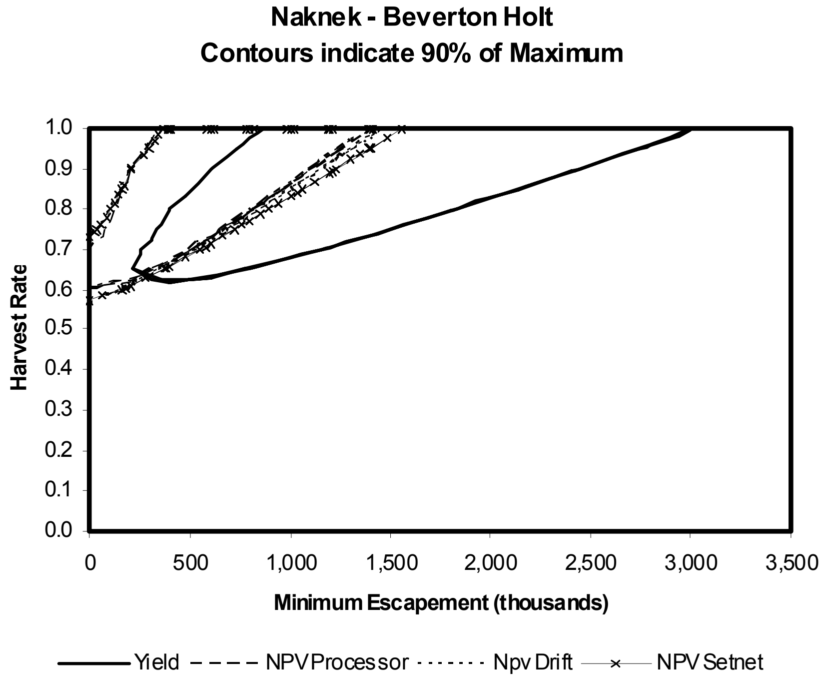
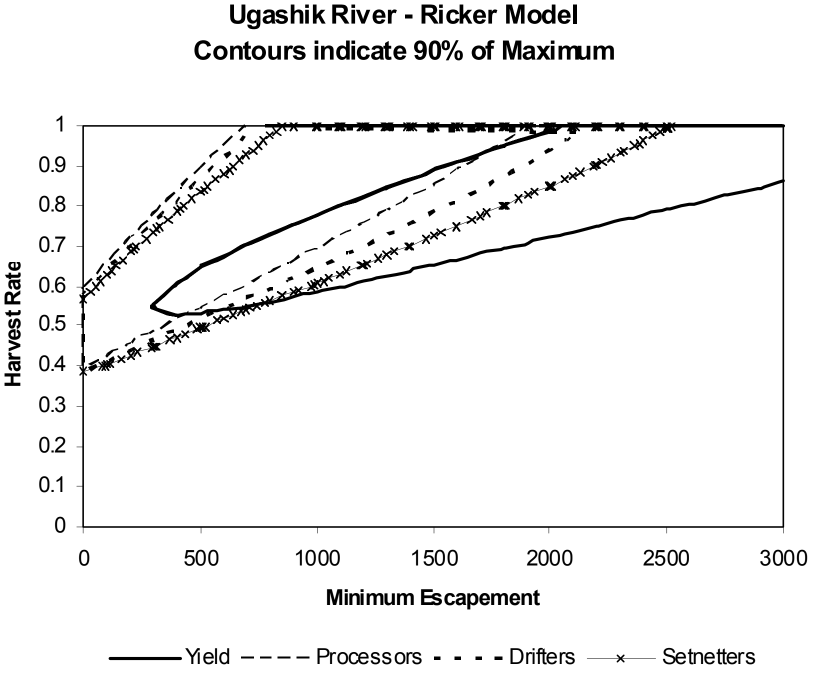


Figure C-1. Ninety-percent density contours for yield and NPV to the fish processors, drifters, and set netters for the Ricker and Beverton Holt spawner recruit models, Naknek River.



