Updated simulation analysis of the CCC harvest policy with separate accounting of males and females*

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* At a special workshop held September 27, 2004, the CCC harvest policy was discussed and the decision was made to discontinue further development. This document was prepared for that workshop and is being included in the RARA for documentation purposes.

Abstract

An updated simulation analysis was conducted on the CCC harvest policy with separate accounting of males and females. The policy performs well with a ceiling harvest rate of 0.25 for all areas and catch ceilings of 15 million lbs. for Area 2B, 15 million pounds for Area 2C, and 47 million pounds for Area 3A. Dropping the current 81 cm size limit would decrease fishing pressure on females and have beneficial effects on average yield, yield variability and preservation of spawning biomass.

Introduction

A new harvest policy, termed the "Conditional Constant Catch" (CCC) policy was developed for managing Pacific halibut (Clark and Hare, 2004a; Hare and Clark 2003). The policy was developed using simulation modeling of a halibut population that was not differentiated by sex. This year a new population assessment model was introduced that provides sex-specific estimates of halibut numbers at age and size at age. Two additional changes were made this year that strongly affected the population assessment. Selectivity is now modeled as a function of length and all halibut are now aged using the break and burn method. The practical effect of these changes are discussed in Clark and Hare (2004b) and the companion paper to this one (Hare and Clark 2005).

In this paper, we report the results of re-examining the CCC harvest policy using a sex-specific simulation model and a new parameterization that matches the new assessment model. As selectivity is now a function of length, female halibut are selected at much younger ages than male halibut due to the differential growth rates. The new assessment model also provides sex-specific estimates of size at age, female spawning biomass, and new estimates of recruitment that differ sharply with previous estimates. We use the new simulation model to examine the performance of the CCC harvest policy across a range of catch ceiling and ceiling harvest rates. The range of catch ceilings has been updated from the original analyses reflecting the new recruitment and size at age estimates.

Simulation model and parameterization

The population and harvesting simulations done for this analysis are a straightforward extension of those done for the original CCC harvest policy analysis (see Hare et al. 2004 for a summary of the original analysis). The simulations now track numbers of males and females separately and selectivity is a fixed function of mean length. Growth is density dependent and is related to the number of adult animals in the population. Thus, as population increases, size at age decreases and therefore selectivity at age decreases. The selectivity, maturity and size at age parameters used in the simulations are detailed in Hare and Clark (2005). With the new population assessment model, recruitment estimates are now 30-50% higher than they were with the old model. Additionally, we lose the historical perspective (back to 1935) on recruitment as the assessment model can only produce recruitment estimates back to 1974. For this analysis, we still invoke the alternating recruitment regimes scenario. Under the new assessment model, average recruitment (in millions of age-6 recruits) for the periods before and after the regime shift of 1977 are listed in the following table. Recruitment estimates have been adjusted for bycatch losses.

Area	1968-1976	1977-1998	All years
2B	1.18	2.35	2.02
2C	1.17	2.16	1.89
3A	2.80	7.39	6.06
Combined	5.14	11.84	9.98

With this new view of recruitment, Area 3A accounts for approximately 60% of total recruitment to the three regions while Areas 2B and 2C each account for about 20%. These proportions differ slightly from the old model where 55% of total recruitment went to Area 3A and 25% to 2B. In addition to the different recruitment levels, there is also more year to year variability (lower autocorrelation) and more overall variability (higher residual standard deviation). For these simulations, we modeled recruitment as alternating regimes of high and low productivity. During productive regimes average recruitment into the three regions was 11.95 million age-6 halibut (50% male and 50% female), and during unproductive regimes average recruitment was 5.14 million age-6 halibut. Variability within regimes was generated using the following relationship:

$$R_6 = \exp(\ln(\mu_i)) + \varepsilon_t$$

$$\varepsilon_t = \rho\varepsilon_{t-1} + e_t$$

where μ is average recruitment, i indexes regime, lag-1 autocorrelation ρ = 0.1, ε_t is autocorrelated error, e_t is normal process error with σ_ε=0.4.

With these higher recruitment levels, estimates of productivity are somewhat larger than they were for the original analysis. The catch ceilings were based on the old productivity estimates. The new catch ceilings we used in this analysis are

Area	Range of catch ceilings (millions of pounds)				
2B	10.0	12.5	15.0	17.5	20.0
2C	10.0	12.5	15.0	17.5	20.0
3A	30.0	35.0	40.0	45.0	50.0
Combined	50.0	60.0	70.0	80.0	90.0

Another aspect of the CCC harvest policy was the use of biological reference points. These were termed spawning biomass limit and threshold points. The new biological reference points are based on female spawning biomass. The limit is the minimum observed spawning biomass while the threshold is 1.5 times the limit. These are used to modify downwards the harvest rate in response to decreasing spawning biomass. The harvest rate is dropped linearly from its maximum when spawning biomass is at the threshold to a rate of zero if female spawning biomass reaches the limit. The biological reference points (in millions of pounds of spawning biomass) that were used:

Area	Limit	Threshold
2B	10	15
2C	15	22.5
3A	37	55.5
Combined	60	90

To assess the robustness of the harvest policy as well as to explore the effect of different management actions, we examined four different scenarios for each of the four areas (2B, 2C, 3A and all areas combined). The different scenarios involve alternate assumptions about the following four factors

1. Growth (density dependent or persistent low growth)
2. Recruitment (alternating productivity regimes or constant low recruitment)
3. Minimum spawning biomass safeguards (use limit and threshold or don't use them)
4. Minimum size limit (keep 81 cm size limit or drop the size limit)

The "Most Likely" scenario, against which the alternative scenarios are all compared, invokes alternating regimes of recruitment, density dependent growth, implementation of the minimum spawning biomass safeguards, and retention of the 81 cm size limit. For each scenario, 100 Monte Carlo runs were made each of 500 years duration. Figure 1 shows examples of several parameters tracked during the 500 years of one Monte Carlo simulation for Area 3A (under the "Most Likely" scenario). The driving factor in the simulations is the alternating regimes of recruitment, and the subsequent density dependent growth response. These regimes lead to a cycling in such population measures as spawning and exploitable biomass, yield and average weight at age. For each of the Monte Carlo runs, a different random number sequence is used. However, for each scenario the same sequences of random numbers are used to allow for direct comparison between scenarios.

Results

For each scenario and each area, we track six sets of performance statistics for each combination of catch ceiling and ceiling harvest rate (Tables 1-4). These are average annual yield, standard deviation of yield, average spawning biomass (as a fraction of spawning biomass with no fishing), frequency of yield being within 90% of the catch ceiling, frequency that spawning biomass drops below the threshold (i.e, when the ceiling harvest rate must be reduced), and fraction of the yield that is female (by weight).

Combined areas

A primary reason for examining the three areas combined is to establish a proper harvest rate. Historically, the same harvest rate has been applied to the three areas which are viewed as comprising a single genetic spawning stock. As in the original analysis, we examined harvest rates up to 0.40 (Table 1). Yield continues to increase with increasing harvest rate; at the same time spawning stock declines uniformly as well. At harvest rates above 0.10, spawning stock also decreases with increasing catch ceiling. A general rule of thumb from many studies on groundfish species (e.g., Clark 1991) is that spawning stock should be kept above at least 30-35% of its unfished level. If we take 30% as the minimum acceptable average spawning biomass, then we eliminate harvest rates above 0.25 in combination with catch ceilings above 70 million pounds. For the combined areas, only once have total removals topped 70 million pounds (71.5 million pounds in 1988). At a harvest rate of 0.25 and a catch ceiling of 70 million pounds, simulations show that spawning biomass would average 31% of its unfished level. Additionally, 10% of the time the spawning biomass would drop below the threshold reference point triggering a reduction in the ceiling harvest rate of 0.25. The spawning biomass does not however drop far below the threshold and does not reach near the limit. If the catch ceiling is limited to 70 million pounds, harvest rates of 0.30-0.40 would double the frequency of reaching the spawning biomass threshold but would not appreciably lower the average spawning biomass. Average yield over the long term would only increase 1-2% with the higher harvest rate if the same catch ceiling were maintained, however.

Catch ceilings of 60 million pounds and below would be obtainable almost every year at harvest rates of 0.25 and above. At a harvest rate of 0.25, 90% of the catch ceiling would be taken 85% of the time. In the first analysis of the CCC policy, a rule of thumb was adopted for choosing a catch ceiling. The rule was that for a given ceiling harvest rate, the catch ceiling was set at the level where 90% of the ceiling would be taken at least 60% of the time. This rule of thumb sets the maximum that the catch ceiling could be at 80 million pounds. The final factor we looked at – percent of yield that is female – does not much vary with ceiling harvest rate or catch ceiling. In general, given the differential growth rates and 81 cm size limit, approximately 75% of the yield (by weight) will always be comprised of females.

Area 2B

For Area 2B, we expanded the range of catch ceilings we had examined in the original analysis (Table 2). Using the rule of thumb described above, the catch ceiling for Area 2B was set at 13 million pounds in the original analysis. With a ceiling harvest rate of 0.25, the new catch ceiling for Area 2B would be 17 million pounds (max removals in 2B since 1974 were 14.5 million lbs in 1998). However, that combination would result in an average spawning biomass below 30% of the unfished level. Lowering the catch ceiling to 15 million pounds raises average spawning biomass above the 30% level and reduces the frequency of reaching the threshold to around 5%. The variability in yield would be quite low – 90% of the catch ceiling would be taken about 80% of the time. Maintaining a catch ceiling of 15 million pounds and increasing the harvest rate would not increase average yield more than 1-2%. The proportion of the catch that would be female is higher in Area 2B than in any of the other areas – generally around 80% by weight. This results from the smaller size at age of males in 2B during periods of both high and low population numbers. As a result females are selected at a higher rate – and this is responsible for the lower average spawning biomass levels and why the recommended catch ceiling increases just slightly from the original analysis.

