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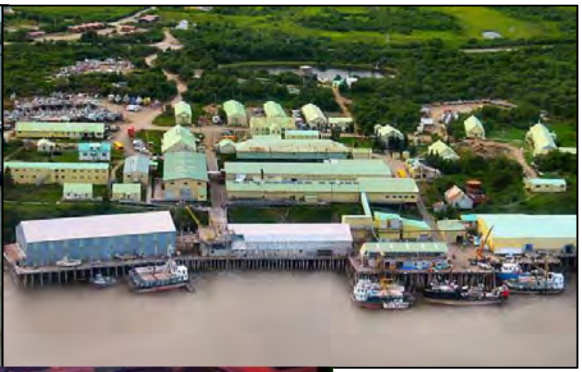
Analysis of Escapement Goals for Bristol Bay Sockeye Salmon taking into Account Biological and Economic Factors

Final Draft Report



March 10, 2015

Analysis of Escapement Goals for Bristol Bay Sockeye Salmon taking into Account Biological and Economic Factors

Final Draft Report

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The Alaska Board of Fisheries
Juneau, AK

March 10, 2015

Executive Summary

At an Alaska Board of Fisheries meeting in December 2012, the Alaska Department of Fish and Game (ADF&G) proposed increasing sockeye escapement goals for several river systems in Bristol Bay. After a movement by industry to get the Board of Fisheries to adopt optimum escapement goals (OEGs) at the then current escapement goal levels, ADF&G agreed to postpone implementing the proposed escapement goals until industry could study the biological and economic implications of changes to existing escapement goals. The industry was to work with ADF&G, fishermen and processors and to report back to the Board of Fisheries in two years, and prior to the 2015 fishing season.

A study was led by the Bristol Bay Science and Research Institute (BBSRI) with financial support from BBEDC and the Bristol Bay Regional Seafood Development Association. Over the last 18 months, fishery scientists and economists from the University of Washington and BBSRI examined the biological and economic impacts of four alternative escapement goal policies, including the current escapement goals. As part of the study, an Advisory Panel (AP) was assembled with representatives of fishermen (set and driftnet), processors, an independent economist, and an ADF&G manager. The AP met five times over the last year to review methods and provide feedback on how to best quantify the impacts of different escapement goal policies.

This report is the second of two reports completed by the study team. In the first report, we examined the process of setting escapement goals believed to maximize catches (also known as BEGs or Biological Escapement Goals) by exploring some approaches different from those used by ADF&G.

Study Approach

We used computer models to simulate the fishery and the individual salmon stocks on a daily basis under alternate harvest policies to understand differences in key variables such as catch, value of harvest to fishermen and processors, and the inter-annual variability in these. Computer models were constructed that mimic the Bay's sockeye stocks, management rules (when to open and close the fishery), harvesting and processing revenues, and the effects of escapement levels on subsequent returns. The model was run for 100-year simulations, and these simulations were repeated 100 times for each escapement goal alternative to characterize differences among policies. We characterized the economic performance (i.e., revenue to harvesters and processors) across all escapement goals examined. All the alternatives we looked at would qualify as either sustainable escapement goals (SEGs) or BEGs, and as such, could be implemented by ADF&G without Board of Fisheries involvement.

Alternative Escapement Goals Examined

1. Current escapement goals (SEGs; in use through 2014)
2. ADF&G proposed SEGs and BEGs (those proposed in December 2012)
3. BEGs developed by ADF&G expected to provide maximum sustained yield (BEGs)

4. Escapement goals that vary with the size of the annual return (total return or TR-based escapement goals).

Key Findings

- Generally, moving to higher escapement goals will produce larger and more variable runs and escapements across Bristol Bay, but this is not expected to translate into larger harvests or revenue to harvesters and processors. In some cases, harvests will be smaller under higher escapement goals.

- We expect a relatively flat plateau of catch and value of catch across a wide range of escapement levels; narrowly defined escapement goals do not seem warranted and, this also has implications for how to define "foregone harvest".

- Current and proposed SEGs are economically robust. In general, the current and the ADF&G proposed escapement goals performed well in terms of harvest and revenue to the harvesting and processing sectors, relative to BEGs.

- Pursuing theoretical maximum yield through traditional BEGs in Bristol Bay will likely lead to less average yield and more variable yield than the current and proposed SEGs, and a TR-based escapement goal policy. Management for BEGs also poses the greatest chance of small Bay-wide annual harvest. Escapement goals that we examined that increased for larger runs (TR-based escapement goals) provided the least variable harvests and lowest probability of small annual Bay-wide harvests.

- Given the dynamics of the Bristol Bay sockeye salmon populations and the fishing industry, the theoretical maximum yield (MSY) is not the practical maximum yield. The fishery cannot take full advantage of occasionally large returns to increase expected catch above alternative policies across many years. As a result, the current and proposed SEGs could be called BEGs, in a more broadly defined version of the term MSY.

- Escapement goal policies should provide for flexibility to managers given the variable and uncertain fish and fishery dynamics within and across fishing districts in the Bay.

Recommendations from the Study's Advisory Panel

The AP's recommendation built upon the results presented here and, essentially, hybridized three of the escapement policies we examined: the lower bound of the current SEGs, the upper bounds of the proposed SEGs, and language in management plans that capture the spirit of the TR-based policy. The effect would be to have wider stock-specific escapement goal ranges than either the current or proposed SEGs, and provide guidelines to managers to achieve lower range escapements in small run years and higher range escapements in larger run years. The AP believed that if ADF&G could adopt a these revised SEGs, and the Board of Fisheries amend management plans, implementation of OEGs by the Board of Fisheries would not be necessary.

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Introduction

In December 2012 the Alaska Board of Fisheries (BoF) struck a committee[1] to oversee the analysis of *optimum escapement goals* (OEGs)[2] for Bristol Bay sockeye salmon. The BoF action was in response to proposed revisions to Bristol Bay sockeye salmon escapement goals by the Alaska Department of Fish and Game (ADF&G; Fair et al. 2012). This report is the outcome of an analysis of escapement goals for Bristol Bay sockeye salmon that take into account biological factors, management uncertainty, and economic factors.

The Bristol Bay Economic Development Corporation (BBEDC) committed to leading an analysis of alternative escapement goals through its non-profit subsidiary, the Bristol Bay Science and Research Institute (BBSRI). BBSRI retained fisheries scientists and economists from the University of Washington to conduct the analyses. Salmon processors in Bristol Bay and the driftnet fleet's Regional Seafood Development Association (RSDA) pledged logistical and/or financial support to the analysis. ADF&G agreed to postpone the implementation of recommended Sustainable and Biological Escapement Goals (SEGs and BEGs) for six sockeye stocks until the 2015 season, pending the results from the analysis, which was expected prior to the 2015 season.

Study Objectives

1. Examine alternative approaches to estimating maximum sustained yield (MSY) escapement goals for Bristol Bay sockeye salmon stocks, and compare to those from Fair et al. (2012).
2. Build a biological model of the population dynamics of 9 Bristol Bay sockeye stocks and simulates daily returns to four of the five Bristol Bay fishing districts (Figure 1) based on previous escapement levels.
3. Build a model of the daily management decisions to mimic fishery manager behavior in Bristol Bay.
4. Build a model that captures key economic factors affecting the value of the catch from the Bristol Bay salmon fishery.
5. Conduct a management strategy evaluation by simulating the daily management, harvesting, and processing over replicate 100-year simulations. Compare alternative escapement goal policies by characterizing at catch, escapement, and harvester and processor revenue among alternatives.

The first objective was addressed and reported by Cunningham et al. (2015).

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[1] Appendix A describes the mission of the "BoF Committee"; this is different from the Advisory Panel set up to provide input to the study (Appendix B).

[2] OEG is a broad term that encompasses alternative fixed escapement goals and harvest policies that attempt to meet objectives such economic or social, while maintaining biological sustainability. From 5 AAC 39.222 f (25) *""optimal escapement goal" or "OEG" means a specific management objective for salmon escapement that considers biological and allocative factors and may differ from the SEG or BEG; an OEG will be sustainable and may be expressed as a range with the lower bound above the level of SET, and will be adopted as a regulation by the board; the department will seek to maintain evenly distributed escapements within the bounds of the OEG."*

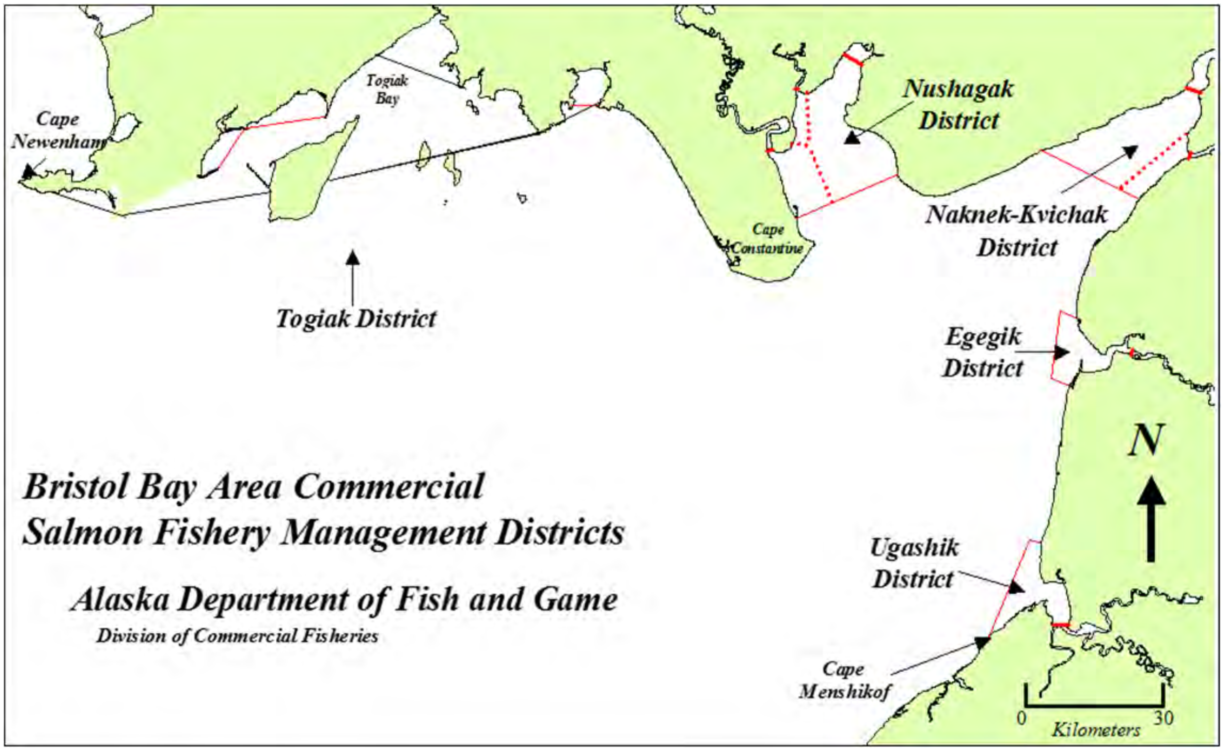

Figure 1. Commercial Salmon Fishery Management Districts, Bristol Bay, Alaska (credit ADF&G).

Study Approach

We used computer models to simulate the fishery and the individual salmon stocks under alternate harvest policies to understand differences in key variables such as catch, value of harvest to fishermen and processors, and the inter-annual variability in these. This is a standard and generally accepted approach referred to in the literature as Management Strategy Evaluation or MSE (Butterworth and Punt 1999; Sainsbury et al. 2000). MSE does not typically seek to prescribe an optimal strategy, but instead provides decision makers with the information on which to base a rational decision, given their objectives, preferences, and attitudes to risk. Computer models were constructed that mimic the Bay's sockeye stocks, management rules (when to open and close the fishery), harvesting and processing revenues, and the effects of escapement levels on subsequent returns. The model was run for 100-year simulations, and these simulations were repeated 100 times for each escapement goal alternative to characterize differences among policies.

We characterized the economic performance (i.e., revenue to harvesters and processors) across all escapement goal alternatives examined. However, all the alternatives we looked at would qualify as either sustainable escapement goals (SEGs) or BEGs and as such, could be implemented by ADF&G without BoF involvement. The term OEG has a relatively narrow application as a management approach that only the BoF can implement, and therefore it was not necessary to use the term OEG to describe any of the alternatives we examined.

Alternative Escapement Goals Examined

We looked at four alternative sockeye salmon escapement goals (EGs) for six river systems in the Bay (Figure 2, Appendix C) including Ugashik, Egegik, Naknek, Nushagak, Wood, and Igushik. Alternative goals for Alagnak, Kvichak, and Togiak were not considered.

1. Current SEGs (sustainable escapement goals; Baker et al. 2006)
2. Proposed SEGs (and BEGs) from Fair et al. (2012)
3. BEGs (biological escapement goals based on maximum sustained yield)
4. Total Return based escapement goals (TR-based EGs).

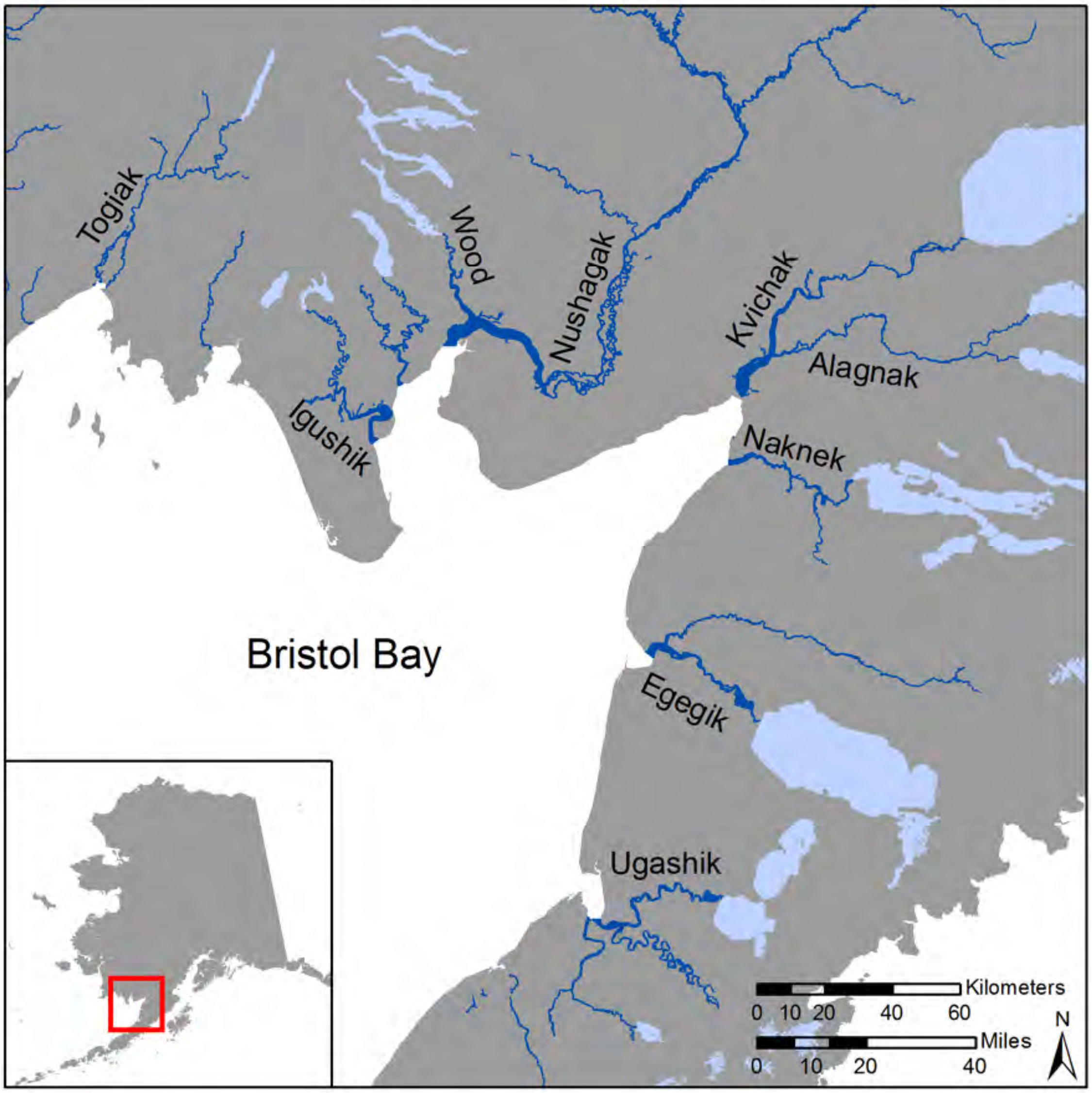

Figure 2. River systems and associated commercial sockeye salmon stocks of Bristol Bay, Alaska.

The first three alternatives stem from current and proposed escapement goals (Baker et al. 2006; Fair et al. 2012). The TR-based EGs were created through work with the Advisory Panel over the last year to develop and refine the study methods and alternative EG policies to examine. Building upon the work of Fair et al. (2012), the group discussed the finding that some of the SEGs in the Bay do not encompass the escapement believed to produce MSY (i.e., the BEG estimate) and, that the industry may be unnecessarily foregoing yield by not reaching some of these higher escapements under the current and proposed SEG regimes. Many on the AP believed that achieving escapement closer to the MSY-based BEG would be more appropriate when runs were large, but to manage for a higher goal in years of low returns would be damaging to the viability of the industry. ADF&G staff noted that they often, through the vagaries of run timing and compression, and the fishing fleet and processing capacity, hit the lower end of the escapement goal ranges in small runs and the upper ends in larger runs.

The AP suggested that we examine an alternative EG policy whereby the escapement goals were a function of run size, similar to what has been done for the Kvichak for many years. The study team created a set of TR-based escapement goals based on:

- Two bins or ranges for the EG, one for annual returns above and one for below the median or 50th percentile of historical returns (1956-2014);
- the lower bin equal to the current SEG bounds; and
- The upper bin designed to encompass or get much closer to the BEG point estimate.

Something important to note about how we modeled management under TR-based EGs is that we essentially mimicked what ADF&G said they often do, but provide for a wider escapement goal range than the current or proposed SEGs. That is, when the runs are large, the modeled management targets the upper end of the range, and vice versa. Whether any TR-based strategy might prefer formal upper and lower bins, or if it would be more beneficial to just provide managers with a single wider EG range to work within, was a topic of discussion for our final AP meeting.

Organization of this Report

The report has been structured as follows.

- Executive Summary: summarize methods and key findings.
- Introduction: impetus for the study, background and previous work on the topic, study design, and the study's Advisory Panel.
- Chapter 1: biological and management model methods and results.
- Chapter 2: economic modeling and results.
- Chapter 3: general conclusions and recommendations.
- Appendices.

The modeling described in Chapters 1 and 2 was tightly interconnected during the analysis, but for accessibility and readability, these components are presented in two standalone documents. Our goal is for each chapter to become the basis for a peer-reviewed journal article.

Background and Previous Work

Fishery scientists and economists, and many of those in the fishing industry, have recognized for some time that economic performance of the Bristol Bay salmon fishery may not be optimized or maximized for escapement levels that, in theory, will provide Maximum Sustained Yield (MSY; i.e., the largest average catch over the long run). Despite large average annual returns and catches, the industry in the Bay had a period of economic losses in the most recent decade, and prompted some to explore opportunities to improve the economic performance of the fishery (Link et al. 2003; Schelle 2004). Further, competition from aquaculture has dramatically reduced prices paid for fish and the profitability of the fishery has declined from its peak in the 1980s. Profitability continues to struggle despite a near record-long series of large catches in the most recent decade.

Link et al. (2003) identified areas of foregone wealth under the current structure of the fishery and suggested a number of methods for improving the economic performance of the fishery, including (1) reducing harvesting capacity, (2) spreading harvesting across time, (3) exploring alternative harvesting methods, (4) improving product quality, (5) improved marketing, and (6) eliminating the race for fish by assigning shares of the harvest to participants. Schelle (2004) found that an optimum number of fishing vessels for economic benefit is considerably less than currently permitted to operate in Bristol Bay.

Hilborn (2006) provided a compelling picture of why a focus on biological yield has led to a biological success story but at the expense of economic success in Bristol Bay. To improve the situation, he points to an obvious need for harvest strategies that maximizes economic return rather than biological return, but notes that there is no party responsible for economic management of the fishery within the State of Alaska.

Bue et al. (2008) examined escapement goal policies to maximize catch and economic returns from the Egegik River stock by taking into account harvesting and processing costs. The analysis was limited to a single fishing district while harvest and processing capacity, and impacts of harvest volume on price, are a Bristol Bay wide phenomena. They found that although a fixed MSY-based escapement goal policy can be expected to maximize catch, revenue will be maximized by periodically harvesting the stock at escapement levels below the MSY level, and that the profit from the fishery would be enhanced by limitations on the harvesting and processing capacity. This work provided some evidence that it may not be economically benefical to maintain capacity to harvest every last fish in occasional large runs.

Valderrama and Anderson (2010) examined market interactions of the Bristol Bay salmon fishery and world aquaculture markets. Their study demonstrated that the initial high profitability of the fishery following limited entry was dissipated by overcapacity in the fishing fleet and price declines caused by aquaculture, further highlighting the need to consider factors beyond MSY if profitability in the fishery is to improve.

Steiner et al. (2011) explored two alternatives to the current fixed escapement goal policy of the Bristol Bay fishery: a fixed harvest rate and a fixed harvest policy, and evaluated whether these could ensure the biological sustainability while enhancing the economic returns. They modeled the dynamics of 9 Bristol Bay stocks under three harvest strategies, the effects of annual Bay and Alaska-wide harvest volume on price, and the future fish price scenarios based on expected aquaculture and natural production. They attempted to isolate whether stabilizing annual catches would lead to greater revenue to the fishery via the inverse relationship between harvest volume and price; they did not attempt to model changes in product mix that might be possible among different harvest strategies, or, most importantly, the intra-season fish and fishery dynamics that affect daily and annual catches and product mixes. Analyses indicated that fixed harvest and harvest rate policies could possibly lead to additional revenue by making higher valued products possible, and might reduce processing costs over those of a fixed escapement goal policy. Steiner et al. (2011) found that transferring the inter-annual variability in catches that occur under a fixed escapement goal policy to the achieved escapement levels under fixed harvest and harvest rate policies could improve the revenue from the fishery, and would not compromise the sustainability of the Bristol Bay stocks.

Valderrama and Anderson (2013) built an econometric model of the Bristol Bay fishery to characterize benefits of management schemes. For example, cooperatives could lower the harvest costs and make the fishery more economically viable in the face of continued competition from the aquaculture sector. Their study predicted that large declines in ex-vessel prices might drive a harvesting cooperative to select escapement targets that exceed MSY BEGs. Their work also predicted that an optimal number of driftnet permits in the fishery is probably closer to 900 vessels from the current 1,860, which is similar to the 800-1,200 recommended as an optimum number by Schelle (2004).

In summary, a growing body of work suggests that the economic performance of the Bristol Bay fishery might be enhanced by shifting emphasis toward economic objectives without harming the long-term biological sustainability of the stocks. No previous work has directly addressed the practicalities of policy implementation given the intra-season dynamics of the fish stocks, fishery and fishery management process. This study set out to include these and other aspects in a comprehensive MSE analysis.

The Study's Advisory Panel

An Advisory Panel (AP) of representatives from harvesting and processing sectors, ADF&G, and independent scientists was formed to provide input to the development of alternative escapement goal strategies and to the economic modeling components of the project. AP input helped to help evaluate the practical consequences of any modifications to escapement goals. The three-person BoF OEG committee members were members of the AP. Appendix B provides the Terms of Reference for the AP, its membership, and the dates and locations of its five meetings over the course of 2014 and 2015.

Acknowledgements

- Keggie Tubbs (BBSRI) provided administrative support for the study team and the AP.
- The Bristol Bay Regional Seafood Development Association contributed funding and provided a person to serve on the AP.
- Trident Seafoods (Heins), North Pacific Seafoods (Monroe), and Deep Sea Fisheries (Boggs) provided a person to serve on the AP.
- North Pacific Seafoods provided meeting space for the AP meetings in Seattle.
- Alaska Department of Fish and Game generously provided staff time (Regnart) to the AP, and Bristol Bay management and research staff provided feedback on the study as it developed, and reviewed a first draft of the two project reports.
- The Southwest Alaska Vocational and Education Center (SAVEC) provided meeting space for the AP and accommodation for the study team in King Salmon.

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Chapter 1

Biological and Management Models Used to Simulate River- and District-specific Annual Returns, Catches, and Escapement under Four Escapement Goal Policies in the Bristol Bay Salmon Fishery

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Introduction

The purpose of this project was to develop a management strategy evaluation (MSE) framework for the commercial sockeye salmon (*Oncorhynchus nerka*) fishery at Bristol Bay, Alaska. This MSE framework simulated future catch, escapement, and run size outcomes of alternative escapement strategies for the eight major sockeye producing river systems of Bristol Bay.

The normal practice in evaluating escapement goals is to fit a spawner-recruit model to available brood table data and generate predictions for the total run size and resulting harvestable surplus or catch, at different levels of potential escapement. Such an approach does not account for the uncertainty in future predictions arising from three processes. First, it does not account for stochastic variation in future recruitment and catch. We are often interested in the variability of catch as well as the average. Second, although the active in-season management practices used in Bristol Bay have proven effective at achieving a valuable and sustainable fishery, the managers rarely are able to precisely hit the mid-point of the escapement goal, which is assumed in normal evaluation of escapement goals. In practice several factors influence this "implementation uncertainty", or the ability of district managers to achieve escapement targets, including run timing, run size, and complex management decisions required for mixed stock fisheries including the Naknek-Kvichak and Nushagak commercial fishing districts. Third, many of the Bristol Bay sockeye stocks show evidence to transition between regimes with differing productivity.

In order to generate more realistic predictions for outcomes from alternative escapement goal strategies, we have created a MSE framework that addresses each of these three sources of uncertainty. We have then used this MSE framework to evaluate four alternative management strategies, by projecting abundance, catch, and escapement forward for 100 years, with replication to simulate the true uncertainty in future production regimes, interannual variation in recruitment, and the daily implementation of seasonal escapement goals. Appendix C describes the four escapement goal policies that we examined.

The first trial management strategy uses the midpoints of the current sustainable escapement goal (SEG) ranges for Bristol Bay stocks (Baker et al. 2006).The second scenario assumes managers target the midpoints of revised SEGs proposed by the Alaska Department of Fish and Game (ADF&G) in 2012 (Fair et al. 2012). The third scenario, sets escapement targets equal the biological escapement goals (BEG), which are the Smsy values estimated by Fair et al. (2012) for each stock. The fourth and final trial management strategy employs total-run based variable escapement goals developed with input from the Advisory Panel for this study (Appendix A). In this TR-based EG scenario, two seasonal escapement goals are defined and the decision of which to target is based on a mid-season assessment of the total run size.

At the beginning of each simulated fishing season, the management model targets the lower goal, however the seasonable escapement goal is shifted upward if an in-season assessment of run size exceeds a specified total run threshold for each river system (Table 1). The Kvichak and Alagnak stocks were not slated for any changes in their escapement goals and their escapement goals were not modified across the policies we examined. However, escapement to these systems is influenced by management of the Naknek stock in the mixed-stock Naknek-Kvichak district and so realized escapement and catches were expected to vary across EG policies examined.

Across all EG scenarios examined, we have attempted to emulate the current rolling Kvichak escapement goal which is based upon 50% of a preseason forecast and a mid-season cumulative catch and escapement based assessment, subject to the overarching 2 – 10 million constraint on the escapement goal (i.e., never less than 2 million or more than 10 million). Given the lack of in-season escapement enumeration for the Alagnak stock and its designation as lower management concern, we do not specify escapement targets for the Alagnak River system and its status does not influence inseason management.

Stock	**Current SEG**	**Proposed SEG**	**BEG**	**TR-based EG**		
				Lower	Upper	TR Breakpoint
Igushik	225	300	291	225	430	720
Wood	1,100	1,300	1,550	1,100	1,500	3,200
Nushagak	590	700	801	590	825	1,200
Kvichak	2,000	2,000	2,000	2,000	2,000	
Alagnak	320	320	320	320	320	
Naknek	1,100	1,450	1,858	1,100	1,900	3,300
Egegik	1,100	1,450	5,242	1,100	1,750	4,700
Ugashik	850	1,000	2,602	850	1,600	2,500

Table 1. Midpoint escapement targets in thousands of sockeye, for the four alternative management strategies. For the TR-based EG, the upper and lower escapement targets are listed, followed by the total run breakpoint with which the in-season assessment is compared. Kvichak and Alagnak escapement targets are listed in red because these systems are not managed separately and the targets did not vary across of the management strategies.

Methods

To address the goal of generating predictions for the outcome of alternative escapement strategies, while accounting for the full range of uncertainty in both the relationship between spawning abundance and realized recruitment, and the management process, we created a MSE framework that incorporated linked biological and management models. The biological model was designed to capture the variability in realized recruitment based upon previous analyses of spawner-recruit data by Cunningham et al. (2015), and allowed for transitions between high and low productivity regimes observed for may Bristol Bay stocks, as well as stochastic and lognormally distributed recruitment deviations. In addition, the biological model incorporated the uncertainty in estimation of model parameters by drawing independent sets of parameter values for 100 replicate simulations.

The management model was meant to emulate the implementation uncertainty in the management process resulting from the difficulty inherent in the daily regulation of fishing effort across multiple fishing districts, with multiple escapement goals, based upon lagged escapement information with uncertainty in arrival timing. Together the biological and management models generated future predictions for sockeye run size, catch, and realized escapement across a 100-year time horizon. The forward simulation process was replicated 100 times to capture the true uncertainty in forward simulation predictions. Each of the 100 replicate simulations of the 100-year time series was repeated under the four alternative management strategies.

Biological Model

The biological component of the MSE framework is intended to capture the uncertainty in future recruitment for each of the eight component stocks from the Igushik, Wood, Nushagak, Kvichak, Alagnak, Naknek, Egegik, and Ugashik Rivers. To simulate the spawner-recruit dynamics for each of these river systems, Cunningham et al. (2015) fit Ricker-type (Eq. 1) spawner-recruit models to data reconstructed by Cunningham et al. (2012) for years 1963 – 2013.

$$R_{y,p} = S_{y,p} \exp\left(\alpha_p \left[1 - \frac{S_{y,p}}{\beta_p} \right] \right) * \exp\left(\varepsilon_p\right) \tag{1}$$

$$\varepsilon_p \sim N\left(0, \sigma_p\right)$$

In this parameterization of the Ricker model, α_p describes maximum productivity (recruits-per-spawner) in the absence of density-dependent compensation, β_p describes equilibrium (unfished) biomass, and σ_p represents the standard deviation of log-normally distributed process uncertainty, for a population p. Three alternative versions of the Ricker model were used to generate predictions for future trends in recruitment for Bristol Bay stocks. A Markov regime transition version of the Ricker model was fit to the Kvichak, Naknek, Egegik, Ugashik, Wood, and Igushik stocks, a more simplistic Bayesian Ricker model was fit to the Alagnak stock, and a maximum likelihood version of the Ricker model to the Nushagak stock.

