Halibut Bycatch Management Research

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Executive Summary

This simulation study examines two potential policy issues for the Pacific halibut fishery: Part 1 explores the potential impacts of reducing halibut bycatch in the Bering Sea and Gulf of Alaska, and Part 2 examines the potential impacts of reducing the minimum size limit in the directed commercial fishery. A sex- age-structured simulation model was developed to account for the dynamics of numbers-at-age, by sex, and biomass of the coastwide population of Pacific halibut. The simulation model was parameterized based on the recent 2011 IPHC stock assessment model and uses model estimates of the numbers-at-age, recruitment, natural mortality, fishing mortality and selectivity to initialize the simulation model from 1996–2011. Three alternative future recruitment scenarios, density-independent and density-dependent growth models are used to simulate a range of alternative scenarios 15 years into the future. Simulation model outputs include, estimates of coastwide exploitable biomass, spawning biomass, commercial yield, discards, wastage, and the value of the directed fishery based on halibut prices in Homer Alaska. The average exploitable biomass, spawning biomass, landed value, or other performance measures, between the years 2020–2025 was used as a summary statistic to compare alternative policy options.

Reducing non-directed fishery bycatch by 50% in the Bering Sea Aleutian Island (BSAI) or the Gulf of Alaska (GOA) had very little impact on the simulated coastwide estimates of exploitable biomass, or spawning biomass. The levels of bycatch reduction were redistributed to the directed fishery; about 90% of the reduced bycatch was recovered by the commercial fishery assuming the same 2011 coastwide selectivities from the 2011 IPHC assessment. Yield loss ratios in the directed commercial fishery were mainly less than 1; the current age/size composition of the stock and the selectivity of the commercial and bycatch gears determine the yield loss ratio. The largest source of mortality in the coastwide stock is the directed commercial fishery.

Reducing the size limit from the current 32 inches to 29 or 26 inches, resulted in an increase in simulated estimates of exploitable biomass. This increase was associated with a reduction in the mortality associated with the commercial wastage. In the simulations, impacts of other users (bycatch, recreational, and personal use) of the halibut resource was assumed constant based on the 2011 harvest values. Decreasing the size limits lowers the overall coastwide landed value because the composition of the catch has a much higher proportion of small low value halibut (assuming $5.00 per pound for halibut in the 5-10 pound size category). The real economic gains to be made in the directed fishery are associated with reduced cost of fishing because fewer sublegal sized fish are discard. Expected proportions of fish caught that are of sublegal size are 60% with a 32 inch size limit and 9% with a 26 inch size limit.

Acknowledgments

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Part I

Impacts of bycatch & wastage on halibut yield

Overarching objective: Investigate the effects of halibut bycatch and wastage in the GOA and BSAI fisheries on halibut yield and spawning biomass.

1.1 Introduction

To examine the effect of halibut bycatch and wastage in the Gulf of Alaska (GOA) and Bering Sea Aleutian Island (BSAI) fisheries, a sex- and age-structured simulation model was developed to simulate halibut exploitable biomass, spawning biomass, yield and wastage in the directed fishery in response to alternative bycatch limits in all other fisheries that incidentally harvest halibut. The simulation model is conditioned on the output of the IPHC annual assessment model (wobblesq) and the model structure is very similar in the components of catch that are removed from the system. In the IPHC assessment model, coastwide removals are aggregated into 5 catch categories that represent the commercial and IPHC research catches, bycatch and wastage in two size categories (U32 and O32), recreational fisheries, and personal use including subsistence harvest.

1.1.1 Overview of total mortality in the IPHC model

Key to understanding the simulation model developed for this report are the various components of the age-specific total mortality rate that are set up in the IPHC assessment model. The IPHC model is set up such that total instantaneous sex- age-specific total mortality rates are used to propagate the estimated numbers-at-age over time. Specifically, the sex-age-specific mortality rate is set up as follows:

$$Z_{h,i,j} = M_h + \sum_k F_{h,i,j,k}$$
$$Z_{h,i,j} = M_h + \sum_k f_{h,i,k} s_{h,i,j,k}$$

where h is an index for sex, i is an index for year, j is an index for age, and k is an index for fishing fleet. This is a separable model for sex- age-specific total mortality where the year effect (fishing mortality $f_{h,i,k}$) is estimated for each gear in each year, and the age effect (selectivity $s_{h,i,j,k}$) is a piece-wise linear function of average length-at-age. The natural mortality rates M_h are assumed to be independent of age and do not vary over time. For each fishing gear there is a total of $I+1$ fishing mortality parameters and 16 estimated selectivity parameters. These are determined by fitting the model to catch-at-age data.

There are five specific fishing fleets (i.e., $k = 5$) in the model and the corresponding catch is aggregated (in some cases disaggregated by sex):

1. Commercial setline and IPHC research,
2. U32 bycatch and wastage,
3. O32 bycatch and wastage,

4. recreational sport fishery,

5. personal use (subsistence fishery).

The U32 and O32 bycatch and wastage are not broken down into specific gear types for specific areas, and to the best of my knowledge, all of this aggregation of the catch data and age-composition is done through a pre-processing of the available data.

In order to accurately represent the age-specific total mortality rates in the simulation model, the annual age/sex specific fishing mortality rate parameters for each gear and the length-based selectivity parameters were used to calculate the total mortality rates in the simulation model. These model parameters were made available by the IPHC commission staff.

Another key component to the IPHC assessment model is the mean length-at-age and mean weight-at-age data. Estimates of exploitable biomass (EBio) and spawning biomass (SBio) from the model is the product of the estimated numbers-at-age (sex) and the empirical weight-at-age that is vulnerable to the coast-wide selectivity in the setline fishery. These empirical data were made available for use in this simulation model herein. In addition to selectivity, weight- and length-at-age data, the calculation of EBio also involves the use of an age-misclassification matrix (smearing). The algorithm for this age-smearing was made available, but was not implemented due to time constraints.

1.2 Simulation Model

A detailed analytical description of the simulation model is provided in Appendix B.2. The following is a summary description of specific model outputs that are used to describe the impacts of bycatch and wastage on halibut biomass, yield, spawning biomass and wastage, as well as, the corresponding size/age composition. Ultimately, a decision table is constructed where the expected outcome (performance measure) is evaluated across alternative future states (good/bad recruitment, increasing/decreasing growth) for a series of alternative policy options. The rows of this table represent alternative future states, and the columns correspond to different harvest policies. Assuming all future scenarios are equally likely, then the performance and sensitivity of alternative harvest polices can be easily compared.

1.2.1 Overview of the simulation model

Running a single realization of the simulation model consists of several steps that can be broken down into two periods: (1) initializing the model from 1996:2011, (2) future projections from 2012:2026. Refer to Appendix B.2 for detailed information on step (1). Future projections in step (2) consist roughly 10 steps described by the following psuedo code:

1. Initialize future recruitment vector based on recruitment scenario

2. Project future weight at age based on growth scenario (done in calcGrowth)

3. Future selectivity continues to be a function of length (done in calcSelectivities)

4. Loop from nyr to nyr+nyr_proj

5. Calculate EBio at the start of the year (EBio = N * sel * wa)

6. Apportion EBio to management areas (l) based on 2011 apportionments

7. Calculate management area CEY as 0.215*EBio$_l$ or 0.16*EBio$_l$

8. Calculate the corresponding fishing rate ($f_{h,i,k}$)

9. Calculate Z and update total mortality.

10. Update numbers at age and return to 4) until end of projection years.

Future recruitment is actually initialized in the year 2007, as halibut are roughly 6 years of age before they recruit to the exploitable biomass based on the setline fishery selectivity. To approximate future growth for each sex, a von Bertalanffy growth model was fit to the IPHC survey mean length-at-age data collected between 1996 and 2011 (Figure 1.1 a,c).

Converting numbers-at-age to weight-at-age, the allometric relationship $w_j = al_j^b$ was used. The scaling and power parameters ($a = 9.321x10^{-6}$ and $b = 3.16$) were taken from Courcelles (2011) and assumed to be the same for females and males (Figure 1.1 b,d). Attempts were made to estimate the corresponding allometric parameters from the empirical survey length-at-age and commercial catch weight-at-age data; however, there was difficulty obtaining reasonable estimates from these two separate sources of information. Log-log plots of these data did not reveal a linear relationship between the log-length and log-weight (estimates of the exponent b were much less than 3 and there was a strong pattern in the residuals). In fact, the empirical weight-at-age data for males shrink from 14 pounds at age-6 to less than 14 pounds at ages 7-10. Therefore, all weight-at-age data in the simulation model are based on the allometric relationship from the Courcelles (2011) study.

Selectivity in the simulation model is the exact same length-based selectivity that is used in the IPHC assessment. The same piece-wise linear function that is used in the IPHC assessment model to convert mean length-at-age to age-based selectivity for the five different harvest categories is also used in this simulation model (Figure 1.2). Overall, males recruit to the various gears at much older ages due to slower growth of male halibut.

Simulated exploitable biomass each year is based on the sum of products between the numbers-at-age, weight-at-age, and selectivity-at-age in the commercial gear for both sexes combined. Apportionment of this coast-wide exploitable biomass to each of the statistical areas is based on the same apportionment scheme used by the IPHC staff in 2011. The constant exploitable yield (CEY$_{i,l}$) in year i for management area l was based on the application of area-specific harvest rate of 0.215 (areas 2A-3A) and 0.161 (areas 3B-4CDE).

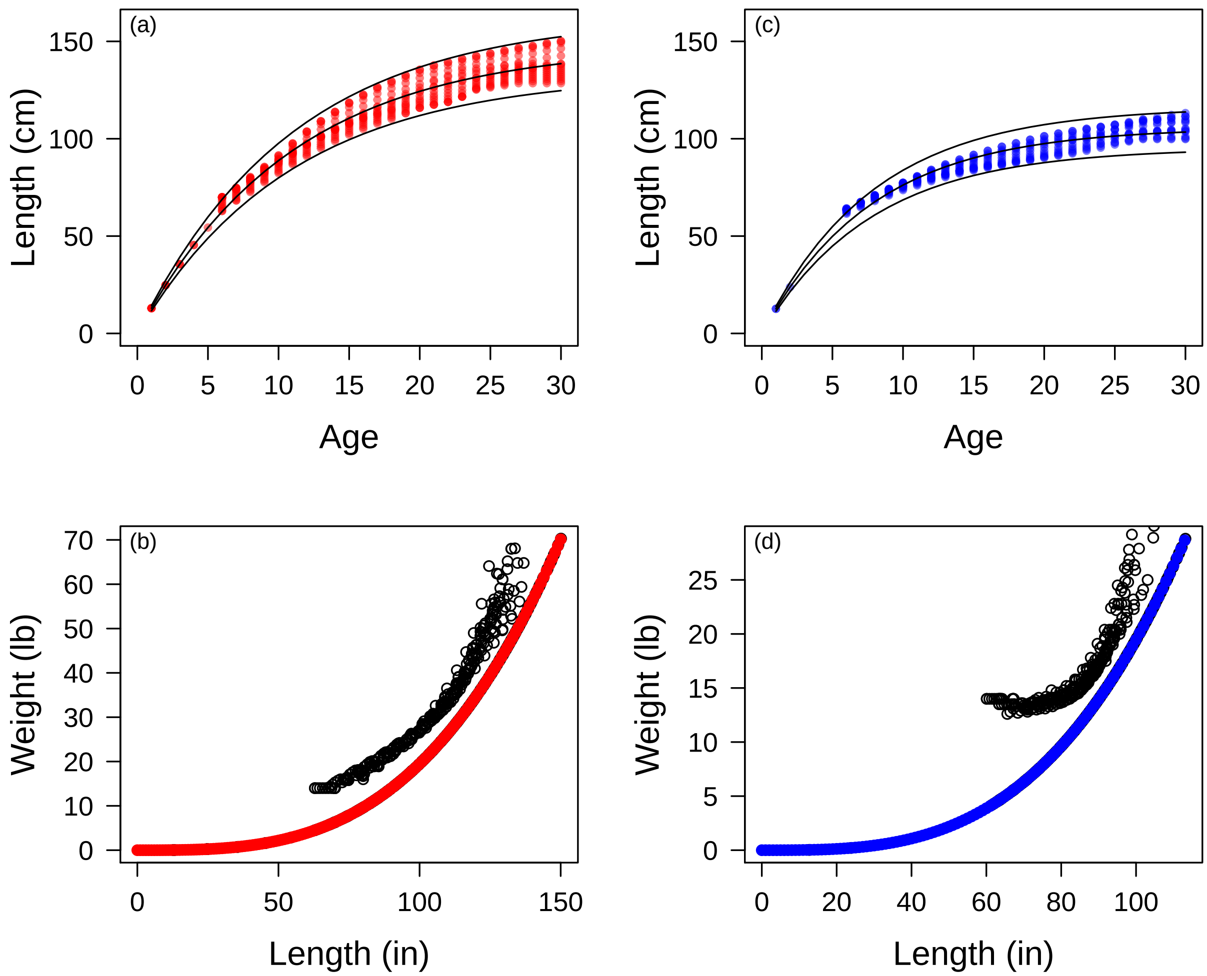

Figure 1.1: Observed mean length-at-age for female (a) and male (c) halibut in the IPHC research surveys between 1996 and 2011. Fitted lines are the von Bertalanffy growth model with the boundaries based on a 10% coefficient of variation in the asymptotic length. Estimated parameters for females are $L_\infty = 148.06$, $k = 0.0915$, and for males $L_\infty = 105.73$, $k = 0.1275$. Panels b (female) and d (male) show the length-weight relationship used in the model, along with the empirical catch weight-at-age data used in the IPHC assessment (open circles).

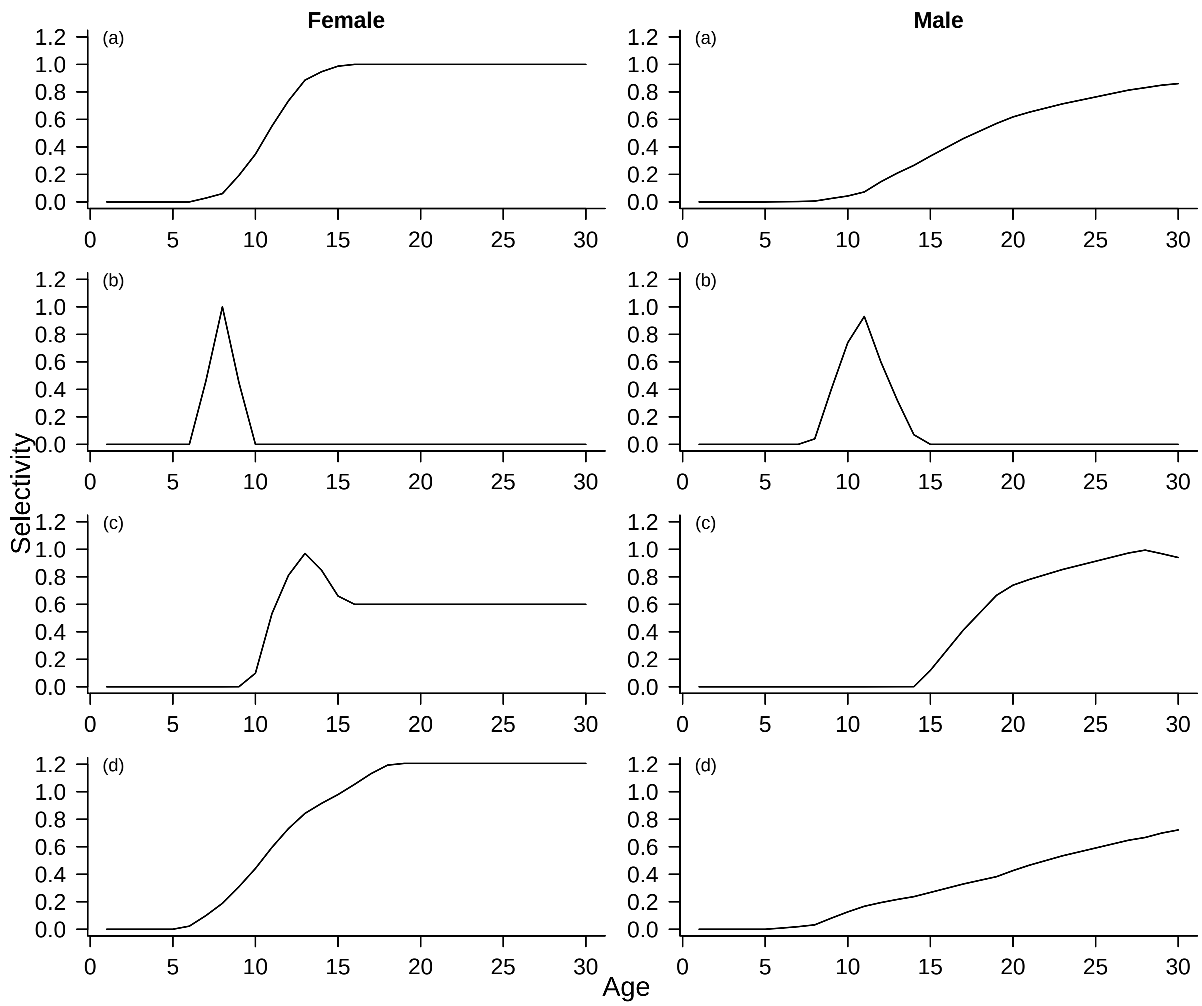

Figure 1.2: Age-based selectivity coefficients for female and male halibut for the setline fishery (a), U32 (b), O32 (c), the recreational and personal use fisheries (d).