Area 2C

For Area 2C, the same range of new catch ceilings that was used for Area 2B was also used for Area 2C (Table 3). The reasoning here is that – despite the historically lower removals in 2C – recruitment levels (from the new sex-specific assessment) are approximately the same. Both males and females are larger at a given age than fish in Area 2B. The recommended catch level for 2C would increase from 12 million pounds in the original analysis to about 19 million pounds in this reanalysis. However, the impact on spawning biomass argues for a lower catch ceiling, somewhere around 15-16 million pounds. The spawning biomass threshold would be reached about 10% of the time at 15 million pounds and about 15% of the time at 16 million pounds. Yield variability would be low around these catch ceilings with 90% of the catch ceiling being taken about 95% of the time. The catch would be comprised of about 75% females at a harvest rate of 0.25 and catch ceiling of 15 million pounds. As in Area 2B, increasing the harvest rate above 0.25 has little effect on average yield at the catch ceiling of 15 million pounds.

Area 3A

Area 3A shows the greatest difference between the original analysis and the reanalysis (Table 4). This is due to the large increase in estimated recruitment to Area 3A and the relatively low catch ceilings examined in the original analysis. For this analysis, we considered catch ceilings between 30 and 50 million pounds (maximum historical total removals were 44.8 million pounds in 1988). Again applying the original rule of thumb, the recommended catch ceiling for a ceiling harvest rate of 0.25 would be 47 million pounds. At this catch ceiling, spawning biomass would average 36% of unfished and the spawning biomass threshold would be just 1% of the time. Males grow to much larger sizes in Area 3A and therefore contribute more to the catch and lessen the impact on spawning biomass at higher harvest rates and ceilings. Yield variability would be similar to Areas 2B and 2C as 90% or more of the catch ceiling would be taken just 66% of the time. At a catch ceiling of 47 million pounds, harvest rates greater than 0.25 increase average up to 10% while average spawning biomass decreases but remains about 35%.

Alternative scenarios

We repeated the simulations under a variety of scenarios. We focus on how the CCC policy performs for the three areas combined but the results are generally applicable to each area individually. These scenarios included making more pessimistic assumptions about future recruitment and growth, and examining the effect of not having minimum biomass safeguards and dropping the minimum size limit. A simple written summary of the alternative scenarios is given here without presentation of the many summary tables that accompany each scenario, with one exception. For the no minimum size limit scenario, the same set of tables as was illustrated for the Most Likely scenario are provided (Tables 5-8).

For recruitment, we explored the possibility of recruitment switching to a low productivity regime and staying at that level. This would be akin to suggesting that the past 30 years were a unique period and the consistently high recruitments are not likely to be seen again. In this scenario, recruitment and spawning biomass average 25% less than under the Most Likely scenario. For a given ceiling harvest rate and catch ceiling, average yields are 10-20% lower. Under the CCC policy, as long as the spawning biomass reference points are maintained, the best action is to lower the catch ceilings by about 25%, and a harvest rate around 0.25 keeps yields high and adequately protects the spawning biomass.

For growth, we examined a scenario where size at age does not increase with declining population size. The reasoning here is that the dramatic change in growth rates may result from a fundamental change in the ecosystem and that halibut will not again grow to the large sizes seen in the past. Under this scenario, spawning biomass with no fishing remains about the same as under the Most Likely scenario, since the large population sizes lead to small sizes at age all the time. Average yield however declines 10-20% at harvest rates of 0.20 and above and average spawning biomass drops below 30% of unfished at much lower catch ceilings. As in the scenario of low recruitment, dropping the catch ceilings in response to lower productivity is required to protect the spawning biomass.

The minimum spawning biomass safeguards were designed to prevent the spawning biomass from ever reaching the observed historic minimum (termed the "limit"). This is accomplished by scaling down the ceiling harvest rate as the spawning biomass drops below the threshold (equal to 1.5 times the limit). Under the Most Likely scenario for growth and recruitment, there is no difference in performance of the CCC harvest policy with and without the minimum biomass safeguards for any combination of ceiling catches of 70 million pounds and less and a ceiling harvest rate of 0.25 and below. The effect of the minimum biomass safeguards becomes more prominent as either of the two CCC policy parameters increase. Without the minimum biomass safeguards, average yield is as much as 5% greater at the higher ceilings however, as one would expect, average spawning biomass can be as much as 10-15% lower. Spawning biomass excursions below the threshold increase for harvest rates over 0.25 and catch ceilings over 70 million pounds. With no catch ceiling, only at a harvest rate of 0.40 does the spawning biomass reach the limit. However, under the alternative growth and recruitment scenarios, the limit is reached at much lower harvest rates and catch ceilings.