The Markov regime transition model assumes that the form of the spawner recruit relationship has alternated between productive and unproductive regimes, and estimates separate model and derived parameters for each of two productivity regimes. This model treats transition between productivity states (regimes) as a 1st-order Markov process where the probabilities for transitioning between states are estimated directly from the data. By treating occupancy of differing productivity states across time as a 1st-order Markov process, successive productivity states are conditioned on the state in the previous brood year. This hidden Markov Ricker model treats the expected recruitment from each brood year (y) as a mixture of two separate spawner-recruit relationships, with the probability that any particular year belongs to the high or low productivity regime depending on which regime (state) observed in brood year y-1 (Eq. 2). More generally, this means that whether recruitment resulting from a particular brood year follows expectations from the high or low productivity Ricker relationship, depends upon whether recruitment in the previous brood year exhibited high or low productivity. This dependency permits estimation of the conditional probability of remaining within a productivity regime or transitioning to another, and allows predictions to be generated for future regime occupancy.

$$
\begin{aligned}
&R_{y,p} = S_{y,p} * \exp\left(\alpha_{y,p} \left[1 - \frac{S_{y,p}}{\beta_{y,p}} \right] \right) * \exp\left(\varepsilon_{y,p}\right) \\
&\varepsilon_{y,p} \sim N\left(0, \sigma_{y,p}\right) \\
&\alpha_{y,p} = \alpha'_{\lambda_{y,p},p} \\
&\beta_{y,p} = \beta'_{\lambda_{y,p},p} \\
&\sigma_{y,p} = \sigma'_{\lambda_{y,p},p} \\
&\lambda_{y,p} \sim Cat\left(\gamma_{y,p,r}\right) \\
&\gamma_{y=1,p,r} = p_{p,r} \\
&\gamma_{y,p,r} = \pi_{\lambda_{y-1},p,s}
\end{aligned}
\tag{2}
$$

In this Markov regime transition version of the Ricker model, $(\alpha_{y,p}, \beta_{y,p}, \sigma_{y,p})$ are treated as varying across time between productivity states, but whose value corresponds to one of the estimated regime r and population p specific values $(\alpha'_{r,p}, \beta'_{r,p}, \sigma'_{r,p})$. The probability of the relationship between spawning stock size and recruitment being described by a Ricker curve whose parameters represent the high or low productivity state (regime) r depends upon the brood year y and population p specific probability of regime occupancy ($\gamma_{y,p,r}$).The categorical distribution is used to assign a regime state for each brood year y and population p ($\lambda_{y,p}$), based upon the probability of regime occupancy for that population in that year ($\gamma_{y,p,r}$). The regime occupancy probability in the first year is based upon a population and regime-specific initial state probability ($p_{p,r}$). For all subsequent brood years, the regime occupancy probability is a function of the transition probability matrix ($\pi_{i,j,p}$) which governs the likelihood of regime (state) occupancy, conditioned upon the previous brood year, for each population p. In this formulation i represents the state from which one is transitioning and j represents the productivity state to which one is transitioning (Eq. 3).

$$(3) \qquad \pi_{i,j,p} = \begin{bmatrix} p_{i=1,j=1} & p_{i=1,j=2} \\ p_{i=2,j=1} & p_{i=2,j=2} \end{bmatrix}$$

The diagonal elements of the transition probability matrix represent the probability of remaining in the same state (regime) from one brood year to the next, while the off-diagonal elements of $\pi_{i,j,p}$ describe the probability of state transitions. A Dirichlet prior ($\alpha = 2{,}2$) for the row elements of $\pi_{i,j,p}$ was used, based on that fact that each row of the transition matrix represents a separate multinomial distribution. This prior provides for a broadly dispersed normal distribution with an expected value of 0.5 for remaining in the same regime and transitioning to the other. The prior distribution for the equilibrium population size parameters ($\beta_{r,p}$) were derived from paleolimnological data collected from nursery lakes of the Bristol Bay river systems (Schindler et al. 2005, 2006, Rogers et al. 2013). Results from fitting the Markov regime transition model using Bayesian methods and the top 20% prior for β were used simulating future recruitment for these six stocks; see Cunningham et al. (2015) for further detail.

The Markov regime transition model provides several key pieces of information necessary for simulating future trends in recruitment. First, this model estimates the parameters of the Ricker model for both the high and low productivity regimes. Second, the model provides estimates for elements of the $\pi_{i,j,p}$ that inform the probability of transitioning between productivity regimes in the future. Finally, the Markov regime transition model provides estimates of the level of process uncertainty observed in brood years occupying each regime.

The Markov regime transition model did not fit available data well for the Alagnak system, so results from a more simplistic Bayesian Ricker model also assuming the top 20% prior on β and a single production regime were used. For the Nushagak system, the lack of paleolimnological data necessary for creating a prior on for the β parameter necessitated the fitting of a Ricker spawner-recruit model using maximum likelihood rather than the Bayesian methods. For both the Alagnak and Nushagak populations, the estimated spawner-recruit model parameters and estimation uncertainty therein were used to simulate future production dynamics for these systems.

The formal forward simulation approximated the abundance of each of the four main age classes 1.2, 1.3, 2.2, and 2.3, for each of the eight populations forward in time from 2014 to 2113. The observed numbers of spawning fish for years 2008 – 2013 were used to initialize these simulations. Spawning abundance in brood year y, of population p, of simulation s, ($S_{y,p,s}$) was translated into recruitment ($R_{y,p,s}$) using the information available from fitting system-specific spawner-recruit relationships. For the six stocks to which the Markov regime transition model was fit (i.e., Kvichak, Naknek, Egegik, Ugashik, Wood, and Igushik), 100 year time-series of future regime states were first generated for each simulation. The presence of a stock in either the high or low productivity regime in each year ($\varphi_{y,p,s}$) was determined by generating random jumps between regimes based upon the estimated elements of the transition probability matrix for each population p ($\pi_{i,j,p}$). An initial random state was drawn for each stock with equal probabilities of occupying the high and low productivity regime. Moving forward the state in year y ($\varphi_{y,p,s}$) was determined by drawing a random deviate (τ) from a uniform (0,1) distribution and comparing it to the probability of remaining in the current state i ($\pi_{i,i,p}$) and the probability of transitioning to the other state (production regime) j ($\pi_{i,j,p}$), depending on the state in brood year y (Eq. 4).

$$\tau \sim unif\left(0,1\right)$$

$$\varphi_{y,p.s} = \begin{cases} i, \tau \leq \pi_{\varphi_{y-1,p.s},i,p} \\ j, \tau > \pi_{\varphi_{y-1,p.s},i,p} \end{cases} \tag{4}$$

This process was repeated until a full matrix of production states for each of the six Markov regime transition populations ($\varphi_{y,p,s}$) were simulated independently for each simulation s of the 100. In this way the future dynamics of stock-specific production regime occupancy were simulated based upon the regime transition tendency exhibited by each population in the past.

Recruitment for each population in each year, based upon the spawning stock size was generated by randomly sampling a value for each parameter from the joint posterior probability distribution for that parameter from the Bayesian Markov regime transition spawner-recruit model and the regime currently occupied (Eq. 5).

$$\hat{R}_{y,p,s} = \hat{S}_{y,p,s} * \exp\left(\hat{\alpha}_{y,p,s}\left[1 - \frac{\hat{S}_{y,p,s}}{\hat{\beta}_{y,p,s}}\right]\right) * \exp\left(\varepsilon_{y,p,s}\right)$$

$$\varepsilon_{y,p,s} \sim N\left(0, \hat{\sigma}_{y,p,s}\right)$$

$$r = \varphi_{y,p.s} \tag{5}$$

$$\hat{\alpha}_{y,p,s} \sim h\left(x \mid \alpha'_{r,p}, \beta'_{r,p}, \sigma'_{r,p}\right)$$

$$\hat{\beta}_{y,p,s} \sim h\left(x \mid \alpha'_{r,p}, \beta'_{r,p}, \sigma'_{r,p}\right)$$

$$\hat{\sigma}_{y,p,s} \sim h\left(x \mid \alpha'_{r,p}, \beta'_{r,p}, \sigma'_{r,p}\right)$$

The Ricker parameters in the forward simulation ($\hat{\alpha}_{y,p,s}, \hat{\beta}_{y,p,s}, \hat{\sigma}_{y,p,s}$) for each year y, population p, and simulation s, were assigned from selecting a random sample from the joint poster $h(x|\alpha'_{r,p}, \beta'_{r,p}, \sigma'_{r,p})$ for these parameters for each simulation s, where the regime r ids defined by the matrix of future regime states ($\varphi_{y,p,s}$). By sampling parameter values from the joint posterior, the correlation amongst these parameters was maintained in all samples.

This method for simulating future trends in recruitment ($\hat{R}_{r,p,s}$) incorporates three essential components of biological uncertainty: uncertainty in future regime occupancy, estimation uncertainty in true parameter values, and process variation in future recruitment. To incorporate future process uncertainty, a random lognormal deviate with standard deviation ($\hat{\sigma}_{y,p,s}$) was multiplied by the expected recruitment, and whose value was in turn a random sample from the posterior for that parameter in that regime r from the Bayesian analysis (Eq. 5).

The procedure for generating future recruitment for the Nushagak and Alagnak systems was conducted in a similar manner, however without regime-specific parameter values. For the Alagnak stock α, β, and σ parameter values were randomly drawn from their joint posterior distribution from the Bayesian spawner-recruit analysis. For the Nushagak stock whose spawner-recruit relationship was fit using maximum likelihood methods, posteriors for Ricker parameters and the process error standard deviation were simulated by using the maximum likelihood estimates as the mean and assuming a CV for each parameter equal to the average of parameter-specific posterior CV's across populations. The random process deviate was included in the same manner described in above, but again in a assuming a single regime.

Simulated future recruitment ($\hat{R}_{y,p,s}$) was then allocated across age classes based upon the average age composition for each river system (Table 2).

Stock	**1.2**	**1.3**	**2.2**	**2.3**
Igushik	0.23	0.67	0.06	0.04
Wood	0.46	0.47	0.05	0.03
Nushagak	0.10	0.82	0.04	0.03
Kvichak	0.24	0.10	0.59	0.07
Alagnak	0.29	0.53	0.10	0.09
Naknek	0.18	0.44	0.18	0.19
Egegik	0.08	0.15	0.45	0.32
Ugashik	0.28	0.31	0.28	0.13

Table 2. Average age composition proportions used to allocate recruitment across age classes.

The number of returning fish in each calendar year t, for each population p, in each simulation s, of age a ($A_{t,p,s,a}$), was calculated by multiplying the simulated recruitment from a brood year by the average age composition proportions for each stock s and age class a ($p_{s,a}$), and applying the correct year offset (ϕ_a) for each age class a, to determine the calendar year t of maturation (Eq. 6).

(6)
$$A_{t,p,s,a} = \hat{R}_{y,p,s} * p_{s,a}$$
$$t = y + \phi_a$$

Returning adult sockeye ($A_{t,p,s,a}$) are them subject to harvest mortality as calculated by the daily management model (detailed below). The spawning abundance is the number of returning adults less the estimated catch ($C_{t,p,s}$) determined for each calendar year, population, and simulation (Eq. 7).

(7)
$$S_{y=t,p,s} = \sum_{a=1}^{Nages=4} A_{t,p,s,a} - C_{t,p,s}$$

Employing the methods described above, the biological model component of the MSE framework generated predicted time-series of spawning stock size and catch, for each of the 100 years, across each of the 100 replicate simulations. The process used to generate recruitment from spawning abundances, resulting from catches generated by the management model, account for the full range of biological uncertainty arising from: 1) transition between production regimes, 2) observed process uncertainty in spawner-recruit relationships, and 3) estimation uncertainty in spawner-recruit model parameters.

Management Model

The management model component of the MSE framework for Bristol Bay is intended to account for implementation uncertainty in the in-season management of commercial fishing effort, by simulating difficulties inherent in the daily decision process. Several factors influence the ability of district managers to achieve seasonal escapement goals. First, commercial fishing effort in Bristol Bay is managed on a daily basis, based in part on a comparison of cumulative escapement to daily cumulative escapement targets based upon population-specific average arrival distributions. However, in practice escapement information is delayed by several days as fish transit between the commercial fishing district and upriver escapement enumeration sites. In effect, escapement data is available to a manager after a time lag determined by migration distance and variation in fish behavior. Second, for mixed stock fisheries, complex management decisions are necessary with respect to the allocation of fishing effort amongst districts and fishing areas to ensure that seasonal escapement goals are met by all component river systems. Third, variation in both run size and the arrival timing of fish can influence a manager's perception of where cumulative escapements should be relative to daily targets.

The purpose of the management model was to imitate the management process for Bristol Bay as a means of introducing implementation uncertainty in the management process into predictions for future catch, escapement and spawning stock size, under alternative management strategies. In order to replicate the management process three pieces of information are required. First, the average arrival distribution for each stock is necessary to create desired daily cumulative escapement targets for a specific seasonal escapement goal. This cumulative escapement curve represents the target cumulative escapement for each day of the season, upon which the simulated manager decides whether to open commercial fishing districts. Second, transit times between commercial fishing districts and escapement enumeration sites on each river are necessary to account for the time lag before in-season escapement information is available to the simulated manager. These transit times come from information provided by ADF&G staff. Third, stock-specific harvest and interception rates for each commercial fishing district, section, and special harvest area are necessary. These harvest rates were originally derived from run reconstructions by Cunningham et al. (2012), which used age and genetic composition of catch information to estimate harvest rates in natal fishing districts and interception rates in non-natal fishing districts, however these harvest rate values were later tuned through an iterative process of comparing management model predicted escapement outcomes to observed escapements for years 1963 – 2008, for which daily run reconstructions were conducted. Finally, given that in-season fishery management in Bristol Bay operates on a daily basis it was necessary to partition returning adult sockeye in each year predicted by the biological model into discrete daily packets of arriving fish.

The arrival of sockeye to fishing districts in Bristol Bay does not follow a normal distribution. In order to emulate the arrival process, for each year in the forward simulation, a year was selected at random from the years for which daily arrivals by stock had been reconstructed and turned into arrival proportions. The proportion of the total annual return of a population arriving on day d was $P_{t,p,s,d}$.

The annual abundance of arriving individuals ($A_{t,p,s,a}$) was then multiplied by $P_{t,p,s,d}$ to generated daily number of fish entering the fishing district for each year and stock ($E_{t,p,s,d}$).

(8) $$E_{t,p,s,d} = P_{t,p,s,d} * \sum_{a=1}^{Nages=4} A_{t,p,s,a}$$

We have assumed that if the fishery f was open on day d then a fraction ($h_{f,p}$) of the population was harvested so the harvest on day d is

(9) $$H_{t,p,s,d} = E_{t,p,s,d} * u_{t,p,s,d}$$

Where $u_{t,p,s,d}$ is either 0 or $h_{f,p}$ depends upon whether the fishery was closed or open.

We assumed each fish reside in the fishing district for two days so the number of fish leaving the fishing district ($L_{t,p,s,d}$) on day d, is the number who entered the fishing district, minus the harvest on each of the preceding days of residency r (Eq. 10).

(10) $$L_{t,p,s,d} = \sum_{r=1}^{2} \left(E_{t,p,s,d-r} - H_{t,p,s,d-r} \right)$$

Escapement at the counting site on day d ($S_{t,p,s,d}$) was the number who entered l days before (l being the lag from departure from the fishing district to reaching the counting site), less the harvest (Eq. 11). Lag times in days between the fishing district and escapement enumeration sites were: Igushik 4, Wood 1, Nushagak 2, Kvichak 3, Alagnak 2, Naknek 1, Egegik 5, Ugashik 2.

(11) $$S_{t,p,s,d+l} = L_{t,p,s,d}$$

The core of the management model is simulation of the in-season decision process on the part of fishery managers. The simulated in-season management process depends upon two key components. The first key component is the matrices of population-specific harvest rates by fishery option ($h_{f,p}$). $h_{f,p}$ describes the realized harvest rate for each population when commercial fishing effort is allowed in a specific district or combination of districts. The management model for the west side of Bristol Bay included the Nushagak Section, Igushik Section, and Wood River Special Harvest area. In total six alternative fishery options were available to the simulated west side manager, including options for no open areas and various combinations of different fishing subdistricts (Table 3).

Fishery Option	Igushik	Wood	Nushagak
Nushagak Section and Igushik Section	44%	60%	80%
Nushagak Section ONLY	20%	60%	80%
Igushik Section ONLY	30%	0%	0%
Wood River Special Harvest Area	0%	80%	0%
NONE	0%	0%	0%
Wood River Special Harvest Area and Igushik Section	30%	80%	0%

Table 3. Matrix of harvest rate by fishery option and population ($h_{f,p}$) for the west side of Bristol Bay.

The east side management model was more complex by necessity, incorporating the Naknek-Kvichak, Egegik, and Ugashik Districts as well as the Naknek River Special Harvest area. In total 9 alternative fishery options were available for in-season management, with differing harvest rates experience by each of the east side Bristol Bay populations (Table 4).

Fishery Option	Kvichak	Alagnak	Naknek	Egegik	Ugashik
NONE	0.0%	0.0%	0.0%	0.0%	0.0%
Nak-Kvi District ONLY	50.0%	45.0%	50.0%	5.2%	2.0%
Egegik District ONLY	5.1%	3.7%	6.5%	95.0%	10.1%
Ugashik District ONLY	0.6%	0.6%	0.4%	3.4%	60.0%
Nak-Kvi AND Egegik Districts	52.5%	47.0%	53.3%	95.3%	11.9%
Nak-Kvi AND Ugashik Districts	50.3%	45.3%	50.2%	8.4%	60.8%
Egegik AND Ugashik Districts	5.7%	4.3%	6.9%	95.2%	64.0%
Nak-Kvi, Egegik, AND Ugashik Districts	52.9%	47.3%	53.4%	95.4%	64.8%
Naknek River SHA	0.0%	0.0%	90.0%	0.0%	0.0%

Table 4. Matrix of harvest rate by fishery option and population ($h_{f,p}$) for the west side of Bristol Bay.

For fishery options in which multiple fishing areas are open, where in each of which fish of population p are harvested or intercepted, the total harvest rate for that population is one minus the product of district-specific survival rates (Eq. 12)

$$(12) \qquad hr_{f,p} = 1 - \left(1 - hr_{1,p}\right) * \left(1 - hr_{2,p}\right)$$

The second key component of the simulated in-season management process, are the decision rules that govern which fishery option is selected on each day of the season. During each day of the simulated season, the cumulative escapement for each population is compared to the target cumulative escapement necessary at that point in the season, if the seasonal escapement goal is to be achieved. The status of each population, with respect to the daily target, is recorded and forms the criteria upon which the optimal fishery option is selected. For example, if Egegik and Ugashik stocks are ahead of their in-season escapement targets through a particular date, while Kvichak and Naknek stocks are not, fishery option sever would be selected and both the Egegik and Ugashik Districts, but not the Naknek-Kvichak District.

In-season management of the Kvichak River population across all four alternative strategies was meant to reflect the rolling escapement goal currently in place. For the Kvichak an initial preseason escapement goal ($PEg_{t,s}$) is set at 50% of a preseason forecast for total Kvichak ($PF_{t,s}$) catch plus escapement. The preseason forecast is equal to the true run size ($RS_{t,s}$) in that year t of simulation s, plus lognormally distributed error proportional to that of the UW-FRI preseason forecast (Eq. 13).

(13)
$$\begin{aligned} RS_{t,s} &= \sum_{a=1}^{Nages=4} A_{t,p=Kvichak,s,a} \\ PF_{t,s} &= RS_{t,s} + RS_{t,s} * \exp\left(\varepsilon_{PF} - 1\right) \\ \varepsilon_{PF} &\sim N\left(\mu_{PF} = 1.02, \sigma_{PF} = 1.24\right) \\ PEg_{t,s} &= 0.5 * PF_{t,s} \end{aligned}$$

In addition, an in-season assessment of Kvichak run size is conducted at the midpoint of the season. This in-season assessment uses cumulative catch plus escapement though that date to generate an in-season prediction for Kvichak run size. The midseason goal for Kvichak total escapement is then adjusted to 50% of this in-season prediction. Both the initial and midseason escapement goals for the Kvichak are subject to the 2 and 10 million lower and upper bound on escapement. Daily escapement targets are adjusted to achieve these seasonal escapement goals.

Management strategy 4, which implements TR-based escapement targets for Bristol Bay stocks, follows a similar in-season assessment procedure to update escapement targets. Initial escapement goals are set at the lower target in the beginning of the season and daily escapement targets established accordingly. At the date on which 50% of seasonal catch plus escapement has historically been observed for each population or the midpoint (MP_p), a simple in-season assessment of run size based on the observed cumulative catch and escapement through that date is conducted to generate an in-season forecast (Eq. 14). If the in-season run size forecast ($IF_{t,p,s}$) exceeded the specified total run breakpoint, the seasonal escapement goal is moved to the higher specified goal (Table 1). Daily escapement targets are then updated accordingly.

(14)
$$IF_{t,p,s} = 2 * \sum_{d=1}^{MP_p} E_{t,p,s,d}$$

Analysis of Management Model Efficacy

In order to determine whether the management model accurately reflects the outcome of the in-season decision process by Bristol Bay commercial fishery managers, we conducted an analysis of management model efficacy. For each of the eight model populations, observed daily salmon arrivals as well as the midpoint of the escapement goal for years 1963 – 2008 were provided to the management model. The predicted escapement achieved by the management model was then compared to the observed escapement in each year. Figures 1, 2, and 3, show a comparison of management model outcomes with observed escapement in each year. This comparison was also used to tune the harvest rates by fishery option for each population ($h_{f,p}$) so that management model outcomes resembled observations as closely as possible. This was an essential component of evaluating whether the management model was accurately reflecting real outcomes and thus introducing the correct level of implementation uncertainty.

In addition to tuning the population-specific harvest rates by fishery ($h_{f,p}$), the process of comparing management model predicted outcomes was also used to test assumptions regarding how much in-season information about run timing should be provided to the management model. In reality, fishery managers often have knowledge of fish abundance prior to their enumeration at escapement sites from in-river test fisheries or aerial surveys. In order for the behavior of the management model to most accurately reflect historical observations, it was necessary to provide the simulated manager with some additional knowledge regarding run timing. For the Kvichak, Naknek, Egegik, and Ugashik stocks, the daily escapement target curves under each escapement scenario were adjusted to mirror the difference between the median arrival date in the current year and the long-term average. It is important to note that this did not influence error in the in-season assessment processes for the Kvichak under all escapement scenarios and for all systems under the TR-based management scenario, introduced by run timing deviations.

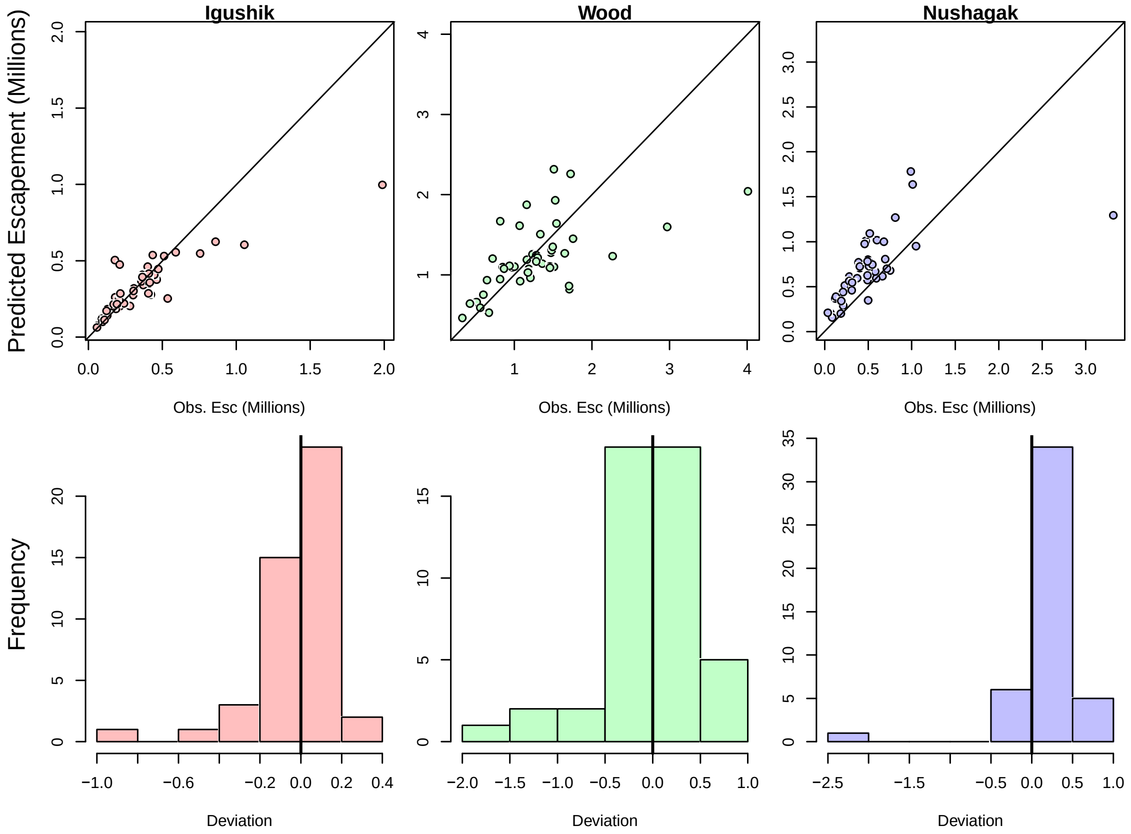

Figure 1. Comparison of escapements achieved by the management model compared with observed escapements for Igushik, Wood, and Nushagak Rivers in years 1963 – 2008. Top panels display the comparison of observed escapement (millions) on the x-axis and escapements achieved by the management model on the y-axis. Bottom panels display the deviation in millions between the management model and observed escapements.

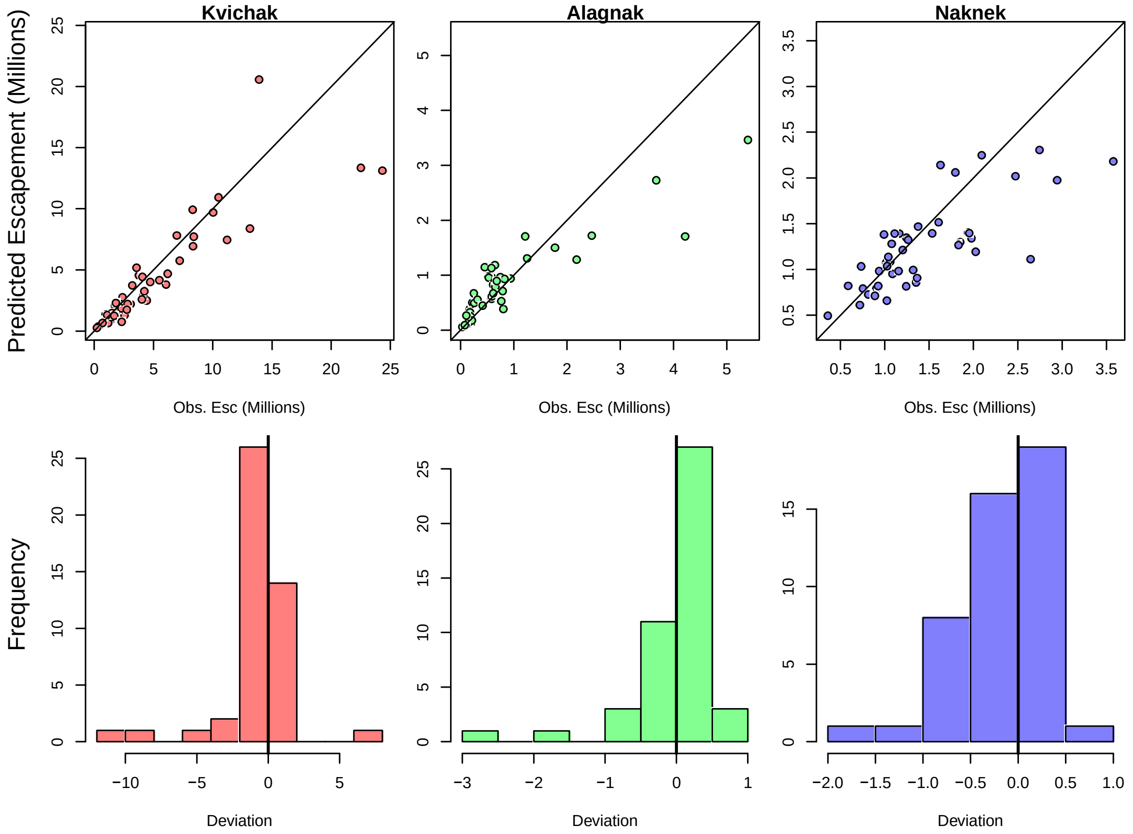

Figure 2. Comparison of escapements achieved by the management model compared with observed escapements for Kvichak, Alagnak, and Naknek Rivers in years 1963 – 2008. Top panels display the comparison of observed escapement (millions) on the x-axis and escapements achieved by the management model on the y-axis. Bottom panels display the deviation in millions between the management model and observed escapements.

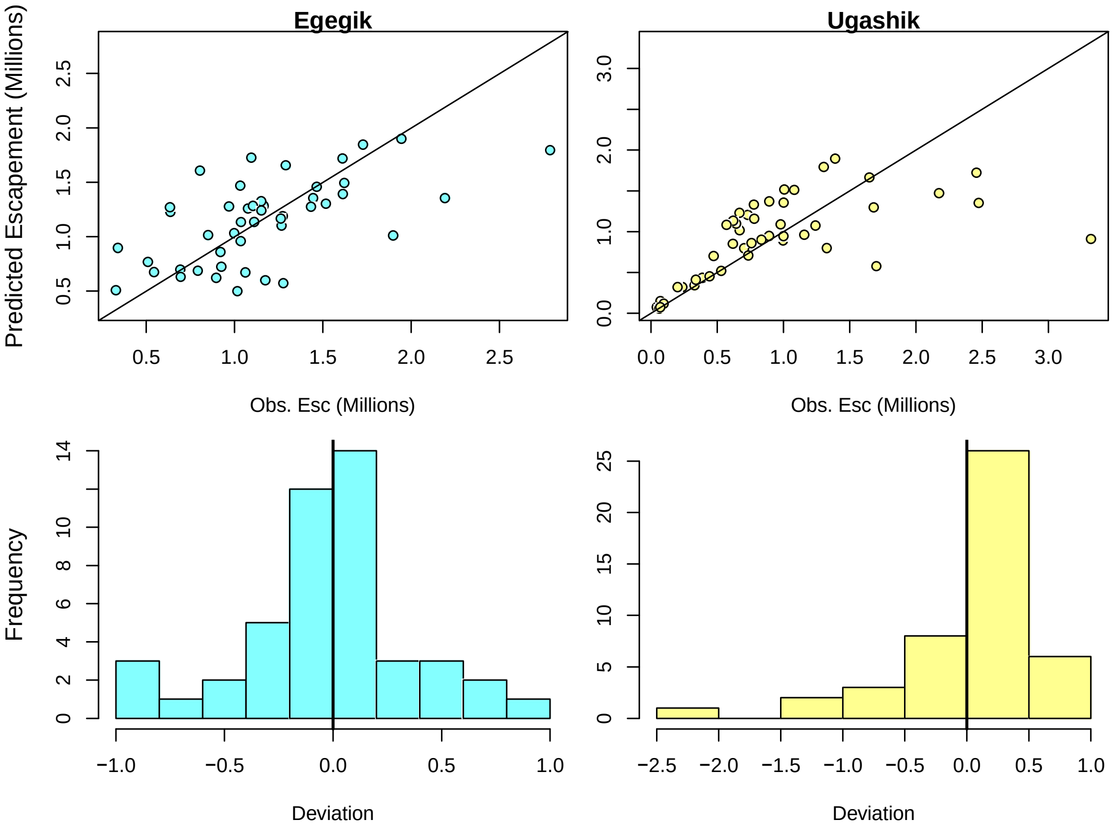

Figure 3. Comparison of escapements achieved by the management model compared with observed escapements for Egegik and Ugashik Rivers in years 1963 – 2008. Top panels display the comparison of observed escapement (millions) on the x-axis and escapements achieved by the management model on the y-axis. Bottom panels display the deviation in millions between the management model and observed escapements.

