2007 IPHC harvest policy analysis: past, present, and future considerations

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Abstract

The IPHC harvest policy is updated to include the "slow up/fast down" fishery CEY adjustment and autocorrelated assessment error, and a range of spawning biomass thresholds considered. We is conclude that a harvest rate of 0.20 in combination with a threshold reference point equal to 1.5 times the limit reference point (i.e., the point at which fishing ceases) provides the optimal combination of yield and spawning biomass conservation, under conditions of either density dependent growth or continued slow growth. The halibut female spawning stock is determined to be well above the minimum reference points, however the harvest rate has been over target for the past few years. Exploitable biomass is declining in all areas. This is occurring in the western regions as the stock is fished down from a lightly exploited state and in the eastern regions because of the passage of two exceptional year classes (1987 and 1988), as well as the buildup of the western area fisheries. Projections indicate that spawning biomass and exploitable biomass will both increase sharply if the incoming 1999 and 2000 year classes remain as strong as the assessment currently estimates them. The current slow growth rate of halibut may not reverse as numbers are fished down due to the large increase in the biomass of arrowtooth flounder.

Introduction

Every year the harvest policy is reviewed and simulations conducted to determine an optimal harvest rate as well as the need for any additional conservation measures. The status of the halibut stock, relative to standard reference points, is now explicitly determined. A review of recent stock performance by major region is conducted and biomass projections are presented in response to industry requests. Further exploration of the growth rate of halibut in relation to other factors is also provided this year.

Determination of stock status relative to reference points

Estimates of age-six recruits are obtained from closed area assessments and expanded to account for pre-recruit mortality in the commercial and bycatch fisheries (Clark and Hare 2006). The vast majority of pre-recruit mortality comes from the well-observed groundfish fisheries in the Bering Sea and Gulf of Alaska. Estimates of IPHC regulatory area pre-recruit mortality are derived using the "intermediate schedule" of the migration model developed by Clark and Hare (1998). For Areas 2B, 2C and 3A combined, the average recruitment for year classes 1947-1976 is 4.13 million age-six halibut. For the year classes 1977-2001 the average is 13.00 million age-six halibut. These two different time periods reflect two phases of the Pacific Decadal Oscillation (Mantua et al. 1997) and correspond to different climate, and halibut productivity, regimes. Thus, halibut recruitment in a low productivity regime is about 32% of recruitment during a high productivity regime.

The next step is to determine what spawning biomass (all references to spawning biomass are to the female component only) would be in the absence of fishing. There are different methods of doing this, but the method we use is to compute spawning biomass per recruit (SBR) in the absence of fishing and then multiply that number with average recruitment. The time period and size at age schedules used in these calculations are critical. One component of the IPHC harvest policy has been to maintain spawning biomass such that it does not drop below the observed historical minimum. It is also instructive to determine what fraction of unfished spawning biomass level the historical minimum represents. That minimum occurred in the early 1970s, at the end of the low productivity period that began in the 1940s. This argues for using recruitment and SBR values from the low productivity period to establish historical, and contemporary, perspective.

Sex-specific size at age for halibut for both the low productivity (earlier) period and current high productivity period are illustrated in Figure 1a. The values are computed by averaging data from Areas 2B, 2C and 3A, weighted by abundance at age for each region. The earlier period values are computed from 1974-1977 length at age data, the later values from data for 2002-2005. The standard size selectivity curve (Fig. 1b) estimated in the coastwide assessment (Clark and Hare 2008) and used in the harvest policy simulations is used to compute SBR values. A single time-invariant maturity schedule is used to determine spawning biomass (Fig. 1c) The extremely divergent length at age schedules for the earlier and later periods give rise to very different SBR schedules (Fig. 1d). In the absence of fishing, SBR for the earlier/less productive period is around 118 lbs per recruit, compared to a value of around 50 lbs per recruit for the later period.

Two minimum spawning biomass limits are established, one for the long-term simulations and one for the coastwide stock. For the simulations, as has been custom in developing the harvest policy, areas 2B/2C/3A are combined. The purpose of establishing a coastwide limit is twofold: it establishes the level of the current biomass in relation to an unfished state and it establishes the point at which more conservative actions should be taken (i.e., lowering of the target harvest rate). Multiplying the low productivity period average recruitment value of 4.13 million age-six recruits by the SBR with no fishing gives an estimate, for areas 2B/2C/3A, of 489 million pounds for $B_{unfished}$.

The minimum spawning biomass limit for the coastwide stock is established in the following manner. For Areas 2B, 2C, and 3A the historical minimum observed spawning biomass (as estimated in the closed area assessments) is 63.7 million pounds. Based on the unfished biomass calculations described above (and summarized in Table 1), the historical minimum observed spawning biomass is 13% of unfished spawning biomass (B_{13}). As noted earlier, a cornerstone of the IPHC harvest policy has been to prevent spawning biomass from falling below the historical minimum and, in reality, to avoid even getting very close to that level. The reasoning for this has been that we can have some confidence that the stock can be (and has been) rebuilt from that level of spawning biomass but we have no indication of stock dynamics at a lower level. For the harvest rate simulations, we set the minimum biomass limit at 20% (rather than 13%) of $B_{unfished}$. This reflects both an extra layer of conservation and recognizes the recent finding that ongoing migration beyond age eight implies that the minimum observed biomass that produced the large recruitments of the 1970's was likely somewhat larger than 63.7 million pounds. The biomass threshold reference point, i.e., the point at which the harvest rate begins to be set lower than the target harvest rate, is set somewhere higher than B_{20} and is discussed in the following section.

For the coastwide stock, we leverage data from 2B/2C/3A to compute $B_{unfished}$ and B_{20} and then determine the current status of the coastwide spawning biomass. From the coastwide assessment, we have recruitment estimates for the period 1996-2007. Because there is substantial uncertainty in the most recent estimates, we use the 1996-2003 data which gives an average of 19.86 million age-six recruits. These recruits are from a productive regime. Using the ratio from areas 2B/2C/3A where recruitment in an unproductive regime is approximately 32% of the average in a productive regime, we estimate that average coastwide recruitment in an unproductive regime would be 6.31 million age-six recruits. Multiplying this number by the SBR (in the absence of fishing) value of 118.5 lbs results in a $B_{unfished}$ value of 748 million pounds. B_{20} is 150 million pounds and the most recent assessment estimate of current spawning biomass ($B_{current}$) is 300 million pounds which translates to a value of B_{40}. This level of spawning biomass is very similar to target values set for many groundfish stocks in Alaska. The conclusion from this exercise is that the halibut stock, on a coastwide basis, is in good shape and not near a level that would trigger more conservative action. The time trajectory of the coastwide spawning biomass in relation to the reference points described above is illustrated in Figure 2.

The determination that $B_{current}$ is well above B_{20} defines the halibut stock, on a coastwide basis, to be well above the minimum reference points, and therefore not in a region of added concern. It has also become common practice to determine whether actual removals are in line with the intent of the harvest policy. We do this by comparing actual harvest rates over time to the target harvest rate. The target harvest has ranged between 0.20 and 0.25 over the past decade. Figure 3 illustrates the currently estimated historical harvest rates compared to the range of target harvest rates. The realized harvest rate increased steadily from 1996 to 2006 rising to a maximum rate of 0.26. The rate has since declined to 0.24 for 2007. This is above target but is headed in the right direction. Incorporation of the "slow up/fast down" adjustment (described below) slows the transition from an above target harvest rate to the actual target rate. Additionally, ongoing retrospective behavior in the assessment has had the result of successively lowering estimates of earlier exploitable biomass thus retroactively raising the realized harvest rate.

Harvest policy analysis

The simulation model used to analyze the IPHC harvest policy remains basically unchanged from the past few years and is fully described in Clark and Hare (2006). The analysis this year focused on three areas of refinement. First, in response to suggestions arising from the Center for Independent (CIE) review (Clark et al. 2008), the analysis now incorporates assessment error (often termed observation error). Adding assessment error to the dynamic simulations should give a more realistic picture of how the harvest policy performs in the (real world) situation where assessments are uncertain and tend to evolve over time. The error was implemented by adding autocorrelated lognormal error to annual spawning biomass. Based on recent retrospective behavior of the halibut assessment model, a value of 0.25 was used for the lognormal standard deviation and lag-one autocorrelation was set at a moderately high value of 0.6. The CIE review also noted that the IPHC has routinely been applying a "Slow Up – Fast Down" (SUFD) adjustment to the Fishery CEY. This adjustment limits abrupt fishery CEY changes from one year to the next in the following manner. If a fishery CEY is greater than the previous year's catch limit, only 33.3% of the increase is allowed. If a fishery CEY is lower than the previous year's catch limit, only 50% of the decrease is allowed. This adjustment was implemented in exactly this fashion for this year's harvest policy simulations. The effect of these two harvest policy simulation adjustments is discussed below.

The third area of refinement concerned the spawning biomass threshold, i.e., the biomass level at which the harvest rate begins to be set below the target rate in order to slow down the decline in biomass. The approach we took to analyze positioning of the spawning biomass threshold was to set it as a variable multiple of the minimum biomass limit (where the harvest rate set is set to zero). The range of values we analyzed was 1.0 (i.e., threshold equal to the limit) to 2.0 (i.e., threshold at B_{40}, double the limit). Analyses were conducted with and without incorporating the SUFD adjustment, and with and without inclusion of observation error. Simulations were conducted for two alternative states of nature ("scenarios"): Standard scenario which incorporates density dependent growth response and Slow Growth scenario which sets growth rate constant at the slow rate currently extant in the population. Thus, a total of eight different combinations were analyzed. It turned out that the effects of both the SUFD adjustment and the inclusion of assessment error were minor and of little influence on the results. Therefore, only two sets of results are illustrated – one for the Standard scenario and one for the Slow Growth scenario and both sets of results incorporate the two adjustments. The Slow Growth scenario is a conservative metric and serves as a "worst case" scenario for management of halibut. Performance of the harvest policy over a range of harvest rates was assessed in terms of impact on spawning biomass, frequency of triggering target harvest rate reduction, fraction of maximum yield taken, and average "realized" harvest rate.