The final scenario we examined was the effect of dropping the minimum size limit (summarized in Tables 5-8). In order to model this, we made the assumption that if there were no minimum size limit, selectivity in the commercial fishery would be the same as selectivity in our survey, i.e., increasing from 0 at 70 cm to 1.0 at 130 cm. We assume that all captured fish would be retained (i.e., no highgrading). The primary incentive for this is to reduce the impact of the fishery on the female portion of the population. As noted earlier, for the Most Likely scenario, catches average 70-80% female (by weight) for all three areas. Dropping the size limit has the effect of reducing the female portion of the catch to 60-70% (lowest in 3A, highest in 2B) For the combined areas, the effects of dropping the minimum size are as follows. Average yields increase steadily for ceiling harvest rates over 0.20 and catch ceilings over 70 million pounds. Yield variability is also reduced except for the case of no catch ceiling. Average spawning biomass is higher across all harvest rate/catch ceiling combinations, often dramatically (i.e., as much as 25% higher). Excursions below the spawning biomass threshold are also reduced, again sometimes dramatically. Finally the frequency with which at least 90% of the catch ceiling is taken also increases at the higher harvest rate/catch ceiling combinations. These results apply to each of the individual areas as well.

Discussion

The CCC harvest policy was developed to provide more stable catch quotas than the constant harvest rate policy used by the IPHC for the past 20 years. A major attraction of the policy is that it is based to a large extent on the long-term productivity of the stock and less so on the annual estimate of exploitable biomass. This reanalysis of the CCC policy, which tracks both sexes and incorporates other new features of the revised stock assessment, generates basically the same results as the original analysis. There is a tradeoff between yield and stability, however the sacrifice in yield is relatively minor compared to the beneficial effects on stability of yield and protection of the spawning biomass. For implementation purposes, the CCC harvest policy requires selection of a ceiling harvest rate, catch ceiling and, optionally, spawning biomass reference points.

To determine area specific policy parameters, we examined several criteria including yield, yield stability, spawning biomass and sex composition of the catch. In the original CCC harvest policy analysis, the parameters were selected using a rule of thumb based on expected yield. For this analysis, we also take into account the impact on the spawning biomass: we ruled out harvest rate/catch ceiling combinations that resulted in an average spawning biomass less than 30% of the unfished level. We also considered how often the spawning biomass dropped below the spawning biomass threshold, a point at which the ceiling harvest rate is adjusted downward to prevent spawning biomass from reaching the observed historical minimum. These considerations show that a harvest rate of 0.25 performs well in combination with catch ceilings that are near the historic maximum removals seen in each area: 14 million lbs. in Area 2B, 15 million lbs. in Area 2C, and 43 million lbs. in Area 3A.

We explored several alternative scenarios. The catch ceilings are particularly useful if the stock dynamics, i.e., growth and recruitment, differ substantially from our "Most Likely" scenario. If the stock is less productive due to changes in growth or recruitment, the catch ceilings provide some protection though they are likely higher than they should be. The possibility that the stock is less productive than modeled is also a major argument in favor of establishing and implementing minimum spawning biomass safeguards such as the threshold and limit.

The final scenario we examined was dropping the current 81 cm minimum size limit. Due to differential growth rates, females comprise a large majority of the catch – generally around 75% by weight. Removing the size limit would allow a much greater fraction of the males to be selected by the fishery, and this is borne out in the simulations which show that the female percentage in the catch would drop to 60-70%. By increasing the fraction of smaller males in the catch, more females are left in the water and average spawning biomass is higher at all harvest rates – except in the case of no ceiling catch. Additionally, yields increase and yield variability decreases. The one downside is that some smaller females will be selected along with the smaller males but the simulations show that this effect is more than offset by the reduced fishing pressure on larger females.

The results of this analysis support a higher ceiling harvest rate than is recommended by a yield per recruit (ypr) analysis (Hare and Clark 2005). That analysis supports harvest rates between 0.15 and 0.20 in order to maintain spawning biomass per recruit above a level of 30-40% of no fishing. As noted in that analysis however, there are a number of limitations to a ypr analysis, the most serious of which is that it does not take into account the dynamic nature of the population in response to changing population size and alternating regimes of recruitment. For that reason, it is recommended that the dynamic analysis should hold sway in determining the appropriate harvest policy and policy parameter settings.

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Table 1. Performance statistics for the CCC harvest policy for Areas 2B, 2C, and 3A combined. These results are for the Most Likely scenario regarding growth and recruitment and uses the current 81 cm size limit to determine selectivity. See text for explanation of individual tables.