In Figures 1 – 3, the upper panels show the observed escapement for year 1963 - 2008 (x-axis) compared with the predicted escapement achieved by the management model (y-axis). If the management model perfectly reflected observed management outcomes, all points would fall directly on the 1:1 line. The lower panels show histograms of the deviation of management model outcomes from observed escapements. Negative values in the histogram, or points below the 1:1 line, indicate that the management model achieved lower escapement than did the actual manager.

Analysis of management model efficacy indicates no significant biases in management outcomes, save a slight tendency of the management model to achieve lower than observed escapements for the Naknek stock (Figure 2). In addition, comparisons for the Alagnak, Naknek and Ugashik stocks (Figures 2 and 3) indicate a tendency for the management model to under-escape relative to historical observations in years of high run size, leading to a slight left skewed distribution of observed deviations. Despite these relatively small differences in predicted and observed escapement outcomes, the management model does a remarkably good job of achieving escapements consistent with those observed and should therefore be expected to represent the true level of implementation uncertainty associated with achieving management goals with reasonable accuracy.

Results

The management strategy evaluation framework for the Bristol Bay sockeye salmon commercial fishery was comprised to two components, and was used to test four alternative escapement goal scenarios. The first component was a biological model which simulated the recruitment dynamics for the eight Bristol Bay stocks, accounting for: 1) observed variation in production regimes and estimates for the stock-specific probability of transitioning from one to another, 2) stochastic recruitment dynamics by add lognormal process deviates, and 3) estimation uncertainty by sampling parameter values from the joint posterior resulting from a Bayesian analysis of the spawner-recruit relationship for each population. The biological model also represented the observed stock-specific differences in maturation schedule. The second component was a management model, which simulated the in-season management process for mixed stock fisheries based upon comparison of cumulative escapement with daily escapement targets throughout the season, and represented the uncertainty in the implementation of fixed and variable escapement goals.

Each of the eight major sockeye salmon producing populations in Bristol Bay were simulated forward in time for 100 years, with annual catch, realized escapement, and run size as output statistics in each year. One hundred replicated 100-year forward simulations were conducted to account for uncertainty in parameter values and future regime occupancy. These replicate forward simulations resulted in 10,000 year-by-simulation predictions for catch, escapement and return numbers for each stock.

Are alternative escapement goals likely to be achieved?

The first question to be addressed by this analysis is whether alternative escapement goals are likely to be achieved given the level of implementation uncertainty associated with management of the Bristol Bay commercial fishery. This implementation uncertainty arises because of several factors. First, implementation uncertainty results from the difficulty associated with managing mixed stock fisheries, and fisheries that intercept non-natal stocks during the return migration to freshwater. Fishery managers must balance a complex series of tradeoffs in the allocation of fishing effort in order to most effectively achieve escapement targets. Second, implementation uncertainty arises as a result of inter-seasonal differences in both the timing and distribution of arriving sockeye. Both deviations from average run timing and a normal arrival distribution can influence a manager's perception of stock status relative to daily escapement targets. Third, implementation uncertainty is introduced into the preseason and in-season run size assessment process for the Kvichak stock and the six Bristol Bay stocks as part of the total run based escapement goals in management scenario four, because deviations from average run timing can cause significant errors in cumulative catch and escapement based predictions for run size.

Results (Figure 4) indicate that across systems higher median escapement is expected for the BEG strategy where escapement goals based upon Smsy estimates, and lower median escapements are likely to be achieved under the current SEG strategy. This pattern in realized escapements is most pronounced for the Naknek, Egegik and Ugashik stocks, which is largely due to the greater disparity between current SEGs and the BEGs for these stocks (Table 1). Realized escapements for the Igushik and Nushagak Rivers are significantly higher than specified escapement goal midpoints across management strategies, while the median realized escapement for the Egegik and Ugashik Rivers, across management scenarios, are quite close to the specified targets (Figure 4).

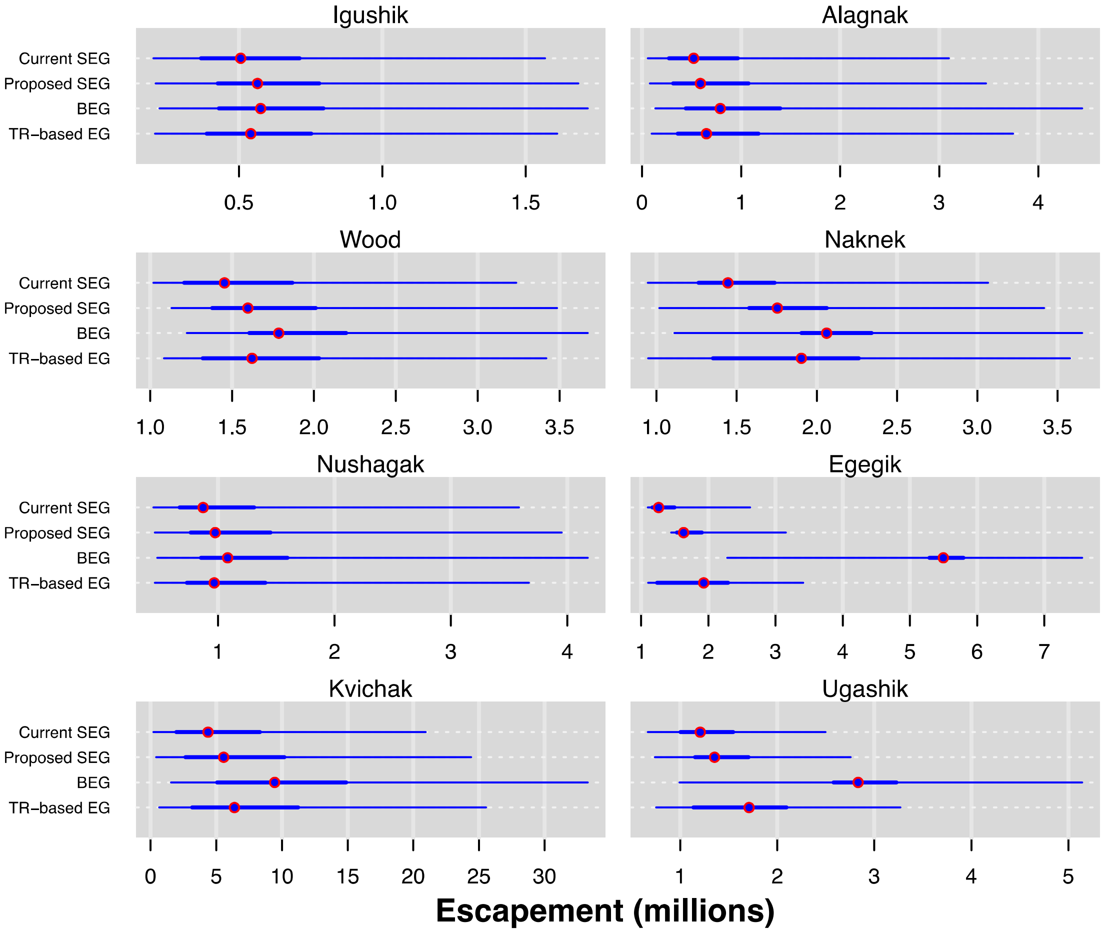

Figure 4. Caterpillar plots describing the distribution of predicted escapement in millions of sockeye, for the 8 major Bristol Bay river systems and 4 alternative escapement strategies, across 100 replicate 100-year simulations for each strategy. The point, thick line, and thin line describe the median, 50% credible interval and 95% credible interval for the prediction.

The observation that realized escapements for the Egegik and Ugashik River systems more closely coincide with escapement targets across management scenarios is not unexpected, given that these two populations are harvested in single-stock terminal fisheries. Harvest in single-stock fisheries simplifies the management of these two populations because managers are not subject to the challenge of balancing the escapement goals for multiple component populations harvested in a common fishing district, despite non-zero interception rates in other commercial fishing districts.

Interestingly the estimated median escapement value for the Kvichak River (Table 5) differs across management strategies, despite the fact that the Kvichak is managed in the same way, using a preseason and in-season assessment based fixed exploitation rate, across strategies. The median value for predicted escapement to the Kvichak is 5.1 million sockeye higher for the BEG scenario than for the scenario modeling current SEGs. Differences in realized Kvichak escapement across management strategies likely result from mixed stock constraints on fishing effort in the Naknek-Kvichak District, due to the necessity of reducing exploitation rates on the Naknek stock in order to achieve higher escapement goals. This outcome is most substantial when the abundance of Naknek stock does not substantially increase in response to Smsy-based escapement objectives under the BEG strategy.

Stock	Strategy	2.5%	25%	50%	75%	97.5%
Igushik	Current SEG	0.20	0.37	0.51	0.71	1.57
	Proposed SEG	0.21	0.43	0.56	0.78	1.68
	BEG	0.22	0.43	0.58	0.80	1.72
	TR-based EG	0.21	0.39	0.54	0.75	1.61
Wood	Current SEG	1.02	1.21	1.45	1.87	3.23
	Proposed SEG	1.13	1.38	1.60	2.01	3.48
	BEG	1.22	1.60	1.79	2.20	3.67
	TR-based EG	1.08	1.32	1.62	2.03	3.42
Nushagak	Current SEG	0.44	0.67	0.87	1.31	3.58
	Proposed SEG	0.46	0.76	0.97	1.45	3.95
	BEG	0.48	0.85	1.08	1.60	4.17
	TR-based EG	0.46	0.73	0.97	1.41	3.67
Kvichak	Current SEG	0.21	1.95	4.37	8.32	20.94
	Proposed SEG	0.42	2.64	5.56	10.18	24.40
	BEG	1.55	5.06	9.44	14.88	33.28
	TR-based EG	0.65	3.16	6.38	11.24	25.53
Alagnak	Current SEG	0.06	0.27	0.52	0.97	3.10
	Proposed SEG	0.08	0.31	0.59	1.08	3.47
	BEG	0.13	0.44	0.79	1.40	4.44
	TR-based EG	0.10	0.36	0.65	1.18	3.74
Naknek	Current SEG	0.95	1.26	1.45	1.74	3.07
	Proposed SEG	1.02	1.58	1.75	2.06	3.42
	BEG	1.11	1.90	2.06	2.34	3.65
	TR-based EG	0.95	1.35	1.90	2.26	3.58
Egegik	Current SEG	1.10	1.17	1.26	1.50	2.62
	Proposed SEG	1.45	1.53	1.63	1.90	3.16
	BEG	2.28	5.29	5.50	5.80	7.56
	TR-based EG	1.10	1.24	1.93	2.30	3.41
Ugashik	Current SEG	0.67	1.00	1.21	1.55	2.50
	Proposed SEG	0.74	1.15	1.35	1.70	2.76
	BEG	0.99	2.58	2.83	3.23	5.14
	TR-based EG	0.75	1.14	1.71	2.10	3.27

Table 5. Quantiles for distribution of predicted escapement in millions of sockeye, for the 8 major Bristol Bay river systems and 4 alternative escapement strategies, across 100 replicate 100-year simulations for each strategy.

Not only are differences in the median and range of escapements predicted under alternative management strategies, we also observed differences in the shape and modality of realized escapements. Figure 5 displays beanplots showing the probability density for each level of predicted escapement. The fourth management scenario implements total run based escapement goals, with higher and lower targets that are assigned in each year conditional on the comparison of predictions from an assessment of run size conducted at the midpoint of the season, with a total run breakpoint or decision rule. With total run breakpoints for this scenario set at the median run size (1956-2014 return years), it is expected that both the upper and lower goals would be targeted in some proportion depending on whether an overall increase in total run size is observed. From figure 5 it is clear that there is significant bimodality in predicted escapements for the Naknek, Egegik, Ugashik and Wood Rivers under the total run based management scenario, while escapement predictions for all other management scenarios appear right skewed but unimodal. This suggests that independent of the implementation uncertainty associated with in-season management, the total run based management scenario is resulting in differences in realize escapement across years. However, it is unclear from this whether these high and low escapements truly due coincide with years of large and small run size for these populations, or if the uncertainty in the in-season assessment process swamps the potential benefit of this strategy through a mismatch between annual escapement targets and run sizes.

Overall, it appears that alternative escapement goals are likely to be achieved across stocks, despite the difficulty in implementing them through the daily regulation of fishing effort.

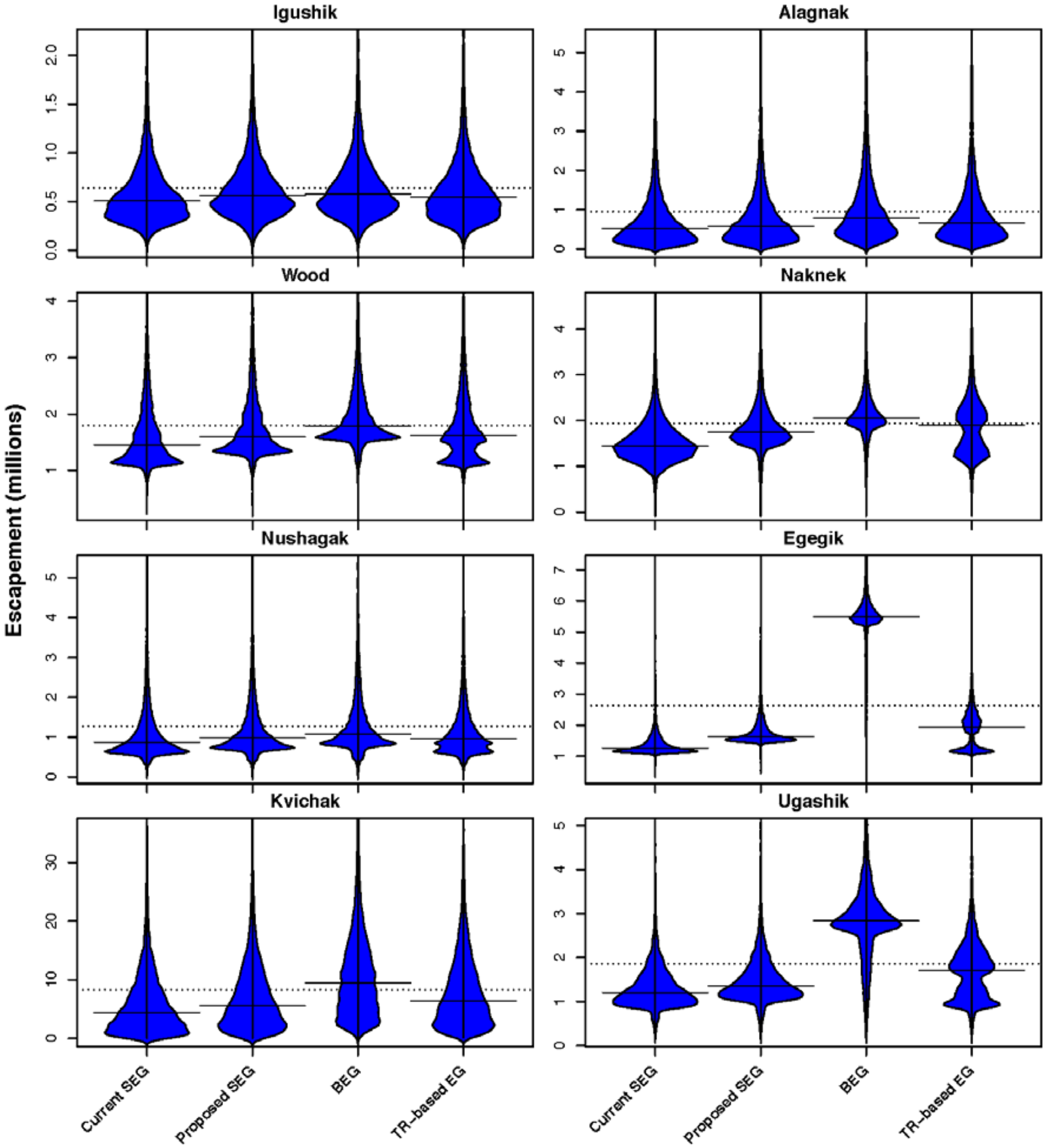

Figure 5. Bean plots describing the distribution of predicted escapement in millions of sockeye, for the 8 major Bristol Bay river systems and 4 alternative escapement strategies, across 100 replicate 100-year simulations for each strategy. The width of the bean at any value indicates the relative probability of that value, the bean-specific line indicates the median value, and the dotted line indicates the global mean across escapement strategies.

Are alternative escapement goals likely to result in differences in future returns?

The second question to be addressed through this analysis was whether differences in escapement goals amongst the alternative management strategies are likely to result in differences in future sockeye returns to Bristol Bay, given uncertainty in future production regimes, stochastic recruitment dynamics, and estimation uncertainty in spawner-recruit model parameters. For the Kvichak, Naknek, Egegik, and Ugashik systems, the median value for predicted future sockeye returns (Figure 6) are greatest for the BEG scenario and lowest for the scenario based upon current SEGs. These findings suggest that for these four systems, increases in realized escapement are likely to result in some increase in median return size. However, there is a significant amount of variation in expected future returns to the Naknek, Ugashik, and Kvichak systems, obscuring differences across management strategies. This is most explicitly observed for the Kvichak system. For the Egegik River however, differences between the BEG based management strategy and the three alternatives are more substantial.

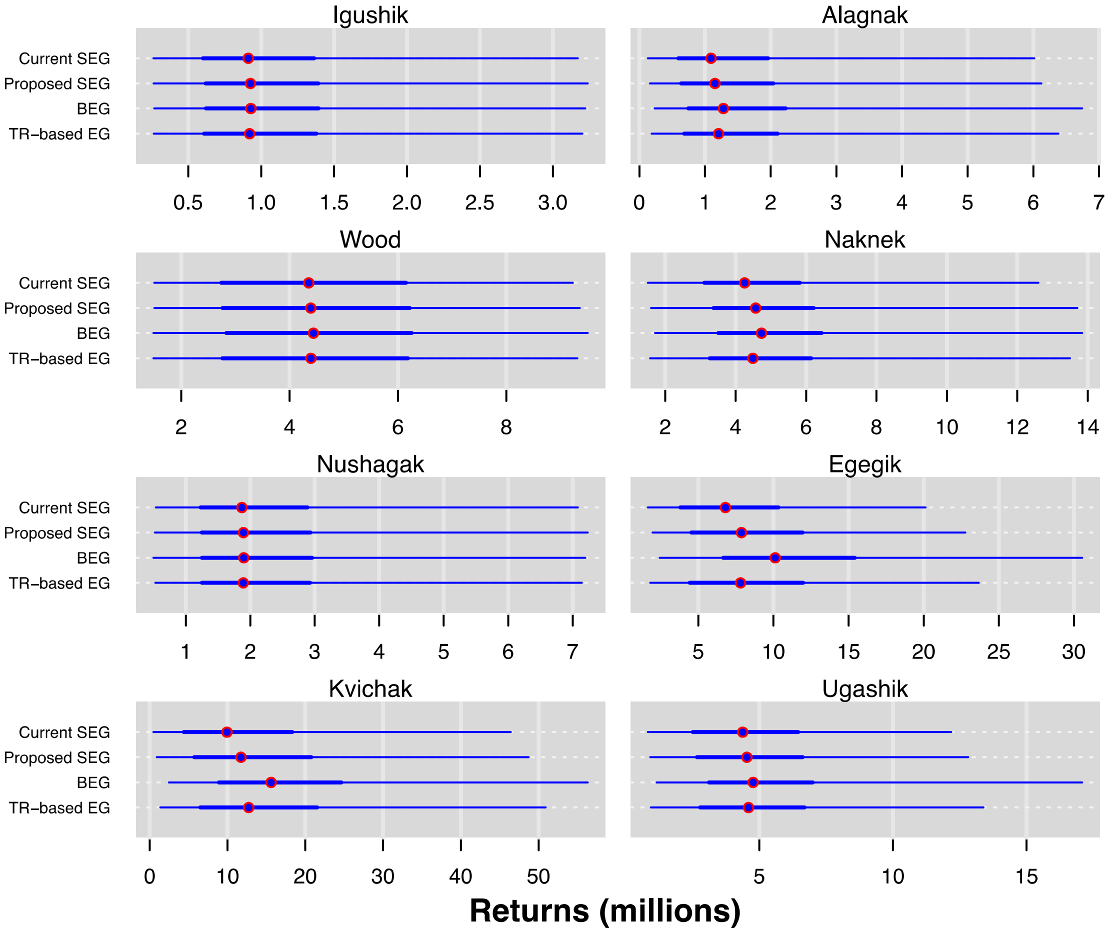

Figure 6. Caterpillar plots describing the distribution of predicted returns in millions of sockeye, for the 8 major Bristol Bay river systems and 4 alternative escapement strategies, across 100 replicate 100-year simulations for each strategy. The point, thick line, and thin line describe the median, 50% credible interval and 95% credible interval for the prediction.

Stock	Strategy	2.5%	25%	50%	75%	97.5%
Igushik	Current SEG	0.26	0.60	0.91	1.36	3.17
	Proposed SEG	0.26	0.62	0.93	1.39	3.24
	BEG	0.27	0.62	0.93	1.39	3.22
	TR-based EG	0.26	0.61	0.92	1.38	3.20
Wood	Current SEG	1.50	2.74	4.35	6.15	9.23
	Proposed SEG	1.50	2.76	4.39	6.22	9.35
	BEG	1.49	2.83	4.44	6.25	9.50
	TR-based EG	1.49	2.76	4.39	6.19	9.31
Nushagak	Current SEG	0.53	1.23	1.87	2.89	7.08
	Proposed SEG	0.52	1.25	1.90	2.93	7.23
	BEG	0.50	1.25	1.90	2.96	7.20
	TR-based EG	0.53	1.25	1.89	2.93	7.14
Kvichak	Current SEG	0.46	4.38	9.94	18.32	46.43
	Proposed SEG	0.90	5.71	11.73	20.76	48.71
	BEG	2.45	8.88	15.61	24.63	56.32
	TR-based EG	1.34	6.48	12.72	21.54	50.90
Alagnak	Current SEG	0.13	0.59	1.09	1.96	6.01
	Proposed SEG	0.16	0.64	1.15	2.04	6.12
	BEG	0.23	0.75	1.28	2.23	6.74
	TR-based EG	0.19	0.68	1.21	2.11	6.38
Naknek	Current SEG	1.51	3.11	4.26	5.82	12.60
	Proposed SEG	1.60	3.37	4.57	6.22	13.71
	BEG	1.71	3.51	4.74	6.44	13.84
	TR-based EG	1.57	3.26	4.49	6.15	13.50
Egegik	Current SEG	1.64	3.80	6.81	10.33	20.12
	Proposed SEG	1.94	4.54	7.88	11.94	22.78
	BEG	2.43	6.66	10.12	15.41	30.55
	TR-based EG	1.80	4.42	7.82	11.98	23.67
Ugashik	Current SEG	0.83	2.51	4.38	6.45	12.19
	Proposed SEG	0.92	2.67	4.54	6.63	12.82
	BEG	1.16	3.12	4.77	7.00	17.08
	TR-based EG	0.94	2.79	4.60	6.70	13.39

Table 6. Quantiles for distribution of predicted returns in millions of sockeye, for the 8 major Bristol Bay river systems and 4 alternative escapement strategies, across 100 replicate 100-year simulations for each strategy.

Will alternative escapement goals lead to differences in future catch?

The third question to be addressed by this management strategy evaluation was whether alternative escapement goals under the four different management strategies are likely to result in substantial differences in future sockeye catches, given implementation, estimation, and biological uncertainty. The distribution of predicted catches across the replicate 100-year simulations (Figure 7) indicates first that there exists substantial variability in future harvest predictions for nearly all socks, across management strategies. However, some differences in predicted median catch are observed. For the Igushik stock predictions for future catch indicate that either current escapement goals or the total run based management strategy will produce the greatest median catch. Likewise for the Wood and Nushagak stocks, the predicted median catch is highest for current SEGs. Median catch for the Egegik stock is predicted to highest for the ADF&G proposed SEGs, or the TR-based management strategy. For the Naknek and Alagnak River systems, the distribution of predicted catches appear very similar under current SEGs, proposed SEGs and the TR-based EGs. For the Ugashik River system, median predicted catch is highest for the management strategies defined by either the current SEGs or the proposed SEGs. Although not managed differently across escapement goal strategies resultant differences in escapement from mixed stock interactions lead to a predicted increase in catch for all alternatives to current SEGs. Interestingly, for no river system did the management strategy based on BEGs (defined by Smsy estimates from the Ricker model in Fair et al. (2012) outperform other strategies, and for the Igushik, Wood, Nushagak, Alagnak, Naknek, Egegik and Ugashik systems the BEGs produced the lowest median catch across years and simulations.

An alternative way to view differences in predictions for future catch is the estimated percent increase or decrease resulting from specific management strategies, relative to the predicted catch under the status quo or current SEG strategy. Figure 8 displays the percent increase, or decrease, in catch expected under the proposed SEG, BEG, and TR-based EG strategies, relative to predictions from the current SEG strategy across the 100-year time series and simulations. Immediately noticeable is that for all systems with the exception of the Kvichak, the BEG strategy is expected to result in a net decrease in catch relative to predictions under the current SEG scenario. The magnitude of this predicted catch difference under the BEG scenario is greatest for the Ugashik and Nushagak stocks, with an estimated median reduction in catch of 31.9% and 20.1% respectively (Table 8). Conversely, results indicate that relative to expectations for future catch under current SEGs, the ADF&G proposed SEG scenario will result in median catches that are higher by 13.7% for the Egegik stock and 1.1% for the Ugashik stock. Higher catches for the proposed SEGs relative to future predictions under current SEGs are not however consistent across stocks, with median catches predicted to be lower by 8.6% for the Igushik stock, 7.7% for the Nushagak stock, and 3% for the Wood River stock. A comparison of estimated future catches for the TR-based EG strategy, relative to the current SEG strategy, indicates that while only slight differences in median catch are predicted for most stocks, a median expectation of 9.1% higher catches is predicted for the Egegik stock under TR-based EG’s. Figure 9 provides the estimated distribution of the sum of 100-year catches across simulations, for each stock by scenario combination, and highlight similar patterns.

Despite the appearance of some difference in catch across scenarios, there exists a significant amount of variability in estimated future catches which vastly obscures the minimal differences in median predicted catch, the percent change in catch relative to current SEGs, or the sum of catch across 100-year simulations. The trifecta of uncertainty in implementing different management strategies, in changes in productivity regimes in the future, and in estimated spawner-recruit model parameters, paired with stochastic recruitment dynamics leads to difficulty in defining an clearly optimal strategy from the perspective of median catch across years and simulations.

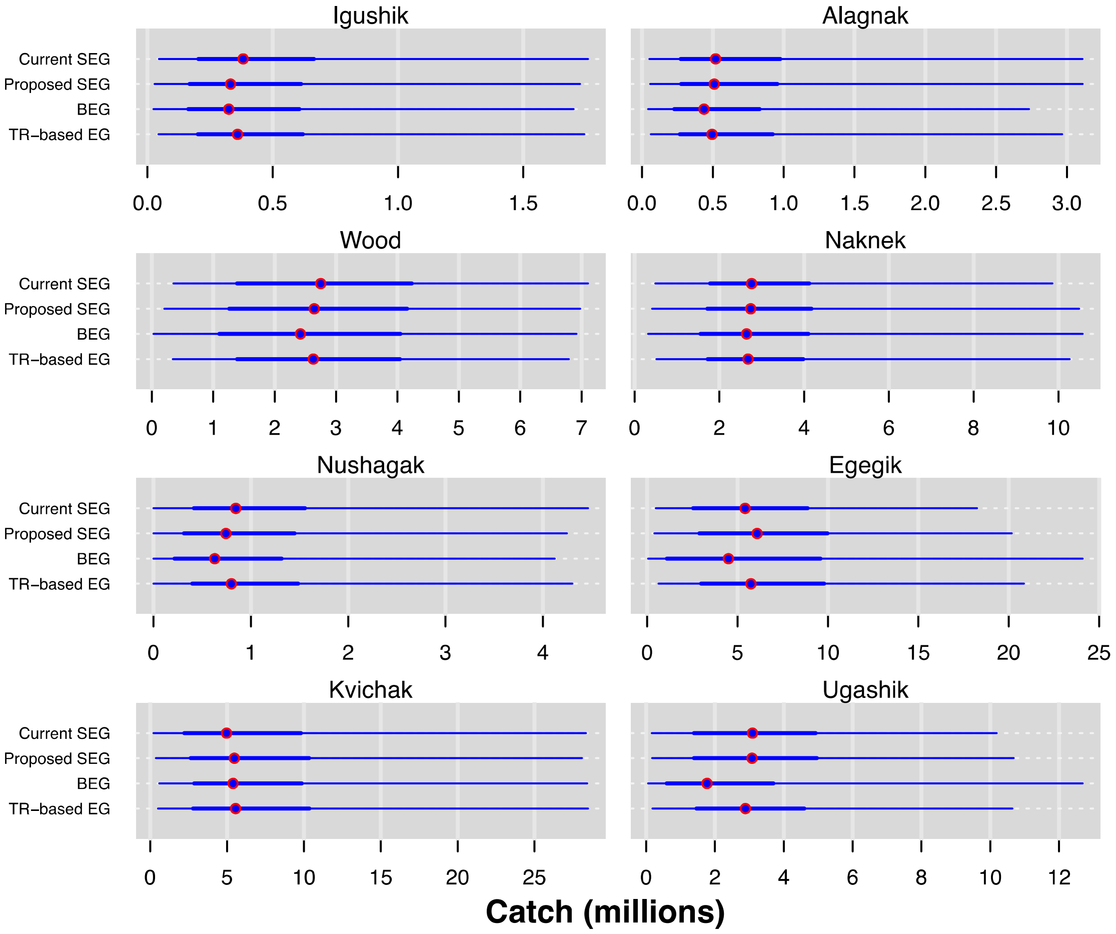

Figure 7. Caterpillar plots describing the distribution of predicted catch in millions of sockeye, for the 8 major Bristol Bay river systems and 4 alternative escapement strategies, across 100 replicate 100-year simulations for each strategy. The point, thick line, and thin line describe the median, 50% credible interval and 95% credible interval for the prediction.