Results for the Standard scenario are illustrated in Figure 4 and results for the Slow Growth scenario are illustrated in Figure 5. In all plots, harvest rate increases from left to right along the x-axis while the biomass threshold increases from bottom to top along the y-axis. Thus any combination of harvest rate and threshold can be considered. For 2006, the target harvest rate was recommended at 0.20 and the threshold at 1.5 times the limit. This combination is indicated by a large dot on all the plots. The four plots for both scenarios illustrate the tradeoff between higher harvest rate and protection to the spawning biomass as well as the impact of the growth rate. The upper left plot shows how often the spawning biomass drops to within 25% of B_{20}. While this is a somewhat arbitrary level of concern, it is a point at which serious concern about the spawning biomass would arise. For a given harvest rate and limit multiplier combination, the frequency of occurrence is substantially greater under the Slow Growth scenario. Under the recommended combination of a 0.20 harvest rate and limit multiplier of 1.5, the spawning biomass drops to within 25% of B_{20} 10% of the time in the Standard scenario and 25% of the time under Slow Growth scenario. Setting a higher harvest rate or a lower threshold increases the frequency relatively sharply.

The upper right plots show how often the spawning biomass reaches the threshold, thereby triggering a reduction from the target harvest rate. Higher harvest rates as well as a larger limit multiplier both result in a more frequent occurrence of a harvest rate reduction. At a harvest rate of 0.20 and limit multiplier of 1.5, the harvest rate reduction would occur approximately 33% of the time under the Standard scenario and 45% of the time under the Slow Growth scenario. The lower right panels illustrate how the average harvest rate would be less than the target harvest rate because of the triggering. The bottom left panels show how much yield would be expected – compared to the maximum that would be obtained at a harvest rate of 0.30 and a limit multiplier of 1.0 (termed Y_{max}) – for the various combinations of harvest rate and limit multipliers. For both scenarios, a target harvest rate of 0.20 and a limit multiplier of 1.5 would give about 85% of the Y_{max}. Of course the Y_{max} is much lower under the Slow Growth scenario – the combination of harvest rate and limit multiplier results in the same Yield fraction relative to the respective Y_{max}'s.

We noted earlier that the simulations reported on above incorporated the IPHC SUFD adjustment to annual catch limits and that the effect was minor. For example, at the 0.20 harvest rate and limit multiplier of 1.5, there is a difference of less than 2% for each of the four measures of harvest policy performance. A small, but positive, benefit is that the spawning biomass threshold is reached less frequently, thus triggering a harvest rate reduction less often. The effect of adding assessment error to the simulations was also relatively minor, however its impact was to cause slightly more aggressive harvesting and a slightly more frequent triggering of the harvest rate reduction. Taking all the factors discussed above, we conclude that a target harvest rate of 0.20, in combination with a spawning biomass threshold of B_{20} and a spawning biomass threshold of B_{30} (i.e., a limit multiplier of 1.5) provides the optimum balance of yield and protection for the spawning biomass. While a slightly more aggressive harvest rate might be entertained under the Standard scenario, uncertainty about the future direction of growth rate (discussed further below) argues for equal, if not greater, attention to be paid to the Slow Growth scenario.

Area by area summary of stock status and biomass indicators

The coastwide assessment indicates a declining spawning biomass but one that is still well above a level of concern or anything close to historic minimums. Survey CPUE indices indicate that catch rates are down in all IPHC regulatory areas over the past 5 to 10 years. The reasons for decline vary from area to area however. The western regions were relatively lightly fished until the mid 1990s while there has been a long history of full exploitation in the eastern regions. Mean size at age continues to decline as well. In this section, we examine indicators of abundance for each region as well as the history of removals, fishing effort, and catch rates and discuss the current biomass trends area by area. Recent trends in harvest rates are illustrated in Figure 6. This set of rates is derived using the coastwide population assessment (Clark and Hare 2008) in combination with a three year running mean of survey partitioning. For comparison, a summary of presumptive harvest rates based solely on the closed area assessments is also provided in Figure 6. There are no closed area assessments for Area 2A and 4CDE. A summary of decadal changes in CPUE, effort, and assessed biomass estimates for each of the regulatory areas is given in Table 2. These values reflect the 2006-2008 average values compared to the 1996-1998 average values; this averaging was done to minimize the influence of any single large deviant value.

Area 2

Area 2A, 2B and 2C indices are illustrated in Figures 7, 8 and 9, respectively. Total removals have been very steady in all three areas for the past decade. In Area 2A, both commercial catch and sport catch increased by a factor of two between 1996 and 2007 while bycatch declined by more than 50% over the period. Commercial fishing effort tripled in 2A over the past decade, remained level in 2B and has increased substantially in 2C the past few years. All three areas show similar trends in the biomass indices. Commercial CPUE has declined 20-30% and survey CPUE has declined around 50% in all three areas since the mid 1990s. The coastwide assessment with survey partitioning estimates an exploitable biomass decline of 27% in 2A, 45% in 2B and 55% in 2C. The closed area assessments in Areas 2B and 2C estimate an exploitable biomass decline of 26% and 17%, respectively.

All the indices are consistent with a picture of a steadily declining exploitable biomass in Area 2. The reasons for the decline are likely twofold. The first is the passing through of the two very large year classes of 1987 and 1988. Every assessment over the past decade has shown that those two year classes were very strong in comparison to the surrounding year classes. Now that those two year classes are 20 years old, their contribution to the exploitable biomass and catches has sharply declined and the drop in biomass is to be expected as they are replaced by year classes of lesser magnitude. A second factor relates to the relatively recent finding that eastward migration apparently continues beyond the age of recruitment to the fishery. Prior to the mid 1990s, the westward regions were relatively lightly fished. However, now that area 3B and westward are fully engaged, there is a decrease in the number of fish that migrate into Area 2. Taken together, the decline in exploitable biomass in Area 2 is understandable and is not cause for undue alarm. However, under a constant exploitation harvest strategy, removals by the fishery must come down as the biomass declines. Our present view of Area 2 is that harvest rates have been much higher than the target rate of 0.20 over the past decade (Figure 6). Such a high target rate was sustainable over decades but was possible only because of the low exploitation rates to the west. As that situation has changed, it has become paramount that harvest rates be brought down to the target harvest rate in Area 2.

Area 3

Area 3A and 3B indices are illustrated in Figures 10 and 11. While these two areas occupy the central area of distribution of the halibut stock, they have substantially different exploitation histories over the past 10-20 years. Area 3A removals, both the total as well as the individual components (commercial, sport, bycatch) have been very stable over the past 10 years. Commercial effort has also seen relatively little variation. The CPUE indices show a slow decline with a drop of 12% in the commercial and 28% in the survey between 1997 and 2007. The coastwide assessment estimates a decline of 11%, while the closed area assessment estimates a decline of 27% over the same time frame. Area 3B saw a large increase in removals beginning in 1996 which peaked in 2002 and has dropped sharply since. Commercial fishing effort more than tripled in the seven years after 1996 and then declined modestly over the past four years. Commercial and survey CPUE both dropped by a bit more than 50% between 1997 and 2007. Both assessments suggest biomass dropped by around 42% between 1997 and 2007.

Area 3A has the appearance of being the most stable of the IPHC regulatory areas. The area has been fully exploited for many decades and there is a wealth of data detailing the population dynamics. The area also sits at the center of halibut distribution and it appears that emigration is roughly equal to immigration resulting in an effectively closed population. Like Area 2, Area 3A benefited from the very large year classes of 1987 and 1988 and the slow decline in exploitable biomass is the result of those year classes dying off. The biomass remains in a healthy state and will continue to support removals of the size seen over the past 2-3 decades. The situation in Area 3B is different. Area 3B was relatively lightly fished until the mid 1990s. With the introduction of a regular survey, quotas were incrementally increased from 4 million pounds to a high of 17 million pounds. Predictably, catch rates declined steadily. Our view of Area 3B is that the area had an accumulated "surplus" biomass that could be (and was) taken but the level of catches was not sustainable. The area has now been fished down and the average annual yield will be somewhere in between the low levels of the mid 1990s and the high levels of 5-6 years ago. As the area is also centrally located, we apply the dynamics of Areas 2 and 3A and believe that a constant harvest rate of 0.20 is appropriate for the region. The coastwide assessment suggests that harvests have been in the 0.15 to 0.19 range over the past six years while the closed area assessment suggests harvest rates have been between 0.23 and 0.33. However, the effect on ongoing eastward emigration out of 3B would cause a closed area assessment to underestimate contemporary biomass and thus overstate harvest rates.

Area 4

Area 4A, 4B and 4CDE indices are illustrated in Figures 12, 13 and 14, respectively. The three areas have roughly similar commercial exploitation histories over the past decade and show similar trends. In all three areas, commercial catches increased from around 1.5 million pounds to around 4-5 million pounds between 1996 and 2001. Catches have since declined in all three areas, most strongly in Areas 4B and 4CDE where a lower target harvest rate of 0.15 was applied the past few years. Commercial effort mirrored the rise in removals from 1996-2001, however the drop in effort was not nearly as sharp as the drop in catches, and the drop in commercial CPUE is evident in the time series. Survey CPUE in Area 4A and 4B has declined around 70% over the past decade; the decline in Area 4D survey CPUE is around 46% (there is no survey index for 4C or 4E). Both the coastwide and closed area assessments indicate an exploitable biomass decline of 67% for 4A and 4B; the coastwide assessment suggests a decadal decline of 49% for Area 4CDE.