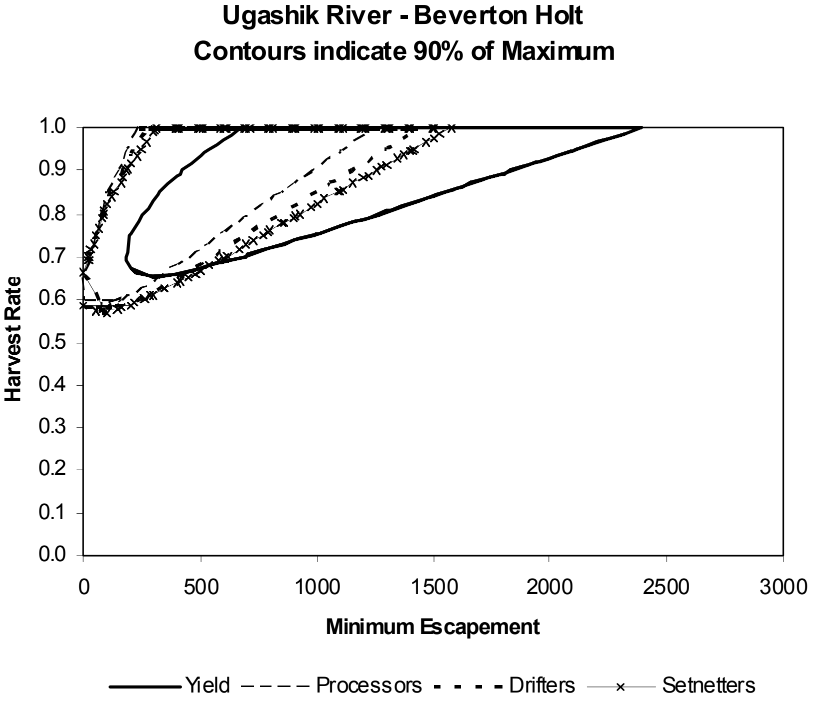


Figure C-2. Ninety-percent density contours for yield and NPV to the fish processors, drifters, and set netters for the Ricker and Beverton Holt spawner recruit models, Ugashik River.