Stock	Strategy	2.5%	25%	50%	75%	97.5%
Igushik	Current SEG	0.04	0.20	0.38	0.66	1.76
	Proposed SEG	0.03	0.17	0.33	0.61	1.73
	BEG	0.02	0.16	0.32	0.61	1.70
	TR-based EG	0.04	0.20	0.36	0.62	1.74
Wood	Current SEG	0.35	1.39	2.75	4.23	7.10
	Proposed SEG	0.20	1.26	2.65	4.16	6.98
	BEG	0.03	1.10	2.42	4.05	6.92
	TR-based EG	0.34	1.39	2.63	4.04	6.79
Nushagak	Current SEG	0.00	0.41	0.85	1.56	4.46
	Proposed SEG	0.00	0.31	0.74	1.45	4.25
	BEG	0.00	0.22	0.63	1.32	4.12
	TR-based EG	0.00	0.40	0.80	1.49	4.30
Kvichak	Current SEG	0.21	2.21	4.98	9.81	28.35
	Proposed SEG	0.37	2.62	5.48	10.35	28.09
	BEG	0.59	2.86	5.39	9.86	28.43
	TR-based EG	0.51	2.78	5.56	10.35	28.48
Alagnak	Current SEG	0.05	0.27	0.52	0.98	3.11
	Proposed SEG	0.06	0.28	0.51	0.96	3.11
	BEG	0.04	0.23	0.44	0.83	2.73
	TR-based EG	0.06	0.27	0.50	0.92	2.97
Naknek	Current SEG	0.49	1.78	2.76	4.12	9.86
	Proposed SEG	0.41	1.71	2.74	4.18	10.49
	BEG	0.32	1.56	2.64	4.10	10.57
	TR-based EG	0.51	1.72	2.68	3.98	10.27
Egegik	Current SEG	0.47	2.54	5.42	8.88	18.25
	Proposed SEG	0.40	2.88	6.09	9.98	20.17
	BEG	0.06	1.08	4.50	9.59	24.09
	TR-based EG	0.63	2.98	5.74	9.79	20.84
Ugashik	Current SEG	0.16	1.39	3.09	4.93	10.19
	Proposed SEG	0.17	1.39	3.08	4.96	10.68
	BEG	0.06	0.60	1.77	3.70	12.69
	TR-based EG	0.18	1.46	2.89	4.59	10.64

Table 7. Quantiles for distribution of predicted catch in millions of sockeye, for the 8 major Bristol Bay river systems and 4 alternative escapement strategies, across 100 replicate 100-year simulations for each strategy.

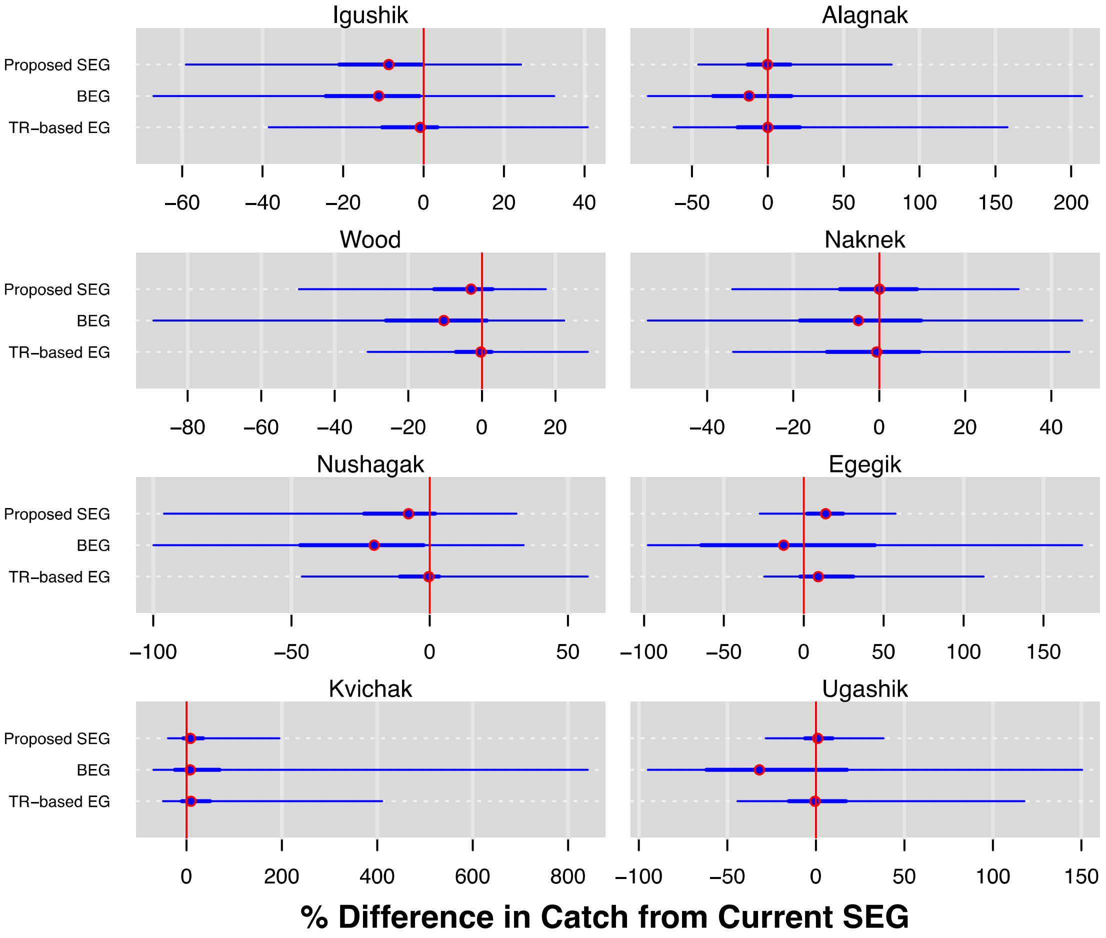

Figure 8. Caterpillar plots describing the distribution of the percent difference in catch between the current SEG's and the proposed SEG, BEG, and TR-based EG strategies for the 8 major Bristol Bay river systems, across 100 replicate 100-year simulations for each strategy. The point, thick line, and thin line describe the median, 50% credible interval and 95% credible interval for the prediction. A value of -50 indicates a 50% reduction in predicted catch relative to the current SEG.

Stock	Strategy	2.5%	25%	50%	75%	97.5%
Igushik	Proposed SEG	-59.1%	-21.0%	-8.6%	-0.1%	24.2%
	BEG	-67.2%	-24.4%	-11.1%	-1.0%	32.5%
	TR-based EG	-38.5%	-10.3%	-0.8%	3.4%	40.8%
Wood	Proposed SEG	-49.7%	-13.0%	-3.0%	2.9%	17.4%
	BEG	-89.3%	-26.1%	-10.3%	1.3%	22.4%
	TR-based EG	-31.1%	-7.1%	-0.2%	2.6%	28.8%
Nushagak	Proposed SEG	-96.1%	-23.8%	-7.7%	1.9%	31.4%
	BEG	-100.0%	-46.9%	-20.1%	-2.2%	34.0%
	TR-based EG	-46.2%	-10.8%	-0.3%	3.3%	57.1%
Kvichak	Proposed SEG	-38.6%	-6.9%	8.3%	34.7%	194.7%
	BEG	-69.4%	-24.3%	7.7%	69.8%	841.2%
	TR-based EG	-49.2%	-9.9%	9.3%	49.3%	410.3%
Alagnak	Proposed SEG	-45.9%	-13.3%	-0.3%	15.0%	81.7%
	BEG	-79.1%	-36.2%	-12.4%	15.6%	207.2%
	TR-based EG	-62.3%	-20.1%	0.0%	21.1%	158.0%
Naknek	Proposed SEG	-34.2%	-9.2%	0.1%	8.8%	32.4%
	BEG	-53.8%	-18.5%	-4.8%	9.8%	47.2%
	TR-based EG	-34.0%	-12.2%	-0.6%	9.4%	44.3%
Egegik	Proposed SEG	-27.6%	1.9%	13.7%	24.7%	57.4%
	BEG	-97.6%	-64.2%	-12.6%	44.4%	174.2%
	TR-based EG	-24.7%	-2.3%	9.1%	31.0%	112.7%
Ugashik	Proposed SEG	-28.4%	-6.1%	1.1%	9.5%	38.2%
	BEG	-94.9%	-61.9%	-31.9%	17.6%	150.5%
	TR-based EG	-44.4%	-15.3%	-0.5%	17.0%	117.8%

Table 8. Quantiles for distribution of the percent difference in catch between the current SEG's and the proposed SEG, BEG, and TR-based EG strategies, for the 8 major Bristol Bay river systems and 4 alternative escapement strategies, across 100 replicate 100-year simulations for each strategy.

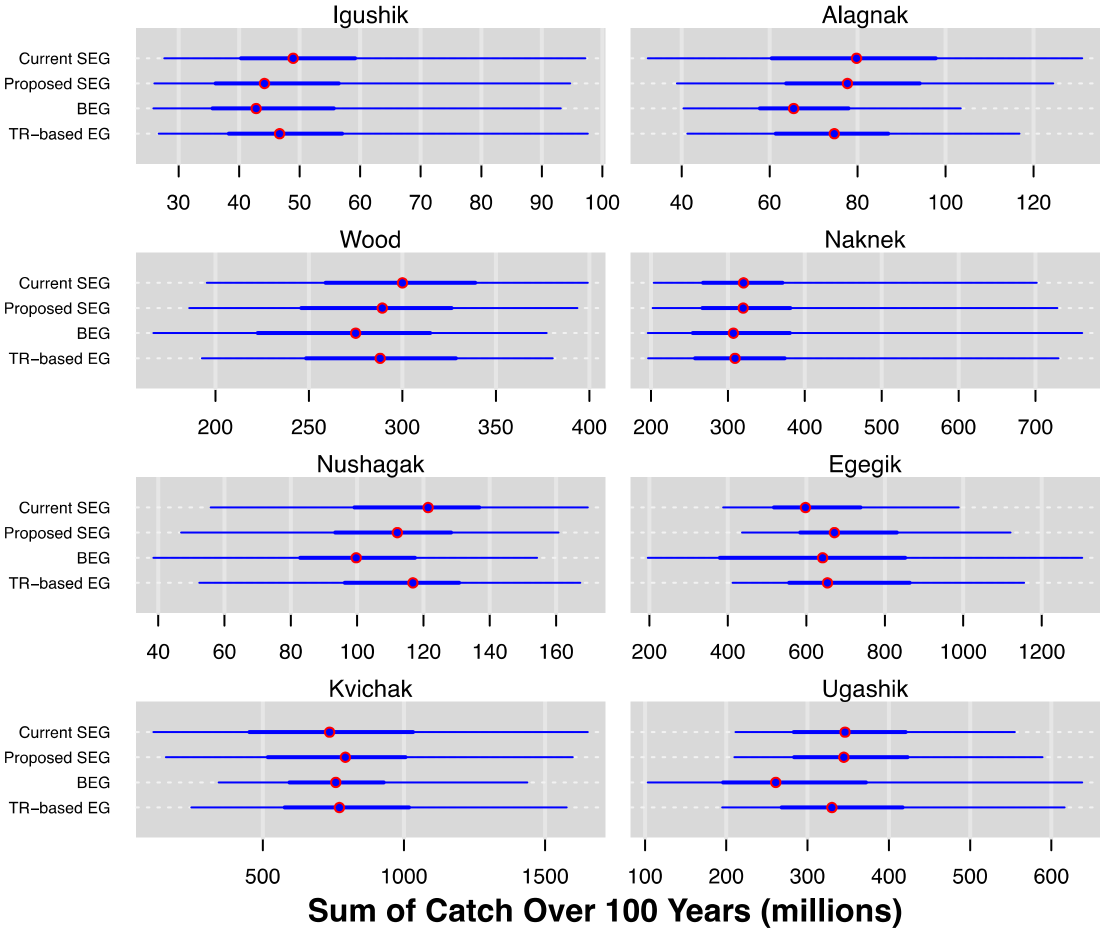

Figure 9. **Caterpillar plots describing the distribution of the predicted sum of catch for 100-year simulations in millions of sockeye, for the 8 major Bristol Bay river systems and 4 alternative escapement strategies, across 100 replicates for each strategy. The point, thick line, and thin line describe the median, 50% credible interval and 95% credible interval for the prediction.**

Are these patterns any different when aggregated at the Bristol Bay level?

When we evaluate the distribution of expected escapement, returns, and catch for Bristol Bay as a whole (Figure 10) across years and simulations, some interesting patterns present themselves. First, as expected and coinciding with results at the stock level, expected escapement is significantly higher for the BEG management strategy when compared to the current SEGs. Median Bristol Bay escapement for the TR-based EG strategy is slightly higher than that using proposed SEGs. A similar pattern in the relative magnitude of Bristol Bay sockeye returns among management strategies is predicted. However, expectations for median future catch suggest that either the proposed SEGs or the TR-based EGs are likely to produce higher catch in the future, although differences are again obscured by the significant uncertainty in these predictions.

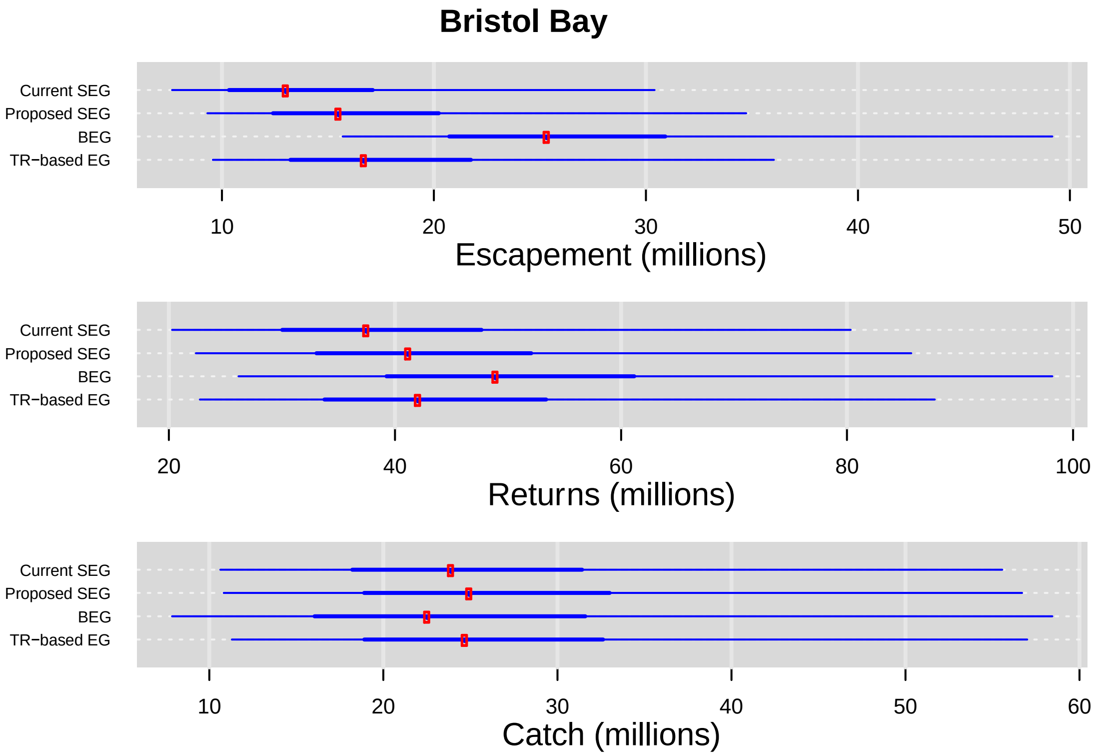

Figure 10. Caterpillar plots describing the distribution of predicted total escapement, returns, and catch for Bristol Bay as a whole in millions of sockeye, for the 4 alternative escapement strategies, across 100 replicate 100-year simulations for each strategy. The point, thick line, and thin line describe the median, 50% credible interval and 95% credible interval for the prediction.

Why don't higher returns translate into higher catches?

Whether aggregated at the Bristol Bay level or at the stock-specific level, results of this management strategy evaluation indicate that although the BEG strategy, which bases escapement targets on estimates of the spawning stock size that would produce maximum sustainable (Smsy) for each river system, is expected to result in higher sockeye returns in the future, it is unlikely to maximize future harvest. There are several reasons for this observation. First, the increase in sockeye total sockeye returns achieved may not completely offset the increase in escapement necessary. In this way, higher escapements may result in a larger number of sockeye salmon returning to Bristol Bay, but with a reduction in harvest opportunities. Second, the higher escapement goals associated with BEGs may push the populations beyond the peak in the yield curve during periods of lower recruitment associated with low productivity regimes.

Will alternative escapement goals lead to differences in the number of years with small catches?

In addition to determining which management strategy is expected to maximize future catches, given implementation and biological uncertainty, it is import to understand whether there are likely be differences in the frequency of years with small catches that may jeopardize economic sustainability of the commercial fishery. Figure 11 illustrates the distribution across simulations of the percent of years in each 100-year times series in which catches are predicted to be less than 5 million, 10 million, and 15 million sockeye. Results indicate that for all management strategies, the median expectation for the percent of years with Bristol Bay catch less than 5 million sockeye is zero. However, the observation that the 50% and 95% credible intervals for the BEG strategy extend beyond zero indicates that for a small proportion of the 100 simulations, the percent of years with catch below 5 million is greater than zero. Results further indicate that for current SEGs, Proposed SEGs, and TR-based EGs, Bristol Bay catches less than 10 million sockeye are expected in 1 – 2% of years, while catches below this level are expected in 5% of years under the BEG strategy. Predictions for the frequency with which Bristol Bay catches less than 15 million are likely to be observed indicate that catches at this level or below will occur in 10% of years under proposed SEGs and in 11 – 12% of years under either current SEGs or TR-based EGs. However, Bristol Bay catches of 15 million or below are expected to be observed significantly more frequently under the BEGs, in a median of 18 – 19% of years in the future. Taken together these results suggest that the frequency of small Bristol Bay catches is significantly increased under the BEG strategy.

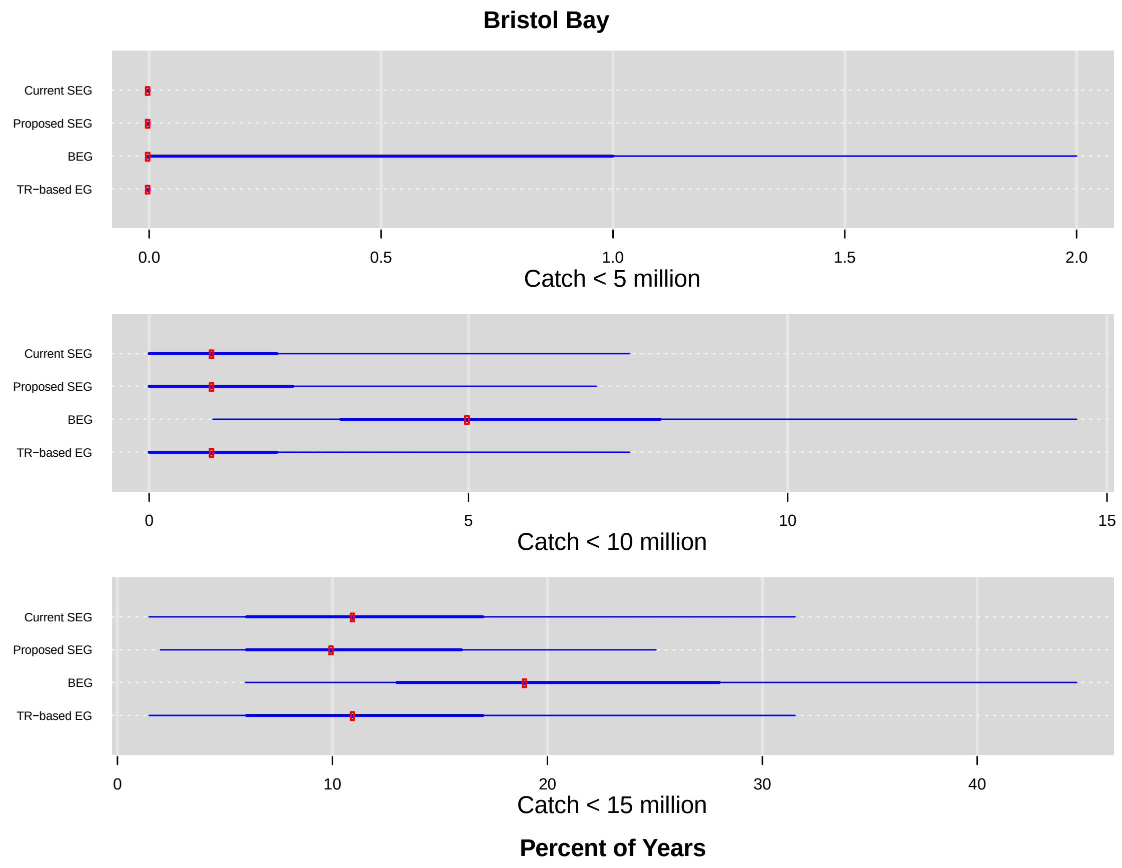

Figure 11. **Caterpillar plots describing the distribution of percent of years in which total Bristol Bay catch will be less than 5, 10, and 15 million sockeye, for the 4 alternative escapement strategies, across 100 replicate simulations for each strategy. The point, thick line, and thin line describe the median, 50% credible interval and 95% credible interval for the prediction.**

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Chapter 2

Economic Modeling to Estimate Harvester and Processor Revenues under Four Escapement Goal Policies for Bristol Bay Sockeye Salmon

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Introduction

We used a simulation model approach to examine the expected impacts of four escapement goal (EG) policies for the Bristol Bay sockeye salmon fishery (Appendix C). The goal of the economic modeling was to translate predicted changes in run sizes under alternative EG policies to expected changes in catches and harvester and processor revenues. Our modeling effort was tightly integrated to the biological and management models described in chapter 1 of this report, but for ease of illustration, we partitioned methods and results for each into separate chapters.

This chapter provides details of how each component of the economic model was designed and how they were integrated in a forward simulation process. The overall purpose of the economic modeling was to predict the average and inter-annual variability in the dollar value of the Bay-wide salmon harvests by taking into account factors known to influence the value of the harvest. Two models were developed to predict the daily and annual harvest and its value.

- Processor Model
    - Determine number of workers hired before the season starts
        - Allow daily processing capacity to adjust downward during low-run years based on preseason forecasts
    - Quantify choices by processors on products to produce given daily catches
        - Determine pounds of fillet, head-and-gutted (H&G), and canned product each day
    - Identify long-term capital investment scenarios for different daily capacity
        - Select the scenario in which number of days exceeding processing capacity most resemble recent observations Bristol Bay
- Pricing Model
    - Predict wholesale prices of canned, H&G, and fillets given annual production from Bristol Bay and recent market conditions
    - Predict ex-vessel price given annual production from Bristol Bay and wholesale prices of canned, H&G, and fillets.

Our focus was to predict *gross value of the harvest*. This was primarily due to a lack of data on costs in the harvesting and processing sectors and so we did not attempt to characterize costs or how they might change under different escapement goal policies. The significance of this simplification is likely related to the degree to which alternative EG policies result in substantially different catches and distribution of catches within and among years.

The work of Steiner et al. (2011) is closely related to our approach, as they attempted to quantity both biological and economic changes under three types of management strategies for Bristol Bay sockeye salmon with forward simulations. With respect to their economic modeling component, Steiner et al. (2011) focused on the responsiveness of the international market to aggregate Bristol Bay harvests using an international market model to estimate future Bristol

Bay processor and harvester revenue streams under various management strategies. The main difference between our approach to economic modeling and Steiner et al. (2011) was our ability to deal with daily run size in relation to product mix decisions. This allowed us to integrate the product-form decision in the ex-vessel revenue and price estimation. Steiner et al. (2011) also assumed that processors were able to process whatever was caught each year, abstracting from the decision to put harvesters on limits, which we were able to integrate.

We originally intended to model harvester decisions to predict the number of vessels (and therefore harvesting capacity) available within each fishing district each day based on relative catch rates among all districts and other factors. We believed this component could add additional realism to the predicted time series of daily and annual harvests. However, we used reconstructed district-specific abundance (Cunningham et al. 2012) to estimate daily harvest rate and compared to the number of vessels present.[1] This analysis suggested the ability to harvest the available fish was independent of the fishing effort, within the range and precision of available data. This is likely not the case at the low end of possible vessel counts in districts, but likely applies across the majority of days and our model results are likely insensitive to this simplification. Any inefficiency in fleet allocation among districts that resulted in being unable catch harvestable fish would result in us overestimating the daily catch and harvest value.

Processor model

The processor model had three components: one predicting preseason decisions for the number of workers to hired, one predicting the daily product-mix decisions, and one characterizing a range of the long-term capital investment decisions and resulting limits to daily capacity. The first and the last components were used to predict the daily catch, which was based on the expected processing capacity and the product mix as processors react to daily catch volume. The overall objective of the processor model was to simulate the Bay-wide processors' decisions from daily planning to long-term investment plans in response to future returns in Bristol Bay that could be expected under different escapement goal policies.

Preseason Hiring Decision Sub Model

The objective of this sub-model was to predict the number of workers hired to work in the processing plants before each season. The number of workers in place affects daily processing capacity, given a fixed upper limit to *in situ* processing capital. Hiring workers above the level needed to operate all lines does not increase the daily processing capacity, but reducing the number of workers below this maximum decreases the processing capability proportionally across different processing lines; processing plants may do this to reduce their

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[1] We used number of vessels, number of vessels*horse power, and number of vessels*fishing hours as proxy for the fishing effort in a district. This result was invariant to the proxy we used. A potential theory which may explain this would be overcapitalized fleets. Previous researches all suggested that the existing fleets are overcapitalized and a reduction of the number of driftnet permits would increase the economic profitability for the fleet without changing the fishing power (Link et al. 2003, Schelle 2004, Hilborn 2006, Valderrama and Anderson 2013). This implied that we may not need that many vessels to catch all available fish once a district is opened.

expenses in years with low predicted harvests. The output from this sub model became an input for the within-season model to predict decisions on daily product form for the processed catch.

Table 1: Variables for equations to predict the number of workers hired based on preseason forecasts of the total run and total harvest in Bristol Bay

VARIABLES	(Model 1)	(Model 2)
preseason run size forecast aggregate across the bay in thousands of fish	0.0738**	
	(0.0237)	
preseason harvest size forecast aggregate across the bay in thousands of fish		0.0847**
		(0.0272)
Constant	1,209	1,583**
	(802.7)	(688.2)
Observations	12	12
R-squared	0.494	0.493

Standard errors in parentheses
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

The data source we used for the model was from the 2001 – 2012 Alaska Department of Labor and Workforce Development [Research and Analysis Section] and the University of Washington Fisheries Research Institute's preseason forecast reports for Bristol Bay salmon. The labor hiring decision was considered because processors have to fly workers up to Bristol Bay in advance of the run, rather than hiring them locally. This implies an almost perfectly inelastic labor supply curve during the fishing season.[2] This provided the foundation to our model where we estimated the number of workers as a function of preseason run forecast (model 1 – table 1).[3] The logic behind this model is that the number of workers employed is a way used by processors to control costs by adjusting down processing capacities when runs are forecast to not require full capacity. As a robustness check, we ran a regression with preseason total harvest forecast as an independent variable instead (Model 2 – Table 1). Model 1 performed slightly better than Model 2 based on goodness of fit. The lower intercept for Model 1 in comparison to Model 2 gave us greater flexibility to adjust the processing capacity

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[2] According to 2010 US census, the total population of Bristol Bay Borough was 997 and the population of Dillingham was 4847. The minimum total number of processing workers employed in our dataset was 2281 in 2002. The percentage of local residents employed in processing ranges from 1.7% - 3.5% within the data range. All these facts suggested an almost perfectly inelastic supply of labor during the fishing season.

[3] Majority of processing workers were hired from abroad (via J-1 visa) before 2012. For those foreign workers (mostly from Eastern Europe), the wage they received from working at the processing plant is a lot in comparison to what they would have received if they were to work in their home country. This implies an almost perfectly elastic labor supply for the processing industry before the fishing season starts. This leaves us with demand for labor driving the labor hiring decision. Preseason forecast is used by the processors to plan out the season before hand.

downward. Hence, Model 1 was selected.[4] Based on Model 1, an increase of 1 million fish in the preseason run size forecast for Bristol Bay would increase the number of workers hired by 74 people.

For the forward-simulation, this sub model used the preseason run size generated from the biological model (Chapter 1) and yielded predicted number of workers hired for the year (Model 1 above).

Within-season Daily Product Form Decision Sub Model

This model predicted daily production, broken down by product form. We considered three products in the model: filleted, H&G, and canned sockeye salmon. We modeled processors' daily production decisions based on a series of cutoff points in the level of daily bay-wide landings. We first calibrated cutoff points such that our final product mix output matched the 2008 – 2013 actual annual product mix from Alaska Department of Tax Revenue (ATR) dataset. Using the cutoff points and decision rules estimated, we then simulated processors' daily product composition decision based on observed or simulated daily catch. The following briefly discusses what the model set up was and assumptions that we made. The estimates for where the cutoff points occurred and decision rules are also included.

Sub Model structure

The following basic assumptions were made regarding processing and product mix capacities based on a series of interviews with Bristol Bay salmon processors during 2013 and 2014.

a. Recent baseline Bristol Bay processing capacity is represented by: 8 fillet lines, 16 H&G lines, 26 canning lines.[5]
b. Processing capacity of a standard fillet per line is 120k round pounds, 250k round pounds per H&G line, and 200k round pounds per canned line.
c. The bay-wide long haul-out capacity was set to 1.5 million round pounds per day and all haul-out fish is canned.
d. Product recovery rate is 0.5 for fillet, 0.72 for HG, and 0.65 for canned. This is based on an Alaska Department of Fish and Game (ADF&G) report and informal discussions with processors.

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[4] The final results are robust to which of the models in table 1 are selected. We believe that model 1 provides a better resemblance to the real world where processors have the ability to adjust the processing capacity downward quite significantly. For instance, total worker count was 2281 in 2002 (minimum) and 4886 (maximum) within our data time frame supports a model with greater flexibility.