1.2.2 Calculating setline fishery catch share

Annual allocations to the directed setline fishery in each of the areas are determined by first subtracting the expected bycatch/wastage from the area CEY. To simulate the same procedure for each statistical area, annual directed setline allocation was calculated as:

$$C_{i,k=1} = \mathrm{CEY}_{i,l} - \sum_{k=2}^{k=5} C_{i,k},$$

where the catch allocations for gears other than the setline fishery ($k > 1$) are determined *a priori*. The rule differs slightly for area l=2B where 88% and 12% of the allocation is given to the commercial and recreational fisheries, respectively. A key component to the calculation of setline fishery catch share is that mandated reductions in bycatch levels are given entirely to the commercial fishery, with the exception of area 2B where the recreational fishery would also receive a corresponding increase.

1.2.3 Calculating area specific fishing mortality rates

A critical component of the simulation model is calculating the sex/age-specific fishing mortality rates from each of the major fisheries that target halibut or intercept them as bycatch. The IPHC uses two terms for the non-targeted mortality: (1) wastage, which is the catch of undersize fish, lost skates and loss at the rail of halibut in the directed fishery, and (2) bycatch, which is the interception of halibut in non-targeted fishery including groundfish trawl, longline, trap, and pelagic trawl.

The catch equation used in the IPHC assessment model and in this simulation model assumes that both natural mortality and fishing mortality occur simultaneously. This equation, also known as the Baranov catch equation, is given by:

$$C_{i,k} = \sum_h \sum_j \frac{N_{h,i,j} w_{h,i,j} f_{h,i,k} s_{h,i,j} (1 - \exp(-Z_{h,i,j}))}{Z_{h,i,j}}$$

In this simulation model, the annual fishing mortality rate ($f_{h,i,k}$) for gear k is solved for using an iterative method where it is assumed that the sex ratio of the catch is the same as the ratio of female:male vulnerable biomass. This approach differs from the approach used in the IPHC assessment, where annual fishing mortality rates for females are treated as latent variables, and the male fishing mortality rate is assumed to be proportional to the female fishing mortality rate. The latter method could not be used in the simulation model because it would require a catch allocation by sex.

For the directed setline fishery, the wastage component from this fishery is a combination of undersized fish and legal sized fish that are lost at the rail, or died. To simulate this process, a joint probability model was developed to account for the wastage of undersized fish only. The joint probability model is defined as:

$$v_{h,i,j,k} = s_{h,i,j,k}(r_{h,i,j,k} + (1 - r_{h,i,j,k})d_k),$$

Table 1.1: Summary calculations for model output

Exploitable Biomass	$EBio_i = \sum_h \sum_{j=6}^{j=30} N_{h,i,j} w_{h,i,j} \exp(\nu_{h,i,j,k=1})$	(T1.1)
Spawning Biomass	$SBio_i = \sum_{j=6}^{j=30} N_{h=1,i,j} w_{h=1,i,j} p_{h=1,j}$	(T1.2)
Commercial Wastage	$WBio_i = \sum_h \sum_j \frac{N_{h,i,j} w_{h,i,j} f_{h,i,k=1} s_{h,i,j,k=1} (1 - r_{h,i,j,k=1}) d_{k=1} (1 - \exp(-Z_{h,i,j}))}{Z_{h,i,j}}$	(T1.3)
Commercial Yield	$YBio_i = \sum_h \sum_j \frac{N_{h,i,j} w_{h,i,j} f_{h,i,k=1} s_{h,i,j,k=1} r_{h,i,j,k=1} (1 - \exp(-Z_{h,i,j}))}{Z_{h,i,j}}$	(T1.4)
Lost Yield	$LBio_i = YBio_i^{(f_{k=2,3}=0)} - YBio_i$	(T1.5)
Bycatch Yield	$BBio_i = \sum_h \sum_j \sum_{k=2}^{k=3} \frac{N_{h,i,j} w_{h,i,j} f_{h,i,k} s_{h,i,j,k} r_{h,i,j,k} (1 - \exp(-Z_{h,i,j}))}{Z_{h,i,j}}$	(T1.6)
Yield Loss Ratio	$YLR_i = \frac{LBio_i}{BBio_i}$	(T1.7)

where $v_{h,i,j,k}$ is the sex/age specific vulnerability to fishing from gear k in year i, $s_{h,i,j,k}$ is the probability of capturing a fish of age j, $r_{h,i,j,k}$ is the retention probability (i.e., the probability of being greater than the size limit for a given age), and d_k is the discard mortality rate associated with gear k. See section 2.2.1 for more details on the development of retention probability model.

1.2.4 Model outputs

Summary equations for the simulated model output are presented in Table 1.1. The simulated exploitable biomass ($EBio_i$) is the vulnerable biomass available to the commercial fishery (T1.1), where $k = 1$ denotes the selectivity for the commercial setline gear. Annual spawning stock biomass ($SBio_i$) is based on the female component only ($h = 1$) and the empirical weight-at-age data and the proportion mature $p_{h,j}$, (T1.2). Note that the exploitable biomass in the IPHC assessment is based on the empirical weight-at-age data from the commercial catches and ranges from ages 6:20 from 1996:2001, and ages 6:25 in 2001:2011 period. The commercial wastage in the simulation model is based only on the undersized fish that are discarded (T1.3), where $s_{h,i,j,k=1}$ is the commercial age-specific selectivity (a function of fish length), $r_{h,k,j,k=1}$ is age-specific retention probability, and $d_{k=1}$ is the discard mortality rate for the commercial fishery and is assumed to be 0.17 for this study. The commercial yield of legal sized fish is given by (T1.4).

To calculate the yield loss due to bycatch in non-directed fisheries, the simulation model was projected forward in time where the only source of fishing mortality is the directed fishery (including deaths from wastage), recreational, and personal use. To do this, bycatch allocations for the U32 and 032 fisheries were set to 0 and the corresponding fishing rates for these two gears are also determined to be 0 for all future projection years. This simulation run is denoted as $YBio_i^{(f_{k=2,3}=0)}$. The lost yield due to bycatch is the difference between the commercial yields with and without bycatch fishing mortality (T1.5). Note also, that with no bycatch fishing mortality, the annual allocation to the commercial fishery is the Constant Exploitable Yield ($\mathrm{CEY}_{i,l}$) minus the recreational and personal use allocations:

$$C_{i,k=1} = \mathrm{CEY}_{i,l} - \sum_{k=4}^{k=5} C_{i,k}.$$

In other words, in the scenario with no bycatch, the commercial fishery allocation increases by the amount normally set assigned for bycatch.

1.3 Simulation Scenarios

The simulations performed in this study are deterministic with a range of recruitment and growth options that roughly correspond to the ranges of observed growth and recruitment between 1996 and 2011. Ideally, future projections of this nature would include a stochastic component for recruitment based on a historical distribution of realized recruits and Monte Carlo procedures would be used to construct plausible ranges of future scenarios. This was not done in this simulation due to time limitations. As an alternative, the deterministic simulations were used to span a wide range of recruitment and growth hypotheses.

Three alternative future recruitment scenarios are explored, where future recruitment is based on the average recruitment estimated between 1996 and 2006 and $\pm 60\%$ average recruitment. These scenarios are denoted as poor, average, and good recruitment. The definition of recruitment in this simulation model is an age-1 halibut, so future recruitment was simulated by altering the number of age-1 fish starting in the year 2007. In this case, the first simulated cohort would enter the fishery in 2012 at age 6.

Two alternative scenarios were used to project future growth of halibut beyond 2011. To simulate alternative states of future growth a density-dependent relationship between cohort strength and the asymptotic length of males and females was developed. Growth varied by adjusting the asymptotic length of each cohort as a function of recruitment density. For example, if recruitment is roughly 2.7 times larger than the average recruitment, the the asymptotic length would decrease from 148 cm to 139 cm under density-dependent growth (Figure 1.3). The other alternative state was to assume that the 2011 mean length-at-age data from the setline survey was the new growth paradigm and remained constant well into the future.

A key component of the density-dependent growth model and the three alternative hypotheses about future recruitment is that it allows for growth to continue to decline under

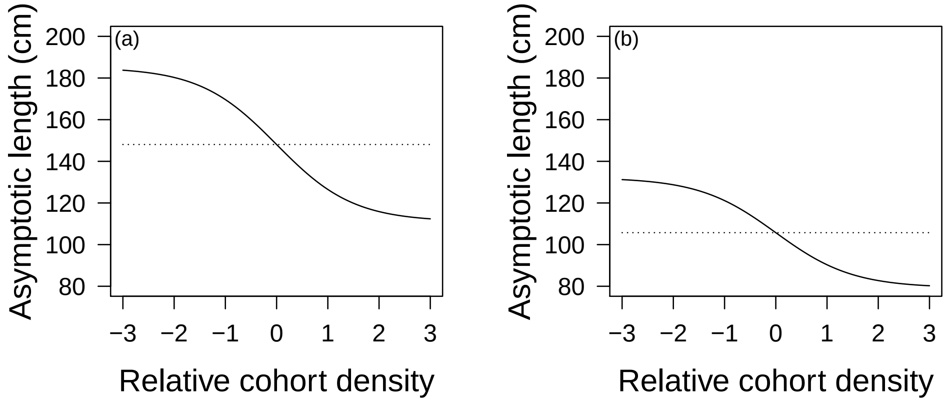

Figure 1.3: Relationship between asymptotic length $l_\infty^{(h)}$ for females (a) and males (b) and cohort density. Under density-dependent growth, $l_\infty^{(h)}$ decreases with increasing density (solid line) and density independent growth (dotted line).

scenarios with increasing recruitment. The opposite case occurs with below average recruitment; growth rates increase with low cohort densities.

1.4 Alternative policy options

Three alternative policies were explored to examine the impacts of bycatch adjustments in the non-directed fisheries. First a status quo policy was developed where the by catch levels observed in the 2011 fishery were held constant for all future simulation years (Table 1.2). The other two policies reduced the bycatch levels in the BSAI (areas 4ABCDE) or the GULF (3AB) to 50% of the 2011 levels, respectively.

For each of the alternative policies, the simulation model was run with a combination of poor, average, and good recruitment with density-independent and density dependent growth (a total of 6 model runs for each policy). Each of these alternative hypotheses were assumed to be equally plausible and a single score was developed to compare alternative policy options. For each of the model outputs (e.g., exploitable biomass, spawning biomass, yield, etc.) the average simulated value between the years 2020 and 2025 were arbitrarily selected for policy comparison.

1.5 Results

The initial numbers-at-age, age-1 recruits, fishing mortality rates and size selectivity parameters were all used to initialize this simulation model. Estimates of the sex/age-specific total mortality rates between this simulation model and the wobblesq model are nearly identical.

Table 1.2: The 2011 area apportionment, harvest rates, and observed landings for U32, O32, recreational (sport) and personal use. These catch levels were assumed constant into the future with the exception of area 2B, where 88% and 12% of the available CEY is allocated to the commercial and recreational fishery, respectively.

Area	Apportionment	Harvest Rate	Comm.	U32	O32	Sport	Personal
2A	0.024	0.215	-	0.040	0.110	0.398	0.025
2B	0.134	0.215	-	0.322	0.172	-	0.405
2C	0.105	0.215	-	0.192	0.219	1.313	0.425
3A	0.354	0.215	-	2.744	1.064	4.541	0.313
3B	0.158	0.161	-	1.507	0.437	0.025	0.023
4A	0.057	0.161	-	0.867	0.479	0.018	0.015
4B	0.055	0.161	-	0.288	0.329	0.000	0.001
4CDE	0.113	0.161	-	2.205	1.367	0.000	0.038

Trends in exploitable biomass between the two models differ due to at least two factors (Figure 1.4): age-smearing and differences in the weight-at-age data used to calculate exploitable biomass. In the IPHC assessment model, the annual calculation of exploitable biomass is based on the predicted numbers-at-age with aging error (smearing) times the empirical weight-at-age data from the commercial fishery. The simulation model does not use an age-misclassification matrix to smear the numbers at age, and the weight-at-age data is based on the allometric length-weight relationship and the empirical mean length-at-age data from the setline survey. The net results is that the predicted exploitable biomass in the simulation model is less than the predicted exploitable biomass from the IPHC assessment (Figure 1.4).

Figure 1.4 summarizes the results of the status quo scenario for the exploitable biomass, where 667 million pounds is the average predicted coastwide exploitable biomass over all three recruitment hypotheses with density-independent growth. This figure is the prototype that will be used to examine all response variables to simulated bycatch reductions.

The effect of increase recruitment density of each simulated cohort on growth rates is summarized in Figure 1.5. The asymptotic length of each cohort is a function of relative cohort density; with high densities the asymptotic length decreases. For example the an age-15 female halibut can weigh as little as 15.3lb. at high recruitment densities and as much as 42.8lb. at low recruitment density. Density-dependent growth has a large effect on the calculation of exploitable biomass, largely due to the increase in proportion of males that are now vulnerable to the fishing gear. Whereas, density-dependent growth is less important in the calculation of female spawning biomass, as females grow much faster and larger than males.

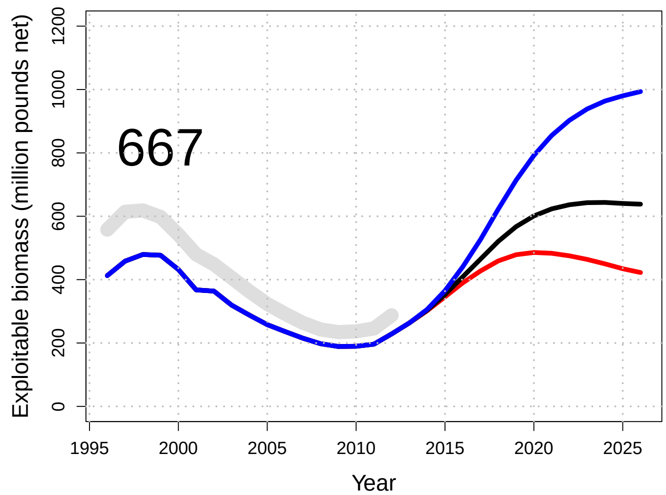

Figure 1.4: Example of simulation model output for the exploitable biomass under poor, average and good recruitment. The thick grey line is the exploitable biomass output from the IPHC wobblesq assessment conducted at the end of the 2011 fishing season.

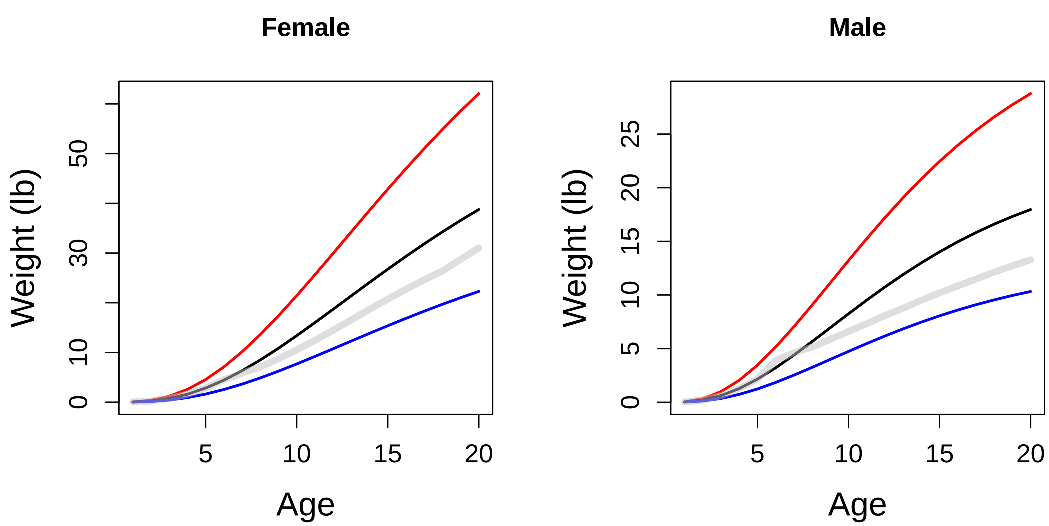

Figure 1.5: Simulated weight-at-age for halibut under low recruitment densities (red), average recruitment densities (black), and high recruitment densities (blue).