The situation in Area 4 is somewhat like Area 3B only more exaggerated. Area 4 was very lightly exploited up until the mid 1990s. With the onset of surveys, quotas were quickly increased and the accumulated surplus biomass quickly removed. Catches of 4-5 million pounds in each area are clearly not sustainable. In Area 4B, where catch limits were dropped most strongly, there is evidence of a reversal in the strong biomass decline. Over the past three years, the CPUE indices have actually increased slightly and the two assessments estimate a level time trend in exploitable biomass. Area 4A, which still has a target harvest rate of 0.20, has not yet shown signs of reversing its strong decline and has become an area of concern to the staff. Area 4CDE is also still declining though the biomass indices appear to be flattening out. Area 4CDE commercial removals may well be near an optimum level but bycatch in the groundfish fisheries is still very large (accounting for more than 50% of total 4CDE removals) thus any future increase in 4CDE will require a reduction in bycatch loss. Areas 4B and 4CDE have a lower target harvest rate due to ongoing concerns about the sustainable level of productivity in those regions. The target harvest rate of 0.20 for the central portion of the stock is based on analyses of decadal long stock dynamics and it is not necessarily appropriate that the same dynamics be assumed for the westward regions. The westward regions differ substantially form the central and eastern regions in that bycatch of juveniles (which strongly affects overall productivity of the stock) is much higher and there is net emigration from Area 4 of exploitable halibut. These concerns will be addressed in a, upcoming study focusing solely on Area 4 population dynamics to help determine whether a single harvest rate, possibly different form the central and eastern regions, should be applied for all of Area 4.

Five-year exploitable and spawning biomass projections

The annual stock assessment produces an estimate of the total number of halibut, ages 6 and older, in the ocean (Fig. 15). With this set of numbers and assuming that life history parameters, such as size at age and maturity at age, remain close to what they are today, we can make biomass and yield projections for several years into the future. Because the age range of halibut in the catch is generally in the 10-20 year old range, estimates of recruitment – which are often imprecise – do not much influence the projections. The time series of abundance shown in Figure 15 illustrate the strength of the celebrated 1987, and to a lesser extent 1988, year classes. The current assessment suggests that two extremely large year classes – 1999 and 2000 – are poised to enter the exploitable biomass over the next few years. Presently, both year classes look to be larger – in terms of numbers – that the 1987 and 1988 year classes. However, it is important to note that size at age is much smaller now than it was 20 years ago. This has two important ramifications – first it means that the 1999 and 200 year classes are only just beginning to reach the exploitable size range and, therefore, their true numbers in the population are still quite uncertain. Secondly, it also means that for a given number of halibut, their collective biomass will be lower. Currently, a large fraction of males never reach the minimum size limit and thus never enter the exploitable biomass. It remains to be seen just how these year classes will develop. If we assume that size at age remains at the values seen this year, then the projections for both the exploitable biomass and spawning biomass are very optimistic (Figure 16) and indicate that the declines we have seen over the past decade are on the verge of reversing. It important to note that removals should still remain at around 20% of the exploitable biomass and not be kept high in anticipation of future increases. As happened in the mid 1990s, when the biomass rises, higher catch limits will follow.

Update on halibut size-at-age

Halibut size at age continues to decline (Fig. 17). Mean size at age for older fish is lower than at any point since size data has been collected. For example, a 20 year old female halibut from the Kodiak Island area weighs, on average, about 32 pounds. Ten years ago, a 20 year old female from the same area averaged about 60 pounds; 20 years ago the average was over 150 pounds. Compared to 20 years ago, mean size at age has decreased at least 50% for all ages over 10. The decline has occurred in all areas though it is greatest for Area 3A. Clark and Hare (2002) compared the growth changes to trends in the environment and halibut stock size. They concluded that the change in growth rate was likely density dependent and related most strongly to the number of adult (age 10+) halibut in the population. Despite the steep decline in exploitable biomass, much of which is due to decreased size at age, the most recent stock assessment estimates there are more halibut in the ocean than 10 years ago. The density dependence argument suggests that growth rates will remain very low until the halibut numbers are thinned.

There has been, however, a stark change in the large marine ecosystem in which halibut reside. While a number of commercially important species have fluctuated in abundance, there is one particular species that has increased exponentially over the past 20 years. The biomass of arrowtooth flounder (*Atheresthes stomias*) in the Gulf of Alaska is estimated to have increased from a level of 400,000 mt in 1970 to over 2.2 million mt in 2006 (Turnock and Wilderbuer 2007). A comparison of arrowtooth biomass, halibut biomass and size at age for three age classes of halibut over the past 40 years is presented in Fig. 18. Arrowtooth flounder, while smaller than halibut, likely exploit much of the same habitat and thus compete for available food. There is no commercial fishery on arrowtooth, they are infrequently seen in the diets of marine mammals and are not know to be cannibalistic. The environmental conditions that accompanied the climatic regime shift of 1976-77 and favored increased productivity of halibut had the same effect on arrowtooth. However, the lack of predation on arrowtooth meant that the population grew – and may still be growing – at an unchecked exponential rate.

It is entirely reasonable to surmise that the current slow growth rate of halibut is due not only to the increased numbers of halibut in the ocean but also the greatly increased number of arrowtooth. It is then also reasonable to conclude that fishing down the number of halibut will not necessarily lead to an increase in halibut growth rates. If this "new world order" persists, then it becomes important to factor this into any analysis of the harvest rate. The performance of the halibut harvest policy under conditions of continued slow growth was presented in Figure 5. It can be anticipated that for any given harvest rate, there will be less yield and more occasions of low spawning biomass under slow growth conditions. This argues for a harvest rate no greater than 0.20 and possibly for something a bit lower. If growth rates continue to decline even further, reevaluation of the harvest rate will be undertaken.

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Table 1. Parameter values in calculation of Spawning Biomass reference points (see text for detail).

	2B/2C/3A	Coastwide	Units
Avg. Recruitment (High productivity)	13.00	19.86	Million age-six halibut
Avg. Recruitment (Low productivity)	4.13 (32% of high)	6.31	Million age-six halibut
SBR (at F=0) (Low productivity)	118.49	118.49	Net lbs. per age-six recruit
$SBio_{unfished}$	489	709	Million pounds (female)
$SBio_{20}$	98	150	Million pounds (female)
$SBio_{30}$	147	224	Million pounds (female)
$SBio_{min.\ obs.}$	64		Million pounds (female)
$SBio_{current}$		300	Million pounds (female)

Table 2. Decadal changes in several indices of abundance and effort. Values indicate change for 2006-2007 average from 1996-1998 average. CPUE is catch per unit effort, effort refers to standard 100 hook skates. CW assessment refers to estimates of exploitable biomass from the coastwide assessment with survey apportionment. CA assessment refers to estimates of exploitable biomass from the closed area assessments (there are no closed area assessments for Areas 2A and 4CDE).

	2A	2B	2C	3A	3B
Commercial CPUE	-31%	-20%	-30%	-12%	-52%
Survey CPUE	-49%	-54%	-55%	-28%	-56%
Commercial effort	+207%	+18%	+41%	+25%	+163%
CW assessment	-27%	-45%	-55%	-11%	-43%
CA assessment	NA	-26%	-17%	-27%	-42%

	4A	4B	4C	4D	4CDE
Commercial CPUE	-55%	-17%	-78%	-61%	NA
Survey CPUE	-71%	-65%	NA	-46%	NA
Commercial effort	+158%	-37%	NA	NA	+211%
CW assessment	-54%	-62%	NA	NA	-49%
CA assessment	-67%	-67%	NA	NA	NA