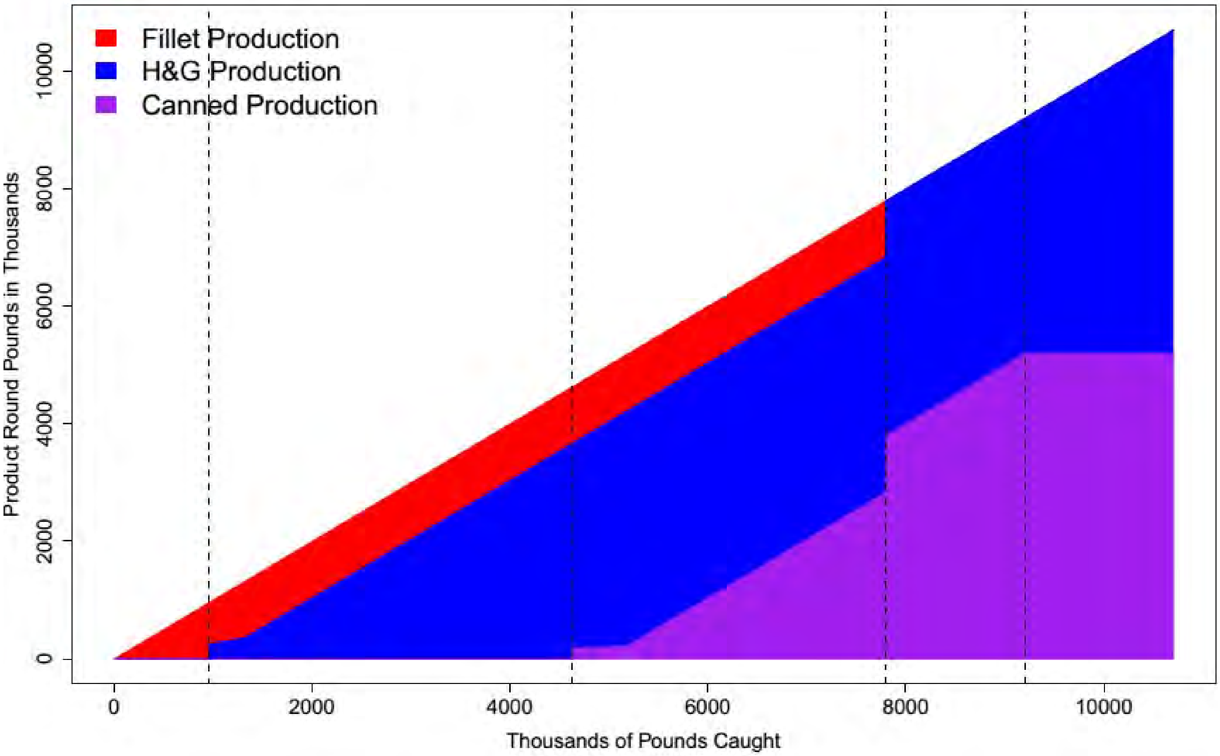
[5] Note we do not yet have production data from a year with the new (2014) Silver Bay Seafoods H&G plant operating, so this assumption reflects the relationships within the data we used. The model was designed to allow variation in the level of fixed capital in Bristol Bay, so we could evaluate future policy scenarios with the additional Silver Bay capacity.

e. We calibrate labor demand so that to run fillet lines at full capacity, it would require 26% of the overall labor force. To run H&G lines at full capacity, it would require 42.5% of labor force. To run canning lines at full capacity would require 57.5% of labor force.
f. The processors' pre-season maximum hiring decisions are calibrated to be enough people to run all the H&G and canned lines simultaneously.
g. We adopted an average 6 pounds per fish assumption based on historical patterns.

Sub Model Structure and Calibration

We used the historical daily Bristol Bay catch data from 2008 – 2013 as a basis for calibrating our model to match its predictions with the aggregate annual product mix from 2008 – 2013; daily production was not available, so this annual production by product form was the only empirical basis for a model. We first divided the range possible daily catch values into five different production decision regions. The cutoff point between each region is denoted: *a12, a23, a34, a45, and a45* (Figure 3). We only need to calibrate cutoff points *a23* and *a34*; *a12* was determined by the total fillet production capacity, which was 960 thousand round pounds per day, and the joint production capacity limit of canned and H&G determined *a45*, which was 9200 thousand round pounds.

Figure 3: The relationship between daily volume of catch and products produced in pounds.



Production decisions associated with each area in Figure 3 are described below:

a. Area 1: Given small quantity of fish caught, processors are only producing fillet here.
b. Area 2: Processors are only producing fillet and H&G. In this area, processors have to decide the proportion of fish caught which they want to fillet. Hence, we estimate the slope of fillet here (s2). S2 is constrained by the fillet production capacity.
c. Area 3: Processors convert daily catch into all three products. In this area, processors first produce fillets at maximum capacity. Then, the rest of the fish caught is divided between H&G and canned. We estimate the proportion of canned the processors will produce (s3).
d. Area 4: Processors produce only H&G and canned products. We estimate the proportion of fish getting produced into H&G or canned products (s4). S4 is constrained by the H&G or canned production capacity.
e. Area 5: Processors run canned and H&G production at full capacity, with extra fish going to haul out tenders and being canned.

The logic behind the overall model design is that processors are going to start producing the most profitable and labor intensive product, fillets, when daily catch is low. When daily catch exceeds the daily production capacity of the filleting lines, the processors will begin producing H&G. At some level of the daily catch, processors will begin producing a mixture of all three products. Eventually, the daily catch will reach a limit such that producing all three products is no longer feasible due to labor constraints – that is when processors switch over to producing only H&G and canned. This basic structure or logic was developed and refined based on informal discussions with processors in 2013 and 2014.

In order to incorporate the processors' forward thinking in making decisions, we first "smoothed" out daily catch by a three-day moving average process before estimating the parameters. This step allows us to capture processors' ability to carry-over some of the catch from one day to the next day. For instance, suppose that the catch for today is 11 million round pounds and the catch for tomorrow is 2 million round pounds. Even though current-day's processing capacity (9.2 million round pounds) has been exceeded, it does not mean that the processors cannot process all 13 million round pounds. Processors can and do utilize tenders to temporarily store the extra 2 million round pounds catch from today and process it the next day; the next day will often see harvesters on limits if catches do not decline.

Calibrated Parameters for Relationship between Volume and Product Mix

• a23 = 4622 round pounds	Cutoff point between area 2 and 3
• a34 = 7796 round pounds	Cutoff point between area 3 and 4
• sf2 = 0.73	Slope of fillet in area 2
• sc3 = 0.05	Slope of canned in area 3
• sc4 = 0.39	Slope of canned in area 4

For a given daily catch, the model predicts how much of each product would be produced, as shown in Figure 3 (blue area is H&G, red area is fillet, and purple area is canned).

For forward simulations, the model used daily catch from the biological model and the number of workers hired from the preseason staffing decision model as inputs. First, it applied the three-day moving average process to the daily catch. Next, it adjusted the cutoff points by scaling them to reflect the predicted number of workers hired. If the number of workers hired exceeded our baseline calibration number, the model then proceeded to the daily product mix prediction without modifying the cutoff points. On the other hand, if the number of workers hired was below the threshold, it scaled the cutoff points by the ratio of the number of workers hired to the baseline number).[6] Lastly, it generated the annual production of canned, fillet, and H&G as output.

We made some adjustments to the daily model to capture the dynamic, season-long decisions processors make. First, since the product mix decision is based on calibration rather than profit maximization, we had years where the model predicted zero canned production as a result of low runs. Since Bristol Bay sockeye canned production has influence over the overall price of canned product, there exists a point at which producing canned may generate more revenues (due to a much higher canned price) than producing fillets, when canned production is low.[7] To deal with this issue, we established a behavioral rule of thumb that if canned production is lower than 5.65 million round pounds by July 11th, all the fish that comes in after that date will be canned until a minimum amount of canned product demand has been fulfilled. This minimum canned amount was selected based on the observed minimum canned produced from 1984 – 2010. The date was picked such that this only happened after the peak of the season.

Second, we captured events where daily catch exceeds processing capacity. Even though we smoothed out the daily catch with the three-day moving average process, we still saw situations where the smoothed daily catch exceeded daily processing capacity. In the field, the processors put harvesters on limits. We incorporated this into the model by allowing the amount of fish exceeding the processing capacity limit to become additional escapement (which was fed back to the biological model and affected future returns later in the simulation).

Long-term Capital Investment Model

Changes in escapement goal policies made to increase future returns and harvests can be expected to stimulate investments (or disinvestments) in processing capacity relative to current conditions. Increased salmon returns to Bristol Bay in the 1980s stimulated investments in processing capacity, and smaller returns in the early 2000s precipitated decreases in short and long-term capital investments by the processing sector. This was evident in changes in the daily

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[6] The threshold number is 3390. This is the number that processors need to staff all H&G and canned lines in our model.

[7] Please refer to canned wholesale prices under the pricing model for a more detailed discussion.

processing capacity of the industry and numbers of companies operating. If we were to ignore the potential for processing capacity to increase with larger returns in the future, our results would underestimate the potential increases in yield from larger escapement goals. However, we also did not want to increase processing capacity to an unrealistic level.[8]

Modeling possible responses by the processing industry to changes in future runs was difficult, and empirical data was confounded with some fundamental changes that occurred in the salmon markets in the late 1990s and early 2000s. Rather than building an empirical model and attempting to control for confounding variables, we developed a simplified approach to predicting future changes in processing capacity. Processors face strong incentives to limit the number of times they must put their fishing fleets on limits during any season. Market share and maintaining a market for their highliners are important to processors' business success. Preseason forecasts and recent years' harvests are used by processors to gauge their short and long-term investments in capacity to minimize use of limits on their fleets within the season. Our simplified model was based on the premise that Bay-wide capacity will not greatly exceed what is required to meet the largest daily catches in most years. In recent years, 2 days on limits per season seems to be the optimum aggregate industry optimum capacity and we used this as a selection criterion to determine likely future processing capacity.

Table 2: Average number of days on limits across a range of assumed changes in processing capacity in Bristol Bay. These were averages from 100 simulations of 100 years each; we used the final 74 years of each 100-year simulation to compute the average.

% increase in daily processing capacity limit	Current SEGs	Proposed SEGs	BEGs	TR-based EGs
No increase	3.78	4.36	4.35	4.21
15%	2.24	2.75	3.2	2.73
20%	***1.91***	2.35	2.87	2.36
25%	1.58	***2.03***	2.57	***2***
35%	1.15	1.46	***2.04***	1.49
40%	0.96	1.24	1.82	1.27

We used outputs from our model to predict future processing capacity under different escapement goal policies. Specifically, we examined the modeled number of days each season that Bay-wide processing capacity was exceeded across a range of future capacity scenarios relative to what capacity was present in 2014. Six scenarios of processing capacity were examined: 0%, 15%, 20%, 25%, 35%, and 40% of daily processing capacity in 2014. These

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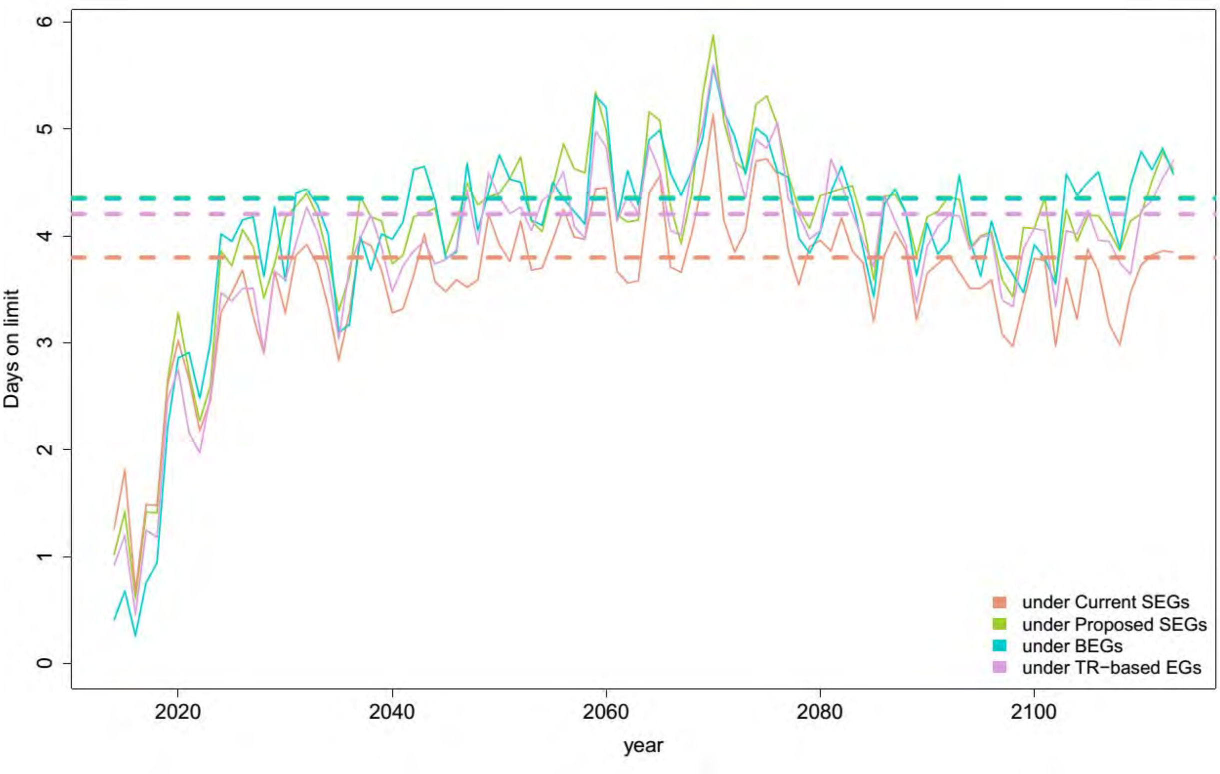
[8] Having high processing capacity level that could only be used once every year was inconsistent with profit maximizing behavior of a firm. Bue et al. (2008) provided some evidences to support this theory.

percentages applied across all products (i.e., fillet, H&G, and canned). Since the way we expanded the capacity was to expand processing capacity of each product proportionally, this implied that we also increased the cutoff points proportionally (Figure 3). However, slopes between cutoff points remained unchanged. When we calculated average number of days on limit for a season across 100 simulations, we removed years where daily processing capacity was exceeded due to planning error.[9] Table 2 displays the average days-on-limits across 100 simulations over final 74 years, excluding planning error.[10] The bold highlighting in Table 2 denotes the capacity selected to evaluate each of the escapement goal policies.

Our results indicated that a 20% increase (for current SEGs), a 25% increase (for proposed SEGs and TR-based EGs), and 35% increase (for BEGs) in processing capacity best fit the selection criterion described above.

Figure 4: Average number of days on limits by simulation year with no increase in daily processing capacity from 2014.

*Solid line: average number of days on limits, dash line: mean of the average number of days on limit of the last 74 years



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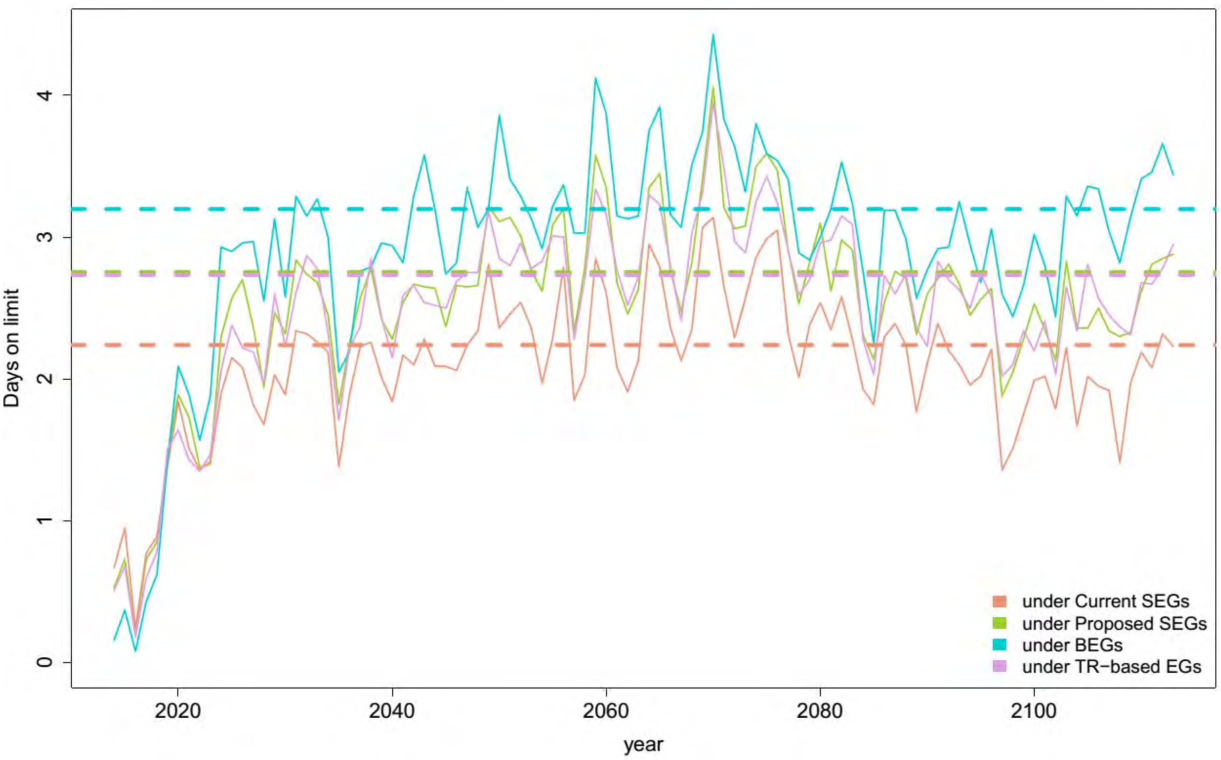
[9] Planning error is defined as not hiring enough of workers to run the processing plants at full capacity.

[10] Years prior to 2040 were considered the transitional period. Including results prior to 2040 would bias our days on limits results downwards. Therefore, the average number here only include predictions from 2040 – 2113.

Figure 5. Average number of days on limits by simulation year with a 15% increase in daily processing capacity from 2014.*



*Solid line: average number of days on limits, dash line: mean of the average number of days on limit of the last 74 years

To examine the veracity of modeled effects of changes processing capacity on the frequency of being put on limits we plotted average annual outputs from the model. Figures 4 through 9 show the average number of days that processing capacity was exceeded within a season by simulation year across 100 simulations excluding planning error years under 6 capacity scenarios. In general, when we increased the daily processing capacity, the number of days-on-limits decreased. The numbers of days-on-limits are highest for BEGs and lowest for current SEGs. These outcomes and their magnitudes seem reasonable and were consistent with our expectations.

Figure 6. Average number of days on limits by simulation year with a 20% increase in daily processing capacity from 2014.*

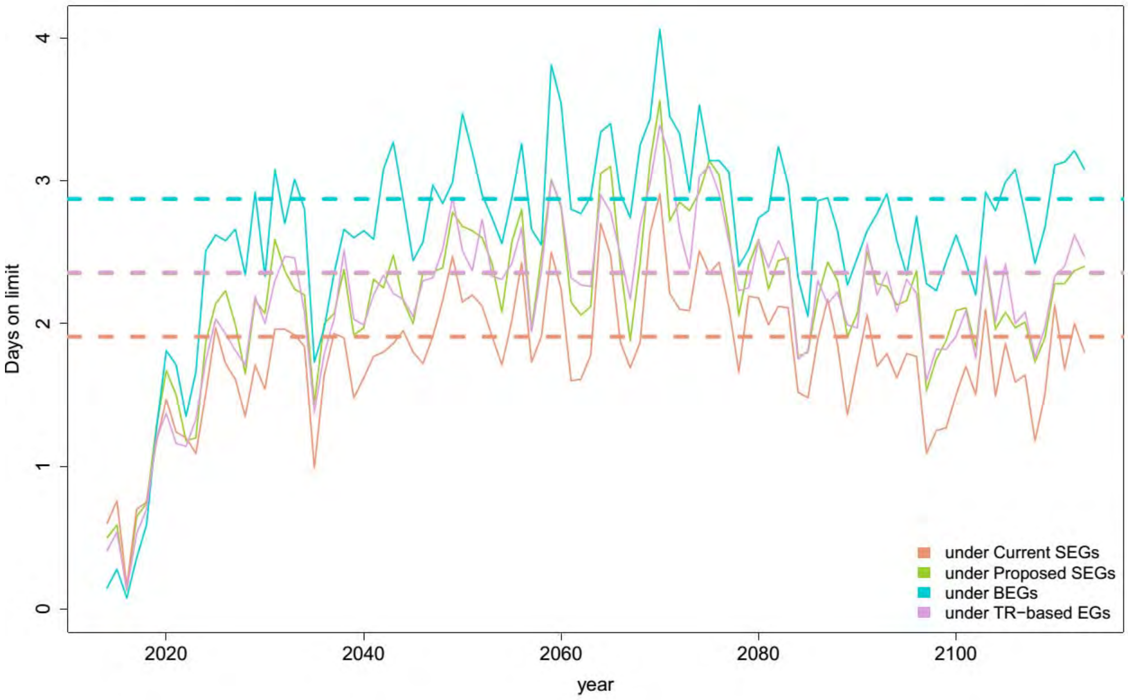
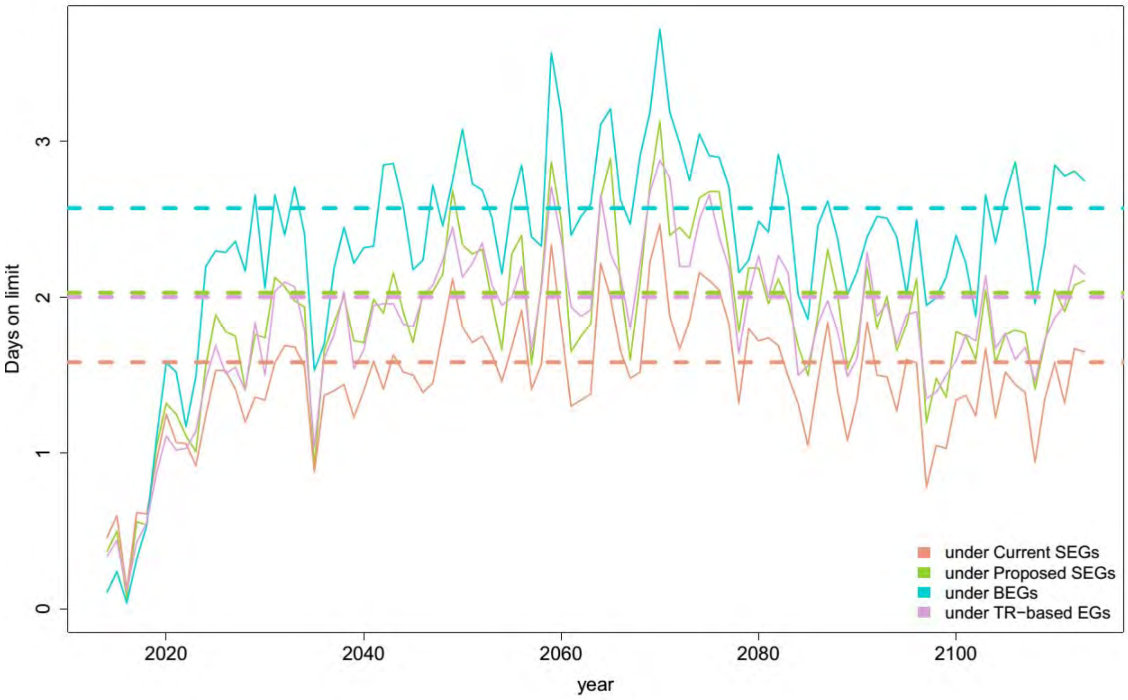


Figure 7. Average number of days on limits by simulation year with a 25% increase in daily processing capacity from 2014.*



*Solid line: average number of days on limits, dash line: mean of the average number of days on limit of the last 74 years

Figure 8. Average number of days on limits by simulation year with a 35% increase in daily processing capacity from 2014.*

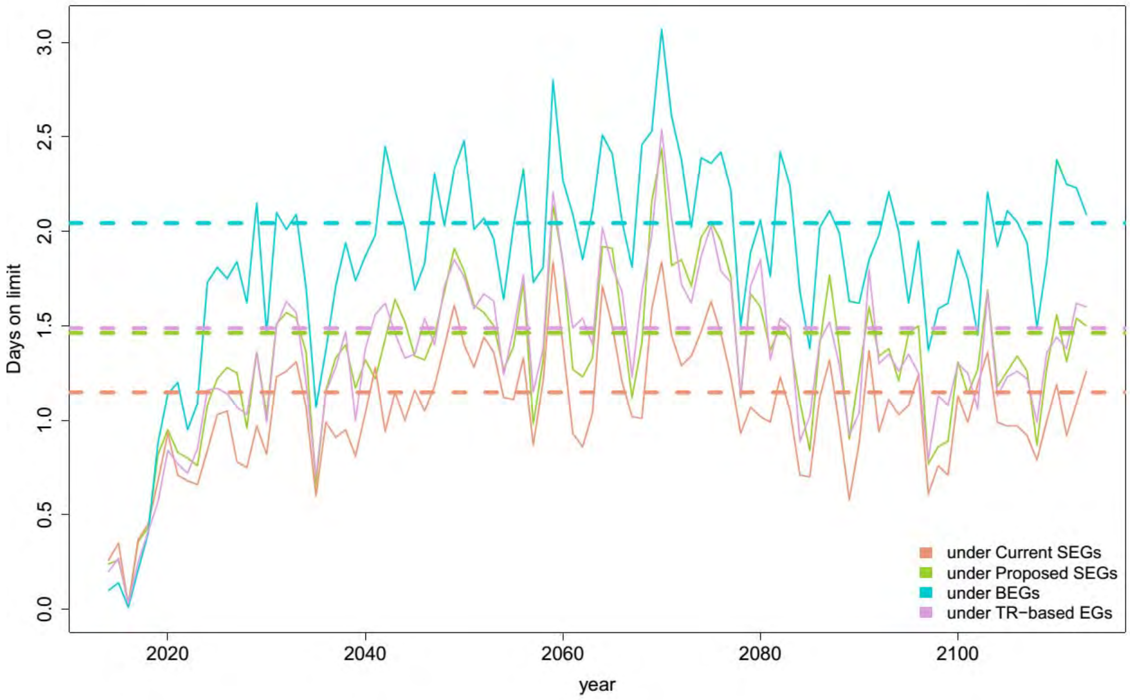
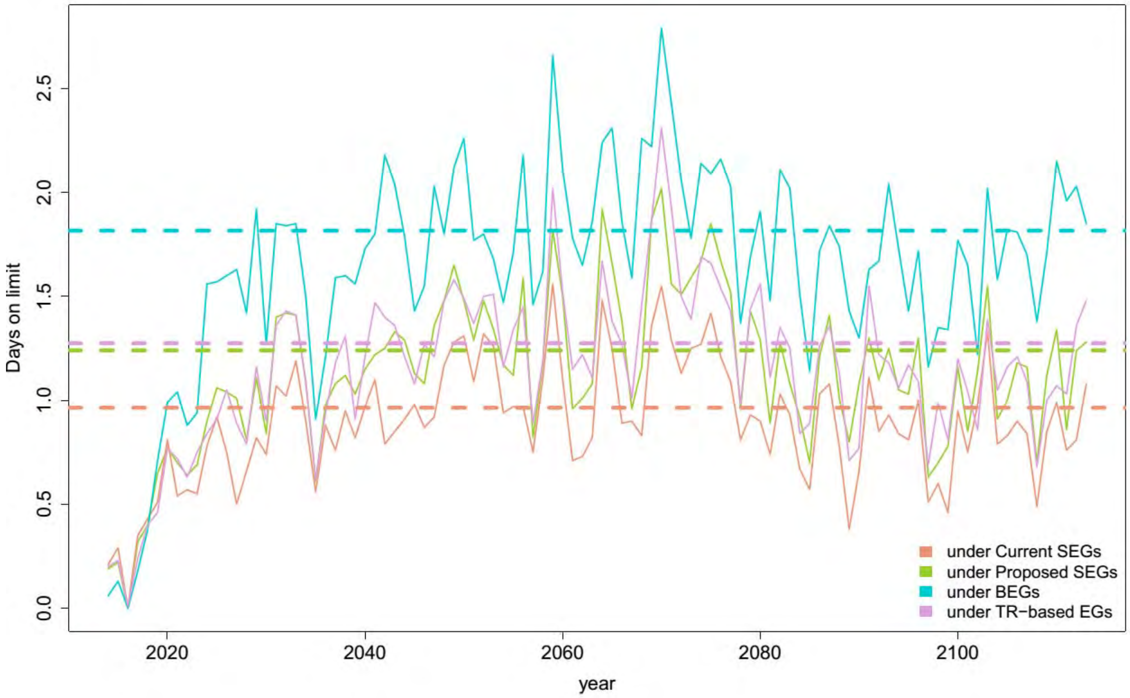


Figure 9. Average number of days on limits by simulation year with a 40% increase in daily processing capacity from 2014.



*Solid line: average number of days on limits, dash line: mean of the average number of days on limit of the last 74 years

Pricing Model

This model attempts to estimate wholesale product prices and the ex-vessel price, given production quantities from the processor model. The pricing model was made up of three components: one to describe the canned wholesale prices, one to describe H&G and fillet wholesale prices, and one to describe the ex-vessel price each year of the simulation. The model was challenging because most models in the literature do not disaggregate pricing by product form, and the data to support product-level analysis is less than ideal. The rest of this section will describe each component's model structure, parameter values estimated, and how each component functioned in the forward-simulation model used to evaluate alternative escapement goal policies.

Canned wholesale prices

Johnson and Wood (1974) analyzed wholesale canned demand and suggested that pink canned was a close substitute for sockeye canned. Our conversations with Bay-wide processors in 2013 suggested this is still the case. Hence, we constructed a model to predict wholesale prices as a function of pink prices and quantities of sockeye canned produced. Note, all the prices mentioned below are 1982 real prices. Three datasets were used to for this part of the analysis:

i. 1990 - 2012 National Oceanic and Atmospheric Administration (NOAA) annual export data set for export canned sockeye prices/quantities and export price of pink
ii. 1990 – 2010 annual COAR dataset: sockeye canned prices and quantities
iii. CPI with 1982 = 100 index [from St. Louis Federal Reserve Bank] to adjust for real prices

We initially adopted the approach reported in Model 1 from Table 3. We linked the export prices and quantities back to Bristol Bay canned wholesale prices and productions by estimating equation (1) and (2) below:

$$\ln(P_{wholesalecanned}) = -1.571 + 1.147 * \ln(P_{exportcanned}) \quad (1)$$
$$Q_{BristolBaysockeyecanned} = 4191.72 + 0.470 * Q_{exportsockeyecanned} \quad (2)$$

This formulation was preferred to alternative specifications. The coefficient for Bristol Bay sockeye canned production from Model 2 was not significantly different from zero. Model 3 had coefficients that were significant but with a much worse goodness of fit than Model 1.

We improved upon Model 1 with Model 4, which was used for our sockeye wholesale canned price model in subsequent analyses. Model 4 involved a two-step process. First, we estimated *log* export price of sockeye canned as a function of *log* export price of pink canned and *log* export quantities of sockeye canned (doing Model 1 first). This generated a predicted *log* export price of sockeye canned, which was then used for the second step of the regression where *log* Bristol Bay sockeye wholesale canned price was a function of *log* Bristol Bay sockeye canned production and predicted log export price of sockeye canned. Model 4 is known as two-stage least-squares regression in the economics literature and controls for shifts in both the supply and demand curves. Model 4 implied that a 1% increase in Bristol Bay sockeye canned production would result in a 0.175% drop in Bristol Bay wholesale sockeye canned price, holding everything else constant.