1.5.1 Effects of bycatch reduction on EBio

Overall, reducing bycatch in BSAI or the GULF by 50% has very little effect on the coastwide exploitable biomass. The average exploitable biomass between 2020 and 2025 ranged from 597 million lbs to 667 million lbs (Figure 1.6). Note that under the density-dependent growth scenario (bottom row of Figure 1.6), the biomass of the poor recruitment scenario is greater than the biomass of the good recruitment scenario. This difference in biomasss, in comparison to the density-independent growth scenario, demonstrates how slower growth under high recruitment density can have a significant impact on the exploitable biomass. Numerically, however, halibut abundance in numbers is much larger in the good recruitment scenario.

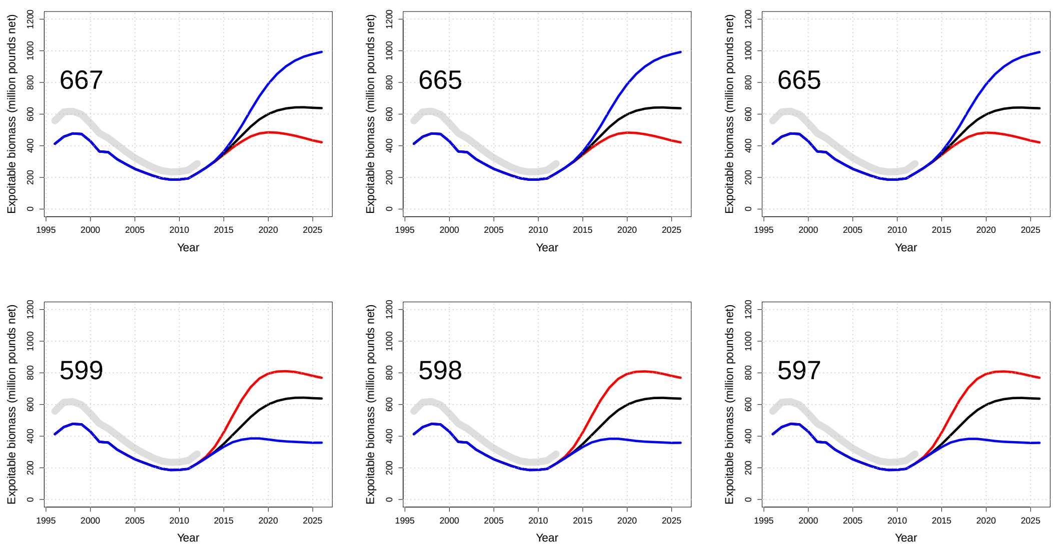

Figure 1.6: Simulated coastwide exploitable biomass under the assumptions of density-independent growth (top row) and density-dependent growth (bottom row) for the Status Quo scenarios (left), 50% bycatch reduction in BSAI (middle), and 50% bycatch reduction in the GULF (right). Poor, average, and good recruitment scenarios denoted with, red, black and blue lines, respectively.

1.5.2 Effects of bycath reduction on Spawning biomass

Reducing bycatch in the BSAI and GULF fisheries also has little impact on the projected coastwide female spawning stock biomass (Figure 1.7). Projected female spawning biomass ranges between 472 million pounds to 506 million pounds under density-dependent and density-independent growth scenarios, respectively. The impacts of density-dependent growth on female spawning stock biomass is much less than the impacts on the exploitable biomass. This is largely due to the addition of faster growing males (at low density) in the calculation of exploitable biomass.

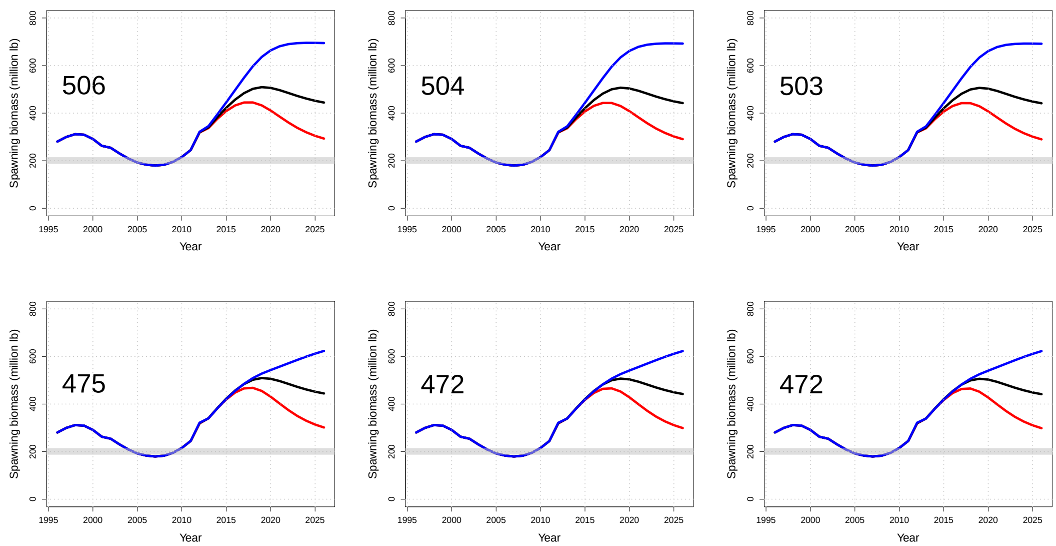

Figure 1.7: Simulated coastwide female spawning biomass under the assumptions of density-independent growth (top row) and density-dependent growth (bottom row) for the Status Quo scenarios (left), 50% bycatch reduction in BSAI (middle), and 50% bycatch reduction in the GULF (right). Poor, average, and good recruitment scenarios denoted with, red, black and blue lines, respectively. The thick grey reference line corresponds to 30% of unfished spawning biomass.

1.5.3 Effects of bycatch reduction on commercial yield

The effects of reducing commercial bycatch in BSAI or the GULF by roughly 2.7 million pounds on the commercial yield is roughly a 2.5 million pound increase in the commercial catch (Figure 1.8). There is not a corresponding 1:1 increase in coastwide commercial yields with a reduction in bycatch in BSAI or the GULF management areas because the yield loss ratio (loss in commercial yield:bycatch) is less than 1 (Figure 1.9).

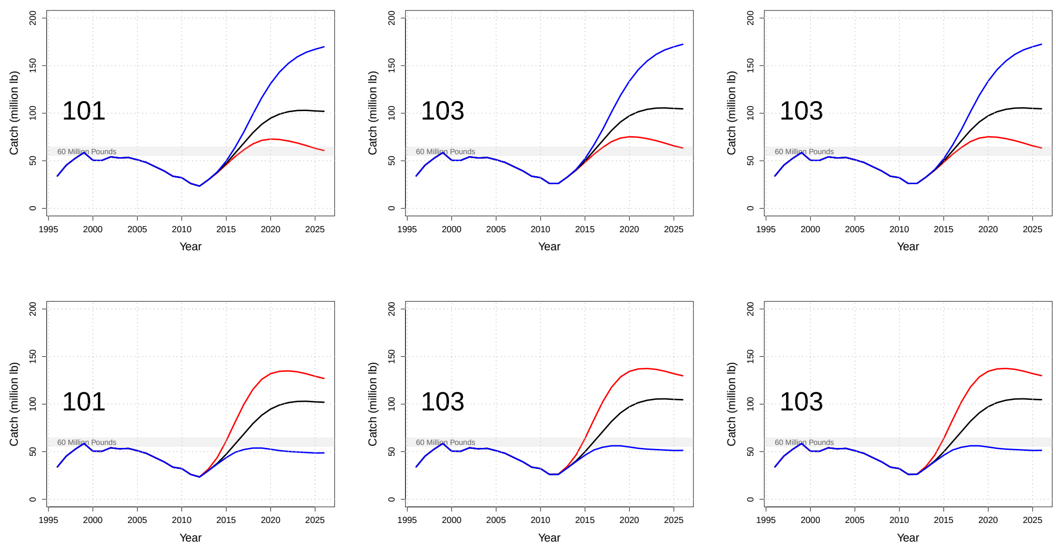

Figure 1.8: Simulated coastwide commercial yield under the assumptions of density-independent growth (top row) and density-dependent growth (bottom row) for the Status Quo scenarios (left), 50% bycatch reduction in BSAI (middle), and 50% bycatch reduction in the GULF (right). Poor, average, and good recruitment scenarios denoted with, red, black and blue lines, respectively.

Trends in the yield loss ratios under constant growth assumptions are very similar due to stabilizing biomass-at-age in the simulated populations. However, under the density-dependent growth hypotheses trends in the yield loss ratios differ markedly. With reduced growth rates, the yield loss ratios are less than scenarios with increased growth rates. In short, there is some compensation in the yield associated with increased growth rates at low density. There is however, no substantial difference in the yield loss ratios with decreasing the bycatch rates in BSAI or the GULF regions (Figure 1.9).

1.5.4 Effects of bycatch reduction on commercial wastage

The modest increases in commercial yield associated with bycatch reduction in the non-targeted fisheries results in a corresponding increase in commercial waste. Waste increases from an average of 2.796 million pounds to 2.891 million pounds under the density independent growth hypotheses (Figure 1.10). Under the density-dependent growth hypothesis

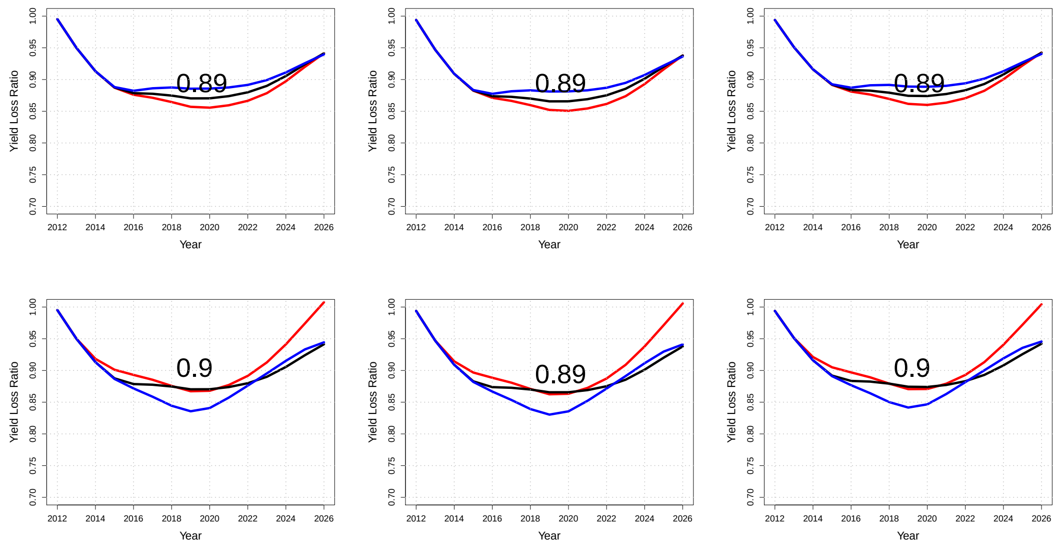

Figure 1.9: Simulated coastwide commercial yield loss ratios under the assumptions of density-independent growth (top row) and density-dependent growth (bottom row) for the Status Quo scenarios (left), 50% bycatch reduction in BSAI (middle), and 50% bycatch reduction in the GULF (right). Poor, average, and good recruitment scenarios denoted with, red, black and blue lines, respectively.

wastage increases from 2.192 million pounds to 2.287 million pounds. At low recruitment densities, increasing growth rates actually result in reduced wastage under the current size limit of 32 inches (81.28 cm).

1.6 Discussion

The overarching objective of this study was to investigate the impacts of bycatch reduction in the BSAI and Gulf of Alaska on the halibut yields, exploitable biomass, spawing biomass and wastage in the directed commercial fishery. This was accomplished by using a sex/age-structured simulation model to account for future biomass and fishing mortality rates under alternative hypotheses about future recruitment and growth rates of halibut. The simulation model was, in part, parameterized using estimates of numbers-at-age and sex in the 1996, age-1 recruits from 1996–2006, empirical length-at-age data from the setline survey, a length-weight relationship from a recent study and fishing mortality rates from the directed fishery, 032, U32, recreational and personal use fishing fleets. All of these parameter inputs were taken from the most recent IPHC assessment of Pacific halibut (see Hare, 2012, wobblesq model). The simulation model did not perfectly replicate estimates of exploitable biomass in the IPHC assessment largely due to the differences in the average weight-at-age data.

The IPHC assessment model uses empirical weight-at-age data obtained from the commercial fishery catch. At ages 6-10 the mean weight-at-age data samples are largely biased

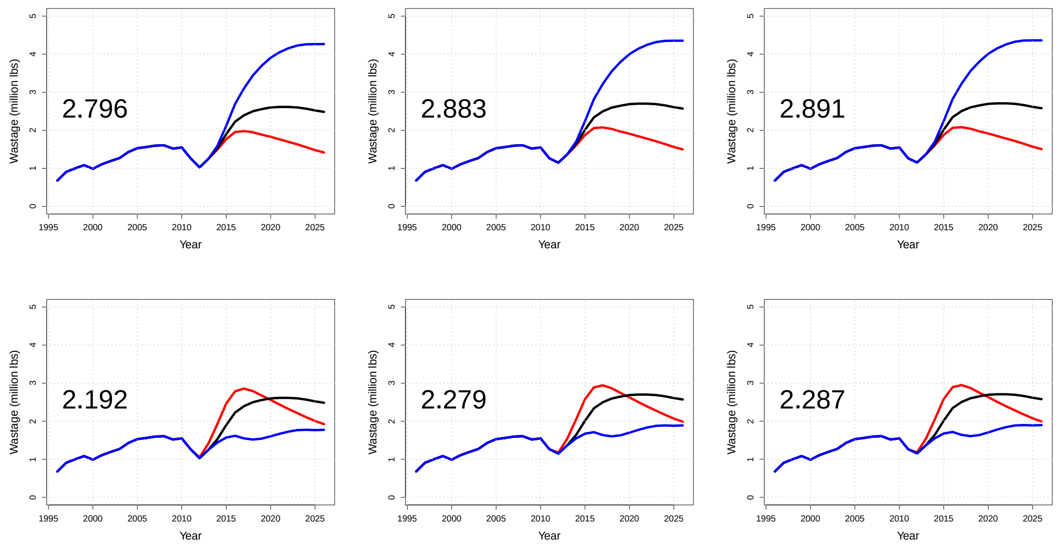

Figure 1.10: Simulated coastwide wastage from the commercial fishery under the assumptions of density-independent growth (top row) and density-dependent growth (bottom row) for the Status Quo scenarios (left), 50% bycatch reduction in BSAI (middle), and 50% bycatch reduction in the GULF (right). Poor, average, and good recruitment scenarios denoted with, red, black and blue lines, respectively.

towards faster growing (larger) fish that are of legal size. For the purposes of simulating future biomass, it was not possible to come up with a simple procedure to replicate this size-selective process. In lieu, growth curves for female and male halibut were constructed from the empirical length-at-age data obtained in the setline survey between 1996–2011. Simulated weight-at-age data was then based on the allometric length-weight relationship developed by Courcelles (2011). The net result of using this growth curve is that simulated exploitable biomass between 1996-2011 was scaled downwards. The overall trends between the biomass simulated in this study and the IPHC assessment were nearly identical. This difference in projected biomass would change the overall scale of the simulated results, but would have very little influence on the relative changes in simulated exploitable biomass (and spawning biomass) over the two alternative management procedures that involve reducing the bycatch of non-targeted fisheries in the BSAI, or the Gulf of Alaska.

There are alternative approaches to modelling density-dependent growth. In the case adopted in this model, growth rates of individual cohorts are established at birth and are strictly a function of the density of that cohort relative to the average cohort density. The reason for adopting this approach, rather than a time-varying approach, is that it conveniently does not allow for individual fish to shrink in length. Unfortunately, this assumption does not allow for growth rates of individual cohorts to change in response to changing environmental conditions (if they were also modelled) or changes in the density of cohorts associated with fishing. For example, it may be plausible that growth rates of an individual cohort may increase over time as the density of halibut is reduced through natural and fishing mortality rates. Growth rate responses to changes in density have been observed in many experimental populations of rainbow trout in freshwater lakes (Post et al., 1999).