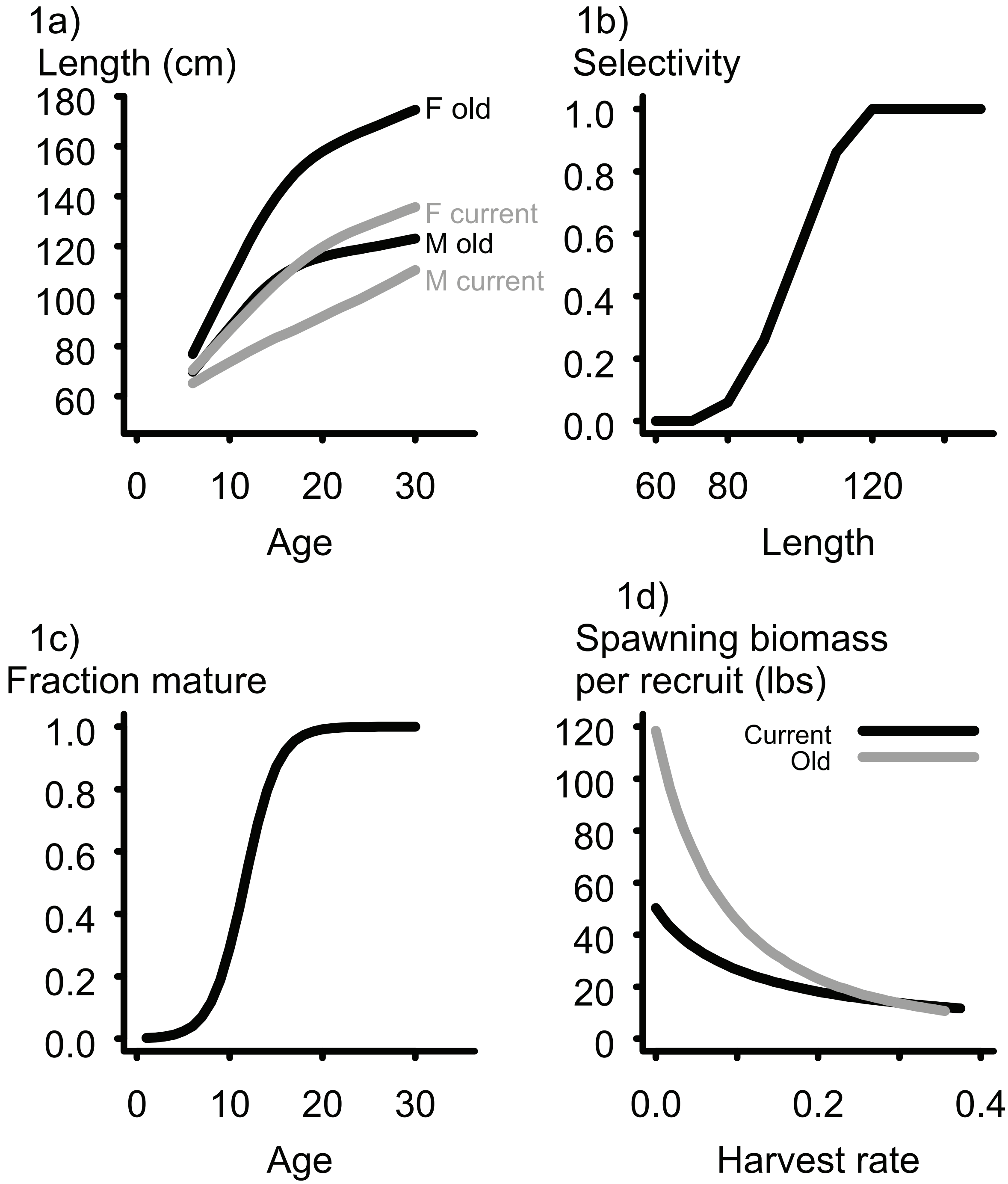


Figure 1. Parameter values used to determine unfished spawning biomass ($B_{unfished}$) and the relationship between harvest rate and spawning biomass per recruit (SBR). See text for details.

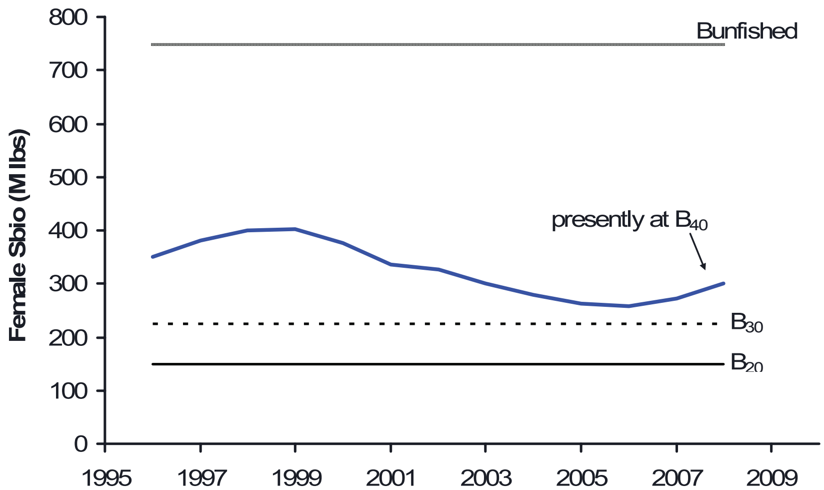


Figure 2. Historical level of spawning biomass in relation to various reference levels.

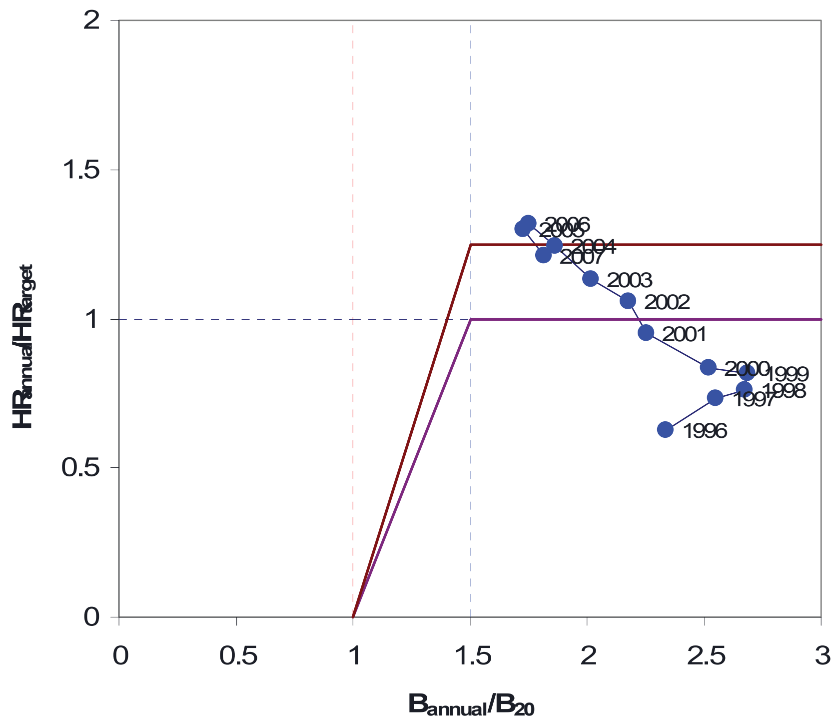


Figure 3. Plot illustrating the performance of the coastwide halibut stock in relation to conservation reference points. Along the x-axis, the annual spawning biomass level (B_{annual}) is shown relative to B_{20}, i.e., spawning biomass at 20% of its unfished value. Along the y-axis, the annual realized harvest rate (HR_{annual}) is show relative to the target harvest rate (HR_{target}). The current target harvest rate of 0.20 corresponds to a value of 1.0. An earlier target harvest rate of 0.25 (used in 2004 and 2006 for some areas) corresponds to a value of 1.25. The sloped lines indicate the reduction in target harvest rate that would occur if B_{annual} drops below the spawning biomass threshold (currently set at 1.5 times B_{20}).

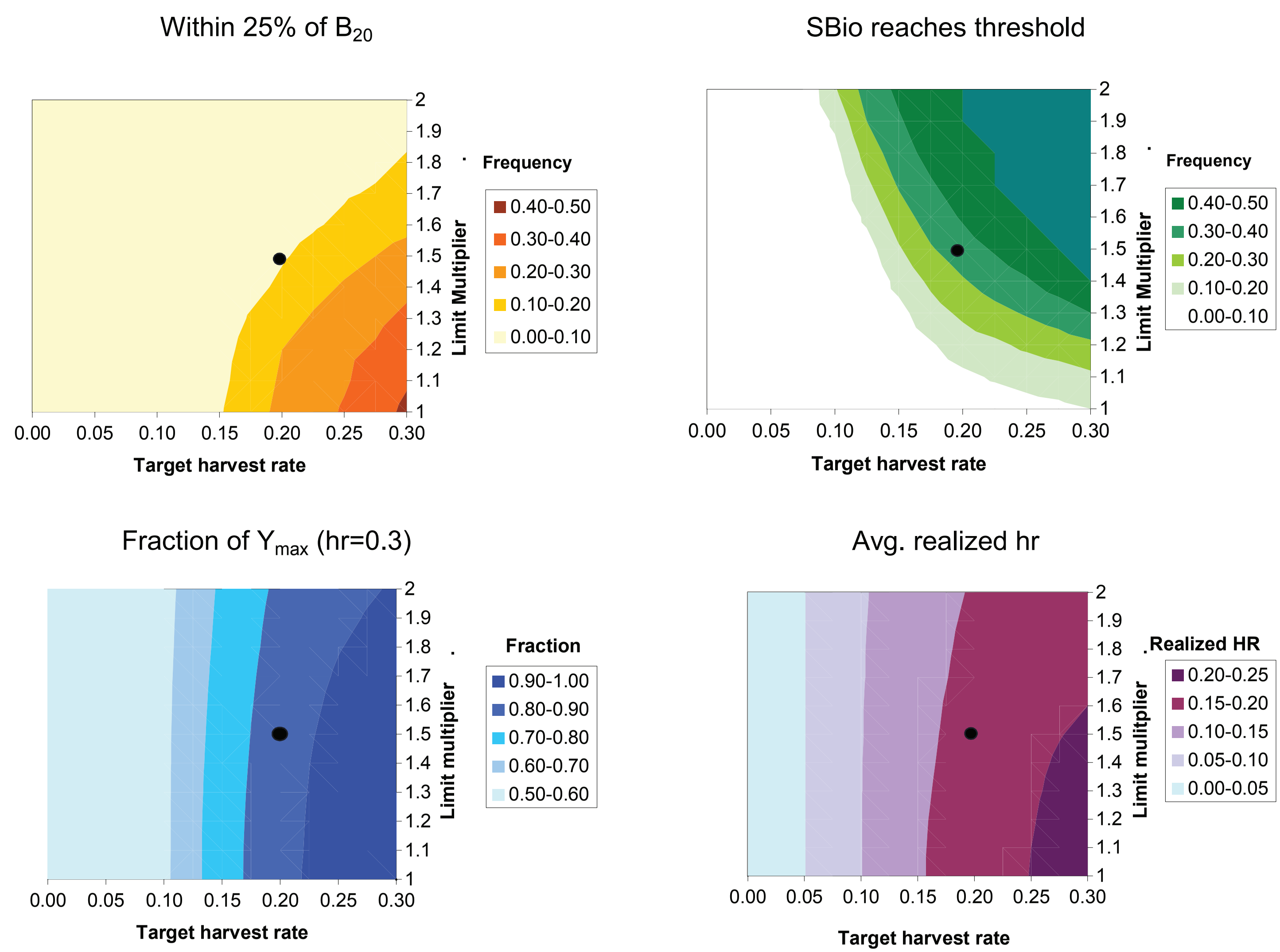


Figure 4. Performance of the harvest policy across a range of target harvest rates and limit multipliers (i.e., setting of spawning biomass limit in relation to spawning biomass threshold) under conditions of density dependent growth. All simulations incorporate autocorrelated assessment error and annual removals are adjusted using the "slow up/fast down" procedure.