Table 3: Regression results for different estimation methods for sockeye canned prices.

VARIABLES	(1) ln(export sockeye canned price)	(2) ln(export sockeye canned price)	(3) ln(Bristol Bay wholesale sockeye canned price)	(4) ln(Bristol Bay wholesale sockeye canned price)
ln(export sockeye canned quantity)	-0.413***			
	(0.0868)			
ln(export pink canned price)	0.390***	0.642***	0.697***	
	(0.0865)	(0.0741)	(0.116)	
ln(Bristol Bay sockeye canned quantity)		-0.0594	-0.227**	-0.175**
		(0.0598)	(0.0939)	(0.0843)
ln(export sockeye canned price)				1.041***
				(0.152)
Constant	5.700***	1.565**	1.881*	0.381
	(0.996)	(0.648)	(1.017)	(1.009)
Observations	24	21	21	21
R-squared	0.833	0.846	0.779	0.809

Standard errors in parentheses
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

A method to evaluate our model performance was to compare our own price and cross-price elasticities with those in the existing literature, noting these values may change some over time. Since we treated price as an independent variable and production as dependent variable, we could not simply take the coefficient value for the sockeye canned production and pink prices as own price and cross-price elasticity (the coefficients are instead price flexibilities). In order to compare with the existing literature, we had two ways of recovering what might be the own-price and cross-price elasticities. One was by taking the reciprocal of price flexibility to get the lower absolute limit of the price elasticity (Houck 1965). Another method was to rerun the regression with sockeye canned production as the dependent variables (Huang 1994). Table 4 documents all the own-price and cross-price elasticity of demand using both methods. All the models from Table 4 suggested that pink canned is a substitute product for sockeye canned (since the coefficient for the parameter is positive).[11] The own-price elasticity ranged from elastic (<-1) to inelastic (>-1).[12]

Table 4: Own-price and cross-price elasticities calculated using different methods for canned product

	Model 1	Model 2	Model 3	Model 4
Own-price elasticity of demand [Houck 1965]	-2.42	-16.82	-4.4	-1.14
Own-price elasticity of demand [Hung 2006]	-1.26	-.87	-1.08	-0.73
Cross-price elasticity of demand with pink canned [Hung 2006]	0.21	0.09	0.38	N/A

The inputs to this component for the forward simulation model are the quantity of canned produced annually from the within-season product mix decision model and *log* export price of sockeye canned. Since the purpose was not to forecast what the export price of sockeye canned would be in the future, we adopted the last 5-year average *log* export sockeye canned price (= 1.76) and took it as constant for our forward simulation model. The predicted wholesale canned price was in 2013 dollars (multiplying by 2.44, which is the conversion rate from 1982 to 2013 dollars).

H&G and Fillet Wholesale Prices

We separated our analysis of canned prices from that of H&G and fillet prices based on previous research and conversations with several processors. They all indicated that H&G and fillet products (grouped as "frozen products" in the data) are not in the same type of market as canned products. Therefore, it made more sense to analyze these two markets separately. The analysis of H&G and fillet wholesale prices was challenging due to many factors. First, previous literature has focused solely on analysis of frozen sockeye interacting with other products (such as Atlantic frozen and fresh farmed and other types of frozen fish), providing limited information on how we should proceed on the estimation process. Second, the import and export NOAA trade data do not distinguish between sockeye frozen fillet and H&G. The only publically available data source we could find that distinguished was from Alaska Department of Tax Revenue (ATR). However, the ATR only had data from 2001 – 2013, limiting the range of

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[11] Johnson and Wood (1974) has cross-price elasticity of 0.18 for pink canned salmon.

[12] This is consistent with what the literature has suggested. DeVoretz (1982) reported that the own price elasticity of canned varies from -12.9 to -16.3. The Canadian Department of Fisheries and Oceans (1989) documented the value of -2.21 and -2.8. Johnson and Wood (1974) report of -0.006 and -0.17. They also report the own price flexibility of -0.14, which is very similar to what we have from model (4) – table 1 (-0.18). Bird (1986) reports the own price elasticity of canned to b -0.87. Anderson and Wilen (1986) estimates the own price elasticity of canned salmon to be anywhere between -1.47 to -12.92. The previous research with regards to canned market has been limited to time periods prior to the 1990s (more recent literature has focused their attention on frozen vs. fresh salmon products rather than canned products due to growing competition from aquaculture salmon products). We, however, felt the previous research may still be somewhat comparable to our current model due to the following reasons. First, farmed salmon is not typically being turned into canned products. Second, conversations with processors indicated that there is still a considerable demand for sockeye canned products in the UK market.

the data and our ability to apply statistical estimation techniques that control for variety of factors. Note that all the prices below are in 1982 dollars.

The objective of this model was to predict Bristol Bay wholesale prices of H&G and fillets given Bristol Bay annual production of these two products. The data sources that we use for the estimation process are listed below:

i. Alaska and Bristol Bay wholesale fillet quantities and prices and wholesale Bristol bay H&G price and quantities from ATR annual dataset 2001 – 2013
ii. NOAA annual import price of salmon Atlantic fillet frozen farmed.

CPI with 1982 = 100 index [from St. Louis Federal Reserve Bank] to adjust for real prices

Previous research has indicated that Atlantic fillet farmed is a close substitute for Pacific wild sockeye frozen salmon products (Williams et al. 2009, Asche et al. 1998). This is indeed what our estimation results suggested. Model 1-a and Model 1-b from Table 5 both had positive coefficients for the Atlantic fillet frozen farmed import price, indicating it was a substitute for Bristol H&G and Alaska sockeye fillet. The regression technique we applied is known as seemingly unrelated regression (SUR) analysis. Rather than estimating each regression separately, SUR analysis estimated both Model 1-a and Model 1-b simultaneously. This technique was adopted because we believed that the equations are related through the correlation in the error terms. We used the Alaska wholesale fillet price rather than the Bristol Bay wholesale price for Model 1-b because data from Bristol Bay alone was not deemed reliable. In addition to the very short times series, the first four years (prior to 2005) saw little fillet production in the Bay.[13]

Recall that our objective was to predict Bristol Bay wholesale prices of fillet given Bristol Bay fillet production. To achieve this objective, we established linkages between the Bristol Bay and Alaska fillet production and wholesale prices. This is where Models 3 and 4 from Table 5 were useful. Model 3 linked the Alaska fillet production with Bristol Bay fillet production, whereas Model 4 linked the Bristol Bay wholesale fillet price to Alaska statewide wholesale prices.

Although our approach may not be ideal, our estimated own-price elasticity were consistent with expectations based on other research that has analyzed the merged product form (Table 6).[14] We have to be cautious when we compare our elasticity estimates with that

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[13] Since ATR is a publically available dataset, ATR cannot report the fillet production quantities if there are less than 3 firms producing fillets for a particular time frame due to confidentiality reason. It may be possible that there were some fillet production activities in the early 2000s but numbers not published due to confidentiality reason. However, conversations with processors did suggest a low volume production of fillets prior to 2005.

[14] Bird (1986) estimates the own price elasticity of frozen sockeye to be -1.35. An AIDS approach yields an estimation of -0.608 and cross price elasticity of 0.15 and 0.449 with frozen and fresh Atlantic fillet farmed by Asche et al. (1998). Although it is not clear as to which pacific frozen salmon they are referring to in the paper. When we look at high value pacific frozen salmon (Chinook, coho, and sockeye), Herrmann (1993) estimated that the own price elasticity of -1.252. Asche and Wessel (2002) estimates the own price elasticity of sockeye frozen to be anywhere between -0.852 and -1.289. Anderson and Wilen (1986)

in the literature due to two factors. First, previous research has not separated frozen fillet and H&G. Second, our regressions yield price flexibilities rather than price elasticities (which implies that our estimation of price elasticity may be slightly biased).[15]

Table 5: Regression results for different models to estimate of Bristol Bay wholesale fillet and H&G prices.

	Models: (1-a)	(1-b)	(2)	(3)	(4)
VARIABLES	ln(Bristol Bay wholesale H&G price)	ln(Alaska wholesale fillet price)	ln(Bristol Bay wholesale fillet price)	ln(Alaska wholesale fillet production)	ln(Bristol Bay wholesale fillet price)
ln(Bristol Bay H&G production)	-0.218***				
	(0.0688)				
ln(import price Atlantic salmon frozen fillet farmed)	0.987***	0.928***	0.461		
	(0.144)	(0.181)	(0.402)		
ln(Alaska wholesale fillet production)		-0.0431*			
		(0.0240)			
ln(Bristol Bay fillet production)			7.25e-05	0.725***	
			(0.0402)	(0.0379)	
ln(Alaska wholesale fillet price)					0.822***
					(0.140)
Constant	3.463***	1.010***	0.500	5.079***	0.0782
	(1.173)	(0.309)	(0.441)	(0.570)	(0.114)
Observations	13	13	11	11	11
R-squared	0.788	0.760	0.374	0.976	0.794

Standard errors in parentheses
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

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estimates that the own price elasticity of fresh and frozen salmon to be anymore between -3.94 to - 9.68. The significant changes in the demand of salmon and substantial increase in farmed salmon. The previous researches mentioned above may not necessarily comparable to our results. However, the more recent research has not been focusing on price analysis between Alaska sockeye and Atlantic farmed salmon as much. Williams et al. (2009) estimates that the price flexibility between Chilean coho salmon and Alaskan sockeye salmon to be 0.32. It is not clear as to whether the Alaskan sockeye salmon indicated here includes canned product or not. They are also not using Atlantic farmed salmon.

[15] Please refer this part of the discussion under canned wholesale prices when we discussed with regards to price elasticities.

Table 6. Own-price and cross-price elasticities calculated using different methods for frozen H&G and fillet products.

	Model 1 – a	Model 1 – b
Own-price elasticity of demand [Houck 1965]	-4.58	-23.22
Own-price elasticity of demand [Hung 2006]	-2.15	-1.12
Cross-price elasticity with Atlantic frozen fillet farmed [Hung 2006]	2.67	6.89

For the forward simulations, we used the annual production of fillet and H&G by aggregating production from the daily product mix model. We also use the recent average log import price of Atlantic salmon frozen fillet farmed, 0.663 (last 5-year averages in 1982 dollars). We first predicted what the Alaska wholesale fillet production would be using Model (3) – Table 5. We then took that as an additional input for models 1-a and 1-b to allow us to predict the Bristol Bay wholesale H&G price and the Alaska wholesale fillet price. With the predicted Alaska wholesale fillet price, we predicted the Bristol Bay wholesale fillet price using Model (4) – Table 5. We then translated the prices back to 2013 dollars, multiplying each price by 2.44.

Ex-vessel price

Gunnar Knapp (2013), in his Trends in Alaska Salmon Markets Report, suggested that the relationship between ex-vessel value and processor revenues has been stable since the early 2000s (Model 1 – Table 6).[16] Instead of looking at the direct link between ex-vessel value and processor revenues, we modified it slightly such that we were looking at the relationship between processor revenues by product and ex-vessel revenues (Model 2 – Table 6).

The intuition behind Model 2 –Table 7 was that processors share a fraction of their revenues with harvesters. Our extension to Knapp's model allowed us to further incorporate how daily product mix decisions impact total harvester revenue, allowing for different (unobserved) profit margins by product. The ex-vessel price was calculated based on equation (3):

$$P_{exvessel} = \frac{(P_{fillet} * Q_{fillet} + P_{HG} * Q_{HG} + P_{wholesalecanned} * Q_{BristolBaysockeyecanned})}{Q_{catch}} \qquad (3)$$

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[16] Williams et al. (2009) applied an international supply and demand market simultaneous equation equilibrium model to analyze Alaska's sockeye salmon ex-vessel prices and revenues. They modelled Alaska statewide sockeye ex-vessel price as a function of real prices of Alaska sockeye salmon exported to Japan and other places, and the lagged ratio of Alaskan real ex-vessel price of sockeye salmon to the real export price of Alaska sockeye salmon exported to Japan. Since our focus was more on how changes in product mix production as a result of daily run timing and harvesting strategies in Bristol Bay, and how they play into ex-vessel pricing decision, we adopted Knapp (2013) approach.

Table 7: Ex-vessel value as a function of wholesale processor value or by-product processor wholesale values

VARIABLES	(1) model 1	(2) model 2
Fillet wholesale value ($P_{fillet} * Q_{fillet}$)		0.303***
		(0.0781)
H&G wholesale value ($P_{HG} * Q_{HG}$)		0.689***
		(0.0410)
Canned wholesale value		0.545***
($P_{wholesalecanned} * Q_{BristolBaysockeyecanned}$)		(0.0524)
Processor wholesale Value	0.566***	
	(0.0274)	
Constant	-9.610e+06**	-1.258e+07***
	(2.895e+06)	(1.917e+06)
Observations	10	10
R-squared	0.982	0.998

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

For the forward simulations, this model component took predicted wholesale prices from the canned, H&G, and fillet pricing models and annual production of H&G, canned and fillet aggregated from the daily product mix model as inputs. The ex-vessel values and prices were predicted based on these. To ensure that harvesters did not end up receiving negative payments (due to the constant term from Model 2—Table 7), we stipulated that processors pay harvesters a minimum of 10 cents per round pound. To translate the ex-vessel price back to 2013 dollars, we multiplied by 2.44.

Escapement Goal Policy Evaluation under Forward Simulations

To evaluate impacts of altering escapement goal policies, the biological, management and economic models were run forward into the future from current conditions of recent stock-specific escapements, and under current global market conditions. These “forward simulations” were based on 100 simulations, each of 100 years duration starting from conditions in 2014 for each of the four different escapement goals policies: current SEGs, ADF&G proposed SEGs (Proposed SEGs), ADF&G’s Ricker BEG escapement goals (BEGs), and the TR-based EGs.

Table 8: Summary statistics from forward simulations. The average variance is based on first calculating the variance of one simulation then takes the average of the variance across all simulations.

Annual return (all units in millions of fish)

	Current BEGs	Proposed BEGs	BEGs	TR-based EGs
Median	36.90	40.87	50.01	42.37
Mean	40.72	44.58	54.03	46.06
Average variance*	445.82	471.60	715.34	522.01

Percent change of annual run between current SEGs and other three escapement policies

	Proposed BEGs	BEGs	TR-based EGs
% change in Median	10.76	35.52	14.82
% change in Mean	9.48	32.68	13.11
% change in Average variance*	5.78	60.45	17.09

Annual catch (all units in millions of fish)

	Current BEGs	Proposed BEGs	BEGs	TR-based EGs
Median	23.11	24.12	22.80	24.14
Mean	23.95	25.02	23.95	25.15
Average variance*	54.83	61.60	81.58	60.64

Percent change of annual catch between current SEGs and other three escapement policies

	Proposed BEGs	BEGs	TR-based EGs
% change in Median	4.37	-1.33	4.48
% change in Mean	4.46	0.00	5.04
% change in Average variance*	12.35	48.78	10.60

Processor wholesale revenues (all units in millions 2013 dollar)

	Current BEGs	Proposed BEGs	BEGs	TR-based EGs
Median	330.48	342.48	328.15	343.32
Mean	335.74	348.16	335.39	350.40
Average variance*	6,909.62	7,653.24	10,272.91	7,493.16

Percent change of processor wholesale revenues between current SEGs and other three escapement policies

	Proposed BEGs	BEGs	TR-based EGs
% change in Median	3.63	-0.71	3.89
% change in Mean	3.70	-0.11	4.36
% change in Average variance*	10.76	48.68	8.45

Vessel revenues (all units in millions 2013 dollars)

	Current BEGs	Proposed BEGs	BEGs	TR-based EGs
Median	155.81	162.71	153.17	162.37
Mean	159.50	166.38	158.03	167.16
Average variance*	2,444.75	2,711.75	3,651.60	2,660.75

Percent change of vessel revenues between current SEGs and other three escapement policies

	Proposed BEGs	BEGs	TR-based EGs
% change in Median	4.43	-1.70	4.21
% change in Mean	4.31	-0.92	4.81
% change in Average variance*	10.92	49.36	8.84

Processor wholesale revenue and harvester revenue results presented below are in 2013 real dollar terms. In assessing the value of harvests, we did not apply any discount rates to future simulation results. Instead, we emphasized different levels stock, capital and revenue variables in eventual steady states by excluding the outcomes during a transitional period prior to year 26 of each 100 simulations. It is important to note that the predicted harvester and processor revenues are generated based on recent global market conditions. We do not intend to forecast decadal or century-scale trends in global seafood markets, but rather facilitate comparisons of different escapement goal policies.

Table 8 presents summary statistics from the simulation results for annual catch, processor wholesale revenues, and vessel revenues. Figures 10-13 show the distributions of total return, total catch, processor revenues, and harvester revenues under the different escapement goal policies.[17] Because run sizes are different under each escapement goal scenario, we selected a scenario-specific outcome for the long-run fixed processing capital model for purposes of comparison; for each scenario, we selected a fixed capital scaling that led to an average level of days-on-limits similar to the two days seen in recent years. For current SEGs, the simulation results were generated using 20% increase in daily processing capacity. For proposed SEGs and TR-based EGs, a 25% increase in daily processing capacity was adopted. A 35% increase in processing capacity was used for BEGs.

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[17] In order to present these density graphs clearly, the long, thin right tails of the density graphs have been truncated.

Figure 10. **Distribution of total return in millions fish under four escapement goals policies across 100 simulations of last 74 years each.**

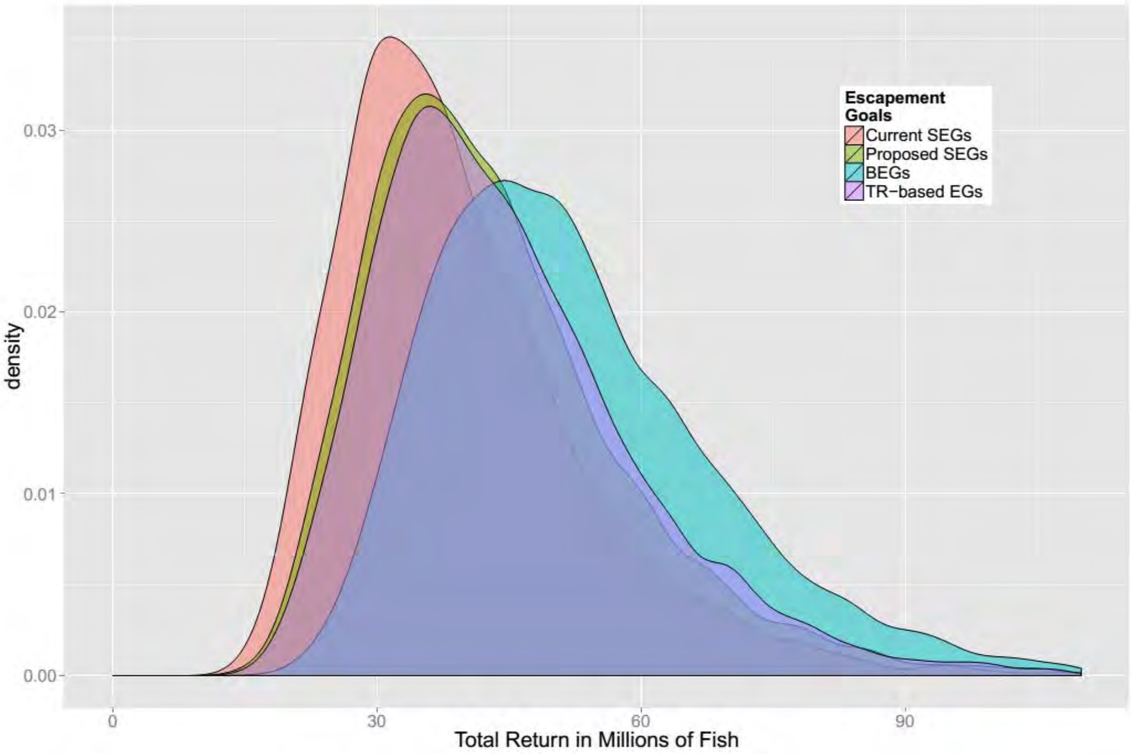
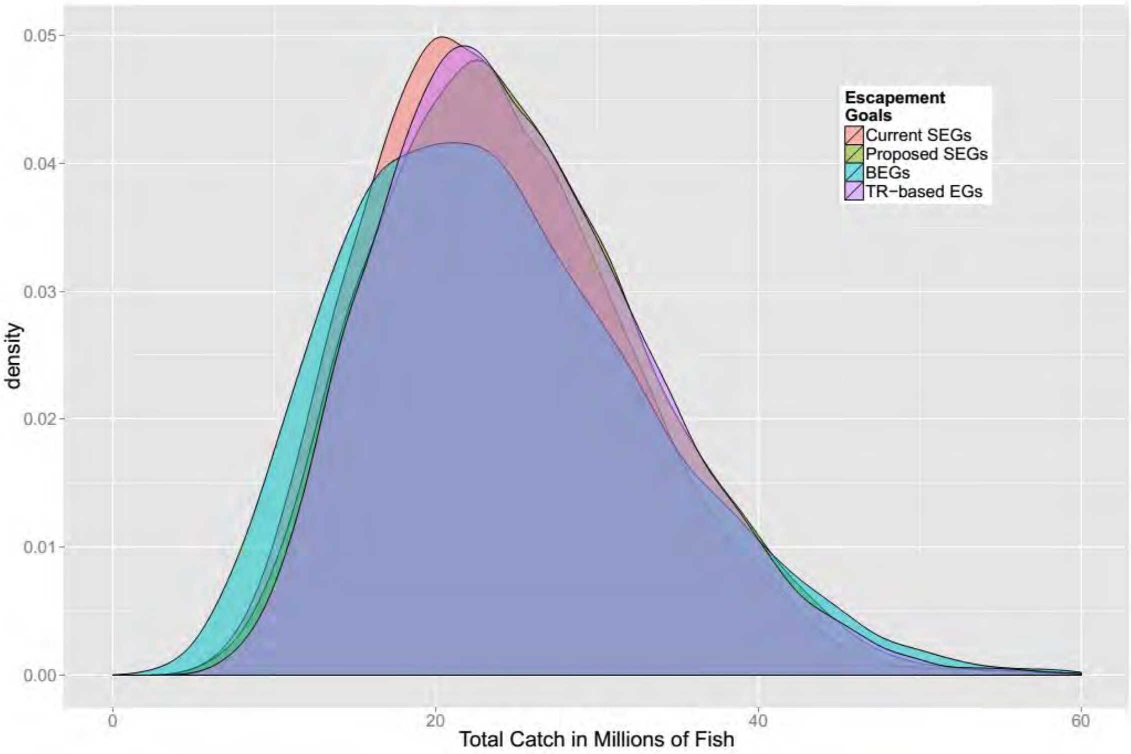
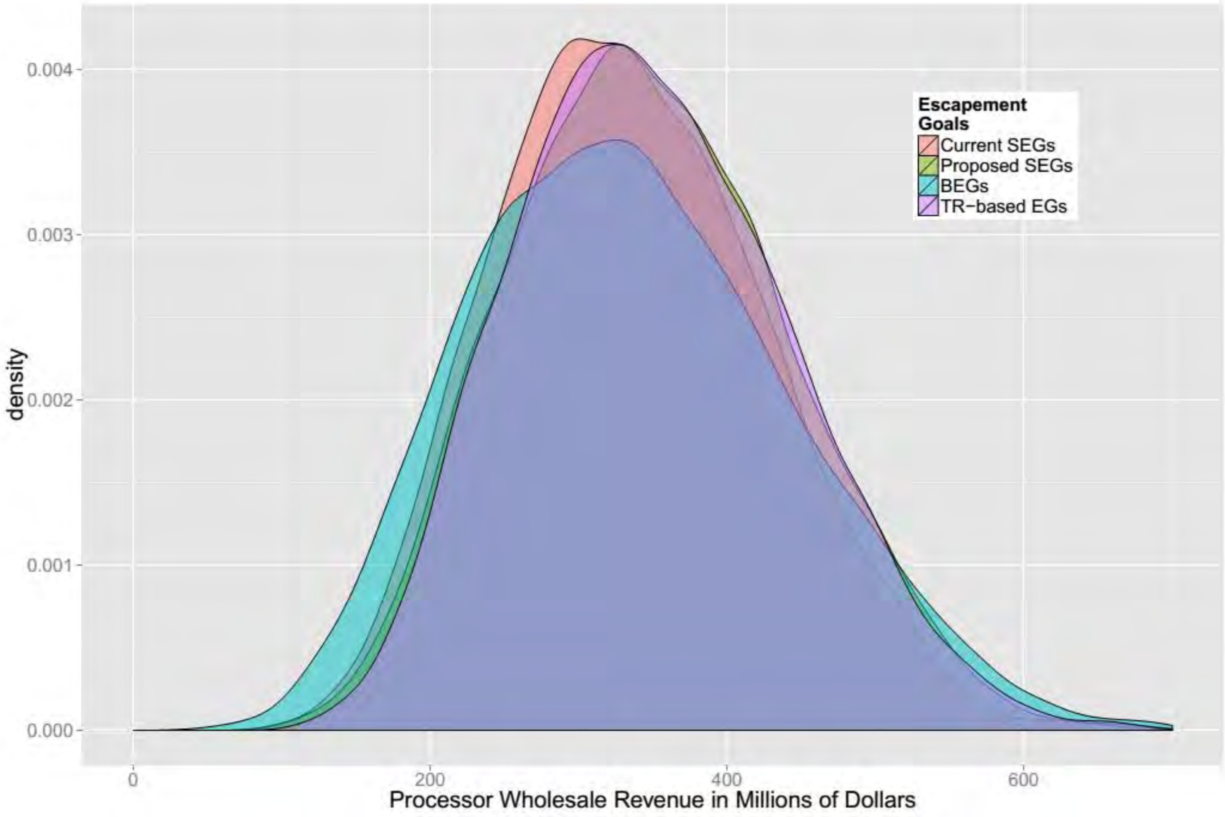


Figure 11. **Distribution of total Bay-wide catch in millions fish under four escapement goals policies across 100 simulations of final 74 years each.**



Higher escapements led to higher average fish returns in the future. However, the variance of the run size also increased as shown in Figure 10 and Table 8. The median, mean, average variance, and average standard deviation were the lowest under current SEGs. The next lowest was proposed SEGs. BEGs are highest among all 4 scenarios we examined. To examine the trade-off relationship between average run size and variance of the run size, we calculated the percentage change of run size between current SEGs and other three scenarios.

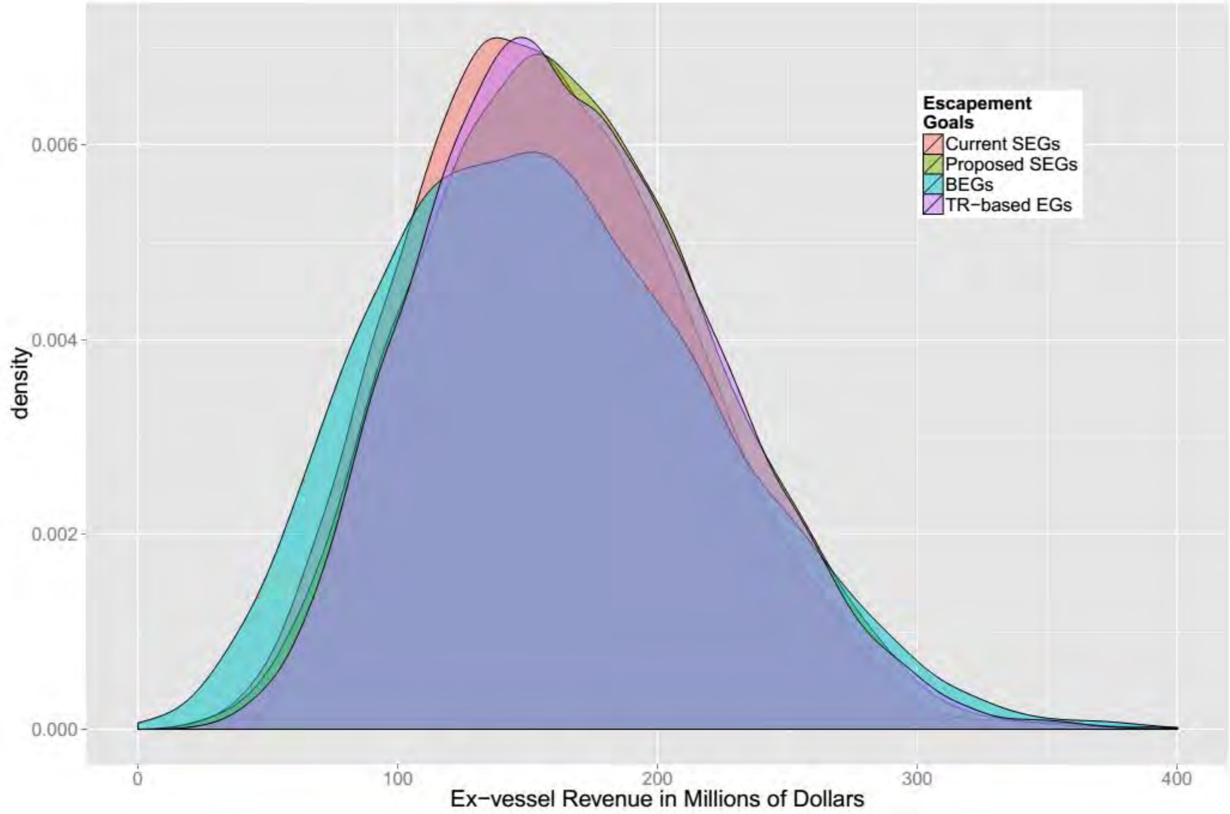
Figure 12. Distribution of processor wholesale revenues under four escapement goals policies across 100 simulations of final 74 years each.



Even though average returns were higher under alternative escapement goals to the current SEGs, it did not necessarily translate into higher catches (hence higher processor and harvester revenues). Graphs 8 – 10 and Table 8 suggested quite similar average catch, average processor revenue, and average harvester revenues across the different scenarios. For BEGs, we predict a lower median, same mean, and higher average variance catch, in comparison to current SEGs. There are two possible explanations for this divergence between run size and catches. First, an increase in escapement goals implies a higher number of returning fish need to be used as escapement rather than catch. Second, the processing sector may not able to process all the additional fish available for catch, leading them to either make less valuable (canned) products or putting harvesters on limits during the peak of the run in abundant years.[18] Comparing the percentage change in total catch and processor revenue between proposed SEGs and TR-based SEGs with current SEGs, the difference is about 1 %. Also, the average variance was reduced by about 1 % when compared between processor and harvester revenues to total catch (table 8). Due to market conditions and different product mix, the differences in average catches across different escapement goal policies are mitigated.

The results above present changes in Bay-wide catches and revenues. This aggregates across outcomes for individual fishing districts, some of which may experience more frequent years with few or no openings in order to meet higher escapement goals. This is important because not all fishermen are mobile among districts and the Bay-wide aggregating masks the distribution of impacts among those in the harvesting sector.

Figure 13. Distribution of ex-vessel revenues under four escapement goals policies across 100 simulations of final 74 years each.