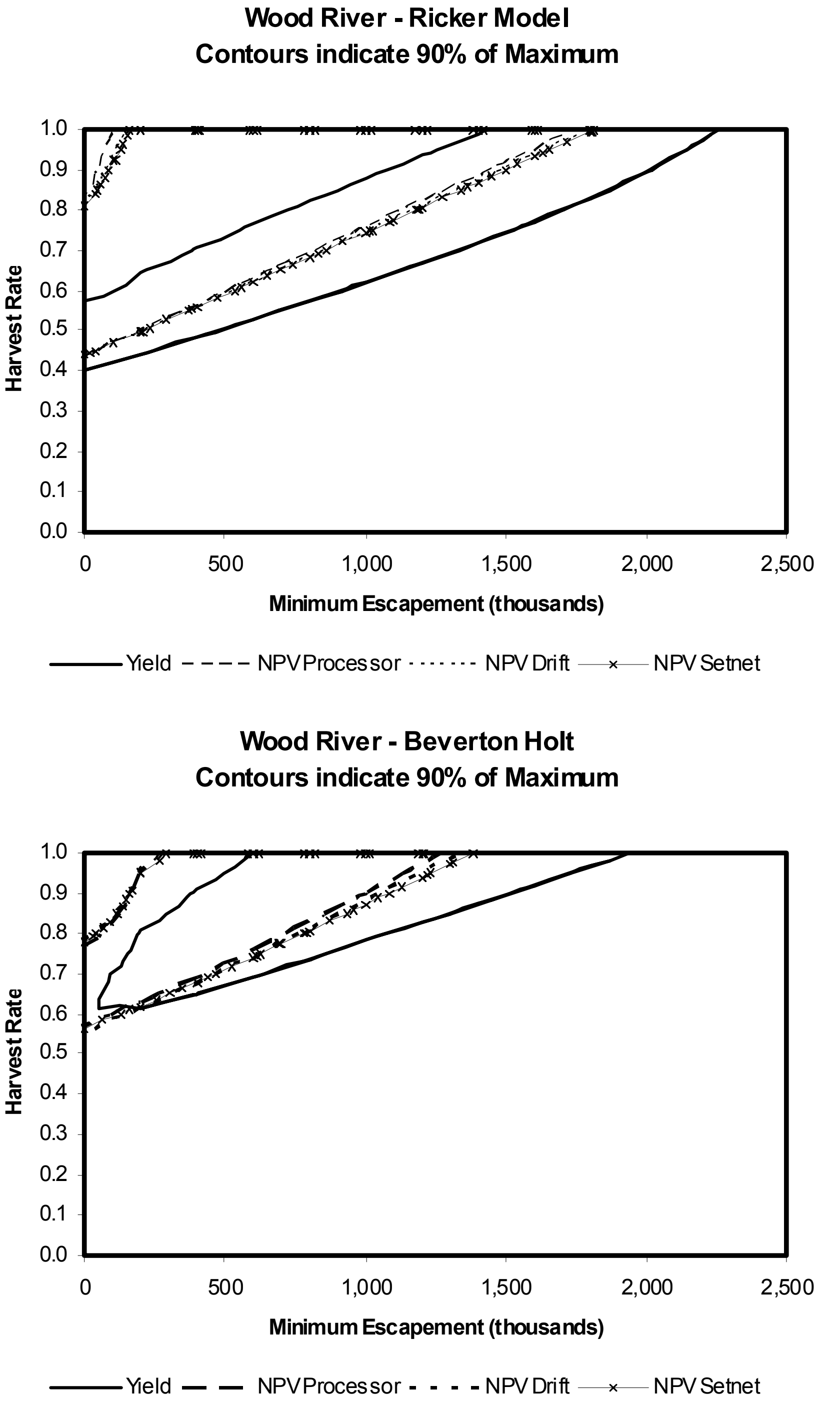
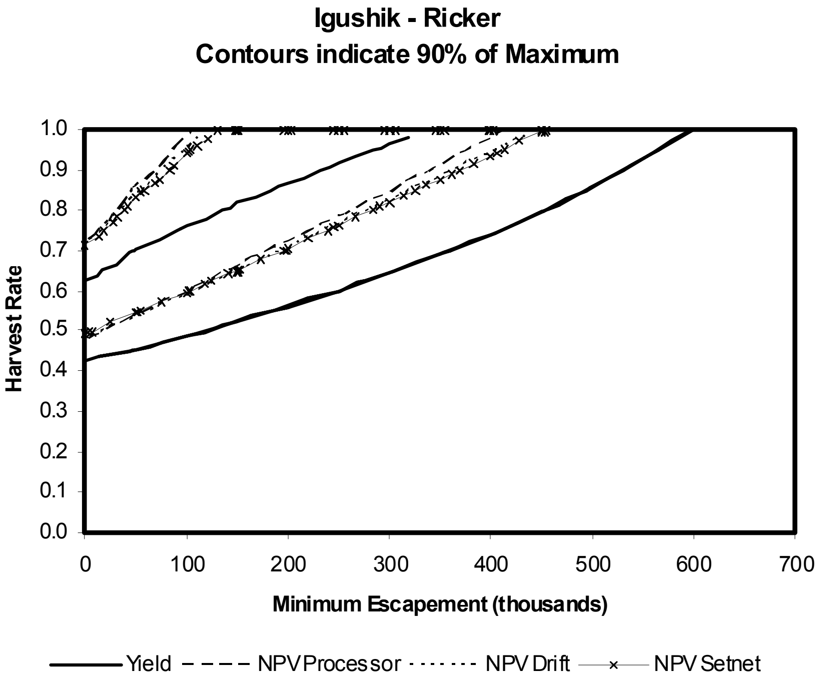


Figure C-3. Ninety-percent density contours for yield and NPV to the fish processors, drifters, and set netters for the Ricker and Beverton Holt spawner recruit models, Wood River.