The results of the bycatch reductions in the BSAI and GOA regions do not appear to have much of an influence on the coastwide estimates of exploitable biomass and spawning biomass. The principle reason is that for every pound of reduced bycatch, there is a corresponding increase in the directed fishery. However, it appears that the directed fishery has more of an impact on the exploitable biomass than the bycatch fishery. This was demonstrated by the ratio of lost yield in the directed fishery per pound of bycatch taken by other fisheries. Or in other words, 10 pounds of bycatch removed is roughly equivalent to 9 pounds of yield lost to the commercial fishery.

Another important point about bycatch impacts on the halibut stocks lies in the small regional scale. In both this simulation model and the assessment model developed by the IPHC, there is no explicit or implicit spatial representation of the large-scale management areas. Unfortunately, it is not possible to examine how reducing bycath in area 4CDE, would affect the exploitable biomass, spawning biomass, wastage, etc. in the specific areas. Migration and movement of halibut between the management areas, and the lack of information about migration, is one of the primary reasons why the coastwide assessment model was adopted. It is possible that a reduction in bycatch in a specific area, may provide a local increase in exploitable biomass and impact catch rates in the directed fishery. But at this time data are insufficient to capture these small scale dynamics.

In summary, reducing halibut bycatch by 50% in the BSAI or GOA regions by 2.7 million pounds has no large impacts on the projected estimates of coastwide spawning biomass or exploitable biomass. Further, this reduction of 2.7 million pounds results in about a 2.5 million pound increase in the directed fishery; simulated yield loss ratios were less than 1.0 and are a function of the current age-structure in the population. The directed commercial fishery is by far the largest component of total mortality in the coastwide assessment model; information is lacking to determine the impacts of various fisheries at smaller spatial scales.

Part II

Effects of reduced minimum-size limits on yield, spawning biomass, and wastage.

Overarching objective: Investigate the short-term and long-term consequences of adopting a smaller (26 inch or 66 cm) size limit on halibut spawning biomass, exploitable biomass, yield, and wastage.

2.1 Introduction

Minimum size limits, or minimum weight limits, have been used in the commercial fishery since 1940. In 1940, a minimum weight limit of 5 lb was used, which at the time corresponded to a fish of roughly 66 cm in length (or 26 inches). In 1974 this minimum size limit was increased to 81.28cm or 32 inches in length. Reasons for adopting a minimum size limit (or MSL hereafter) include conservation of juvenile halibut and increases in yield per recruit. Female halibut grow much faster than male halibut and recruit to the legal size at a much younger age than males. The sex composition of the commercial catch is predominately females, and the age composition of landed males is much more uniform than the female fish (Hare, 2012).

Since at least 1996, the mean size-at-age of halibut in the setline survey has declined steadily over time. Halibut seem to be experiencing slow than recent historical average growth rates. Due to slower growth and a fixed 32 inch size limit, the age-at recruitment to the fishery should be shifting towards older females, and much older males. Under a fixed exploitation rate policy, if the size-selectivity of the fishing gear captures fish below the minimum size, then it would be expected that the individual fish of sub-legal size would be capture more frequently when growth is slow.

The term wastage in the commercial setline fishery traditionally refers to fish that are captured by the fishing gear but not landed because the gear is either lost (something that occurred frequently during the days of the derby fishery), the fish is lost at the rail and dies, or the fish is returned to the ocean and dies. In the directed commercial fishery, it is assumed that 16% of the sublegal fish that are returned to the ocean die due to delayed mortality. In the trawl fishery, discard mortality rates are assumed to be much higher (ca. 80-90%).

In 2011, an estimated 2.2 million pounds of halibut were treated as wastage. Assuming a modest value of $5 per pound for fish in the 26-32 inch size category, this roughly equates to $11 million dollars per year of halibut that are thrown overboard and assumed to have died. Assuming a 16% mortality rate, this would imply that roughly 13.75 million pounds were captured in the directed fishery and thrown overboard because they were of sublegal size. Clearly there is an added cost for halibut conservation through the use of extra fuel and handling time to catch a given quota of legal size (13.75 million pounds).

In this part of the report, a simulation model is used to evaluate the potential gains and losses of adopting a smaller size limit for the current directed fishery. First a joint probability model for capturing and retaining a halibut of legal size is developed. Followed by a series of simulations under alternative hypotheses about recruitment and future growth with the status quo size limit of 32 inches, a 29 inch size limit and a 26 inch size limit. A series of performance metrics including future yield, wastage and the value of the catch and wastage is computed to evaluate the potential gains in yield and value in the directed setline fishery.

2.2 Methods

Details of the simulation model are documented in Appendix B.2. In short, the simulation model is a sex- and age-structured population dynamics model were the initial 1996 age-structure and age-1 recruits from 1996-2006 is based on the IPHC assessment conducted by Hare (2012). Total mortality rates for the 1996-2011 period were based on the same values estimated in the IPHC assessment and historical and simulated weight-at-age data is based on the mean length-at-age data for males and females in the setline survey.

Future projections were based on poor, average, and good recruitment (defined as $\pm 60\%$ in average recruitment). Growth was modelled either as density-independent, or density-dependent where the asymptotic length of halibut would decrease with increasing cohort density, and vice versa. It was assumed that selectivity in the directed commercial fishery remained unchanged in all future simulations. Selectivity is a function of length, and therefore, with decreasing mean size-at-age the fishery would target older fish. The length-based selectivity function was based on the same piece-wise linear function where fish less than 60 cm have a selectivity of 0 and fish greater than 120 cm were fully vulnerable.

Additional model assumptions include a fixed natural mortality rate for each sex, the coefficient of variation in length-at-age is 0.1, the discard mortality rate in the directed fishery is 0.17 per year, and all future catches are based on the constand harvest rate policy (0.215, or 0.16 depending on area). Area specific biomass apportionment is based on the 2011 apportionment values, and discard rates for O32 and U32 fish are carried forward from the 2011 realized values. The price per pound is based on prices in Homer Alaska, 10-20lbs at \$6.75, 20-40lbs at \$7.35 and 40+lbs at \$7.50. An assumed price of \$5.00 per for fish in the length interval of 66cm to 81cm was adopted to calculate the value of the wastage or value of fish less than 81 cm. The definition of wastage for this simulation is the amount of fish (in lbs) that is caught but is less than the minimum size limit and is assumed to die.

2.2.1 Joint probability model for retention

The probability of capturing a fish in a given size interval x is a property of the selectivity of the fishing gear and the number of available fish in the size interval (x). This simulation model, and the IPHC assessment model, does not model the number of fish at length explicitly; rather, the accounting system is based on the numbers-at-age. The estimated selectivity function is based on length, and the probability of capturing a fish of a given age is approximated by the mean length-at-age in a given year. In the IPHC assessment model, a series of selectivity coefficients are estimated for the length intervals 60,70, …, 120 and the probability of capturing a fish of a given age is a function of the mean length-at-age. With variable growth rates the probability of capturing a fish of a given age can change from year to year with changes in fish size. As fish grow slower, the age at recruitment to the fishery shift to an older age.

The probability of retaining a fish of a given age j is also a function of the mean length-at-age and the minimum size limit. Therefore the probability of capturing a fish of a given age and keeping it ($p(c_j)$) is a joint probability model that can be defined as follows:

$$p(c_j) = p(j) \cdot p(r_j),$$

where $p(j)$ is the probability of capturing a fish of age j, and $p(r_j)$ is the probability of retaining a fish of age j. The probability of capture $p(j)$ is the piece-wise linear interpolation of the mean length-at-age (length-based selectivity), and the probability that an individual age-j fish is greater than the minimum size limit is:

$$p(r_j) = \int_{l_j=\mathrm{MSL}}^{l_j=\infty} \frac{1}{\sqrt{2\pi}\sigma_j} \exp\left[-\frac{(l_j - \mathrm{MSL})^2}{2\sigma_j^2}\right] dl_j$$

where MSL is the minimum size limit, l_j is the mean length-at-age j, and σ_j is the standard deviation in the mean length-at-age. To approximate the above integral, a logistic function was used with a mean (50% probability of capture) corresponding to the MSL, and the standard deviation based on a CV of 0.1 for the mean length-at-age.

The probability of a fishing dying at a given age is then the probability of capturing a fish of a given age j times the probability of retention times the probability of discarding $(1 - p(r_j))$ the fish times the discard mortality rate:

$$p(h_j) = p(j)[p(r_j)(1 - p(r_j))d],$$

where d is the discard mortality rate.

2.2.2 Simulation scenarios

Three alternative size-limit policy options were explored, the status quo policy of 32 inch size limit, and a 29 and 26 inch size limit (Figure B.19). For each of the policy options, a total of 6 simulation runs were performed with poor, average, and good recruitment under two alternative hypotheses about future growth of halibut. These scenarios are summarized in the form of a graphical decision table where the rows of the table correspond to alternative growth models, and the columns correspond to alternative size limit policies.

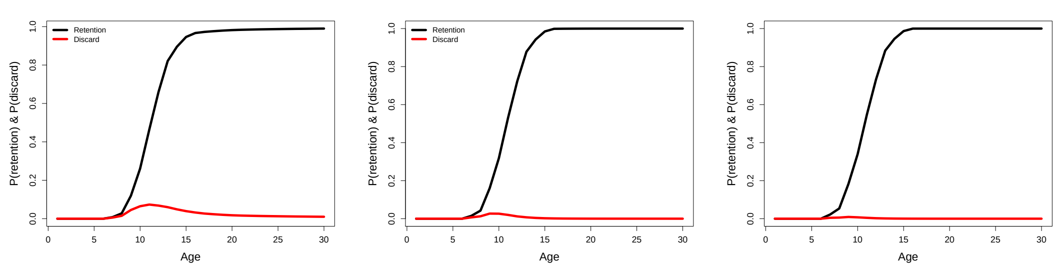

Figure 2.11: Example of retention- and discard-at-age probabilities for a given growth curve over 32 inch (left) 29 inch (middle) and 26 inch (right) minimum size limit.

2.3 Results

2.3.1 Impacts of MSL on exploitable biomass

Decreasing the minimum size limit from 32 inches to 26 inches results in a 2 million pound increase in the average simulated exploitable biomass between the years 2020 and 2025 (Figure 2.12). Note that the exploitable biomass calculation is based on the product of the numbers-at-age, the weight-at-age, and the age-specific capture probabilities (commercial fishery selectivity). Under density-independent growth, exploitable biomass is highest for the good recruitment scenarios; whereas, under density-dependent growth larger exploitable biomass is expected due to growth compensation at low densities (note red & blue lines in Figure 2.12).

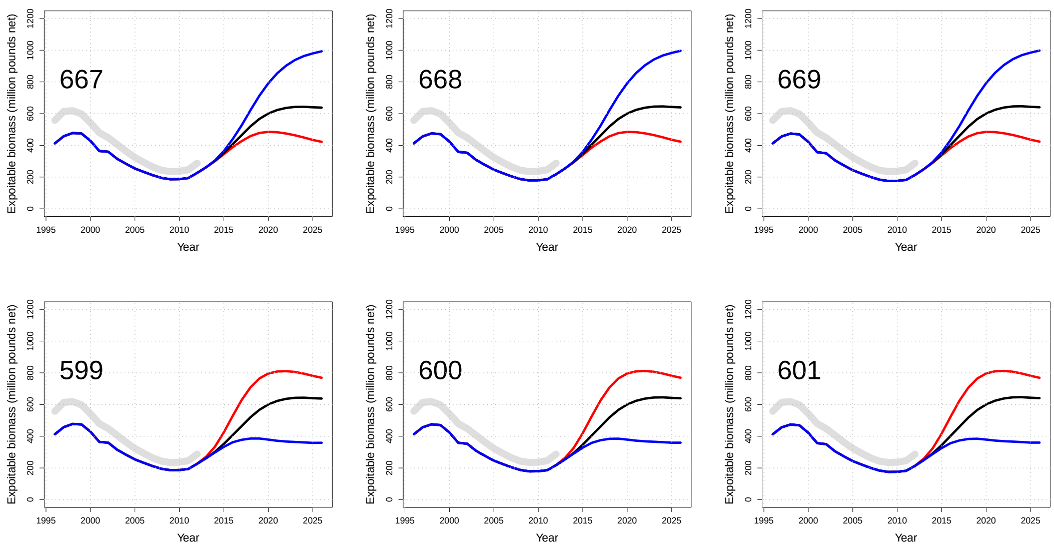

Figure 2.12: Effects of MSL on exploitable biomass under the assumptions of density-independent growth (top row) and density-dependent growth (bottom row) for 32 inch (left), 29 inch (middle), and 26 inch (right) size limits. Poor, average, and good recruitment are denoted by red, black and blue lines, respectively. Value on each panel corresponds to 2020-2025 average over 3 recruitment hypotheses.

2.3.2 Impacts of MSL on commercial yield

A modest increase of 300,000 to 500,000 pounds in the average coastwide commercial yields (between the years 2020–2025) is projected with a decrease in the minimum size limit from 32 inches to 26 inches (Figure 2.13). This increase owes to the overall reduction in total mortality rates associated with commercial wastage. Note also that these results also assume that bycatch levels and removals by the recreational fishery and personal use, including subsistence harvest, remains at the 2011 levels.

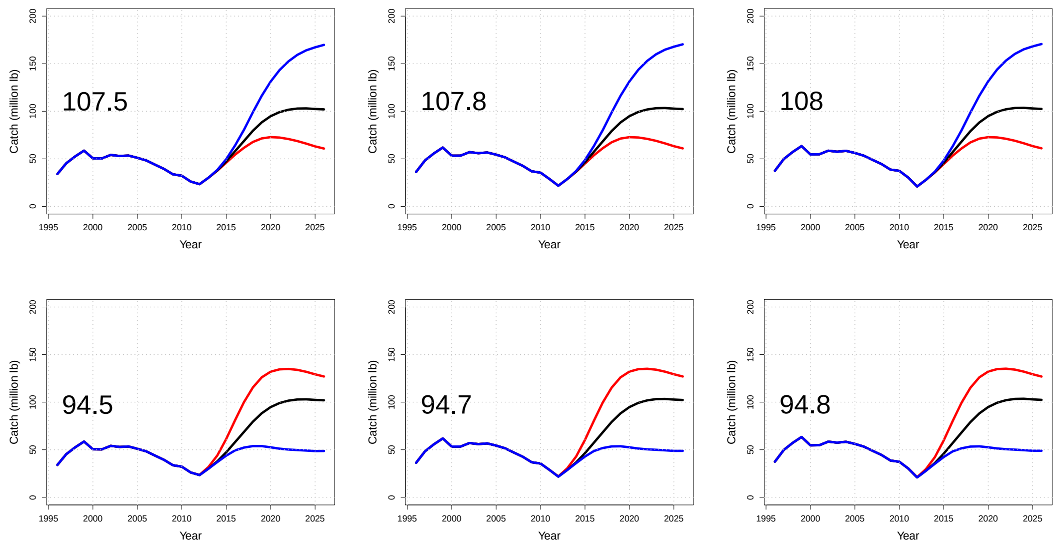

Figure 2.13: Effects of MSL on commercial yield under the assumptions of density-independent growth (top row) and density-dependent growth (bottom row) for 32 inch (left), 29 inch (middle), and 26 inch (right) size limits. Poor, average, and good recruitment are denoted by red, black and blue lines, respectively. Value on each panel corresponds to 2020-2025 average over 3 recruitment hypotheses.

2.3.3 Impacts of MSL on commercial wastage

Substantial reductions in commercial wastage occur with a reduction in the minimum size limit. Under a 32 inch size limit, simulated wastage between 2020 and 20205 averaged 2.494 million pounds and this declined by nearly 90% to 0.26 million pounds under a 26 inch size limit (Figure 2.14). Reductions in wastage could also translate into reduced operation costs, as fewer fish have to be captured and discarded to make up the individual vessel quota. Between the years 2020–2025 and estimated 60% of the halibut captured in the commercial fishery (assuming a fixed length-based selectivity) are of sublegal size and discarded (Figure 2.15). Reducing the size limit from 32 inches to 29 or 26 inches would reduce this fraction to 30% and 10%, respectively. Reducing the size limit from 32 to 26 inches increases the overall retention probability from 40% to 90%.

2.3.4 Impacts of MSL on economic value

Decreasing the MLS to smaller sizes reduces the overall landed value of the commercial fishery because the composition of the catch contains a higher fraction of lower value 5-10 pound fish (assuming $5.00 per pound). The simulated projected landed value between 2020–2025 decreases from $684.7 million to $683 million (or $1.7 million) with a change in MLS of 32 inches to 26 inches (Figure 2.16).