As one way to examine this issue, we calculated number of days a particular sub-district is opened within a year from June 20 to July 17.[19] Figure 14 shows the fraction of years a sub-district was closed a given number of days within a year (after the transition phase of our

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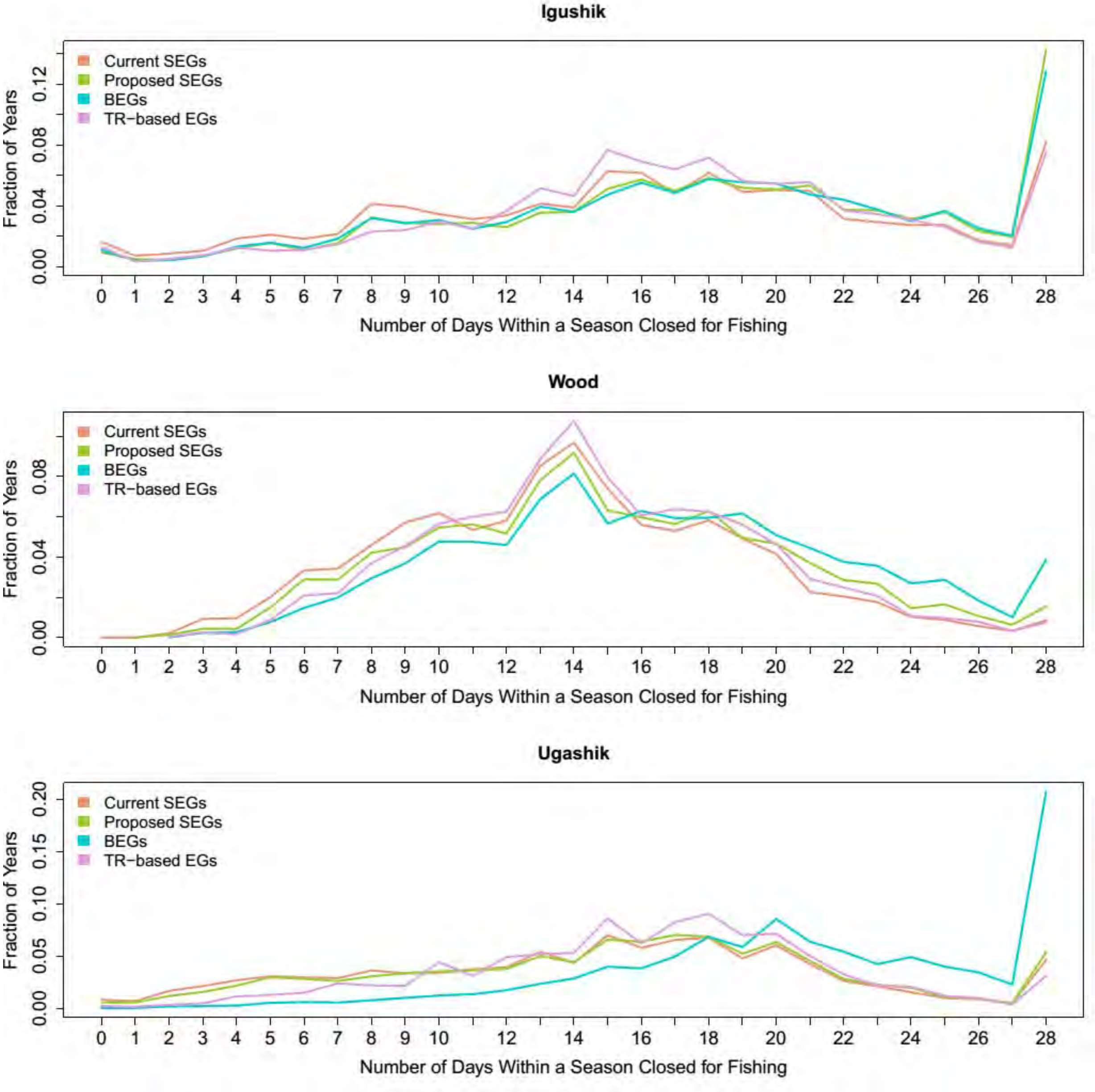
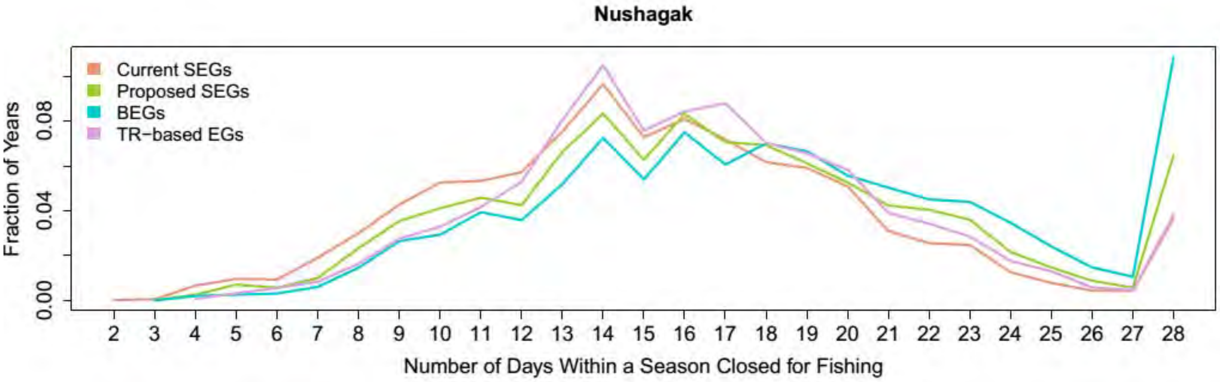
[18] The BEG run scenarios had more unusually abundant years than the other escapement goal policies, so processing capacity would have to be far more responsive to rare utilization than recent capitalization decisions suggest to capture the value associated with these fish.

[19] June 20th to July 17th is the time range where most of the fishing activities occur in Bristol Bay.

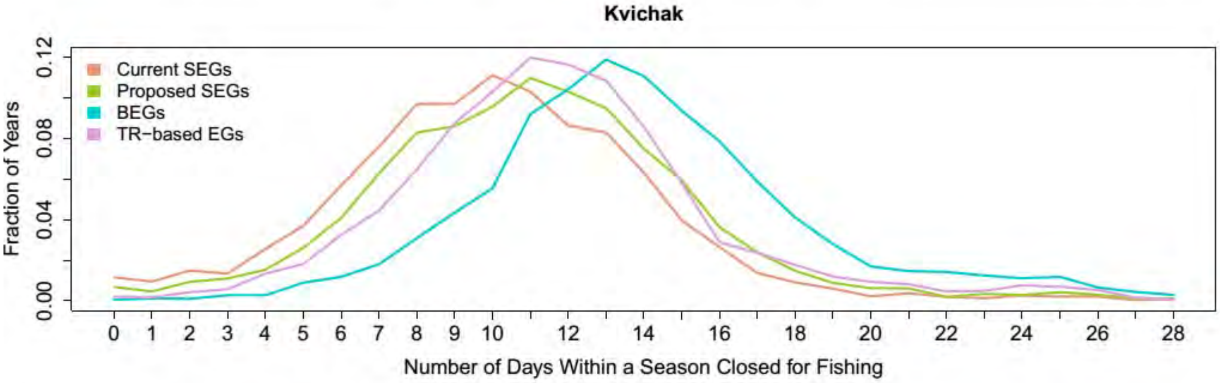
forward simulations). In general, current SEGs had the fewest days of closures for most of the sub-districts. Also, current SEGs, proposed SEGs, and TR-based EGs follow similar patterns, whereas BEGs is to the right of the other three scenarios. This means that all sub-districts tended not to open as often under BEG management, in comparison to the other three scenarios. For instance, our result predicted that Ugashik is going to experience zero fishing opportunity for a season once every five years where as for other three escapement goal policies, Ugashik is likely to be closed once every 20 years.

Figure 14. Fraction of the simulated years in which a given sub-district was closed for a specified number of days during the period June 20 to July 17.

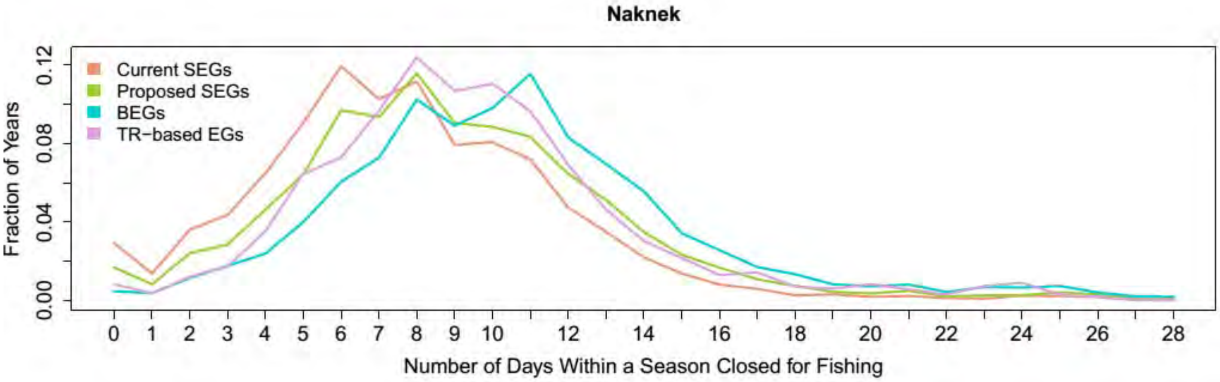




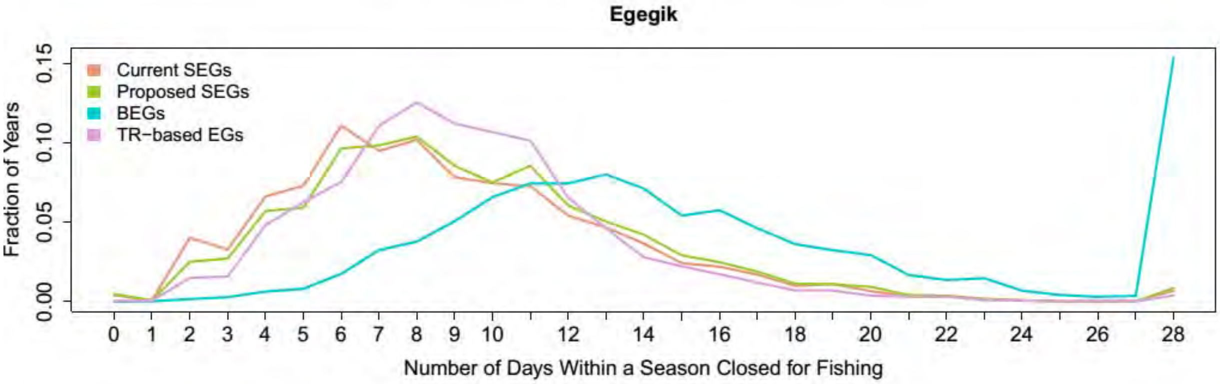
Nushagak



Kvichak

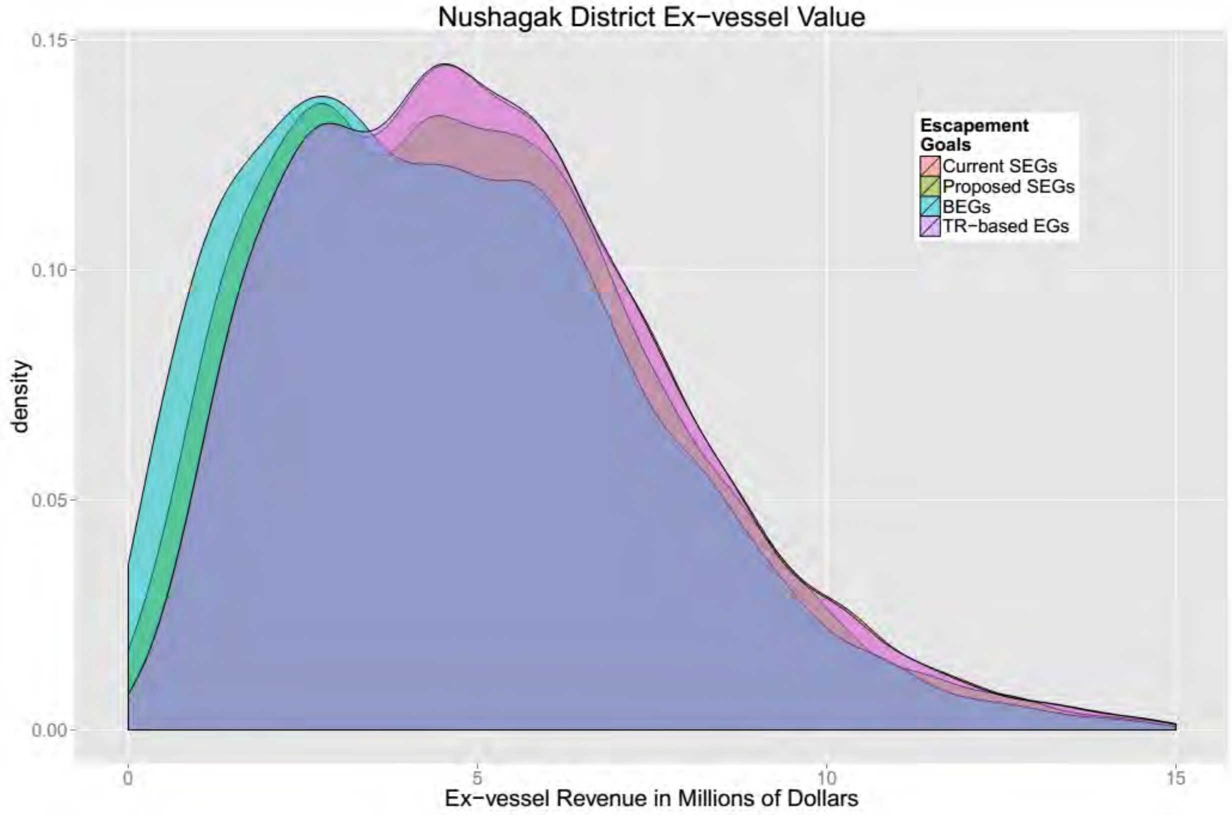


Naknek



Egegik

Figure 15. Distributions of ex-vessel revenues from the Nushagak district under four escapement goals policies across 100 simulations of final 74 years each. In order to present all of these next two density figures clearly, the long, thin right tails of the distributions have been truncated.



Fewer opening days per season may not necessarily translate into lower ex-vessel revenues per district.[20] Ex-vessel revenue per district is especially crucial for setnet harvesters and driftnet harvesters who do not switch districts. We construct the distribution of ex-vessel revenue graphs for Nushagak district, and stock-based ex-vessel revenue estimates for the Naknek-Kvichak, Egegik, and Ugashik (Figures 15 and 16).[21] In these Figures, the y-axis intercept represents the proportion of years with no harvest in the district or stock. For Nushagak district, Egegik, and Ugashik stock, BEG has significantly higher chance of

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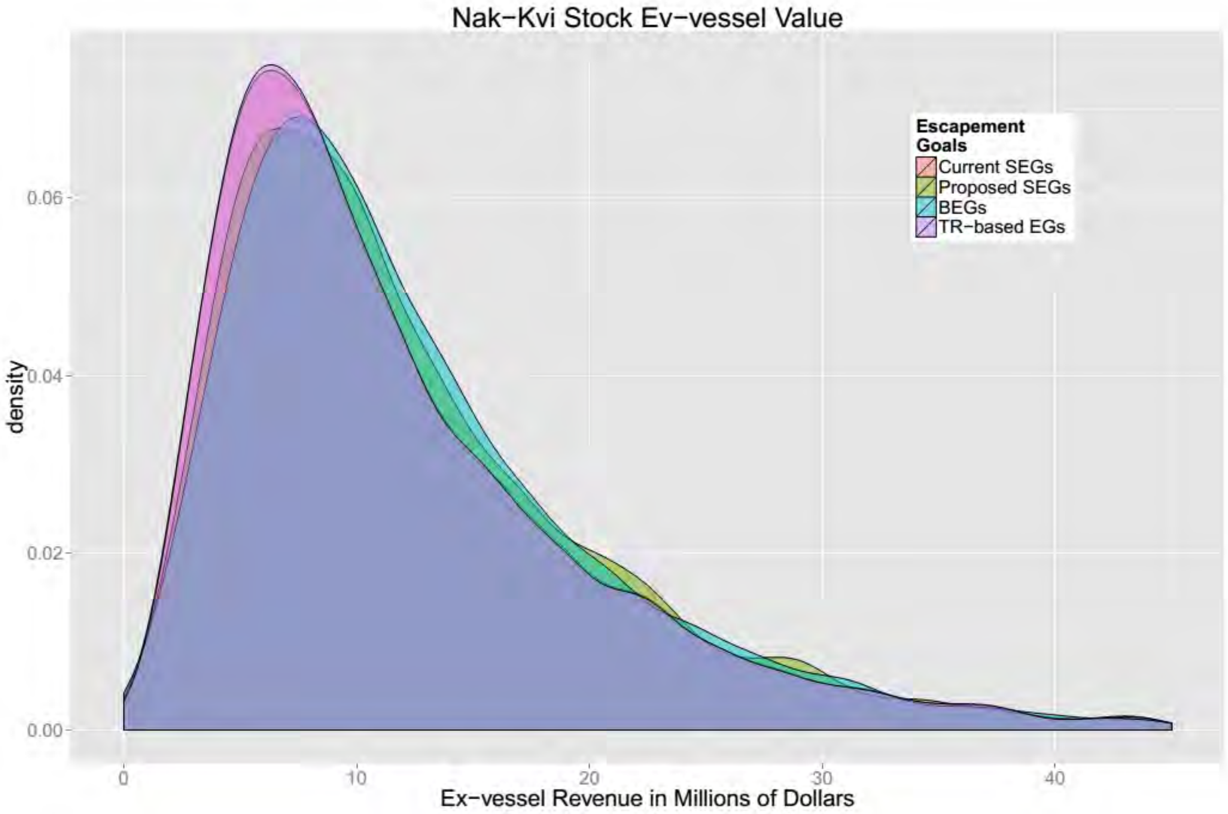
[20] Here we focused on revenues, but fewer openings would also be expected to reduce harvesting costs, so the argument is stronger when framed in terms of net revenues. Also, as long as harvesters can catch as much fish during the period that a district is opened, number of days that a district is opened would not be a good proxy to measure welfare of a harvester under each escapement policy.

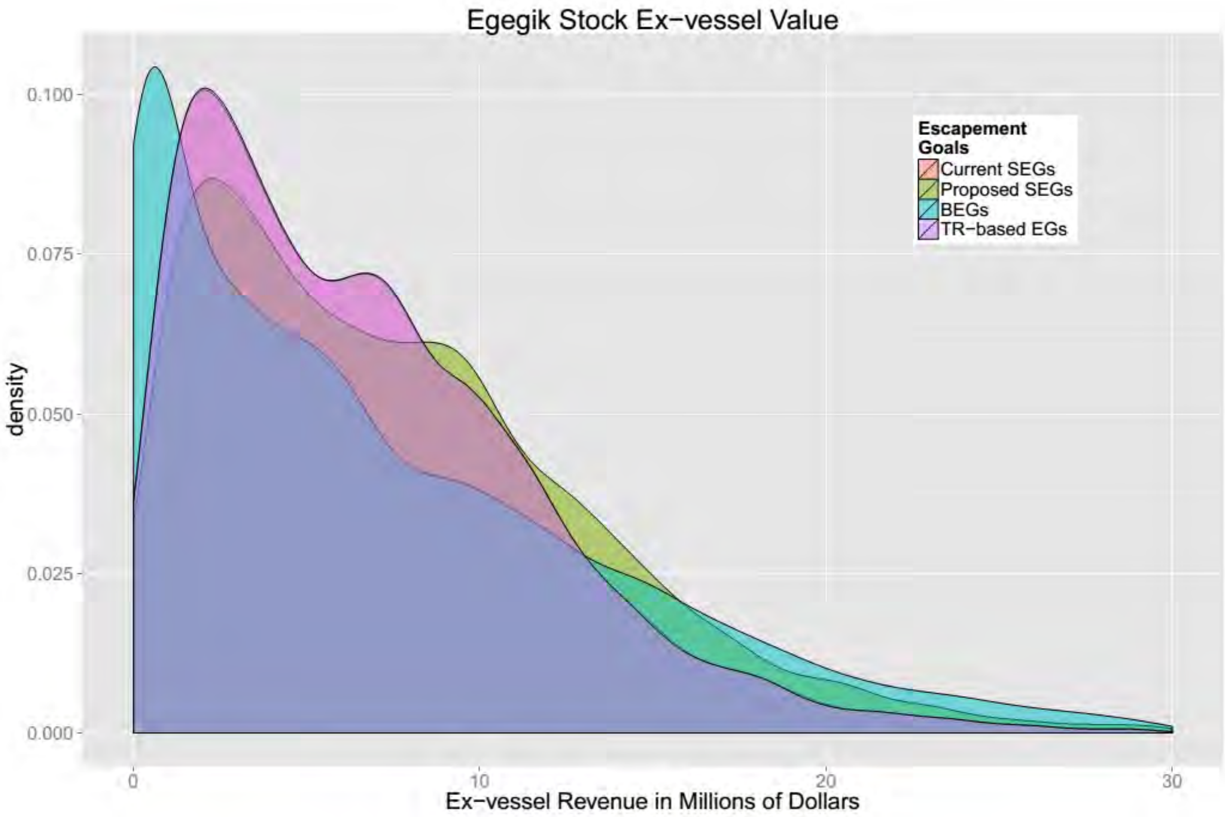
[21] The daily catch data was constructed using harvest rate by stock rather than harvest rate by district. Since there is no interception between west side and east side stocks, it was easy to accurately reconstruct annual ex-vessel revenue for Nushagak district (by adding up daily ex-vessel revenues for Igushik, Wood, and Nushagak stocks). However, the stock-based structure of the models makes it infeasible to reconstruct ex-vessel revenues for the east side districts due to cross-stock catch. For example, when Ugashik district is opened, harvesters catch not only Ugahisk stock, but also Naknek, Kvichak, and Egegik stock as well. Hence, the east side stocks' ex-vessel revenue density graphs can only be used as a proxy for potential ex-vessel revenues generated in the east side districts.

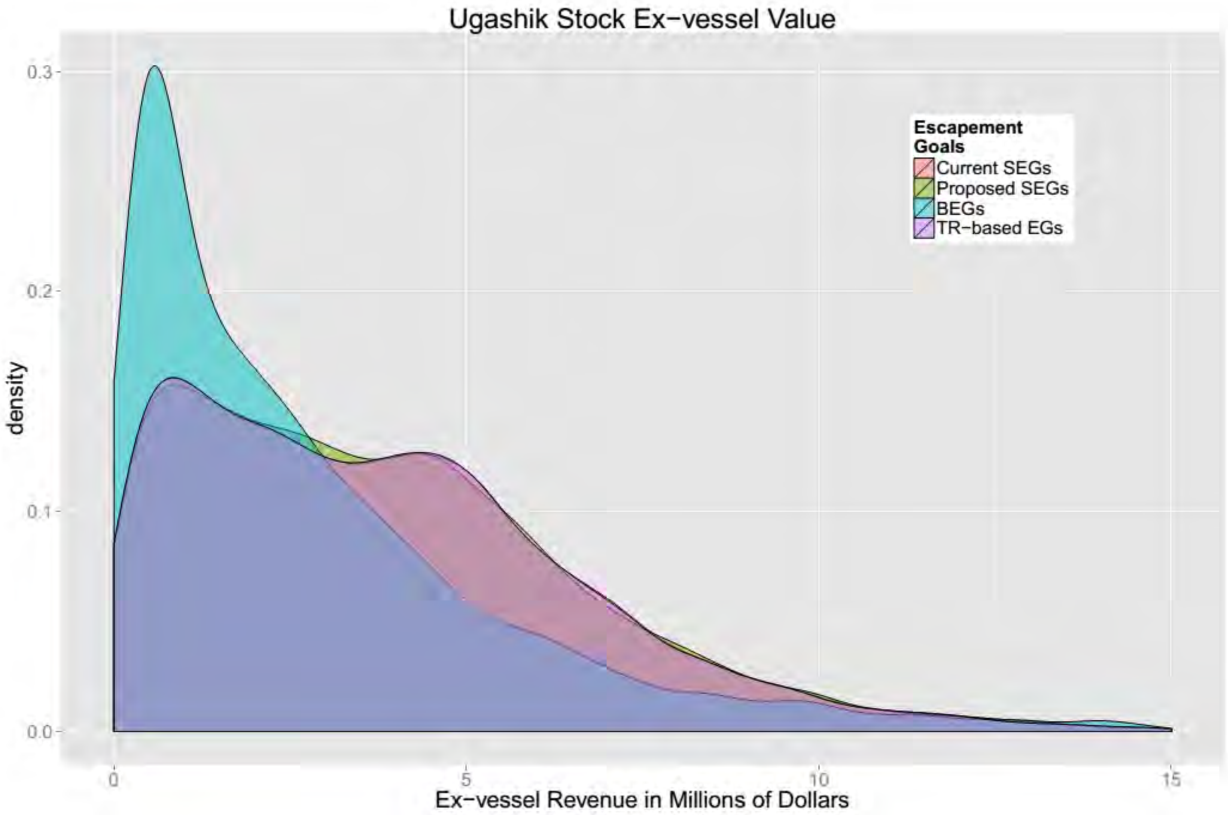
experiencing zero ex-vessel revenues and lower average ex-vessel revenues than other escapement goal policies. In general, current SEGs and TR-based EGs yield similar pattern of ex-vessel revenues across district or stocks. Proposed SEGs either performs slightly better or worse than the current SEGs.

Both sub-district closure frequencies and ex-vessel revenues per district/stock suggest that even if higher escapement goals would lead to higher mean annual catch, the setnet sector and vessels who do not switch districts within a season may not necessarily such benefits. Although the number of days open in each sub-district decreases when the escapement goals increase, the Bay-wide total annual catches still increased. This implies that the independent stochasticity (variability) in returns across different river systems helps to insure mobile harvesters against closures in any particular district. Even if one sub-district is closed for fishing (due to lack of returns for the season), other sub-districts can experience average higher returns supported by higher escapement goals, so the total catch can still be higher.

Figure 16. Distributions of ex-vessel revenues from the Naknek-Kvichak, Egegik, and Ugashik Stocks under four escapement goals policies across 100 simulations of final 74 years each.




Egegik Stock Ex−vessel Value
0.100
0.075
0.050
0.025
0.000
density
0
10
20
30
Ex−vessel Revenue in Millions of Dollars
Escapement Goals
Current SEGs
Proposed SEGs
BEGs
TR−based EGs


Ugashik Stock Ex−vessel Value
0.3
0.2
0.1
0.0
density
0
5
10
15
Ex−vessel Revenue in Millions of Dollars
Escapement Goals
Current SEGs
Proposed SEGs
BEGs
TR−based EGs

The decrease in district-specific openings under some EG policies may also increase the proportion of years where little or no harvest opportunities are provided. Table 9 shows the probability of having total Bay-wide catch of less than 5, 10 and 15 million fish under each EG policy. Based on our simulation results, the BEG policy was the only scenario where very low harvests are much more likely than under the status quo. Under BEGs, there was a catch of less than 10 million fish once about every 25 years. For the other three scenarios, this occurred about once to twice every 100 years. In addition, harvests of less than 15 million fish occurred 18.1% of the time under BEG management, almost twice as often as the other escapement goal policies.

Table 9. Percent of years when catches were less than 5, 10, and 15 million fish, Bay wide, across four escapement goal policies.

Probability of catching less than:	Current BEGs	Proposed BEGs	BEGs	TR-based EGs
5 Million Fish	0%	0.00%	0.23%	0%
10 Million Fish	1.70%	1.47%	4.39%	0.95%
15 Million Fish	12.9%	11.1%	18.1%	10%

Discussion

We developed models of processing decisions and product pricing to convert modeled sockeye salmon runs into predicted catches and harvester and processor revenues under four escapement goal policies: current SEGs, proposed SEGs, BEGs, and TR-based EGs. Even though average annual returns were significantly higher under alternative escapement policies, average annual catches, processor wholesale revenues, and harvester revenues were fairly similar.

Similar average annual catches across different escapement goal policies also translated into similar average processor and harvester revenues. This result illustrated the fallacy in the argument that fishery management policies that achieve maximum sustainable yield (MSY) also support better economic and social outcomes for the fishery. Previous research aimed an identifying MSY suggested that the current SEGs are significantly lower than the optimal escapement targets (BEGs). Even when the research had recognized the fallacy, the analysis still showed that a fixed MSY-based escapement goal policy could maximize catch (Bue et al. 2008). Our model indicated that without taking into account the limits to daily processing capacity in the Bay, larger fish returns may not necessarily yield higher catches. In fact, the MSY-based BEGs yielded lower mean annual catch than the current (and lowest overall escapement) SEGs in our simulation.

Our simulation results also showed that a higher mean return of fish was associated with a higher variance in the annual returns and catch. This translated into a higher probability of low-catch years with the higher EG policies. The higher mean and variance of return under fixed harvest policy result from Steiner et al. (2011) also demonstrated this type of trade-off. A typical MSY analysis (e.g., Ricker analysis) ignores this tradeoff, which is crucial to the stability of income to the harvesting and the processing sectors. This is particularly true for harvesters who specialize in one district in the Bay, as an increase in their district's escapement goal(s) would lead to higher district closure rates and lower average ex-vessel revenue for them. In other words, even if the average Bay-wide catch was higher under proposed SEGs and TR-based EGs, the benefits will not be distributed equally across all harvesters. Setnet harvesters and driftnet harvesters who do not switch districts might be worse off on average, and could be more financially vulnerable when their district experiences a low catch, low-income year. This type of analysis would not have been feasible without taking into account daily management scheme and daily processing capacity limit.

There are several limitations to our current model. Our analysis focused strictly on the long-term projection of revenues without taking into account potential losses incurred during the transitional period as runs build from policies to increase the escapement goals, and the costs incurred due to any commensurate increases in processing capacity (i.e., we present the last 74 years of the 100-year simulations). We generated future wholesale prices based on recent global market conditions and these will likely change over time. With continued competition from aquaculture, we may have further overestimated the potential value in increases in escapement goals and average run sizes. Schelle (2004) and Valderrama and Anderson (2013) suggested that a reduction in number of permits were necessary to increase harvester rents in the long-term. Our analysis had assumed that the harvesting power would not influence the revenue from alternative escapement goal policies. To the extent that harvesting power is a constraint to the analysis of higher run sizes, revenues from increases to escapement goals (and runs) may have been overestimated here.

Several improvements to the economic model are possible with more and better data collection in the future. First, the number of observations we had for production of fillets was limited since Bristol Bay did not start production of fillets until the early 2000s. Also, most of the publically available data sources do not distinguish the production of sockeye frozen fillets and H&G. Both factors limited the choices of pricing model for H&G and fillet we could employ. The processor model could be better developed with annual surveys of average number of days on limits and bay-wide processing capacity per line.