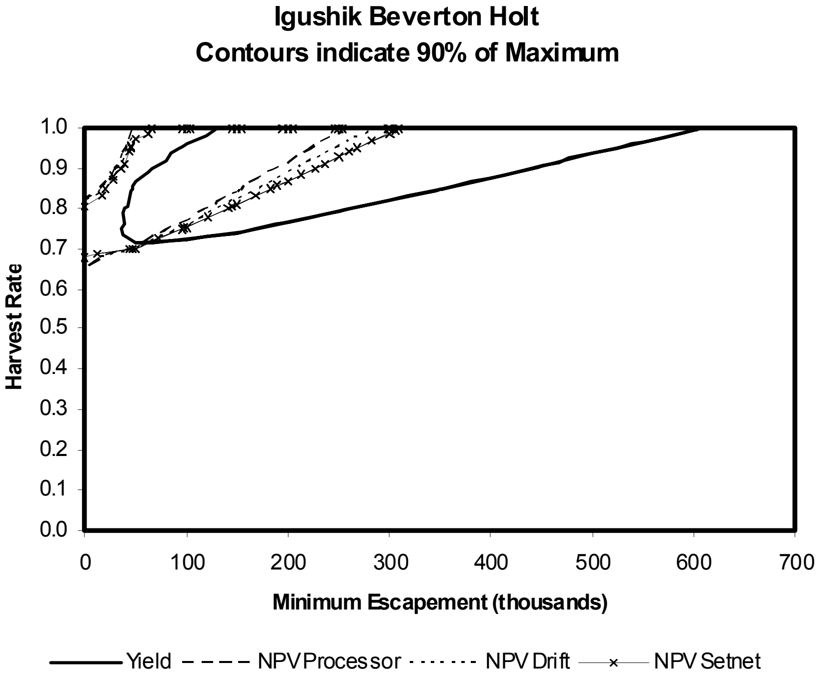


Figure C-4. Ninety-percent density contours for yield and NPV to the fish processors, drifters, and set netters for the Ricker and Beverton Holt spawner recruit models, Igushik River.

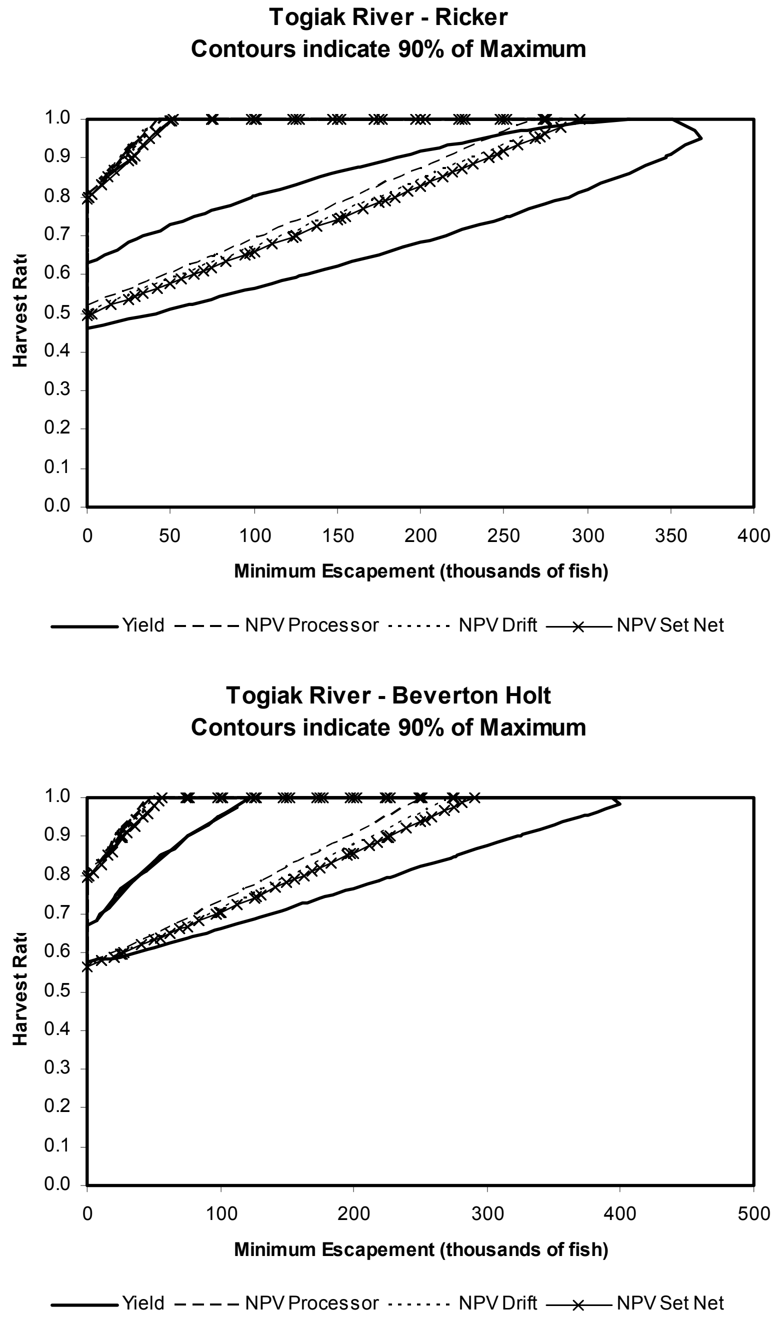


Figure C-5. Ninety-percent density contours for yield and NPV to the fish processors, drifters, and set netters for the Ricker and Beverton Holt spawner recruit models, Togiak River.