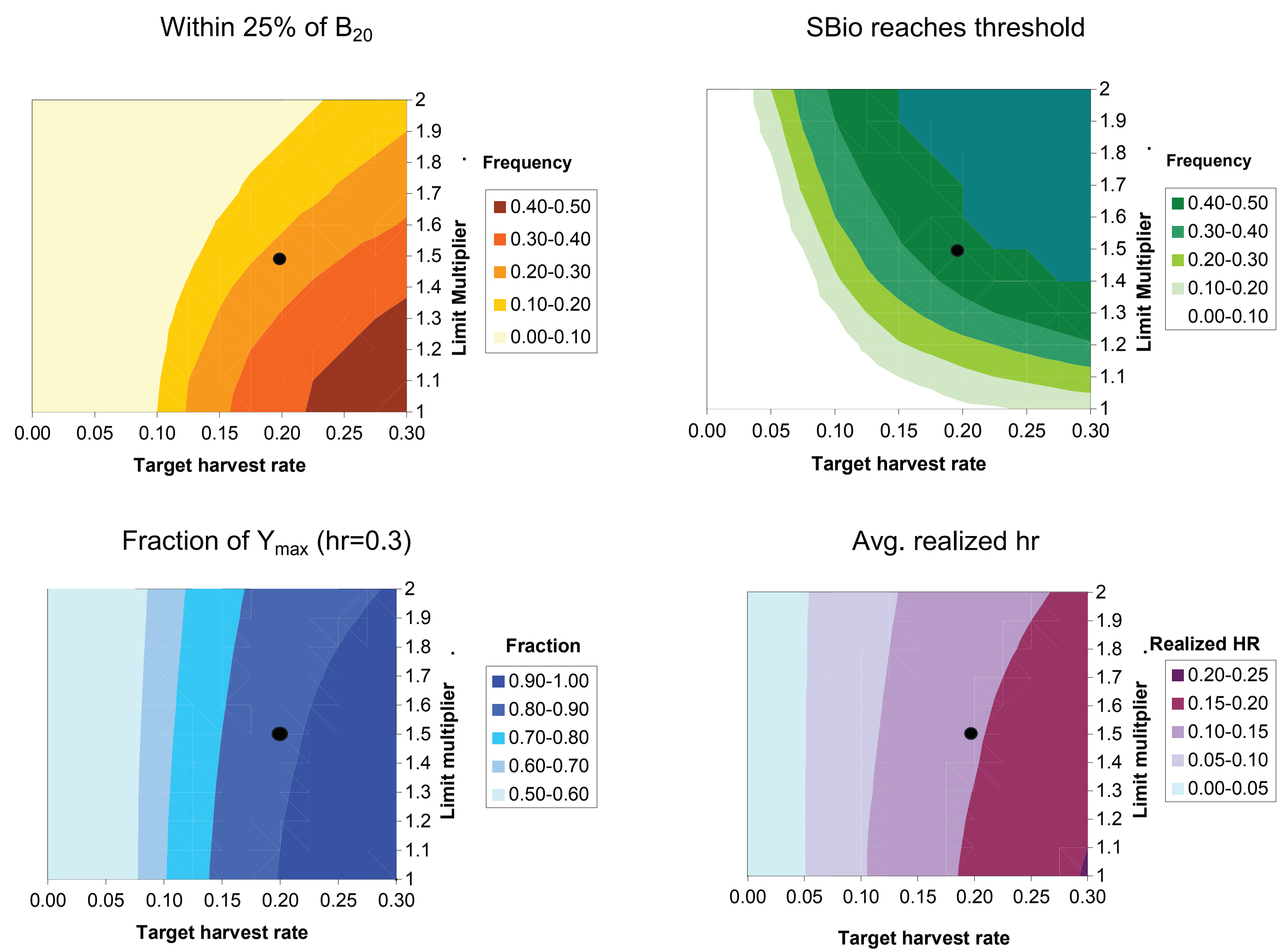
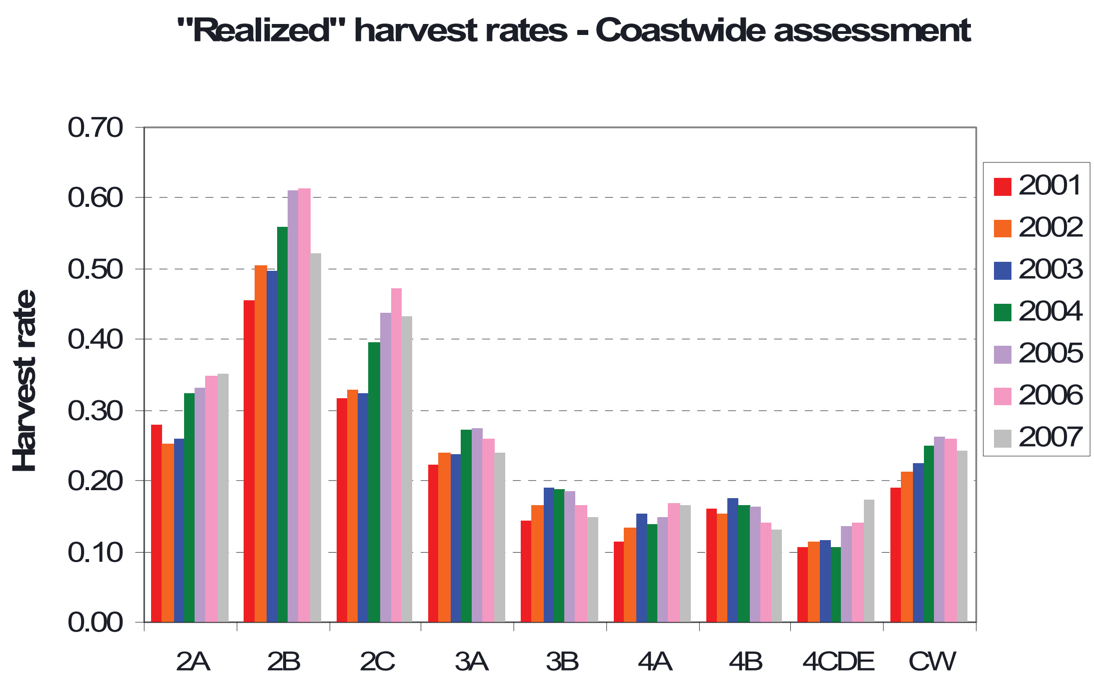


Figure 5. Performance of the harvest policy across a range of target harvest rates and limit multipliers (i.e., setting of spawning biomass limit in relation to spawning biomass threshold) under conditions of constant slow growth. All simulations incorporate autocorrelated assessment error and annual removals are adjusted using the "slow up/fast down" procedure.



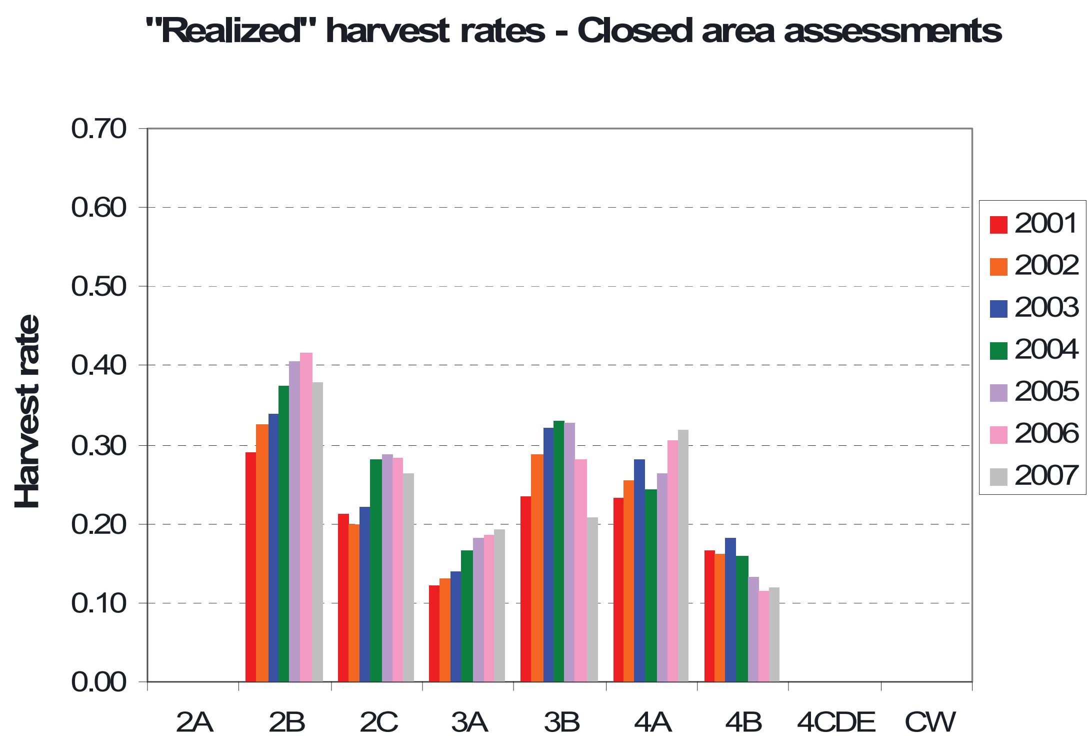


Figure 6. Summary of realized harvest rates from (top) the coastwide assessment (using survey partitioning) and (bottom) closed area assessments (there are no closed area assessments for Areas 2A and 4CDE.