Average annual yield (million lbs.)

	Catch ceiling					
HR	50	60	70	80	90	None
0.00	0.0	0.0	0.0	0.0	0.0	0.0
0.05	26.3	26.3	26.3	26.3	26.3	26.3
0.10	43.7	44.3	44.3	44.3	44.3	44.3
0.15	49.8	55.6	57.8	58.2	58.2	58.2
0.20	50.0	59.5	65.5	68.6	69.8	70.1
0.25	50.0	60.0	68.7	74.2	77.7	80.5
0.30	50.0	60.0	69.4	76.6	81.6	89.1
0.35	50.0	60.0	69.5	77.2	83.0	95.5
0.40	50.0	60.0	69.6	77.4	83.5	100.4

Standard deviation of yield (million lbs.)

	Catch ceiling					
HR	50	60	70	80	90	None
0.00	0.0	0.0	0.0	0.0	0.0	0.0
0.05	3.6	3.6	3.6	3.6	3.6	3.6
0.10	5.0	6.0	6.1	6.1	6.1	6.1
0.15	0.8	4.9	7.8	8.7	8.8	8.8
0.20	0.0	1.4	5.5	9.0	10.9	11.8
0.25	0.0	0.3	3.0	7.0	10.6	14.9
0.30	0.0	0.2	2.6	6.5	10.4	19.0
0.35	0.0	0.2	2.5	6.6	10.7	23.7
0.40	0.0	0.1	2.3	6.6	10.8	28.1

Average spawning biomass (fraction of HR=0.00 biomass)

	Catch ceiling					
HR	50	60	70	80	90	None
0.00	555.20	555.20	555.20	555.20	555.20	555.20
0.05	0.70	0.70	0.70	0.70	0.70	0.70
0.10	0.53	0.52	0.52	0.52	0.52	0.52
0.15	0.48	0.43	0.41	0.41	0.40	0.40
0.20	0.48	0.40	0.35	0.33	0.32	0.32
0.25	0.48	0.40	0.33	0.30	0.28	0.26
0.30	0.48	0.40	0.33	0.28	0.25	0.22
0.35	0.48	0.40	0.33	0.28	0.24	0.19
0.40	0.48	0.40	0.33	0.28	0.24	0.17

Yield ³ 90% of catch ceiling (million lbs.)

	Catch ceiling					
HR	50	60	70	80	90	None
0.00	0	0	0	0	0	0
0.05	0	0	0	0	0	0
0.10	45	7	0	0	0	0
0.15	100	63	29	8	1	0
0.20	100	98	68	39	20	0
0.25	100	100	93	65	43	0
0.30	100	100	96	82	62	0
0.35	100	100	97	86	69	0
0.40	100	100	98	87	73	0

Spawning biomass reaches threshold (percent of years)

	Catch ceiling					
HR	50	60	70	80	90	None
0.00	0	0	0	0	0	0
0.05	0	0	0	0	0	0
0.10	0	0	0	0	0	0
0.15	0	0	0	0	0	0
0.20	0	0	0	0	0	0
0.25	0	0	2	3	3	3
0.30	0	1	8	17	20	22
0.35	0	1	9	24	32	40
0.40	0	1	9	25	37	52

Female % of yield by weight (percent)

	Catch ceiling					
HR	50	60	70	80	90	None
0.00						
0.05	84	84	84	84	84	84
0.10	81	81	81	81	81	81
0.15	79	79	78	78	78	78
0.20	79	77	77	76	76	76
0.25	79	77	76	75	74	74
0.30	79	77	76	74	74	72
0.35	79	77	76	74	73	71
0.40	79	77	76	74	73	70

Table 2. Same as Table 1, but with results for Area 2B.

Average annual yield (million lbs.)

HR	Catch ceiling 10	12.5	15	17.5	20	None
0.00	0.0	0.0	0.0	0.0	0.0	0.0
0.05	6.3	6.3	6.3	6.3	6.3	6.3
0.10	9.4	10.2	10.2	10.2	10.2	10.2
0.15	10.0	11.8	12.8	13.1	13.1	13.1
0.20	10.0	12.3	13.9	14.8	15.2	15.3
0.25	10.0	12.5	14.4	15.6	16.5	16.9
0.30	10.0	12.5	14.5	16.0	17.0	18.0
0.35	10.0	12.5	14.6	16.0	17.2	18.7
0.40	10.0	12.5	14.6	16.1	17.3	19.2

Standard deviation of yield (million lbs.)