Based on the allometric length-weight relationship a 26 inch halibut is roughly 5 pounds

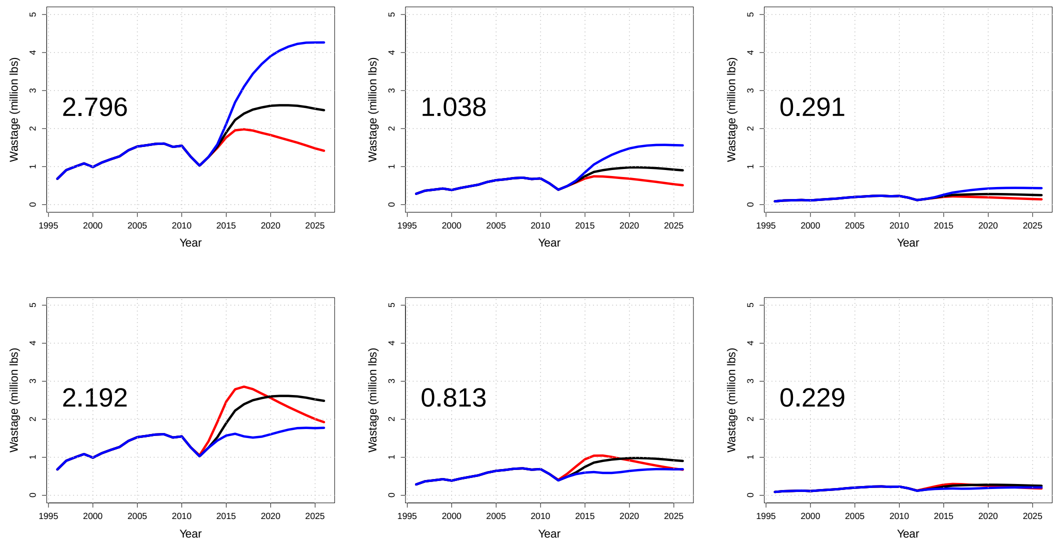

Figure 2.14: Effects of MSL on commercial wastage under the assumptions of density-independent growth (top row) and density-dependent growth (bottom row) for 32 inch (left), 29 inch (middle), and 26 inch (right) size limits. Poor, average, and good recruitment are denoted by red, black and blue lines, respectively. Value on each panel corresponds to 2020-2025 average over 3 recruitment hypotheses.

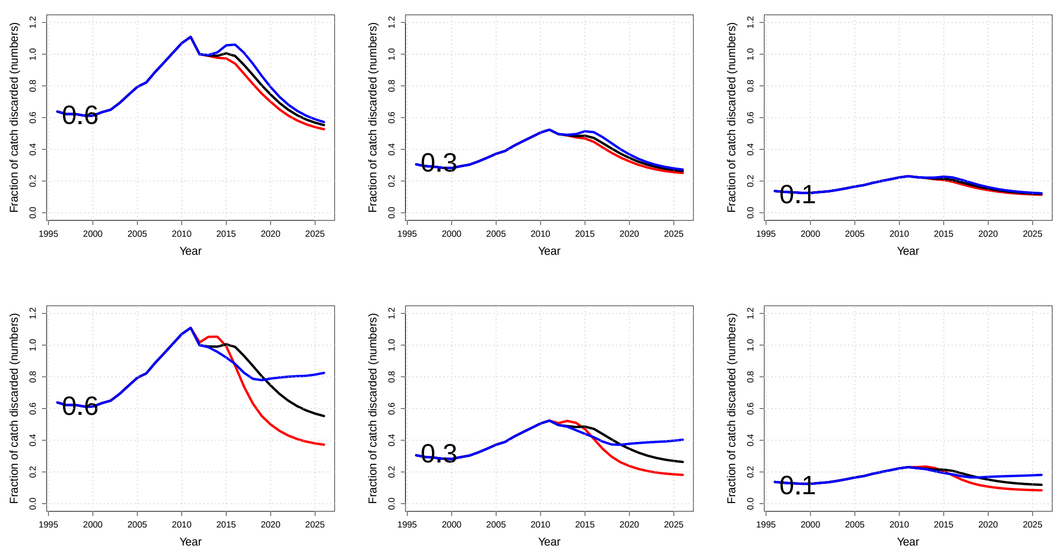

Figure 2.15: Fraction of captured fish discarded in the commercial fishery under the assumptions of density-independent growth (top row) and density-dependent growth (bottom row) for 32 inch (left), 29 inch (middle), and 26 inch (right) size limits. Poor, average, and good recruitment are denoted by red, black and blue lines, respectively. Value on each panel corresponds to 2020-2025 average over 3 recruitment hypotheses.

net weight, and a 32 inch halibut is roughly 10 pounds net weight. Assuming a price of \$5.00 per pound for halibut in the 5-10 pound range, the potential value of the sub-legal fish that are discarded and assumed to die (with 16% discard mortality rate) can be calculated. Under a 32 inch size limit the average value of the wastage is \$15.5 million, and under a 26 inch size limit the value of the wastage is reduced by 90% to \$1.55 million (Figure 2.17). Moreover, the value of this wastage is of dead fish that cannot be recovered in the future.

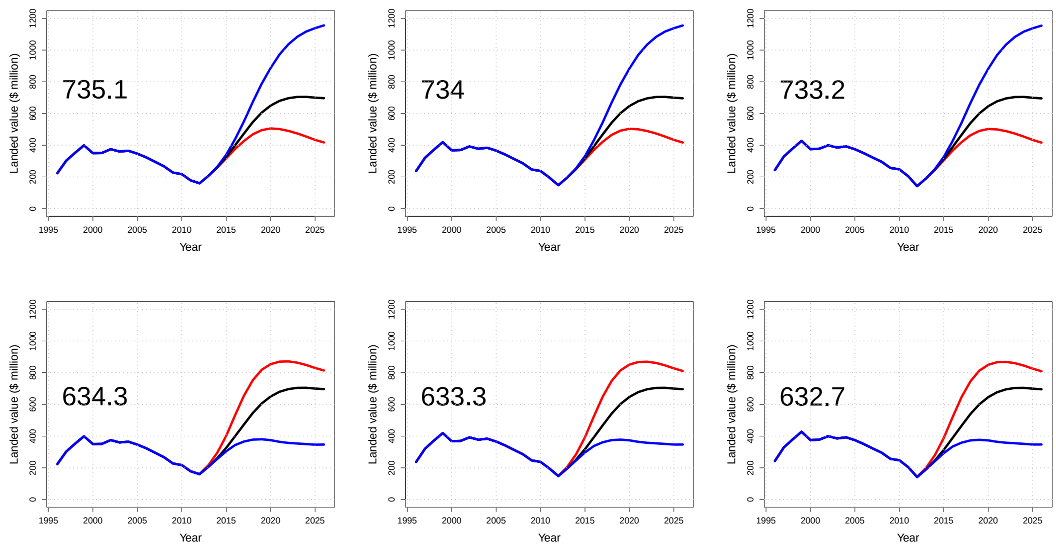

Figure 2.16: Landed value for the commercial fisher under the assumptions of density-independent growth (top row) and density-dependent growth (bottom row) for 32 inch (left), 29 inch (middle), and 26 inch (right) size limits. Poor, average, and good recruitment are denoted by red, black and blue lines, respectively. Value on each panel corresponds to 2020-2025 average over 3 recruitment hypotheses.

Not all of the commercial fish that are captured die due to handling mortality; the estimated discard mortality rate for this fishery is 16%. The average simulated coastwide value of the commercial fish landed that are of sublegal size (assuming \$5.00 per pound) under a 32 inch size limit is \$91 million. Reducing the size limit to 29 and 26 inches reduces the value of sublegal fish captured to \$33 and \$9 million, respectively (Figure 2.18).

The practice of discarding sublegal size fish can be considered an added cost associated with handling time and lower capture probabilities of legal size fish due to competition for hooks. These cost can be significant and would increase or decrease with changes in size limits as shown in Figure 2.18. A proximate measure for fishing efficiency from an economic standpoint of view is can be defined as:

$$1 - \frac{\text{value of discards}}{\text{value of landings}}.$$

This term is a measure of the economic efficiency and under a 32 inch size limit this value is roughly 87% in comparison to 98.7% under a 26 inch size limit (Table 2.3). Another

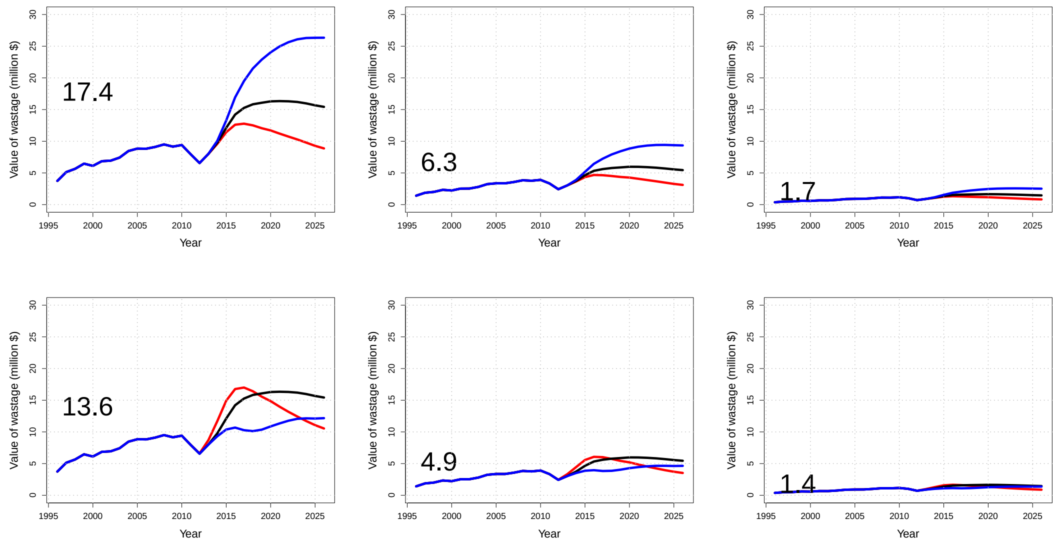

Figure 2.17: Value of commercial wastage under the assumptions of density-independent growth (top row) and density-dependent growth (bottom row) for 32 inch (left), 29 inch (middle), and 26 inch (right) size limits. Poor, average, and good recruitment are denoted by red, black and blue lines, respectively. Value on each panel corresponds to 2020-2025 average over 3 recruitment hypotheses.

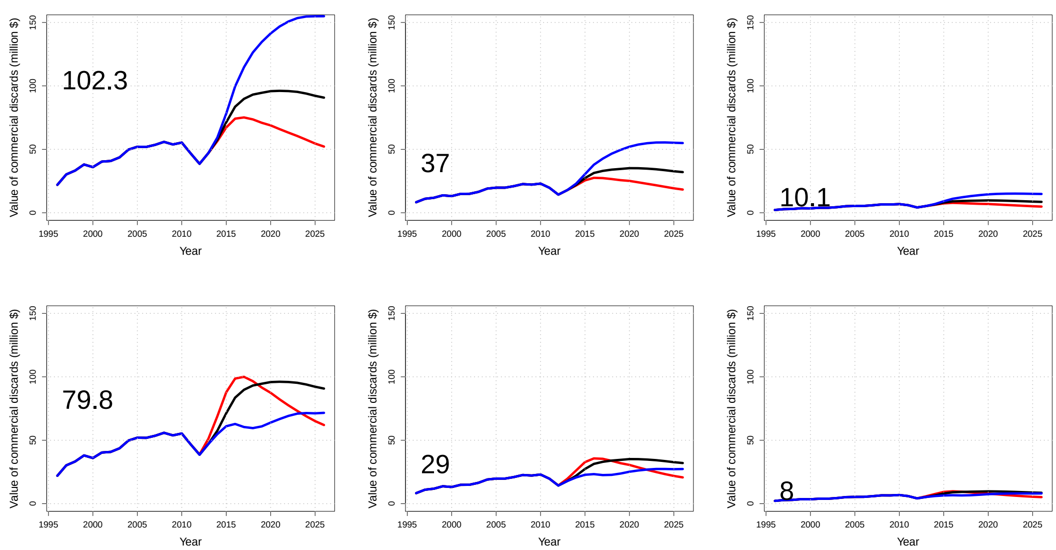

Figure 2.18: Value of all commercial sublegal size fish under the assumptions of density-independent growth (top row) and density-dependent growth (bottom row) for 32 inch (left), 29 inch (middle), and 26 inch (right) size limits. Poor, average, and good recruitment are denoted by red, black and blue lines, respectively. Value on each panel corresponds to 2020-2025 average over 3 recruitment hypotheses.

Table 2.3: Summary of simulated performance measures for three alternative size limit policies averaged over 3 recruitment levels and 2 alternative hypthoses about halibut growth.

Response (million lb)	32" MSL	29" MSL	26" MSL
EBio	633	634	635
Yield	101	101.25	101.4
Wastage	2.494	0.925	0.260
Response (million)			
Landed Value	$684.7	$683.6	$683
Waste Value[1]	$15.5	$5.6	$1.55
Discard Value[2]	$91	$33	$9
Efficiency	86.7%	95.2%	98.7%
Handling Efficiency	40%	66%	91%

proximate measure is the handling efficiency, or simply what fraction of the fish captured that are retained. Under a 32 inch size-limit the average simulated handling efficiency between 2020-2025 is 40%. In other words, 60 out of 100 captured halibut are below the minimum legal size and are discarded. Whereas, under a 26 inch size limit the handling efficiency increases to 91%, or 9 out of 100 captured halibut are below the minimum legal size (Table 2.3).

2.4 Discussion

Reducing the minimum size limit from 32 inches to 29 or 26 inches does not appear pose any substantial conservation risks. Simulated estimates of coastwide exploitable biomass actually increase with a reduction in the minimum size limit due to reduced overall total mortality rates associated with wastage in the directed commercial fishery. Female spawning biomass is also expected to increase with reductions in the minimum size limit. If the the discard mortality rate is greater than the assumed value, this increase in exploitable biomass could be even more substantial. This result seems counterintuitive, the general expectation would be a general decrease in spawning and exploitable biomass with decreasing size limits. Pine III et al. (2008) demonstrated that with increases in discard mortality rates (or a decrease in post-release survival rates), the overall spawning potential ratio (SPR) would decrease with with increasing size limits when fishing at rates equal to or greater than the maximum sustainable yield.

The overall landed value of the halibut fishery actually decreases slightly with a decrease in the minimum size limit. With a lower size limit the size composition of the catch contains a much higher fraction of low-value 5-10 pound fish. This result is also an artifact of the assumed $5.00 per pound price for 5-10 pound halibut. If this price is less, there would be even less of an economic incentive to lower the size limit. The real potential economic benefit of lowering the size limit is associated with operational costs; with a lower size limit, the time required to catch an individuals quota could be substantially reduced because the majority of fish landed would be retained, rather than discarded.

There may also be a potential benefit from reducing the size limit if intraspecific competition for food resources is one of the factors that is related to reduced halibut growth. Retention of smaller, more abundance halibut, could potentially improve halibut growth rates by lowering the overall halibut density and improving foraging conditions (Walters and Juanes, 1993; Walters and Martell, 2004). Unfortunately the density-dependent growth model used in this simulation study is not related to annual halibut density, so it could not be used to explore this hypothesis.

One of the major caveats in this study is that the assumed coastwide selectivity curve in the commercial fishery does not change in response to changes in the size limit. If in fact the commercial fishery selectivity did shift towards smaller sizes, then discarding of sublegal size fish would likely increase and lead to even more severe growth overfishing for this stock. However, it is clear that there are potential economic gains to be made by reducing the minimum size limit by reducing the time required to land the quota and the operational costs. To ensure selectivity does not change, an enforceable policy option might be to standardize fishing gear in the directed fishery. For example, limits on hook size, hook spacing, or other tactics could be out in place to prevent a massive shift in selectivity and increase the risk of growth over fishing. Alternatively, individual accountability for all mortality could be assigned to the individual quota holder. In this case, say 17% of the discarded halibut of sublegal size would count against the quota. The latter option would almost certainly create the appropriate behavioural incentives to shift away from small halibut, but would also require 100% observer coverage or electronic monitoring.

Lastly, even if the current minimum size limit of 32 inches is kept in place, then target fishing mortality rates need to be adjusted on an annual basis to ensure that the current fishing rate policy is commensurate with the spawning biomass reference points associated with changing growth rates. If alternative size limits were adopted, the target fishing mortality rate would almost certainly have to be reduced to ensure it is commensurate with the $SB_{30\%}$ and $SB_{20\%}$ spawning biomass reference points assuming constant growth. If, however, there is some persistent transition to lower or higher growth rates, then the corresponding absolute spawning biomass reference points would also decrease with lower growth rates, or increase with higher growth rates. If halibut growth rates increase, then fishing mortality reference points that correspond to $B_{30\%}$ would also increase, and vice-versa.