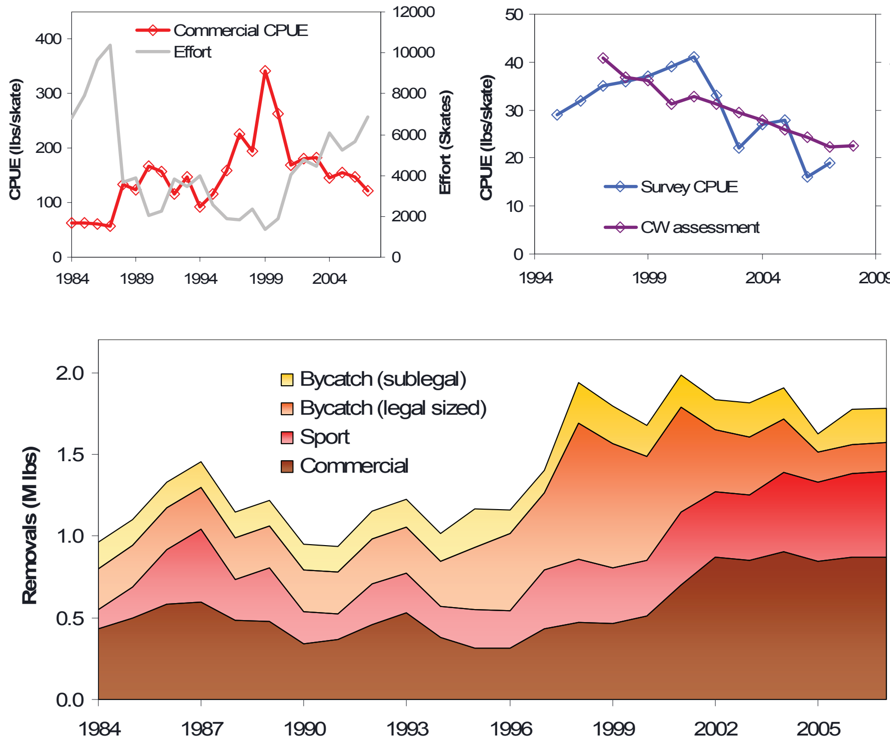


Figure 7. Summary of removals, effort and stock indicators for Area 2A. See text for details.

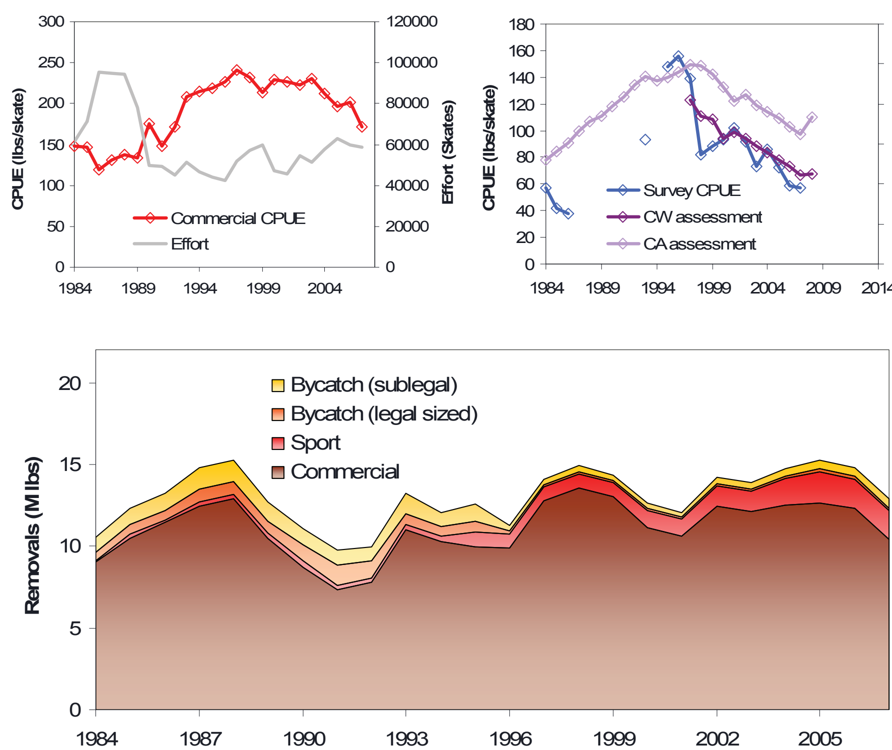


Figure 8. Summary of removals, effort and stock indicators for Area 2B See text for details.

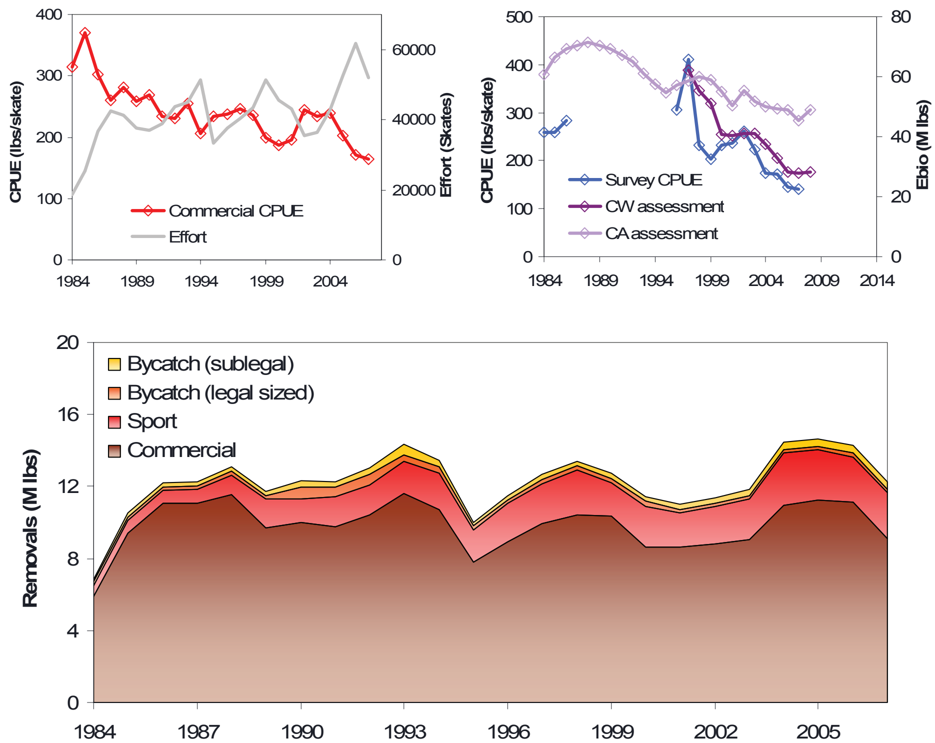


Figure 9. Summary of removals, effort and stock indicators for Area 2C See text for details.

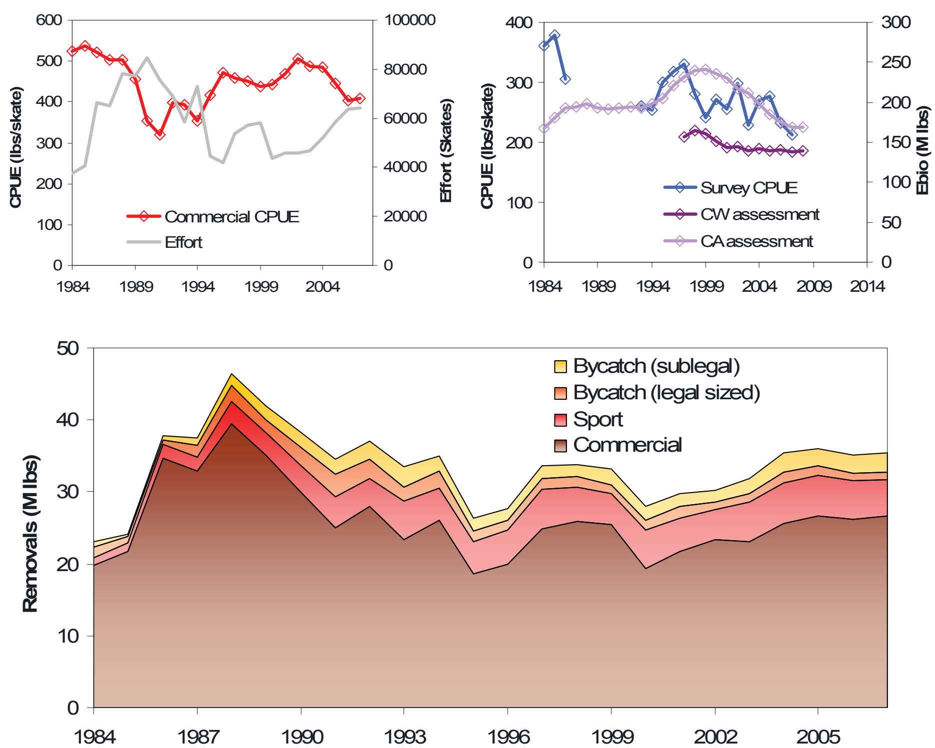


Figure 10. Summary of removals, effort and stock indicators for Area 3A. See text for details.