HR	Catch ceiling 10	12.5	15	17.5	20	None
0.00	0.0	0.0	0.0	0.0	0.0	0.0
0.05	1.0	1.0	1.0	1.0	1.0	1.0
0.10	0.8	1.6	1.8	1.8	1.8	1.8
0.15	0.1	1.0	2.0	2.5	2.5	2.5
0.20	0.0	0.5	1.5	2.6	3.1	3.3
0.25	0.0	0.2	1.2	2.3	3.3	4.0
0.30	0.0	0.2	1.3	2.4	3.5	4.9
0.35	0.0	0.2	1.3	2.5	3.6	5.7
0.40	0.0	0.2	1.2	2.5	3.7	6.4

Average spawning biomass (fraction of HR=0.00 biomass)

HR	Catch ceiling 10	12.5	15	17.5	20	None
0.00	112.20	112.20	112.20	112.20	112.20	112.20
0.05	0.66	0.66	0.66	0.66	0.66	0.66
0.10	0.50	0.47	0.46	0.46	0.46	0.46
0.15	0.48	0.39	0.35	0.34	0.34	0.34
0.20	0.48	0.37	0.31	0.27	0.26	0.26
0.25	0.48	0.37	0.29	0.24	0.21	0.20
0.30	0.48	0.37	0.28	0.23	0.20	0.17
0.35	0.48	0.37	0.28	0.23	0.19	0.14
0.40	0.48	0.37	0.28	0.22	0.19	0.13

Yield ³ 90% of catch ceiling (million lbs.)

HR	Catch ceiling 10	12.5	15	17.5	20	None
0.00	0	0	0	0	0	0
0.05	0	0	0	0	0	0
0.10	71	33	3	0	0	0
0.15	100	73	46	17	2	0
0.20	100	95	67	46	25	0
0.25	100	99	82	59	44	0
0.30	100	99	88	70	53	0
0.35	100	99	89	73	59	0
0.40	100	99	90	74	61	0

Spawning biomass reaches threshold (percent of years)

HR	Catch ceiling 10	12.5	15	17.5	20	None
0.00	0	0	0	0	0	0
0.05	0	0	0	0	0	0
0.10	0	0	0	0	0	0
0.15	0	0	0	0	0	0
0.20	0	0	0	0	0	0
0.25	0	1	5	7	8	8
0.30	0	2	16	26	31	34
0.35	0	2	18	33	41	50
0.40	0	2	19	34	45	68

Female % of yield by weight (percent)

HR	Catch ceiling 10	12.5	15	17.5	20	None
0.00						
0.05	81	81	81	81	81	81
0.10	80	79	79	79	79	79
0.15	79	78	78	78	78	78
0.20	79	78	77	76	76	76
0.25	79	78	76	76	75	75
0.30	79	78	77	75	75	74
0.35	79	78	77	76	74	74
0.40	79	78	76	75	75	73

Table 3. Same as Table 1, but with results for Area 2C.

	Average annual yield (million lbs.) Catch ceiling					
HR	10	12.5	15	17.5	20	None
0.00	0.0	0.0	0.0	0.0	0.0	0.0
0.05	6.5	6.5	6.5	6.5	6.5	6.5
0.10	9.7	10.5	10.6	10.6	10.6	10.6
0.15	10.0	12.2	13.3	13.6	13.6	13.6
0.20	10.0	12.5	14.4	15.4	15.9	15.9
0.25	10.0	12.5	14.7	16.2	17.2	17.7
0.30	10.0	12.5	14.8	16.4	17.6	19.0
0.35	10.0	12.5	14.8	16.5	17.8	19.9
0.40	10.0	12.5	14.8	16.6	17.9	20.5

	Standard deviation of yield (million lbs.) Catch ceiling					
HR	10	12.5	15	17.5	20	None
0.00	0.0	0.0	0.0	0.0	0.0	0.0
0.05	1.0	1.0	1.0	1.0	1.0	1.0
0.10	0.5	1.4	1.6	1.6	1.6	1.6
0.15	0.0	0.6	1.7	2.1	2.2	2.2
0.20	0.0	0.1	1.1	2.1	2.7	2.8
0.25	0.0	0.1	0.9	1.9	2.9	3.7
0.30	0.0	0.1	0.8	2.0	3.1	4.7
0.35	0.0	0.0	0.8	2.0	3.1	5.6
0.40	0.0	0.0	0.7	2.0	3.1	6.3

	Average spawning biomass (fraction of HR=0.00 biomass) Catch ceiling					
HR	10	12.5	15	17.5	20	None
0.00	130.90	130.90	130.90	130.90	130.90	130.90
0.05	0.68	0.68	0.68	0.68	0.68	0.68
0.10	0.54	0.50	0.50	0.50	0.50	0.50
0.15	0.53	0.44	0.39	0.38	0.38	0.38
0.20	0.53	0.42	0.35	0.31	0.30	0.29
0.25	0.53	0.42	0.34	0.29	0.25	0.24
0.30	0.53	0.42	0.34	0.28	0.24	0.20
0.35	0.53	0.42	0.34	0.28	0.24	0.18
0.40	0.53	0.42	0.33	0.27	0.23	0.17