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Part III

Appendices

A.1 Input files for the Simulation Model

In this appendix, the input data, parameter controls and initial parameter values for the Halibut simulation model are given. Electronic copies of these files are available from a code repository hosted at: `http://code.google.com/p/iscam-project/source/browse/`. The source code is also available from the same repository under the Halibut branch. A history of the code development can be viewed here: `http://code.google.com/p/iscam-project/source/list?name=halibut`.

The following is the data file where, the # symbol to the left of any number denotes comment lines to document the data file.

```
## ------------------------------------------------------------------------ ##
## TEMPLATE DATA FILE FOR iSCAM                                             ##
## TIPS: -use '#' as comment character for the data file                    ##
##       -use '#' on all blank lines (windows compatible)                   ##
##                                                                          ##
##                                                                          ##
##                                                                          ##
## TEMPLATE is based on Flack Lake Trout (ADMB catage example)              ##
## ------------------------------------------------------------------------ ##
##
##
##
## ------------------------------------------------------------------------ ##
## MODEL DIMENSIONS                                                         ##
## ------------------------------------------------------------------------ ##
1996        # -first year of data           (syr)
2011        # -last year of data            (nyr)
1           # -age of youngest age class    (sage)
30          # -age of plus group            (nage)
40          # -minimum length               (slen)
140         # -maximum length               (nlen)
21          # -number of length bins        (nlbin)
5           # -number of gears              (ngear)
2           # -number of sexes              (nsex)
6  6  6  6  6  6  6  6  6  6  6  6  6  6  6   # vector of firstAge(j_sage)##
#20 20 20 20 20 20 25 25 25 25 25 25 25 25 25 25  # vector of plusAge (j_nage)##
25 25 25 25 25 25 25 25 25 25 25 25 25 25 25 25  # vector of plusAge (j_nage)##  Overwrote the wt_obs with a*pow(length-age,b)
# (j_nage)
##
## ------------------------------------------------------------------------ ##
## Allocation for each gear in (ngear), use 0 for survey gears.             ##
## Type of catch: an ivector based on legend below                          ##
##              1 = catch in weight                                         ##
##              2 = catch in numbers                                        ##
##              3 = catch in spawn (roe)                                    ##
## ------------------------------------------------------------------------ ##
1 0 0 0 0                                                   ## ALLOCATION     ##
1 1 1 1 1                                                   ## TYPE OF CATCH  ##
##                                                                          ##
## ------------------------------------------------------------------------ ##
## Age-schedule and population parameters                                   ##
## ------------------------------------------------------------------------ ##
##0.15 0.135474        # -natural mortality rate (m_fixed) TOBE DEPRECATED
##145 110             # -asymptotic length (linf)
##0.10 0.12            # -brody growth coefficient (k)
##-1.219753 -1.219753       # -theoretical age at zero length (to)
##6.921e-6 6.921e-6        # -scaler in length-weight allometry (a)
##3.24 3.24            # -power parameter in length-weight allometry (b)
##11.59 11.59           # -age at 50% maturity (approx with log(3.0)/k)
##1.776 1.776           # -std at 50% maturity (CV ~ 0.1)
##
## ------------------------------------------------------------------------ ##
## TIME SERIES DATA                                                         ##
## Observed catch (row dimensions syr:nyr) (col dimensions yr,1:ngear)      ##
## Units are in millions of pounds, net weight. From Hare 2012 RARA         ##
## Note that the setline includes IPHC research catch (assumed to have the  ##
## same selectivity).                                                       ##
## ------------------------------------------------------------------------ ##
## yrs   CatchWt  DiscardWt  BycatchWt  SportCatchWt  PersUseWt
   1996  47.692   0.726      14.375     8.083         0.543
   1997  65.485   1.048      13.513     9.025         0.543
   1998  70.115   1.198      13.432     8.586         0.709
   1999  74.700   1.335      13.844     7.379         0.741
   2000  68.550   1.287      13.290     9.016         0.748
   2001  70.970   1.442      13.159     8.106         0.746
   2002  74.949   1.658      12.610     8.012         0.746
   2003  73.356   1.770      12.003     9.347         1.383
```

```
   2004  73.307   1.933     12.224    10.703       1.520
   2005  72.111   2.030     12.335    10.859       1.537
   2006  68.120   2.045     13.081    10.212       1.537
   2007  63.025   2.286     12.124    11.461       1.483
   2008  58.699   2.337     10.788    10.750       1.489
   2009  52.176   2.624     11.377     8.751       1.306
   2010  49.825   3.038     10.632     7.825       1.239
   2011  39.286   2.213      9.996     7.515       1.245
##
## ----------------------------------------------------------------------- ##
## ABUNDANCE INDICES -A RAGGED ARRAY: (1,nit,1,nit_nobs,1,5)               ##
## ----------------------------------------------------------------------- ##
2              # Number of abundance series        int(nit)
14  15         # Number of observations in series   ivector(nit_nobs(1,nit))
2   2          # Survey type (see key below)        ivector(survey_type(1,nit))
## 1 = survey is proportional to vulnerable numbers
## 2 = survey is proportional to vulnerable biomass
## 3 = survey is proportional to spawning biomass (e.g., a spawn survey)
##
## survey_data (setline wpue)
#iyr    it       gear  wt  survey timing
 1997   138       2     1   0.5
 1998   134       2     1   0.5
 1999   126       2     1   0.5
 2000   121       2     1   0.5
 2001   112       2     1   0.5
 2002   109       2     1   0.5
 2003    92       2     1   0.5
 2004    89       2     1   0.5
 2005    82       2     1   0.5
 2006    71       2     1   0.5
 2007    66       2     1   0.5
 2008    61       2     1   0.5
 2009    56       2     1   0.5
 2010    47       2     1   0.5
## commercial wpue (all areas)
#1984 350        1     1   0.5
#1985 395        1     1   0.5
#1986 351        1     1   0.5
#1987 345        1     1   0.5
#1988 387        1     1   0.5
#1989 376        1     1   0.5
#1990 334        1     1   0.5
#1991 333        1     1   0.5
#1992 338        1     1   0.5
#1993 399        1     1   0.5
#1994 328        1     1   0.5
#1995 351        1     1   0.5
 1996 415        1     1   0.5
 1997 423        1     1   0.5
 1998 429        1     1   0.5
 1999 398        1     1   0.5
 2000 416        1     1   0.5
 2001 382        1     1   0.5
 2002 379        1     1   0.5
 2003 346        1     1   0.5
 2004 338        1     1   0.5
 2005 314        1     1   0.5
 2006 283        1     1   0.5
 2007 268        1     1   0.5
 2008 249        1     1   0.5
 2009 237        1     1   0.5
 2010 222        1     1   0.5
##
## ----------------------------------------------------------------------- ##
## AGE COMPOSITION DATA (ROW YEAR, COL=AGE) Ragged object                  ##
## ----------------------------------------------------------------------- ##
2          # Number of gears with age-comps int(na_gears)
1   1      # Number of rows in the matrix   ivector(na_nobs)
4   4      # Youngest age column            ivector(a_sage)
26  26     # Oldest age column +group       ivector(a_nage)
## year gear age colums (numbers or proportions)
   2010 1    0.000000 0.000382 0.000446 0.004583 0.028833 0.060976 0.122207 0.167399 0.137356 0.081153 0.068296 0.057921
             0.048183 0.029915 0.024251 0.018522 0.021132 0.021195 0.024378 0.023869 0.013685 0.008147 0.037171
##
   2010 2    0.000071 0.002060 0.010582 0.035156 0.092401 0.107812 0.145952 0.165980 0.122798 0.060156 0.050710 0.044247
             0.033026 0.021449 0.014560 0.010724 0.010014 0.011932 0.011790 0.013210 0.009588 0.004616 0.021165
##
## ----------------------------------------------------------------------- ##
## EMPIRICAL WEIGHT-AT-AGE DATA                                            ##
## ----------------------------------------------------------------------- ##
16         # Number of years of weight-at-age data int(n_wt_obs)
21         # Number of columns in the weight at age data
6          # age_min_wt
#6  6  6  6  6  6  6  6  6  6  6  6  6  6  6  6          # sage_wt_obs
#20 20 20 20 20 20 25 25 25 25 25 25 25 25 25 25         # nage_wt_obs (A plus group)
## year age columns (sage, nage) of weight at age data
```

```
## Catch-weight-at-age for females
1996 14 16.0 16.0 18.9 22.3 25.9 29.9 34.3 39.0 44.3 50.0 56.6 61.1 68.0 77.8 -99.0 -99.0 -99.0 -99.0 -99.0
1997 14 16.0 16.7 19.3 22.3 26.0 30.2 34.6 39.1 43.9 49.1 54.8 61.1 68.0 77.8 -99.0 -99.0 -99.0 -99.0 -99.0
1998 14 16.0 16.9 19.0 21.7 25.0 28.9 33.2 37.5 42.0 46.8 51.9 57.3 63.4 68.1 -99.0 -99.0 -99.0 -99.0 -99.0
1999 14 16.0 17.2 18.9 21.2 24.1 27.6 31.4 35.4 39.7 44.2 48.8 54.0 59.1 65.2 -99.0 -99.0 -99.0 -99.0 -99.0
2000 14 16.0 17.7 19.0 20.9 23.4 26.5 29.9 33.6 37.7 42.0 46.3 50.7 55.6 62.3 -99.0 -99.0 -99.0 -99.0 -99.0
2001 14 16.0 17.7 19.6 21.2 23.3 26.0 29.1 32.6 36.5 40.6 44.7 49.0 55.6 64.1 -99.0 -99.0 -99.0 -99.0 -99.0
2002 14 15.8 17.2 19.2 21.3 23.6 25.8 28.2 30.6 33.1 35.7 38.3 41.0 43.9 46.8  49.8  52.9  56.1  59.4  64.8
2003 14 15.8 17.8 19.8 21.9 24.0 26.2 28.5 30.8 33.2 35.6 38.0 40.7 43.4 46.2  49.1  52.1  55.1  58.5  64.8
2004 14 15.9 18.1 20.1 22.1 24.2 26.3 28.4 30.6 32.8 35.0 37.2 39.7 42.4 45.1  48.0  51.0  54.2  57.6  52.2
2005 14 16.0 18.1 20.1 22.1 24.1 26.1 28.1 30.2 32.2 34.1 36.2 38.5 41.1 43.8  46.7  49.8  53.2  56.7  58.9
2006 14 16.0 18.0 19.9 21.8 23.8 25.7 27.6 29.5 31.4 33.2 35.1 37.3 39.8 42.5  45.4  48.6  52.2  55.9  54.9
2007 14 15.7 17.6 19.4 21.3 23.2 25.0 26.9 28.8 30.6 32.3 34.2 36.3 38.9 41.5  44.5  47.4  51.2  55.0  49.6
2008 14 15.3 17.1 18.8 20.6 22.5 24.2 26.1 28.0 29.8 31.6 33.4 35.6 38.1 40.7  43.5  46.4  50.2  54.1  56.0
2009 14 14.8 16.4 18.1 19.8 21.6 23.4 25.3 27.2 29.2 31.0 33.0 35.2 37.6 40.2  42.9  45.7  49.3  53.2  62.4
2010 14 14.3 15.8 17.4 19.1 20.9 22.8 24.7 26.7 28.7 30.7 32.8 35.0 37.5 40.0  42.8  45.4  48.3  52.4  55.9
2011 14 14.3 15.3 16.9 18.6 20.4 22.3 24.4 26.4 28.5 30.7 32.9 35.2 37.6 40.0  42.8  45.5  48.4  51.5  49.4
## Catch-weight-at-age for males
1996 14 14.0 13.1 14.1 14.8 14.8 15.7 16.8 17.2 19.7 20.1 20.4 25.9 26.4 31.4 -99.0 -99.0 -99.0 -99.0 -99.0
1997 14 14.0 13.1 13.5 14.1 14.8 15.7 16.8 17.2 19.7 20.1 20.4 25.9 26.4 31.4 -99.0 -99.0 -99.0 -99.0 -99.0
1998 14 14.0 13.1 13.3 13.8 14.4 15.1 16.1 17.2 18.7 20.1 20.4 24.0 26.4 30.6 -99.0 -99.0 -99.0 -99.0 -99.0
1999 14 14.0 13.1 13.5 13.9 14.4 15.0 15.8 16.7 17.8 19.5 20.4 22.7 24.9 29.2 -99.0 -99.0 -99.0 -99.0 -99.0
2000 14 14.0 13.1 13.7 14.1 14.6 15.2 15.8 16.6 17.6 18.9 20.4 22.2 24.3 27.8 -99.0 -99.0 -99.0 -99.0 -99.0
2001 14 14.0 13.1 13.9 14.2 14.6 15.2 15.8 16.7 17.8 19.1 20.4 22.4 24.5 26.1 -99.0 -99.0 -99.0 -99.0 -99.0
2002 14 13.5 13.0 13.3 13.6 13.9 14.3 14.8 15.3 15.9 16.6 17.3 18.1 19.0 20.0  21.1  22.3  23.6  25.0  30.0
2003 14 13.5 13.3 13.5 13.8 14.1 14.4 14.7 15.1 15.6 16.2 16.8 17.5 18.4 19.3  20.4  21.5  22.7  24.1  28.9
2004 14 13.5 13.4 13.7 13.9 14.1 14.3 14.6 15.0 15.4 15.8 16.3 16.9 17.8 18.6  19.6  20.7  22.1  23.2  27.9
2005 14 13.5 13.6 13.7 13.9 14.1 14.3 14.4 14.8 15.1 15.5 15.9 16.5 17.2 18.1  19.0  20.2  21.5  22.7  26.9
2006 14 13.5 13.6 13.7 13.8 14.0 14.1 14.3 14.6 14.9 15.3 15.7 16.3 16.9 17.7  18.6  19.7  20.9  22.1  25.9
2007 14 13.5 13.5 13.6 13.7 13.8 13.9 14.1 14.3 14.6 15.0 15.4 16.0 16.5 17.3  18.3  19.2  20.3  21.5  24.8
2008 14 13.5 13.3 13.4 13.5 13.6 13.7 13.9 14.1 14.4 14.8 15.2 15.8 16.3 17.0  17.9  18.7  19.7  20.9  23.8
2009 14 13.5 13.1 13.1 13.2 13.4 13.5 13.7 13.9 14.2 14.6 15.0 15.5 16.1 16.7  17.5  18.3  19.2  20.3  22.8
2010 14 13.5 12.8 12.9 13.0 13.1 13.3 13.5 13.7 14.0 14.4 14.8 15.3 16.1 16.4  17.1  17.9  18.8  19.7  22.8
2011 14 13.5 12.6 12.7 12.8 13.0 13.1 13.3 13.6 13.9 14.2 14.5 15.3 16.1 16.1  16.8  17.5  18.3  19.7  22.8
##
## ------------------------------------------------------------------------ ##
## EMPIRICAL LENGTH-AT-AGE DATA                                             ##
## ------------------------------------------------------------------------ ##
16          # Number of years of length-at-age data int(n_lt_obs)
31          # Number of columns for the length-at-age data
1           # age_min_lt
## Mean length-at-age for female halibut (SurvLTrue_F)
1996   -99.0 -99.0 -99.0 -99.0 -99.0  69.9  74.6  80.0  85.5  91.4  97.6 103.7 109.0 113.8 118.5 122.6 126.4 129.4 132.5 135.4 137.6 139.3 141.0 142.4 143.8 145.2 146.6
1997   -99.0 -99.0 -99.0 -99.0 -99.0  69.9  74.6  80.0  85.5  91.4  97.6 103.7 109.0 113.8 118.5 122.6 126.4 129.4 132.5 135.4 137.6 139.3 141.0 142.4 143.8 145.2 146.6
1998   -99.0 -99.0 -99.0 -99.0 -99.0  70.0  74.4  79.4  84.8  90.7  97.2 103.5 108.8 113.5 118.1 121.9 125.5 128.3 131.1 133.8 135.8 137.7 139.5 141.0 142.5 144.0 145.4
1999   -99.0 -99.0 -99.0 -99.0 -99.0  70.0  74.2  78.8  83.9  89.7  96.1 102.3 107.5 111.9 116.2 119.9 123.2 125.9 128.6 131.2 133.2 135.0 136.8 138.3 139.8 141.2 142.7
2000   -99.0 -99.0 -99.0 -99.0 -99.0  70.0  74.0  78.4  83.2  88.5  94.3  99.9 104.8 109.0 113.2 116.7 120.0 122.8 125.4 128.1 130.1 131.8 133.5 134.9 136.3 137.7 139.1
2001   -99.0 -99.0 -99.0 -99.0 -99.0  70.0  74.0  78.0  82.4  87.2  92.2  97.2 101.6 105.7 109.7 113.2 116.5 119.2 122.0 124.6 126.6 128.3 129.9 131.2 132.5 133.8 135.2
2002   -99.0 -99.0 -99.0 -99.0 -99.0  69.8  74.8  80.4  85.0  89.4  93.6  97.7 101.6 105.4 109.1 112.7 116.2 119.6 123.0 126.3 129.4 132.4 135.4 136.1 136.9 137.6 138.4
2003   -99.0 -99.0 -99.0 -99.0 -99.0  69.8  74.8  79.7  84.4  88.9  93.2  97.2 101.0 104.8 108.3 111.6 114.7 117.8 120.8 123.9 126.7 129.5 132.2 133.4 134.7 136.0 137.3
2004   -99.0 -99.0 -99.0 -99.0 -99.0  68.8  73.9  79.0  83.9  88.5  92.9  97.1 101.0 104.7 108.0 111.0 113.8 116.5 119.2 121.9 124.5 127.1 129.5 131.2 132.8 134.5 136.2
2005   -99.0 -99.0 -99.0 -99.0 -99.0  67.7  73.0  78.2  83.2  88.0  92.5  96.9 100.9 104.5 107.7 110.5 113.0 115.4 117.9 120.3 122.7 125.3 127.1 129.8 131.6 133.3 135.1
2006   -99.0 -99.0 -99.0 -99.0 -99.0  66.7  72.0  77.3  82.4  87.3  91.9  96.5 100.7 104.4 107.6 110.3 112.6 114.9 117.2 119.4 121.4 123.5 125.0 128.6 130.4 132.2 134.0
2007   -99.0 -99.0 -99.0 -99.0 -99.0  65.7  71.1  76.3  81.5  86.3  90.9  95.4  99.6 103.3 106.6 109.4 112.0 114.3 116.4 118.4 120.2 121.8 123.3 127.5 129.3 131.1 132.9
2008   -99.0 -99.0 -99.0 -99.0 -99.0  64.7  70.1  75.3  80.4  85.2  89.8  94.2  98.3 102.0 105.4 108.3 111.0 113.3 115.3 117.2 118.8 120.3 121.6 126.4 128.2 130.0 131.8
2009   -99.0 -99.0 -99.0 -99.0 -99.0  63.8  69.2  74.3  79.3  84.1  88.7  93.0  97.1 100.9 104.2 107.2 109.8 112.1 114.1 115.9 117.5 118.9 121.6 125.8 127.4 129.0 130.7
2010   -99.0 -99.0 -99.0 -99.0 -99.0  62.9  68.3  73.4  78.4  83.1  87.6  91.9  96.0  99.7 103.0 106.0 108.7 111.1 113.1 115.9 117.5 118.9 121.6 125.5 126.8 128.2 129.6
2011   -99.0 -99.0 -99.0 -99.0 -99.0  62.9  68.3  72.6  77.6  82.3  86.8  91.0  95.0  98.7 102.0 105.0 107.7 110.1 113.1 115.9 117.5 118.9 121.6 125.2 126.3 127.4 128.5
## Mean length-at-age for male halibut (SurvLTrue_M)
1996   -99.0 -99.0 -99.0 -99.0 -99.0  63.3  67.0  70.4  74.0  77.4  80.7  84.0  86.8  89.3  91.7  93.8  95.9  97.7  99.5 101.3 102.7 103.9 105.1 106.1 107.1 108.1 109.1
1997   -99.0 -99.0 -99.0 -99.0 -99.0  63.3  67.0  70.4  74.0  77.4  80.7  84.0  86.8  89.3  91.7  93.8  95.9  97.7  99.5 101.3 102.7 103.9 105.1 106.1 107.1 108.1 109.1
1998   -99.0 -99.0 -99.0 -99.0 -99.0  63.6  67.2  70.7  74.1  77.3  80.5  83.5  86.1  88.3  90.4  92.4  94.3  96.0  97.8  99.7 101.3 102.9 104.6 105.9 107.3 108.6 109.9
1999   -99.0 -99.0 -99.0 -99.0 -99.0  63.6  67.2  71.0  74.3  77.3  80.2  83.0  85.4  87.6  89.8  91.7  93.6  95.3  97.1  98.9 100.3 101.5 102.7 103.7 104.7 105.6 106.6
2000   -99.0 -99.0 -99.0 -99.0 -99.0  63.8  67.3  70.9  74.0  77.0  79.7  82.4  84.8  86.9  89.1  91.0  92.9  94.7  96.4  98.1  99.3 100.1 100.9 101.5 102.0 102.6 103.2
2001   -99.0 -99.0 -99.0 -99.0 -99.0  63.8  67.3  70.0  73.1  76.0  78.7  81.4  83.7  85.8  87.9  89.7  91.6  93.3  95.1  97.0  98.3  99.3 100.2 101.0 101.8 102.5 103.3
2002   -99.0 -99.0 -99.0 -99.0 -99.0  64.2  67.5  71.0  73.8  76.4  78.7  80.9  82.9  84.9  86.8  88.5  90.2  92.0  93.8  95.6  97.5  99.4 101.4 103.1 104.8 106.6 108.3
2003   -99.0 -99.0 -99.0 -99.0 -99.0  64.2  67.5  70.5  73.3  75.8  78.2  80.2  82.1  83.9  85.7  87.3  88.8  90.4  92.1  93.8  95.6  97.4  99.5 101.9 104.6 107.2 109.8
2004   -99.0 -99.0 -99.0 -99.0 -99.0  63.7  67.0  70.1  72.9  75.5  77.9  79.9  81.7  83.6  85.2  86.6  87.9  89.3  90.9  92.5  94.2  95.9  97.6  99.3 100.8 102.2 103.7
2005   -99.0 -99.0 -99.0 -99.0 -99.0  63.2  66.6  69.7  72.6  75.3  77.7  79.7  81.6  83.4  84.9  86.2  87.4  88.7  90.1  91.6  93.1  94.7  96.3  97.4  98.2  99.0  99.8
2006   -99.0 -99.0 -99.0 -99.0 -99.0  62.7  66.0  69.3  72.2  74.9  77.3  79.5  81.4  83.2  84.7  85.9  87.0  88.3  89.5  90.9  92.4  93.8  95.5  97.7  99.8 101.9 104.0
2007   -99.0 -99.0 -99.0 -99.0 -99.0  62.1  65.5  68.7  71.6  74.3  76.7  78.9  80.9  82.7  84.2  85.5  86.6  87.9  89.1  90.5  91.7  93.0  94.6  96.3  97.9  99.5 101.1
2008   -99.0 -99.0 -99.0 -99.0 -99.0  61.5  64.8  68.0  70.9  73.6  76.0  78.2  80.2  82.1  83.7  85.0  86.3  87.6  88.8  90.1  91.3  92.4  93.8  95.4  97.0  98.6 100.2
2009   -99.0 -99.0 -99.0 -99.0 -99.0  60.8  64.1  67.2  70.1  72.7  75.2  77.4  79.4  81.3  83.0  84.5  85.9  87.3  88.5  89.8  90.9  91.9  93.0  94.5  96.1  97.7  99.3
2010   -99.0 -99.0 -99.0 -99.0 -99.0  60.1  63.4  66.4  69.2  71.9  74.3  76.5  78.6  80.5  82.3  83.9  85.4  86.8  88.1  89.3  90.3  91.9  92.3  93.8  95.2  96.5  97.9
2011   -99.0 -99.0 -99.0 -99.0 -99.0  60.1  63.4  65.6  68.4  71.0  73.4  75.7  77.7  79.7  81.5  83.1  84.6  86.1  87.4  88.6  89.7  91.9  92.3  93.2  94.2  95.2  96.2
##
## ------------------------------------------------------------------------ ##
## MARKER FOR END OF DATA FILE (eof)                                        ##
## ------------------------------------------------------------------------ ##
999
```