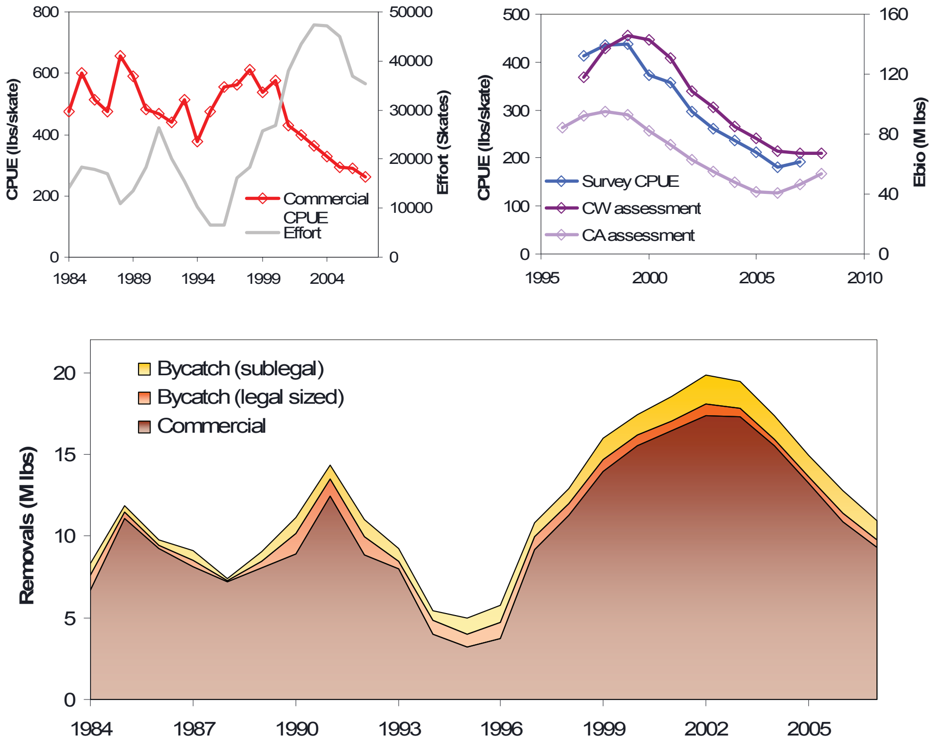


Figure 11. Summary of removals, effort and stock indicators for Area 3B See text for details.

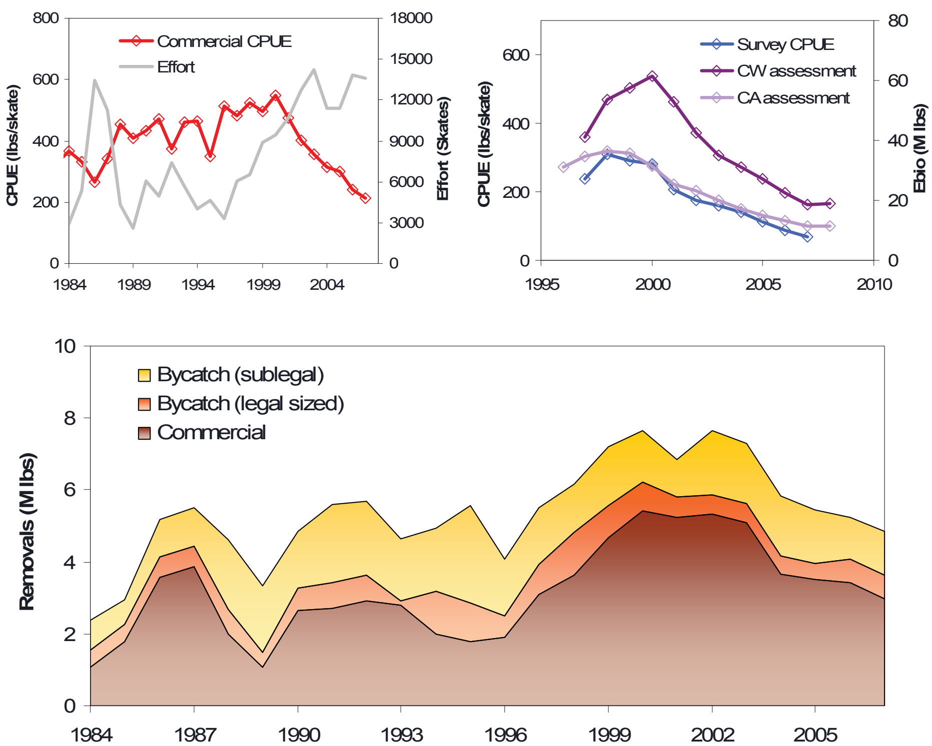


Figure 12. Summary of removals, effort and stock indicators for Area 4A. See text for details.

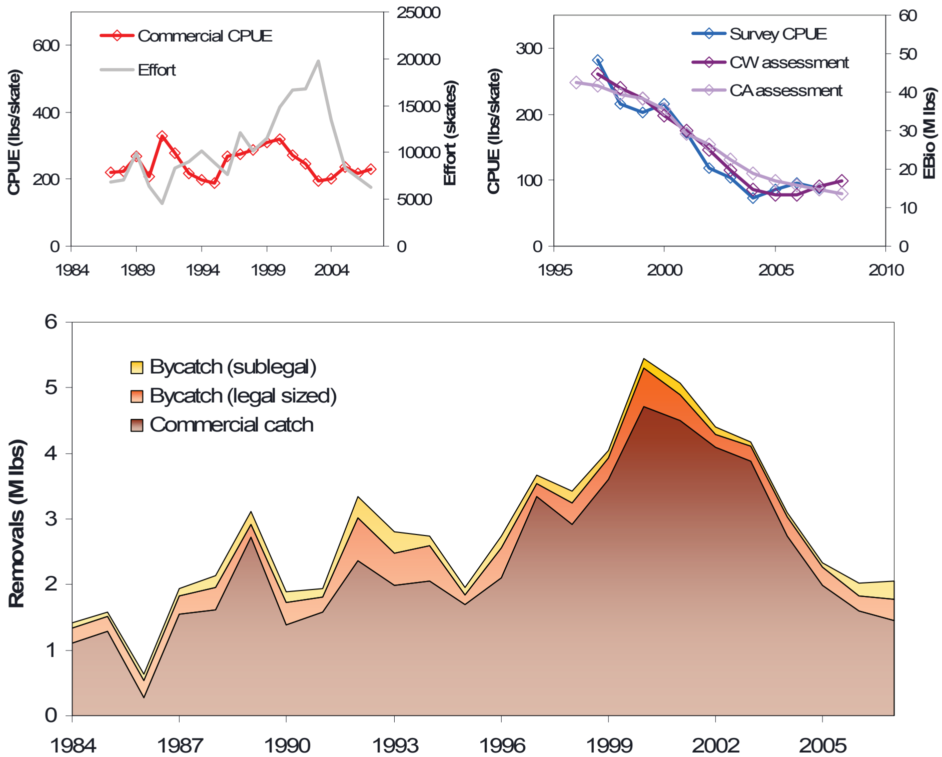


Figure 13. Summary of removals, effort and stock indicators for Area 4B See text for details.

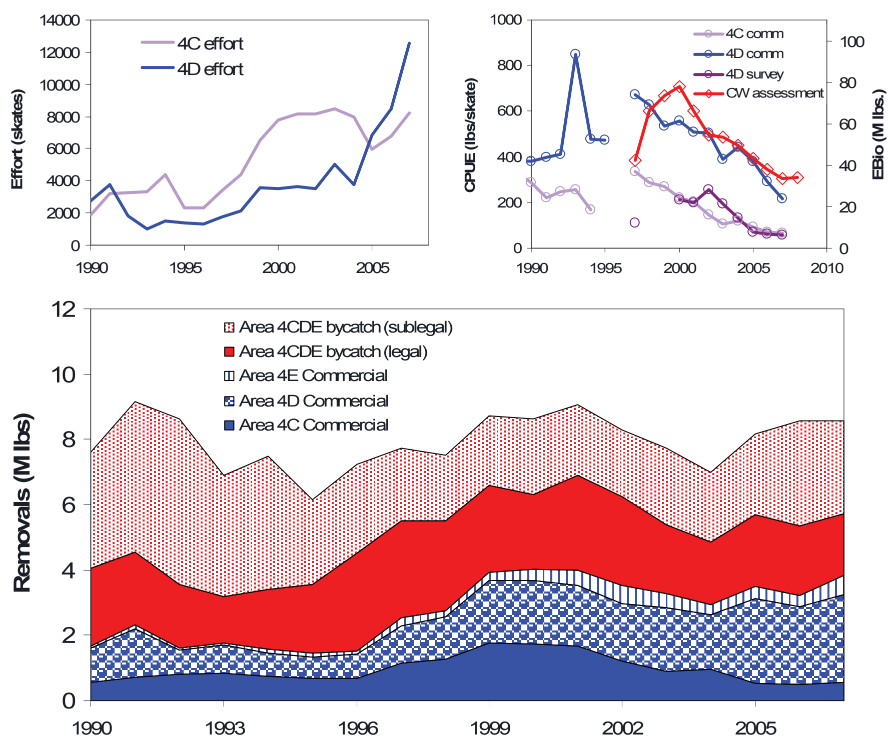


Figure 14. Summary of removals, effort and stock indicators for Area 4CDE. See text fo details