	Yield ³ 90% of catch ceiling (million lbs.) Catch ceiling					
HR	10	12.5	15	17.5	20	None
0.00	0	0	0	0	0	0
0.05	1	0	0	0	0	0
0.10	85	38	3	0	0	0
0.15	100	88	51	18	2	0
0.20	100	100	79	52	28	0
0.25	100	100	93	69	49	0
0.30	100	100	94	77	61	0
0.35	100	100	95	79	64	0
0.40	100	100	95	80	66	0

	Spawning biomass reaches threshold (percent of years) Catch ceiling					
HR	10	12.5	15	17.5	20	None
0.00	0	0	0	0	0	0
0.05	0	0	0	0	0	0
0.10	0	0	0	0	0	0
0.15	0	0	0	0	0	0
0.20	0	0	1	1	1	1
0.25	0	1	10	16	17	18
0.30	0	1	12	28	36	39
0.35	0	1	13	31	41	53
0.40	0	1	14	32	42	70

	Female % of yield by weight (percent) Catch ceiling					
HR	10	12.5	15	17.5	20	None
0.00						
0.05	82	82	82	82	82	82
0.10	79	79	78	78	78	78
0.15	79	78	77	76	76	76
0.20	79	77	76	75	75	75
0.25	79	77	76	75	74	74
0.30	79	77	76	74	73	73
0.35	79	77	76	75	74	72
0.40	79	77	76	74	73	72

Table 4. Same as Table 1, but with results for Area 3A.

Average annual yield (million lbs.)

HR	Catch ceiling 30	35	40	45	50	None
0.00	0.0	0.0	0.0	0.0	0.0	0.0
0.05	13.1	13.1	13.1	13.1	13.1	13.1
0.10	23.4	23.5	23.5	23.5	23.5	23.5
0.15	28.7	30.8	31.9	32.4	32.6	32.6
0.20	29.9	33.9	36.7	38.6	39.8	41.2
0.25	30.0	34.8	38.8	41.9	44.3	49.7
0.30	30.0	35.0	39.7	43.5	46.7	57.3
0.35	30.0	35.0	39.9	44.3	47.8	63.4
0.40	30.0	35.0	40.0	44.6	48.4	68.1

Standard deviation of yield (million lbs.)

HR	Catch ceiling 30	35	40	45	50	None
0.00	0.0	0.0	0.0	0.0	0.0	0.0
0.05	1.9	1.9	1.9	1.9	1.9	1.9
0.10	3.7	4.1	4.1	4.1	4.1	4.1
0.15	2.2	4.1	5.5	6.4	6.8	6.9
0.20	0.4	2.2	4.2	5.9	7.3	9.5
0.25	0.0	0.7	2.5	4.4	6.2	11.6
0.30	0.0	0.0	1.1	3.0	4.9	13.6
0.35	0.0	0.0	0.5	2.0	3.9	16.2
0.40	0.0	0.0	0.4	1.7	3.4	19.1

Average spawning biomass (fraction of HR=0.00 biomass)

HR	Catch ceiling 30	35	40	45	50	None
0.00	281.10	281.10	281.10	281.10	281.10	281.10
0.05	0.74	0.74	0.74	0.74	0.74	0.74
0.10	0.58	0.58	0.58	0.58	0.58	0.58
0.15	0.52	0.49	0.48	0.47	0.47	0.47
0.20	0.50	0.45	0.42	0.41	0.39	0.38
0.25	0.50	0.45	0.40	0.37	0.35	0.32
0.30	0.50	0.44	0.39	0.36	0.33	0.27
0.35	0.50	0.44	0.39	0.35	0.32	0.23
0.40	0.50	0.44	0.39	0.35	0.31	0.21

Yield ³ 90% of catch ceiling (million lbs.)

HR	Catch ceiling 30	35	40	45	50	None
0.00	0	0	0	0	0	0
0.05	0	0	0	0	0	0
0.10	20	5	1	0	0	0
0.15	78	50	29	15	6	0
0.20	100	84	64	45	30	0
0.25	100	99	86	70	55	0
0.30	100	100	97	84	71	0
0.35	100	100	100	93	80	0
0.40	100	100	100	96	86	0

Spawning biomass reaches threshold (percent of years)

HR	Catch ceiling 30	35	40	45	50	None
0.00	0	0	0	0	0	0
0.05	0	0	0	0	0	0
0.10	0	0	0	0	0	0
0.15	0	0	0	0	0	0
0.20	0	0	0	0	0	0
0.25	0	0	0	1	1	2
0.30	0	0	2	6	11	19
0.35	0	0	3	9	17	38
0.40	0	0	3	12	21	53

Female % of yield by weight (percent)

HR	Catch ceiling 30	35	40	45	50	None
0.00						
0.05	82	82	82	82	82	82
0.10	78	78	78	78	78	78
0.15	76	75	75	75	75	75
0.20	75	74	73	73	72	72
0.25	75	74	73	72	71	70
0.30	75	74	72	71	70	68
0.35	75	74	72	71	70	67
0.40	75	74	72	71	70	66

Table 5. Same as Table 1, but showing effect of dropping the 81cm minimum size limit for IPHC Areas 2B, 2C, and 3A combined.