The following text is the control file for the halibut simulation model

```
## ------------------------------------------------------------------------ ##
## CONTROL FILE TEMPLATE                                                    ##
```

```
## ------------------------------------------------------------------------ ##
##
##
## ------------------------------------------------------------------------ ##
## CONTROLS FOR LEADING PARAMETERS                                          ##
##  Prior descriptions:                                                     ##
##                      -0 uniform      (0,0)                               ##
##                      -1 normal       (p1=mu,p2=sig)                      ##
##                      -2 lognormal    (p1=log(mu),p2=sig)                 ##
##                      -3 beta         (p1=alpha,p2=beta)                  ##
##                      -4 gamma        (p1=alpha,p2=beta)                  ##
## ------------------------------------------------------------------------ ##
## npar
5
## ival         lb      ub      phz     prior   p1      p2      #parameter   ##
   16.8452      -5.0    15      1       0       -5.0    15      #log_ro      ##
   0.75         0.2     1.0     1       3       1.01    1.01    #steepness   ##
   17.93703     -5.0    15      1       0       -5.0    15      #log_avgrec  ##
   0.5          0.01    0.99    -3      3       1.01    1.01    #rho         ##
   0.8          0.01    5.0     -3      4       1.01    1.01    #vartheta    ##
## ------------------------------------------------------------------------ ##
##
## ------------------------------------------------------------------------ ##
## CONTROLS FOR SEX BASED PARAMETERS (nsex arrays, 9 rows, 7 cols)          ##
## ------------------------------------------------------------------------ ##
## FEMALE                                                                   ##
## ival         lb      ub      phz     prior   p1      p2      #parameter   ##
## ------------------------------------------------------------------------ ##
   15.18892     -5.0    15      1       0       -5.0    15      #log_recinit ##
   -1.89712     -3.0    2.0     -1      1       -1.74   0.1     #log_m_f     ##
   148.0627     0.0     200     -1      0       0.0     200     #linf        ##
   0.09154536   0.01    1.0     -1      0       0.01    1.0     #vonk        ##
   0            -2.0    0.0     -1      0       -2.0    0.0     #to          ##
   9.321e-6     0.0     1.0     -1      0       0.0     1.0     #a           ##
   3.16         2.0     3.5     -1      0       2.0     3.5     #b           ##
   11.59        0.0     30.     -1      0       0.0     30.     #ah          ##  11.49
   1.776        0.0     30.     -1      0       0.0     30.     #gh          ##  1.776
## ------------------------------------------------------------------------ ##
## MALE                                                                     ##
## ival         lb      ub      phz     prior   p1      p2      #parameter   ##
## ------------------------------------------------------------------------ ##
   15.34718     -5.0    15      1       0       -5.0    15      #log_recinit ##
   -1.99897     -3.0    2.0     -1      1       -1.74   0.1     #log_m_f     ##
   105.7311     0.0     200     -1      0       0.0     200     #linf        ##
   0.1275141    0.01    1.0     -1      0       0.01    1.0     #vonk        ##
   0            -2.0    0.0     -1      0       -2.0    0.0     #to          ##
   9.321e-6     0.0     1.0     -1      0       0.0     1.0     #a           ##
   3.16         2.0     3.5     -1      0       2.0     3.5     #b           ##
   11.49        0.0     30.     -1      0       0.0     30.     #ah          ##
   1.776        0.0     30.     -1      0       0.0     30.     #gh          ##
## ------------------------------------------------------------------------ ##

##
##
## ------------------------------------------------------------------------ ##
## SELECTIVITY PARAMETERS Columns for gear                                  ##
## OPTIONS FOR SELECTIVITY (isel_type):                                     ##
##      1) logistic selectivity parameters                                  ##
##      2) selectivity coefficients                                         ##
##      3) a constant cubic spline with age-nodes                           ##
##      4) a time varying cubic spline with age-nodes                       ##
##      5) a time varying bicubic spline with age & year nodes.             ##
##      6) fixed logistic (set isel_type=6, and estimation phase to -1)     ##
##      7) logistic function of body weight.                                ##
##      8) logistic with weight deviations (3 parameters)                   ##
##      11) logistic selectivity with 2 parameters based on mean length     ##
##      12) length-based selectivity coefficients with spline interpolation ##
##      sig=0.05 0.10 0.15 0.20 0.30 0.40 0.50                              ##
##      wt =200. 50.0 22.2 12.5 5.56 3.12 2.00                              ##
## ------------------------------------------------------------------------ ##
##CatchWt  DiscardWt BycatchWt SportCatchWt PersUseWt
  13    13    13    13    13                # -selectivity type ivector(isel_type) for gear
  97.13 97.13 97.13 97.13 97.133            # -Age/length at 50% selectivity (logistic)
  6     6     6     6     6                 # -STD at 50% selectivity (logistic)
  8     8     13    8     8                 # -No. of age/length nodes for each gear (0=ignore)
  0     0     0     0     0                 # -No. of year nodes for 2d spline(0=ignore)
  -2    -2    -2    -2    -2                # -Phase of estimation (-1 for fixed)
  2     2     2     2     2                 # -Penalty wt for 2nd differences w=1/(2*sig^2)
  3     3     3     3     3                 # -Penalty wt for dome-shaped w=1/(2*sig^2)
  81.28 0     0     0     0                 # -Size limit (cm) 81.28 for halibut or 26in (66.04cm) 73.66
  0.16  0     0     0     0.16              # -Discard mortality rate
## ------------------------------------------------------------------------ ##
##
##
##
## ------------------------------------------------------------------------ ##
## PRIORS FOR SURVEY Q                                                      ##
```

```
## Prior type:                                                              ##
## 0 - uninformative prior                                         ##
## 1 - normal prior density for log(q)                             ##
## 2 - random walk in q                                            ##
## ------------------------------------------------------------------------ ##
2 # -number of surveys (nits)
0 2    # -prior type (see legend above)
0 0    # -prior log(mean)
0 0.01    # -prior sd
## ------------------------------------------------------------------------ ##
##

## ------------------------------------------------------------------------ ##
## OTHER MISCELANEOUS CONTROLS                                              ##
## ------------------------------------------------------------------------ ##
0           # 1  -verbose ADMB output (0=off, 1=on)
1           # 2  -recruitment model (1=beverton-holt, 2=ricker)
0.100       # 3  -std in observed catches in first phase.
0.0707      # 4  -std in observed catches in last phase.
0           # 5  -Assume unfished in first year (0=FALSE, 1=TRUE)
0.00        # 6  -Minimum proportion to consider in age-proportions for dmvlogistic
0.20        # 7  -Mean fishing mortality for regularizing the estimates of Ft
0.01        # 8  -std in mean fishing mortality in first phase
2.00        # 9  -std in mean fishing mortality in last phase
-3          # 10 -phase for estimating m_deviations (use -1 to turn off mdevs)
0.1         # 11 -std in deviations for natural mortality
12          # 12 -number of estimated nodes for deviations in natural mortality
0.50        # 13 -fraction of total mortality that takes place prior to spawning
1           # 14 -switch for age-composition likelihood (1=dmvlogistic,2=dmultinom)
#81.28       # 15 -Size limit (cm) for retention (logistic with 10% CV)
#0.17        # 16 -Base discard mortality rate (age-size independent)
##
## ------------------------------------------------------------------------ ##
## MARKER FOR END OF CONTROL FILE (eofc)
## ------------------------------------------------------------------------ ##
999


# Number of parameters = 285  Objective function value = 3667.07  Maximum gradient component = 0.00000
# theta[1]:  #log_Ro
15.9
# theta[2]:  #steepness
0.750000000000
# theta[3]:  #log_Rbar
17.93703
# theta[4]:
8.00000000000
# theta[5]:
8.00000000000
# female parameters
15.18892
-1.89712
148.0627
0.09154536
-1.2197
9.321e-6 # a
3.16     # b
11.49
1.776
# male parameters
15.34718
-1.99897
105.7311
0.1275141
-1.2197
9.321e-6 #a
3.16     #b
11.49
1.776
# sel_par[1]:
1.63176e-09 3.25739e-09 0.0603022 0.300891 0.630344 0.913893 1 1
2.17169e-09 0.00396878 0.0567109 0.281436 0.585461 0.835614 1 1
# sel_par[2]:
0 0 1 0 0 0 0 0
0 0 1 0 0 0 0 0
# sel_par[3]:
0 0 0 0.001 0.7 1 0.6 0.6 0.6 0.6 0.6 0.6 0.6
0 0 0 0.001 0.7 1 0.6 0.6 0.6 0.6 0.6 0.6 0.6
# sel_par[4]:
0 0.0227976 0.18854 0.407238 0.654921 0.863483 1 1.20589
0 0.0266741 0.161269 0.242839 0.389576 0.673042 1 1.32696
# sel_par[5]:
0 0.0227976 0.18854 0.407238 0.654921 0.863483 1 1.20589
0 0.0266741 0.161269 0.242839 0.389576 0.673042 1 1.32696
# log_ft_pars:
-2.307296 -2.102751 -1.992090 -1.862461 -1.899322 -1.716355 -1.625466 -1.513355 -1.371879 -1.288079 -1.249249 -1.231001 -1.238392 -1.346766 -1.390905 -1.644806 -5.748506
-4.799907 -4.634285 -4.611588 -4.579337 -4.419579 -4.378035 -4.474458 -4.495733 -4.572945 -4.468456 -4.353657 -4.712525 -3.815718 -3.875378 -3.873048 -3.822219 -3.823495
```

```
-3.932297 -3.962359 -3.955437 -4.088814 -4.268712 -4.289695 -4.398994 -4.485602 -4.264599 -4.234448 -4.299606 -4.406967 -4.092137 -4.031404 -4.020839 -3.750274 -3.499536
-3.230384 -3.425503 -3.556316 -3.642721 -6.964999 -7.045085 -6.793632 -6.705370 -6.581514 -6.417055 -6.394806 -5.661074 -5.451366 -5.342769 -5.280884 -5.253524 -5.207165
# FMX(sex-based multiplier for ft)
1 0.925001
1 1
1 1
1 1.99269
1 1.99269
# init_log_rec_devs (females):
1.593029 0.8881916 0.9450568 1.074646 1.176216 1.339384 1.890281 2.337506 1.494435 1.052563 1.215801 1.293796 0.7483233
0.3074295 0.6185686 0.5827836 0.1066623 0.8227823 -1.411234 -1.510765 -1.610295 -1.709829 -1.80936 -1.908888 -2.008424
-2.107953 -2.207485 -2.307016 -0.8962065
# init_log_rec_devs (males):
 1.349134 0.678651 0.7432793 0.8673499 0.9717188 1.159698 1.68465 2.125607 1.344155 0.9419811 1.146674 1.295268 0.8127713
0.4089091 0.7391368 0.7059838 0.2194272 0.9217337 -1.331316 -1.423383 -1.515451 -1.607518 -1.699585 -1.791651 -1.883719
-1.975785 -2.067851 -2.15992 -0.6599482
# log_rec_devs:
 -0.39744428 -0.68985032 -0.72321874 -0.18832470 0.21952123 0.10200122 -0.01069562 0.26045469 0.19992632 0.32715933
0.60199112 0.04974662 0.04974662 0.04974662 0.04974662 0.04974662 0.04974662
# log_m_nodes:
 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000
 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000
 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000 0.00000000000
```

B.2 Model Description

The following detailed documentation is a description of the simulation model used to generate model output in this report. The description is broken down into three subsections: 1) simulation model input, 2) state dynamics, and 3) model outputs. A series of tables along with a detailed written description is used to document the model. The tables of equations are meant to represent the logical progression of using input data to initialize the population model, simulating dynamical responses to alternative policies and deriving model outputs.