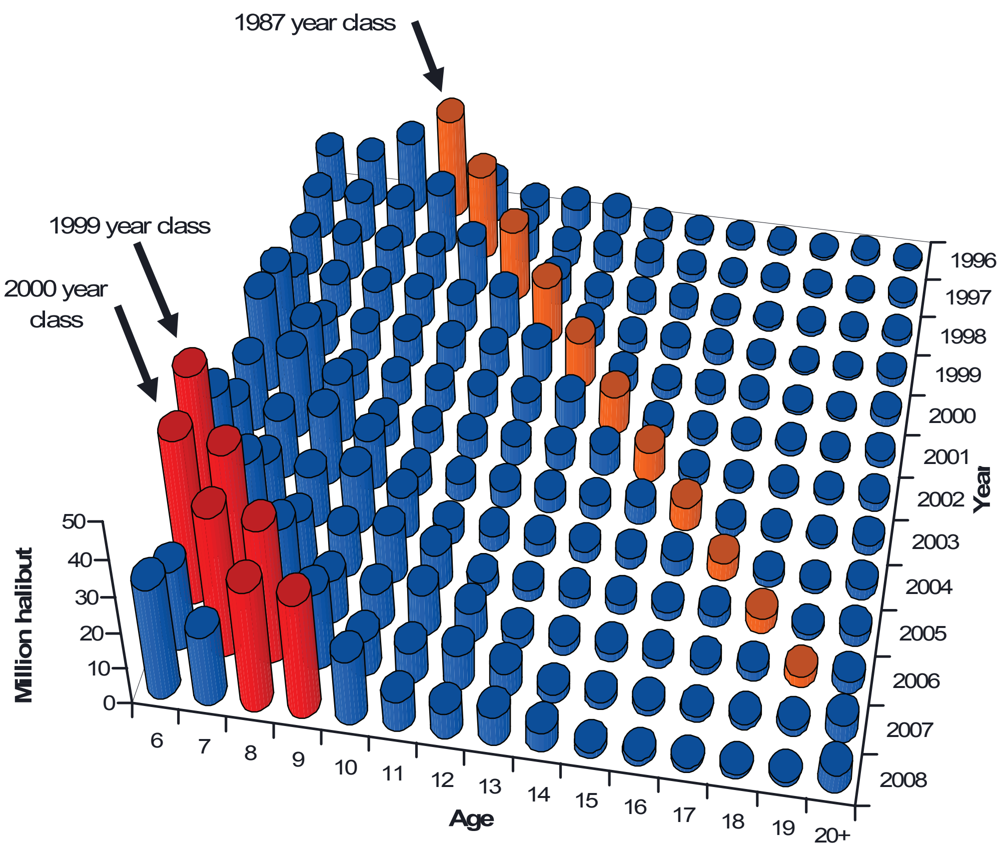


Figure 15. Coastwide population estimates of halibut in the most recent stock assessment (Clark and Hare 2007). Several very large year classes are noted.

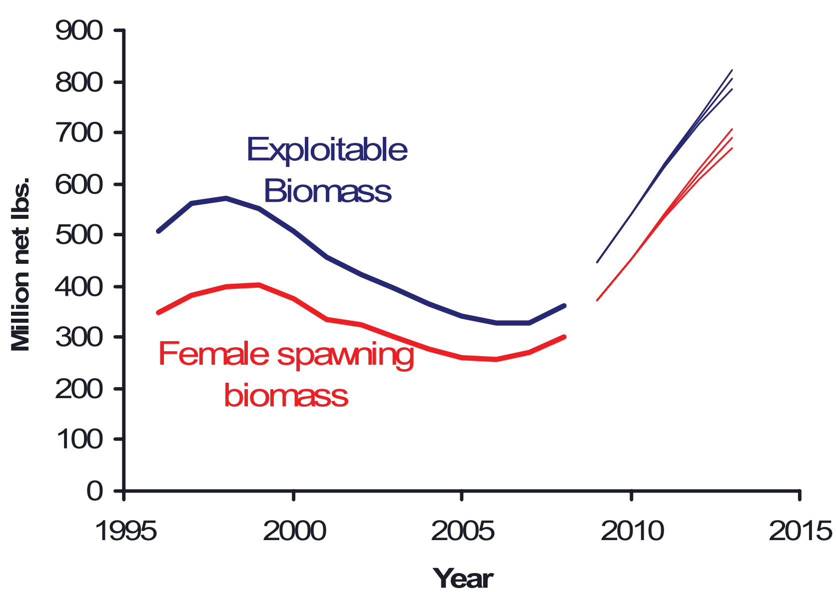


Figure 16. Projected exploitable and spawning biomasses for the coastwide population of halibut.

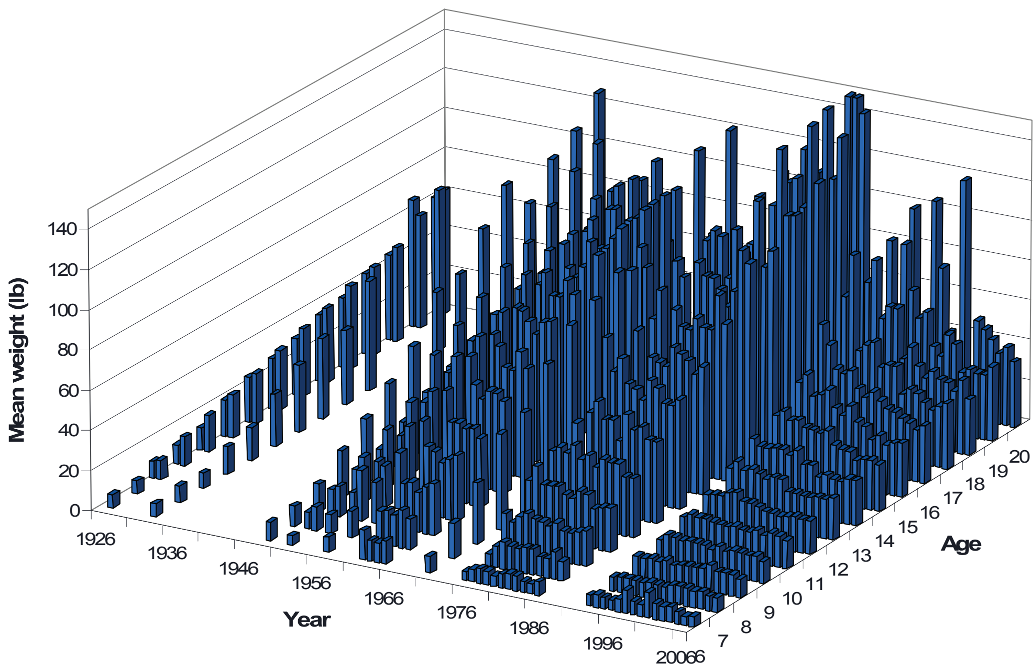


Figure 17. Mean weight at age of females in Area 3A from survey and research data collected back to 1926.

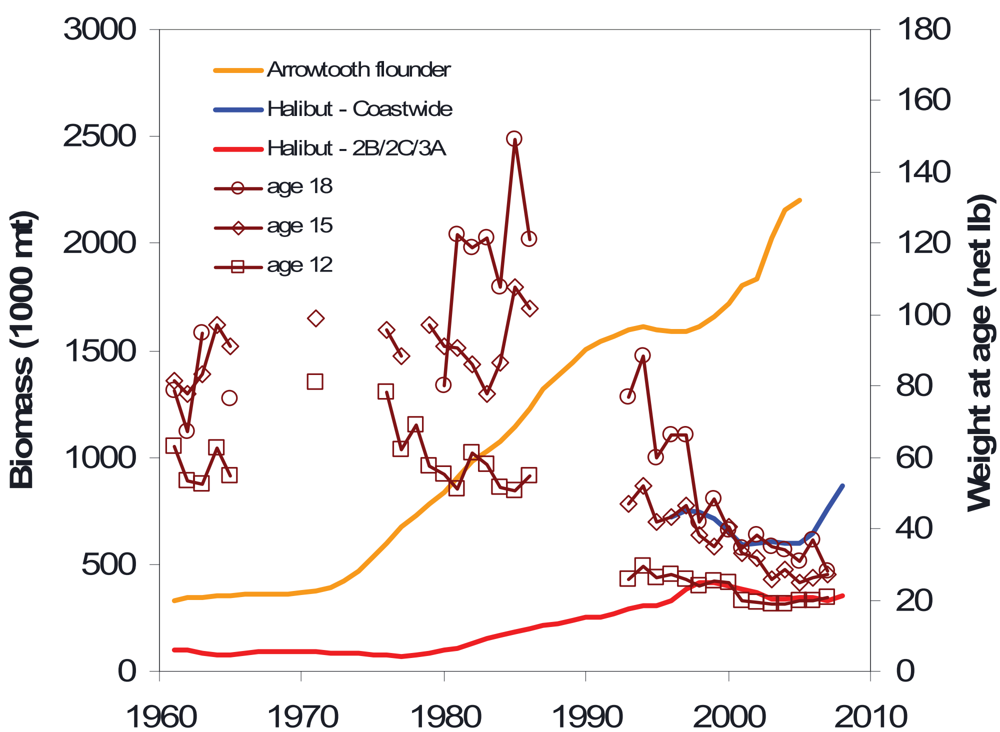


Figure 18. Summary of arrowtooth flounder and Pacific halibut biomass trends along with trends in size at age for halibut.