Data sources

- Alaska Department of Revenue: wholesale prices and quantity produced of fillet, H&G, and canned [trimester level] from 2002 – 2013 in Bristol Bay
- Monthly import and export quantities and prices from NOAA monthly trade data from 1980 – 2013
- Commercial Operator Annual Report (COAR): annual wholesale value and quantity produced in Bristol Bay from 1980 – 2010

- ADF&G Commercial Salmon Harvests and Ex-vessel Values: 1994 – 2013 ex-vessel prices for Bristol Bay
- Consumer Price Index (CPI) from St. Louis Federal Reserve Bank
- 2001 – 2012 Alaska Department of Labor and Workforce Development [Research and Analysis Section]
- FRI preseason forecast report 2001 – 2012

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Chapter 3

Conclusions from an Analysis of Alternative Escapement Goal Policies for Bristol Bay Salmon

Prepared by

Michael Link. Curry Cunningham, and Jocelyn Wang

March 10, 2015

Chapter 3 - Table of Contents

Introduction

In this chapter we will pull back from the technical details of the methods and results presented in Chapter 1 and 2 to make some general observations and draw conclusions based on the results of the analysis, as well as our knowledge of management of the fishery as it pertains to escapement goals (EGs). In the spirit of management strategy evaluation (MSE), we present the information upon which decision makers can make choices, given their objectives, preferences, and attitudes to risk. Early drafts of this chapter were presented to ADF&G and the study's Advisory Panel (AP) in March 2015 and this final version incorporates their input.

In general, we found there are limits to potential yield by increasing escapement goals to the theoretical levels that are expected to produce maximum sustained yield.

Factors that Limit the Direct Applicability of the Results to a Policy Prescription

Below are factors that highlight limitations of our analysis with respect to the prescription of specific escapement goal policies. As a result of these, and especially the first factor, it is up to decision makers and in our case the AP, to take these factors and our results in formulating recommendations to the Board of Fisheries and ADF&G.

1. What is best is a function of decision makers' objectives and risk profile. There is a fundamental trade-off between run and catch size and variation. Is variability and probability of really small catch years more important than median yield? Distributional effects among harvesters will be important to many; these were noted but not directly assessed or quantified.

2. We assumed future market and many industry conditions are the same as in the recent past. We did provide for additional processing capacity in policies that could be expected to increase daily catches, but factors such as the effect of aquaculture competition on some prices, would reduce the value of future catches and result in us overestimating the value of the harvest due to increases in escapement.

3. We did not factor in costs, only gross revenues from the catch. For example, the cost to markets and/or debt maintenance from really small runs was ignored. Also, for the policies to increase escapement such as BEGs, we ignored the cost to industry of this additional capacity. The result that significantly greater processing capacity would be needed to handle periodically large runs, while providing little increase and possibly decreases in average harvest. This highlights the potentially significant bias in our valuation of large increases in escapement like that from BEGs – the same or fewer fish would be caught at potentially much greater expense.

4. We modeled the midpoint of hypothetical ranges and did not directly assess the width of the ranges. However, the management model likely created somewhat similar outcomes in achieved escapement that we would expect from range-based escapement goal policies.

5. Transition costs to higher escapement levels were ignored in economic evaluation. In addition, we did not apply any discount rate to future revenue. To the extent these phenomenon are real, we have overestimated the value of future catches, and hence provide an optimistic valuation of BEGs and other higher escapement goal policies.

6. We used a less sophisticated assessment model of TR than would be available in reality. For example, we did not use an in-season estimate of run timing, which would improve accuracy and precision of the TR estimates. There are other indicators of run strength (e.g. Port Moller Test Fishery), which were not incorporated into the decision model. This simplification would result in undervaluing the yield and revenues from the TR-based policy.

Conclusions

1. We can expect a relatively flat plateau of catch and value of catch across a range of escapement levels; this has implications for EG setting and how to define "foregone harvest"

Our work has characterized uncertainty in how alternative escapement goal policies might perform in the future. This uncertainty stems from the following.

- Stock-specific changes in productivity over time.
- Our ability to accurately estimate spawner-recruit model parameters from the data.
- Random deviations from expected recruitment at any spawning abundance.
- Interannual differences in the timing and distribution of arriving fish that influence the efficacy of in-season management measures.
- The variability in run timing and its influence on our ability to predict run size.
- Responses of the fishing fleet and processors to harvest fish.
- Changing market conditions and value of Bristol Bay salmon.
- Value of Bristol Bay salmon changes based on the aggregate output by product form.

Given this uncertainty, narrowly defined escapement goals do not seem warranted.

What is "foregone harvest", and should it be used evaluate management performance? Our results presented in this report, Cunningham et al. (2015) and those of others (Fair et al. 2012) suggest that yields from Bristol Bay stocks are similar across wide ranges of escapement. We saw that fairly significant changes in escapement levels might change yields by as little as plus or minus 5% over the in the long term. Uncertainty in the magnitude of future Bristol Bay returns, associated with future transitions among high or low productivity regimes, estimation uncertainty in spawner-recruit model parameters, the observed spread in observed recruitment above and below model expectations (stochastic recruitment), and implementation uncertainty in achieving escapement goals, dwarf some of these differences (Chapter 1, and Cunningham et al. 2015).

In recent years there has been considerable consternation toward ADF&G management of the Bay fishery over the belief that all fish above the upper escapement range represents *foregone* harvest, never to be recaptured. In many systems, the data and our results do not support this. Additional fish in the escapement above most current SEGs will often replace themselves (making their offspring available to harvest in 4-5 years), or they will produce more than themselves, providing greater harvest in 4-5 years than they would have in the current year. Furthermore, there is little evidence from the Bristol Bay spawner-recruit data to suggest that extreme overcompensation (i.e., declining productivity) at high escapement levels leads to detrimental effects on future recruitment. Regardless, there are times when fish behavior (run timing, compression) increase implementation error. Managers in the Bay are, however, generally very good at achieving escapement targets and taking them to task on issues that are often either out of their control, or might actually produce more fish, seems unproductive.

Fishery managers should still be accountable for making good decisions, but our sense of this issue is that it would be much more constructive to evaluate performance based on the information they have at various points, and the behavior of the fish, the fleet and the processors, rather than simply the outcomes (i.e., final escapement achieved). That is, evaluate decisions based on process rather than outcomes. We see benefits to the Bay fishery by moving away from the current simplified and often erroneous metric of foregone harvest.

2. Current and Proposed SEGs are Economically Robust

In general, current and proposed SEGs performed well in terms of catches and revenue to the harvesting and processing sectors. This is likely not a coincidence.

The history of escapement goal setting in Bristol Bay suggests that the current suite of SEGs evolved under the influence of economic factors and limits created by management implementation (e.g., from mixed stock fishery concerns). Stakeholders' reaction to previous proposed changes to EGs, including in December 2012 (and in 2003) are consistent with this assertion. Our results showing the superior performance of current (and similar) proposed SEGs from explicitly taking into account economics further supports the idea that the Bristol Bay's SEGs have evolved to be optimal with respect to future catch and revenue. It would be helpful (and potentially less costly) if this could be more explicitly acknowledged and the less distinction drawn between SEG and OEGs.

3. Pursuing theoretical maximum yield through traditional BEGs will likely lead to less average yield and more variable yield than pursuing current and proposed SEGs, and the TR-based escapement goal policy we examined.

In Bristol Bay, BEGs equal to the spawning abundance that is theoretically expected to produce maximum sustainable yield (MSY) based on the traditional Ricker analysis (Fair et al. 2012), are not likely to yield the greatest catch (or the catch of the greatest value to harvesters and processors). We found that management implementation uncertainty and future variation in production will hinder the achievement of this theoretical maximum. Implementation uncertainty relates to the inability of the current fishery management structure and the industry to achieve theoretical MSY-based escapement goals across a wide range of run sizes given natural variation in run timing, fleet dynamics, processing capacities, and broadly or narrowly distributed fish arrivals. In addition, while setting BEG targets is likely to increase future sockeye returns for some stocks, this increase in returns may not be sufficient to overcome the increase in escapement required, leading to reductions future catch opportunity. Instead, MSY from this fishery may actually be achieved by managing to EG levels that are lower than the theoretical optimum.

The State of Alaska's Policy for the Management of Salmon Fisheries (5 AAC 39.222) describes BEGs and MSY as:

> *f (3) "Biological escapement goal" or "BEG" means the escapement that provides the greatest potential for maximum sustained yield; BEG will the primary management objective for the escapement unless an optimal escapement or inriver run goal has been adopted; BEG will be developed from the best available biological information, and should be scientifically defensible on the basis of available biological information; BEG will be determined by the department and will be expressed as a range based on factors such as salmon stock productivity and data uncertainty; the department will seek to maintain evenly distributed salmon escapement within the bound of BEG;….*
>
> *f (22) "maximum sustained yield" or "MSY" means the greatest average annual yield from a salmon stock; in practice MSY is achieved when a level of escapement is maintained with a specific range on an annual basis, regardless of run strength; the achievement of MSY requires a high degree of management precision and scientific information regarding the relationship between salmon escapement and subsequent return; the concept of MSY should be interpreted in a broad ecosystem context to take into account species interactions, environmental changes, an array of ecosystem goods and services, and scientific uncertainty;*

Why does any of this matter? ADF&G has a mandate to strive for MSY production through the use of BEGs. Bristol Bay has a long time series of high quality data on escapement and subsequent returns, and qualifies as a place where BEGs should be pursued by ADF&G. The concept of applying OEGs (optimum escapement goals)[1] in Bristol Bay arose in the December 2012 Board of Fisheries (BoF) meeting because some in the industry believed yield would be maximized at levels closer to the current SEGs. Generalizing, our results suggest the three alternative EG policies are likely to perform better in maximizing future yield when compared to the Ricker-based approach for estimating BEGs, and it seems various combinations of current and proposed SEGs could simply be adopted as defensible BEGs, thereby eliminating the ongoing tension between a Department mandate to find theoretical MSY when the practical MSY is likely to be achieved at lower escapement levels. Furthermore, this would eliminate a possible ongoing need for the Department to address one version of MSY and the BoF prerogative (or propensity) to impose an OEG that hits the practical maximum (via an OEG).

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[1] *f (25) "optimal escapement goal" or "OEG" means a specific management objective for salmon escapement that considers biological and allocative factors and may differ from the SEG or BEG; an OEG will be sustainable and may be expressed as a range with the lower bound above the level of SET, and will be adopted as a regulation by the board; the department will seek to maintain evenly distributed escapements within the bounds of the OEG.*

4. ***We predict some increase in yield from Egegik under the proposed SEGs and the TR-based EG than under the current SEG goal. Despite some increase in yield, the revenue from the harvests would likely be very similar.***

Results from Chapter 1 showed that we would expect harvest from Egegik to increase under the proposed SEGs (14%) and TR-based EGs (9%) compared to the current SEG (Chapter 1, Table 8). However, the economic analysis suggests that, in the long run, it is not likely that these increases would result in any higher ex-vessel revenue from the catch (Chapter 2, Figure 16). In this case, the economics modeling took into account how greater catches in the Bay would translate into different product mixes and a higher catch may not always translate into greater value to harvesters.

5. ***TR-based EGs, current SEGs, and proposed SEGs showed the least variability in expected annual catch; management of all stocks under a BEG policy significantly increases the chance of small Bay-wide annual harvests***

We saw significant increases in the variability in annual catches as escapement goals were increased. Although much of this variation was heavily influenced by the stocks not currently near the MSY-based BEG (i.e., Egegik and Ugashik) it did highlight a general phenomenon that management for BEGs will increase the chances of small catches in the Bay as a whole. Very small annual catches can be costly to the industry. We saw the chances of an annual harvest 10 million fish or less almost triple from current and proposed SEGs to the BEG, and four times more likely than under a TR-based policy (Chapter 2, Table 9). For harvests of under 15 million fish, the ratio ranged from 40-80% higher for BEG policy compared to the other three policies. The TR-based scenario had the least likely probably of Bay-wide catches below 10 and 15 million fish across all four policies examined.

6. ***The Need for Flexible and Adaptive Management***

We ranked the merits and expected outcomes of alternative EG policies using a suite of computer models approximating the Bristol Bay management system and the biology of major Bristol Bay salmon stocks, based historical data. There are multiple sources of uncertainty and biological variability in these predictions of future outcomes, some of which we quantified through various figures, tables, and statistical measures. However, all factors influencing decisions made by managers and those in industry could not be captured by our analyses.

Those on the AP were quick to acknowledge the limits of modeling based on data from the past, uncertainty of results, and, where some important simplifications had to be made. We have done our best to account for the estimation uncertainty in generating predictions for future recruitment from the historically observed spawner-recruit relationship by utilizing Bayesian methods when fitting spawner-recruit models and propagating the uncertainty in parameter values forward as we modeled predicted future outcomes. Future runs, product mixes, prices, and harvesting and processing revenues and costs may well differ substantially compared to the past. For example, if in the future, a guaranteed supply of fish was worth twice as much as an uncertain supply, managing to the lower ends of EGs may be superior to the midpoints.

The AP concerns arose most noticeably when we discussed the concept of TR-based escapement goals and ways of implementing them through management plans. There was a consensus among those on the AP to pursue benefits of a sliding scale escapement goal while maximizing the flexibility of managers to adapt to conditions in the future circumstances in a given year.

As an example to highlight the value of flexibility, in our evaluation of a TR-based EG for Egegik, we did not take into account the benefit of lower escapement from large runs when the rivers elsewhere in the Bay were producing little harvest. In this situation, the value of the harvest from Egegik would be higher than we estimate because our model adjusts the escapement goal upward. In this situation, taken in isolation, a TR-based goal would appear superior to a narrower SEG, when in fact it is not. This topic led to the conclusion that in such a situation, a wider EG, with more flexibility or discretion for the manager to hit in the lower or upper end of that range would be preferable to a more rigid and/or complex management plan that might produce suboptimal outcomes.

Finally, more rigid management plans and EG policies will likely lead to more frequent reconsideration of them by the Board of Fisheries as conditions change. Flexibility in the implementation of broader goals is valuable as long as managers are responsive to the circumstances in the fishery and in general, fishery managers in the Bay are responsive.

Recommendations of the Study's Advisory Panel

The study's AP met for its 5th and final meeting on March 5, 2015 to review the final project reports and discuss conclusions and recommendations to make to the Board of Fisheries. During this meeting, study team members presented the results from each chapter and the AP provided a useful critical review of assumptions and results. In light of the results, the AP formulated a consensus set of conclusions and recommendations to the Board of Fisheries to fulfill the charge of the study originally set out by the Board in December 2012.

The AP's recommendations build upon and hybridize three of the escapement policies we examined in this study: the current SEGs, proposed SEGs, along with language that captures the spirit of the TR-based policy (to achieve higher escapements in times of larger than average runs). The AP believed that if ADF&G could adopt a set of SEGs that are biologically sustainable and economically robust, implementation of OEGs by the Board of Fisheries would not be necessary. Specifically, there was a consensus among those on the AP to recommend the following, as quoted (italics and the table) from a letter from the AP to the Board of Fisheries (the full letter is provided in Appendix D).

> ***Conclusions***
>
> *A combination of existing and proposed SEGs (Dec. 2012) addresses biological and economic concerns of the industry.*

If the escapement goals proposed here are adopted by ADF&G and the Board of Fisheries makes the change below to management plan (s), the AP believes OEGs for these stocks are not necessary.

Recommendations

ADF&G adopt as SEGs (or BEGs) the lower bound from the existing escapement goals and the upper bound of the proposed goals (Table 1 below).

The Board of Fisheries implements regulatory language in district-specific management plans as to where generally within the adopted SEG range the Department should manage. For example:

The Department will manage for escapement to fall within the lower or upper half of the adopted river-specific escapement goal ranges, commensurate with pre-season and ongoing in-season assessment of run strength to the fishing district.

	Development of Recommended Ranges				
Stock	Current SEGs	ADF&G proposed (Dec. 2012)	**Advisory Panel (March 2015)**	Lower half of EG range	Upper half of EG range
Ugashik					
Lower	500	600	**500**	500	950
Upper	1,200	1,400	**1,400**	950	1,400
Mid/*Median*	850	1,000	-	725	1,175
Egegik					
Lower	800	900	**800**	800	1,400
Upper	1,400	2,000	**2,000**	1,400	2,000
Mid/*Median*	1,100	1,450		1,100	1,700
Igushik					
Lower	150	200	**150**	150	275
Upper	300	400	**400**	275	400
Mid/*Median*	225	300		213	338
Naknek					
Lower	800	900	**800**	800	1,400
Upper	1,400	2,000	**2,000**	1,400	2,000
Mid/*Median*	1,100	1,450		1,100	1,700
Wood					
Lower	700	800	**700**	700	1,250
Upper	1,500	1,800	**1,800**	1,250	1,800
Mid/*Median*	1,100	1,300		975	1,525
Nushagak					
Lower	370	400	**370**	370	635
Upper	840	900	**900**	635	900
Mid/*Median*	655	700		503	768
Kvichak					
Lower	2,000	---------------no change----------------------			
Upper	10,000				

These recommendations will be taken up at the Board of Fisheries meeting planned for March 17-20 in Anchorage, Alaska.

References

Fair, L.F., C.E. Brazil, X. Zhang, R.A. Clark, and J.W. Erickson. 2012. Review of salmon escapement goals in Bristol Bay, Alaska, 2012. Alaska Department Fish and Game, Anchorage, Alaska. Fisheries Manuscript Series No. 12-04.

Appendix A. Mission Statement for the Board of Fisheries Committee on Bristol Bay OEGs.

From the Board of Fisheries record, December 2012.

"*Purpose*: *ADF&G has agreed to suspend the adoption of various recommended sockeye salmon escapement goals for two years, meaning that the goal will go into effect for the 2015 salmon season. The recommended escapement goals being deferred are Ugashik, Egegik, Naknek, Wood, Igushik, and Nushagak river sockeye salmon. The Nushagak River SEG and OEG will change in 2013, but only to account for the sonar conversion from Bendix to DIDSON. This delay in implementation is intended to give the industry time to meet, discuss, and analyze economic information that would assist the Board in developing OEGs.*

It is the intention of the Board that a committee be formed with Board member Webster, an ADF&G designee, and a representative of BBSRI (Michael Link). The commercial fishing industry has pledged a commitment to integrate a professional scientist and an economist in the discussion."

Appendix B. Terms of Reference for the Study’s Advisory Panel and a Summary of Meeting Date and Locations.

Bristol Bay Science and Research Institute

Terms of Reference

Advisory Panel to a Study of Alternative Escapement Goals for Bristol Bay, Alaska

February 2014

Introduction and Purpose

This Advisory Panel (AP) has been formed to provide information, expertise, and feedback during the execution of a scientific study to examine alternative escapement goals for sockeye salmon in Bristol Bay.

The AP was created to help make the results from the scientific study empirically based, practical, and useable by those in the industry and on the Alaska Board of Fisheries.

Background

In December 2012 the Alaska Board of Fisheries (Board) struck a committee to oversee the analysis of *optimum escapement goals* (OEGs) for Bristol Bay sockeye salmon. OEG is a broad term that encompasses escapement goals designed to take into account factors other than biological yield. OEGs can be fixed escapement goals or policies designed to meet objectives such as fixed harvest rates or fixed catches. The Board action was in response to proposed revisions to Bristol Bay sockeye salmon escapement goals by the Alaska Department of Fish and Game (ADF&G). At the time, the Board stated that the OEG analysis was:

> "*… intended to give industry time to meet, discuss, and analyze economic information that would assist the Board in developing OEGs*"

ADF&G agreed to postpone the implementation of recommended Biological Escapement Goals (BEGs) for six sockeye stocks until the 2015 season, pending the results of an OEG analysis, which are expected prior to the 2015 season.

The Bristol Bay Economic Development Corporation (BBEDC) committed to helping lead an analysis of alternative escapement goals for Bristol Bay sockeye salmon. Some salmon processors in Bristol Bay and the driftnet fleet's Regional Seafood Development Association (BB-RSDA) also pledged financial support to the analysis.

Advisory Panel Membership

Prerequisites for serving on the AP will be expertise in Bristol Bay in one or more of the following areas:

- Harvesting
- Processing
- Fishery management
- The regulatory process of the Alaska Board of Fisheries

In addition, scientists and economists familiar with the methods used in this study may serve on the AP.

AP members will be selected by the Project Manager (M. Link) based their expertise and knowledge of the Bristol Bay salmon fishery; he will also rely on input from BBEDC, BB-RSDA, ADF&G, and others in the Bay's harvesting and processing industry. The 3-person OEG committee appointed by the Board of Fisheries (Regnart, Johnson, and Link) will also serve on the AP.

The Project Manager serves as the Chair of the AP. AP members serve at the discretion of the Chair. Although the Chair may remove an AP member for any reason, diverse opinions and perspectives will not be grounds for removal. Removals would be reserved primarily for any obvious violations of the guiding principles of the AP (see Section 6).

Any temporary or permanent replacements for individual members must be approved in advance by the Chair.

Role of the Advisory Panel

The AP will assist the study team by providing input in several ways.

- Identify sources of foregone wealth in the fishery that might be captured under alternative escapement goal management.
- Provide information and data on harvesting and processing costs.
- Help to characterize how harvesting and processing costs and product value might change under alternate escapement goal strategies.
- Assist with the development of alternative escapement goal strategies for the study team to analyze.
- Help characterize long-term processor investment decisions and long-term harvester fishing decisions under alternative escapement goal strategies.
- Help evaluate the practical consequences of any modifications to escapement goal management in Bristol Bay.
- Act as ambassadors to the study within the greater Bristol Bay fisheries community by providing colleagues and others with their first-hand experience with the transparency and applicability of methods and rigor of the study.

Input to the study team will be done in a workgroup manner and input by the AP is not binding. However, a constructive and positive treatment of AP input can be expected given the goal of AP members acting as ambassadors to the greater community.

Scope and Methods of Work

The AP will provide its input to the study team primarily through 5 or 6 one-day meetings beginning in March 2014 and ending December 2014.

The study team acknowledges the value of AP members' time and will strive to respect that and operate meetings in the most efficient manner. The Project Manager will provide the AP with an agenda and packet of supporting materials approximately 2 weeks prior to each meeting. The packet will contain materials to read before the upcoming meeting and/or questions to ponder. The AP members should prepare to address these questions during the meetings. Preparation for each meeting will typically require 1 day of effort.

The AP meeting format will be along the lines of a "workgroup" or "working group", where questions and discussion are encouraged at any time during the meeting. On rare occasions during presentations, the Chair may ask to hold questions until the end. AP members are free to suggest modifications to the meeting format and content.

Code of Conduct, Fairness, and Impartiality

AP members have volunteered for service because of their long history and passion for the sustainability of the Bristol Bay salmon fishery.

AP members recognize that with a fair and equitable examination of escapement goals in Bristol Bay has the potential to improve the economic condition for all in the fishery. The value of the study will ultimately depend on the degree to which others view this as a fair and equitable examination of the issues.

AP members will adhere to the following guiding principles.

- Be considerate of the time and efforts of fellow AP members and those on the study team.
- Help to build trust and maintain a creative and supportive environment during meetings.
- Separate ideas from individuals; critique ideas and not individuals.
- Recognize the value of trust when brainstorming new ideas and use discretion when discussing AP dialogue outside of the AP.
- Respect confidentiality when members explore hypothetical situations or share information on cost or revenue data.
- Not distribute or discuss with others preliminary results that the study team asks to remain confidential until further analysis and review is complete.
- Employ fairness and impartiality when describing the study results to others; put differently, avoid manipulating results from the study.

Expenses and Compensation

The study will cover the costs associated with travel and accommodation, and will provide a stipend to compensate for AP members’ time for each meeting attended.

Measures of Success

The AP will have been successful if the study provides the following.

- An accurate and empirically based examination of the potential benefits of alternate and realistic escapement goal policies.
- Others in the fishery community with access to their peers who understand the strengths, weaknesses, and applicability of the study results and conclusions.
- Can speak to the study’s results in a fair and impartial manner in the regulatory environment.

Panel Members

Jeff Regnart, Director,
Commercial Fisheries Division, ADF&G

Michael Link, Project Manager,
LGL Alaska Research Associates, Inc.

Abe Williams, Bristol Bay driftnet
fisherman, *F/V*

Bill Monroe, Fleet Manager
North Pacific Seafoods, Inc.

John Boggs, President and CEO
Deep Sea Fisheries, Inc.

Fritz Johnson, Regional Fisheries
Coordinator, BBEDC; Alaska Board of
Fisheries

Matt Luck, Bristol Bay driftnet fisherman
F/V Meg J

Vince Webster, Setnet fisherman,
Naknek-Kvichak District

John Heins, General Manager, North
Naknek Plant, Trident Seafoods

Dr. Matt Reimer, Institute of Social
Science Research, University of
Alaska Anchorage

Meeting dates and locations for the Advisory Panel of the Bristol Bay OEG Study, 2014-15.

March 5, 2014	Millennium Hotel, Anchorage, AK
March 24, 2014	North Pacific Seafoods, Seattle, WA
June 9, 2014,	Southwest Alaska Vocational and Education Center, King Salmon, AK
Sept. 25, 2014	North Pacific Seafoods, Seattle, WA
March 5, 2015	North Pacific Seafoods, Seattle, WA

Appendix C. Alternative escapement goal ranges and targets in thousands of fish across four management strategies examined (TR = Total Run).

	Management Strategies / Escapement Goals and Ranges					
	1	2	3	4		
Stock	Current SEGs	Proposed SEGs	BEGs	TR-Based EGs (based on 50th percentile of historic		Difference
Ugashik				TR < 2.5M	TR > 2.5 M	
Lower	500	600	1,972	500	900	
Upper	1,200	1,400	3,178	1,200	2,300	
Mid/*Median*	**850**	**1,000**	***2,602***	**850**	**1,600**	**750**
Egegik				TR < 4.7 M	TR > 4.7 M	
Lower	800	900	3,704	800	1,200	
Upper	1,400	2,000	7,213	1,400	2,300	
Mid/*Median*	**1,100**	**1,450**	***5,242***	**1,100**	**1,750**	**650**
Igushik				TR < .72M	TR > 0.72M	
Lower	150	200	194	150	260	
Upper	300	400	402	300	600	
Mid/*Median*	**225**	**300**	***291***	**225**	**430**	**205**
Naknek				TR < 3.3 M	TR > 3.3 M	
Lower	800	900	1,326	800	1,200	
Upper	1,400	2,000	2,480	1,400	2,600	
Mid/*Median*	**1,100**	**1,450**	***1,858***	**1,100**	**1,900**	**800**
Wood				TR < 3.2M	TR > 3.2M	
Lower	700	800	962	700	900	
Upper	1,500	1,800	5,741	1,500	2,100	
Mid/*Median*	**1,100**	**1,300**	***1,550***	**1,100**	**1,500**	**400**
Nushagak				TR < 1.2M	TR > 1.2 M	
Lower	370	400	549	340	550	
Upper	840	900	1,083	760	1,100	
Mid/*Median*	**655**	**700**	***801***	**590**	**825**	**235**
Kvichak						
Lower	2,000	---------------no change-------------				
Upper	10,000		---------			
		Total Difference in escapement if all runs were in large TR bin:				**3,040**

Appendix D. Letter to the Alaska Board of Fisheries, from the Advisory Panel to a study of alternative sockeye salmon escapement goals in Bristol Bay, March 10, 2015.

BBSRI

Bristol Bay Science
And Research Institute

March 10, 2015

Tom Kluberton
Chairman, Alaska Board of Fisheries

RE: Evaluation of escapement goals for Bristol Bay

Dear Mr. Kluberton,

Following up on my letter of 19 January 2015, please find attached two draft reports from a study of alternative escapement goals for Bristol Bay.

> *Analysis of Escapement Goals for Bristol Bay Sockeye Salmon taking into Account Biological and Economic Factors*
>
> *An evaluation of biological escapement goals for sockeye salmon of Bristol Bay, Alaska.*

The study's Advisory Panel (AP) met in Seattle on March 5, 2015 to review the study's results and conclusions. Here in this letter, the AP unanimously puts forward for the Board of Fisheries and ADF&G consideration at the March 17-20 meeting in Anchorage the following.

Conclusions

- A combination of existing and proposed SEGs (Dec. 2012) addresses biological and economic concerns of the industry.
- If the escapement goals proposed here are adopted by ADF&G *and* the Board of Fisheries makes the change below to management plan (s), the AP believes OEGs for these stocks are not necessary.

Recommendations

- ADF&G adopt as SEGs (or BEGs) the lower bound from the existing escapement goals and the upper bound of the proposed goals (Table 1 below).
- The Board of Fisheries implements regulatory language in district-specific management plans as to where generally within the adopted SEG range the Department should manage. For example:
    - *The Department will manage for escapement to fall within the lower or upper half of the adopted river-specific escapement goal ranges, commensurate with pre-season and ongoing in-season assessment of run strength to the fishing district.*

For illustration purposes, Table 1 also provides the ranges of the lower and upper half of its proposed escapement goal ranges. With this recommended language for management plans, the AP does not envision that the Department be held accountable for falling tightly within these ranges as a function of run size, in all years. Instead, the AP believes the proposed language (above) provides sufficient guidance and flexibility for the Department to achieve higher escapements at times of large runs to the Bay.

Table 1. Current, previously proposed, and Advisory Panel proposed escapement goal ranges in thousands of fish for six sockeye salmon stocks in Bristol Bay, Alaska.

	Development of Recommended Ranges				
Stock	Current SEGs	ADF&G proposed (Dec. 2012)	**Advisory Panel (March 2015)**	Lower half of EG range	Upper half of EG range
Ugashik					
Lower	500	600	**500**	500	950
Upper	1,200	1,400	**1,400**	950	1,400
Mid/*Median*	850	1,000	-	725	1,175
Egegik					
Lower	800	900	**800**	800	1,400
Upper	1,400	2,000	**2,000**	1,400	2,000
Mid/*Median*	1,100	1,450		1,100	1,700
Igushik					
Lower	150	200	**150**	150	275
Upper	300	400	**400**	275	400
Mid/*Median*	225	300		213	338
Naknek					
Lower	800	900	**800**	800	1,400
Upper	1,400	2,000	**2,000**	1,400	2,000
Mid/*Median*	1,100	1,450		1,100	1,700
Wood					
Lower	700	800	**700**	700	1,250
Upper	1,500	1,800	**1,800**	1,250	1,800
Mid/*Median*	1,100	1,300		975	1,525
Nushagak					
Lower	370	400	**370**	370	635
Upper	840	900	**900**	635	900
Mid/*Median*	655	700		503	768
Kvichak					
Lower	2,000	--------------no change---------------------			
Upper	10,000				

We will have at least three members from the AP available for the March 17-20 meeting in Anchorage (Regnart, Webster, Link), and if you like, I am willing to make an evening presentation to Board members and interested public.

On behalf of the Study's Advisory Panel,

Michael Link

Michael R. Link
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cc.
Advisory Panel: J. Regnart, F. Johnson, M. Luck, A. Williams, V. Webster, B. Monroe, J. Heins, J. Boggs, M. Reimer

Keggie Tubbs, BBSRI Executive Director

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