To summarize the following subsections that describe the model in detail, the following pseudocode represents the general order of operations (implemented as specific functions within the computer code).

<u>Pseudocode:</u>

1. Read simulation model inputs, (biological data, fishery data and model parameters).
2. Initialize model parameters (initial age-structure, annual recruitment, etc).
3. Calculate length-based selectivities for each gear type for each sex.
4. Partition fishing mortality to each fishing sector.
5. Calculate age-specific total mortality rate for each year where the probability of capture and discard is a function of selectivity and size limits.
6. Calculate numbers-at-age each year based on annual values of Z.
7. Compute model outputs and performance measures.

The underlying model design is and age-structured population model with an annual time step. The population model has two periods: (1) a historical period in which the population model is initialized with numbers-at-age in the first year, and annual recruitments for each year up to the present, and (2) a projection period where the numbers-at-age are simulated

15 years into the future under alternative scenarios and harvest policy options. Information for the initialization of the population model is based on the most recent stock assessment for Pacific Halibut (Hare, 2012). At each time step in the model, total age/sex-specific mortality rates are computed as a sum of natural and fishing mortalities from each of the directed and non-directed fisheries.

The detailed analytical description of the simulation model that follows is arranged in a series of tables of equations that are intended to provide a concise description, as well as, provide the logical order of operations in which the code is executed. A list of parameter symbols, the units, and description is provided in Table A-1. The source code for this simulation model can also be obtained from a code.google repository at `http://code.google.com/p/iscam-project/`.

Permitted bycatch mortality in BSAI groundfish fisheries in 2012 are 900 mt for the fixed gear and 3,525 mt for the trawl gear. The accounting system for trawl by catch is that 80% of the net halibut weight landed is assumed to die, and in the case of the pollock fishery a 90% discard mortality is assumed.

B.2.1 Simulation model input

Input data for the simulation model was provided by Steve Hare from the IPHC in the form of the report file from the assessment model presented at the 2012 annual meeting (Hare, 2012). The input data for the simulation model, along with the control file and initial parameter value can be found in appendix A.1. The following list is a summary description of the model inputs that are required to run the simulation model.

List of model input:

1. Model dimensions (i.e., years, number of gears, number of age-classes).

2. Historical catch data and fishing mortality rates for 5 gear types.

3. Annual recruitment from 1996 to present.

4. Initial numbers-at-age (2-30) by sex.

5. Selectivity parameters (length-based selectivity).

6. Size limit, target harvest rate, & other policy related parameters (e.g., SUFD).

The model dimensions are consistent with the IPHC assessment model where the model starts in 1996 and is conditioned on the assessment data through 2011, the number of ages ranges from 1–30, and the fisheries are broken down into five distinct components:

1. the setline fishery (including the IPHC research catch),

2. the sublegal discards (including U32 wastage and U32 bycatch),

3. the fully recruited by catch (O32 wastage and bycatch),

4. the recreational sport fishery, and
5. and the personal use (subsistence fishery).

Each of these 'gears' have there own length-based selectivity coefficients and fishing mortality rates that are based on the most recent assessment model output. The historical catch data for each of these gears are also given in the input data, but are not used to calculate total mortality rates in anyway.

Table A-1: List of symbols, units and description of variables for the simulation model.

Symbol	Units	Description
h	-	index for sex
i	-	index for year
j	-	index for age
k	-	index for gear
l	-	index for length
Input Parameters		
R_0	millions	unfished recruitment
h	-	steepness of the stock-recruitment relationship
M_h	yr^{-1}	instantaneous natural mortality rate by sex (0.15 female, 0.135 male).
$\bar{R}$	millions	average recruitment
$\ddot{R}$	millions	initial recruitment
ω_i	-	annual recruitment deviation in year i (assume 50:50 sex ratio at age-1)
$\ddot{\omega}_{h,j}$	-	initial recruitment deviation for sex h and age j
Dynamic Variables		
$F_{h,i,k}$	yr^{-1}	Fishing mortality rate by sex h in year i, for gear k
$s_{h,l,k}$	-	log selectivity for sex h, length l for gear k
$\nu_{h,i,j,k}$	-	log selectivity for sex h, year i, age j in gear k
$Z_{h,i,j}$	yr^{-1}	Age-specific total mortality rate for sex h in year i
$N_{h,i,j}$	millions	numbers of halibut of sex h, in year i, at age j
SB_i	million pounds	Female spawning biomass in year i

B.2.2 Analytical description

Initial states (i=1996:2011)

The simulation model is initialized using the model estimates of numbers-at-age and annual recruitment produced by the IPHC 2011 halibut stock assessment (Hare, 2012). Two parameter vectors, Θ and Φ are used to categorize population parameters as sex independent and dependent, respectively. Components of these two vectors are defined in (T2.1) and (T2.2), where R_0 and h define the unfished age-1 recruits and steepness of the stock recruitment relationship. Note that these terms (R_0, h) are not of interest in this simulation model, because we do not use a stock recruitment relationship to simulate future recruitment. The average recruitment $\bar{R}$ and annual deviations ω_i are used to initialize age-1 recruits from 1996 to 2011 (T2.7), where these values were obtained from the IPHC assessment report file. The sex-specific parameters Φ consists of the initial average recruitment $\ddot{R}_h$ and cohort specific deviations $\ddot{\omega}_j$ which makes up the initial numbers at age in 1996 (T2.7). Sex-specific natural mortality M_h rates were set at 0.15 and 0.135 for females and males, respectively. The annual fishing mortality rates $f_{h,i,k}$ (on a log scale) for sex, year, and gear were taken from the IPHC assessment along with the selectivity coefficients $s_{h,l,k}$ (also on a log scale) for sex, length, and gear. Age-specific selectivities for each gear, year, and sex $(\nu_{h,i,j})$ were based on a piece-wise liner interpolation (T2.4) of the length-based selectivity coefficients $S_{h,i,k}$ and the mean length-at-age $l_{h,i,j}$ in the annual IPHC setline survey (T2.3). In (T2.4) the $l^{(0)}$ and $l^{(1)}$ terms correspond to the length intervals on either side of the current $l_{h,i,j}$ values (Note that this function is equivalent to the `approx` function implemented in the R-scripting (R Development Core Team, 2009) language). Annual sex- age-specific fishing mortality rates are based on (T2.5) for each gear k, and the total mortality is the sum of natural and fishing mortalities (T2.6).

The numbers-at-age by sex are initialized using (T2.7) and are updated using (T2.8) and (T2.9) for the plus group. Female spawning biomass each year is calculated as the product of the number of females surviving half the Z in a given year, the proportion mature-at-age, and the observed average catch weight-at-age $w_{h,i,j}$ in a given year. Prior to 2001, aging data ranged from age-6 to age-20, and post 2001 break and burn methods were used to age halibut upto age-25, where 25 is the new plus group. This calculation (T2.10) of spawning biomass differs slightly from the IPHC code, where the numbers-at-age each year are smeared by an aging error matrix, and the average weight at age from the survey was used. The predicted catch in year i for gear k is given by (T2.11), which is the sum over the catch-at-age by sex.

Joint probability model for fishing & discard mortality

For the future simulations ($i \geq 2012$), the directed setline fishery for halibut is based on the probability of capturing a fish of age j times the probability of retaining a fish of age j. This joint probability is represented by the age-selectivity of the fishing gear (which is a length-based function) and variation in growth of male and female halibut. The age-based selectivity is based on (T2.4). The probability of retaining a fish of age j is the based on the probability of an age j fish being larger than the size limit. This integral was approximated using a logistic function of the mean length-at-age and assuming a coefficient of variation of 0.1 in length-at-age such that the standard deviation in length-at-age σ_j increases as a linear function of length:

$$p(r)_j = \frac{1}{1 + \exp(-(l_j - \text{MSL})/\sigma_j)}$$

Table A-2: Analytical description of the sex-based age-structured model used for simulation projections.

Model parameters

$$\Theta = \{R_0, h, \bar{R}, \omega_i\} \tag{T2.1}$$

$$\Phi = \{\ddot{R}_h, \ddot{\omega}_{h,j}, M_h, f_{h,i,k}, s_{h,l,k}, a_{50}, \gamma_{50}\} \tag{T2.2}$$

Input data

$$C_{i,k}, l_{h,i,j}, w_{h,i,j} \tag{T2.3}$$

Initialize state variables

$$\nu_{h,i,j} = s_{h,l}^{(0)} + \frac{(l_{h,i,j} - l^{(0)})s_{h,l}^{(1)} - (l_{h,i,j} - l^{(0)})s_{h,l}^{(0)}}{l^{(1)} - l^{(0)}}, \quad \text{where} \quad l^{(0)} \leq l_{h,i,j} \leq l^{(1)} \tag{T2.4}$$

$$F_{h,i,j,k} = \exp(f_{h,i,k} + \nu_{h,i,j,k}) \tag{T2.5}$$

$$Z_{h,i,j} = M_h + \sum_k F_{h,i,j,k} \tag{T2.6}$$

Numbers at age

$$N_{h,i,j} = \begin{cases} \ddot{R}_h \exp(\ddot{\omega}_{h,j} - M_h(j-1)), & \text{for } 2 < j < 30 \\ 0.5 R_h \exp(\omega_i), \quad \text{for } 1996 < i < 2026 \end{cases} \tag{T2.7}$$

$$N_{h,i+1,j+1} = N_{h,i,j} \exp(-Z_{h,i,j}), \quad \text{for } 1 < j < 30 \tag{T2.8}$$

$$N_{h,i+1,j} = N_{h,i,j-1} + N_{h,i,j} \exp(-Z_{h,i,j}), \quad \text{for } j = 30 \tag{T2.9}$$

Model outputs

$$SB_i = \sum_{j=6}^{j=30} N_{h,i,j} \exp(-0.5 Z_{h,i,j}) p_{h,j} w_{h,i,j}, \quad \text{where } h = 1 \tag{T2.10}$$

$$C_{i,k} = \sum_h \sum_j \frac{N_{h,i,j} w_{h,i,j} f_{h,i,k} s_{h,i,j}(1 - \exp(-Z_{h,i,j}))}{Z_{h,i,j}} \tag{T2.11}$$

$$EB_i = \sum_h \sum_{j=6}^{j=30} N_{h,i,j} w_{h,i,j} \exp(\nu_{h,i,j,k=1}) \tag{T2.12}$$

$$YBio_i = \sum_h \sum_j \frac{N_{h,i,j} w_{h,i,j} f_{h,i,k=1} s_{h,i,j,k=1} r_{h,i,j,k=1}(1 - \exp(-Z_{h,i,j}))}{Z_{h,i,j}} \tag{T2.13}$$

$$WBio_i = \sum_h \sum_j \frac{N_{h,i,j} w_{h,i,j} f_{h,i,k=1} s_{h,i,j,k=1}(1 - r_{h,i,j,k=1}) d_{k=1}(1 - \exp(-Z_{h,i,j}))}{Z_{h,i,j}} \tag{T2.14}$$

$$LBio_i = YBio_i^{(f_{k=2,3}=0)} - YBio_i \tag{T2.15}$$

$$BBio_i = \sum_h \sum_j \sum_{k=2}^{k=3} \frac{N_{h,i,j} w_{h,i,j} f_{h,i,k} s_{h,i,j,k} r_{h,i,j,k}(1 - \exp(-Z_{h,i,j}))}{Z_{h,i,j}} \tag{T2.16}$$

$$YLR_i = \frac{LBio_i}{BBio_i} \tag{T2.17}$$

The probability of discarding a fish of age j is defined as $1 - p(r)_j$. Figure B.19 shows how retention and discarding probabilities vary with age with a 32 inch size limit in place. Note that when the mean length-at-age gets smaller, this retention probability shifts to the right (older ages) and fish recruit to the fishing gear later in life.

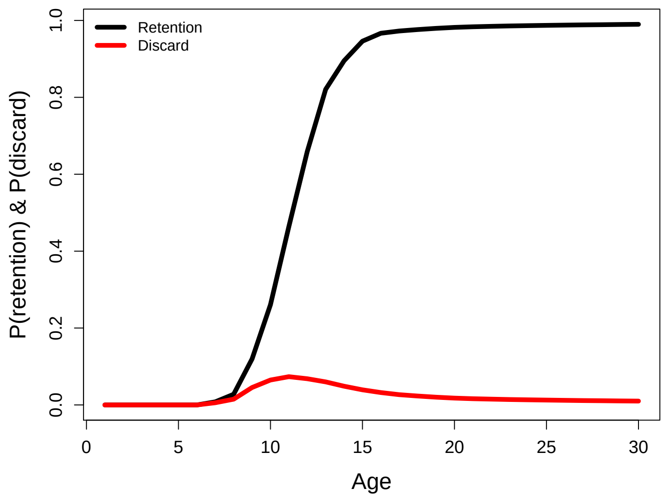

Figure B.19: Probability of retention and discarding a halibut with a 32 inch size limit in place.

In the more recent stock assessment models, the age/sex/size composition of the commercial landings are estimated externally to the model. These data were not available to be used in this analysis. For the 1996 to 2011 period, fishing mortality rates were taken from the IPHC assessment model. For the projection period ($i > 2011$), fishing mortality rates were based on the projected catches for each of the five gears (commercial, U32, O32, recreational, personal). Sex-specific fishing mortality rates were determined using a numerical procedure to solve the Baranov catch equation (T2.11). An initial guess for the sex-specific fishing rate $f_{h,i,k}$ for gear k in year i, followed by the use of Newtons' root finding method to find the appropriate values of $f_{h,i,k}$ such that the sum of the predicted female and male catches for each gear was equivalent to the catch allocated to that gear.

B.2.3 Model outputs

Simulation model outputs of interest for this study are:

1. Exploitable biomass, EBio defined by (T2.12).
2. Female spawning biomass, SBio defined by (T2.10).
3. Commercial Yield, YBio defined by (T2.13).

4. Wastage from the commercial fishery, WBio defined by (T2.14).
5. Lost yield due to bycatch from non-directed fisheries, LBio defined by (T2.15).
6. Bycatch from non-directed fisheries, BBio defined by (T2.16).
7. The yield loss ratio, YLR defined by (T2.17).

Note that in order to calculate the lost yield (T2.15), the model was run as if there were no bycatch of halibut in other fisheries, and all of the available CEY for each area was allocated to the commercial gear. The lost yield is the difference between the yield obtained with no bycatch and the yield obtained with bycatch allotments in place.