Average annual yield (million lbs.)

	Catch ceiling					
HR	50	60	70	80	90	None
0.00	0.0	0.0	0.0	0.0	0.0	0.0
0.05	27.4	27.4	27.4	27.4	27.4	27.4
0.10	45.4	46.8	46.9	46.9	46.9	46.9
0.15	50.0	57.3	61.2	62.5	62.6	62.6
0.20	50.0	59.9	67.4	72.2	75.0	76.3
0.25	50.0	60.0	69.5	76.5	81.5	88.2
0.30	50.0	60.0	69.8	78.1	84.3	97.4
0.35	50.0	60.0	69.8	78.4	85.1	103.8
0.40	50.0	60.0	69.8	78.5	85.4	108.5

Standard deviation of yield (million lbs.)

	Catch ceiling					
HR	50	60	70	80	90	None
0.00	0.0	0.0	0.0	0.0	0.0	0.0
0.05	3.9	3.9	3.9	3.9	3.9	3.9
0.10	4.7	6.7	6.8	6.9	6.9	6.9
0.15	0.3	3.8	7.7	9.6	10.0	10.1
0.20	0.0	0.6	4.1	8.2	11.4	13.7
0.25	0.0	0.1	1.8	5.6	9.7	17.6
0.30	0.0	0.1	1.6	5.2	9.2	22.7
0.35	0.0	0.0	1.4	5.3	9.6	28.2
0.40	0.0	0.0	1.3	5.1	9.7	33.1

Average spawning biomass (fraction of HR=0.00 biomass)

	Catch ceiling					
HR	50	60	70	80	90	None
0.00	555.20	555.20	555.20	555.20	555.20	555.20
0.05	0.70	0.70	0.70	0.70	0.70	0.70
0.10	0.54	0.53	0.53	0.53	0.53	0.53
0.15	0.51	0.45	0.42	0.41	0.41	0.41
0.20	0.51	0.43	0.38	0.35	0.34	0.33
0.25	0.51	0.43	0.37	0.32	0.30	0.27
0.30	0.51	0.43	0.37	0.31	0.28	0.22
0.35	0.51	0.43	0.37	0.31	0.27	0.19
0.40	0.51	0.43	0.37	0.31	0.27	0.17

Yield ³ 90% of catch ceiling (million lbs.)

	Catch ceiling					
HR	50	60	70	80	90	None
0.00	0	0	0	0	0	0
0.05	0	0	0	0	0	0
0.10	56	18	1	0	0	0
0.15	100	78	46	20	5	0
0.20	100	100	83	55	37	0
0.25	100	100	98	79	57	0
0.30	100	100	99	91	74	0
0.35	100	100	99	92	79	0
0.40	100	100	99	93	81	0

Spawning biomass reaches threshold (percent of years)

	Catch ceiling					
HR	50	60	70	80	90	None
0.00	0	0	0	0	0	0
0.05	0	0	0	0	0	0
0.10	0	0	0	0	0	0
0.15	0	0	0	0	0	0
0.20	0	0	0	0	0	0
0.25	0	0	1	1	2	2
0.30	0	0	3	12	16	20
0.35	0	0	4	15	27	39
0.40	0	0	4	16	29	52

Female % of yield by weight (percent)

	Catch ceiling					
HR	50	60	70	80	90	None
0.00						
0.05	80	80	80	80	80	80
0.10	77	77	77	77	77	77
0.15	76	75	75	74	74	74
0.20	76	74	73	73	72	72
0.25	76	75	73	72	71	70
0.30	76	75	73	72	71	69
0.35	76	75	73	71	71	68
0.40	76	75	73	71	70	67

Table 6. Same as Table 1, but showing effect of dropping the 81 cm minimum size limit for IPHC Area 2B.

	Average annual yield (million lbs.)					
	Catch ceiling					
HR	10	12.5	15	17.5	20	None
0.00	0.0	0.0	0.0	0.0	0.0	0.0
0.05	6.7	6.7	6.7	6.7	6.7	6.7
0.10	9.6	10.7	10.9	11.0	11.0	11.0
0.15	10.0	12.1	13.3	13.9	14.1	14.1
0.20	10.0	12.4	14.2	15.4	16.1	16.4
0.25	10.0	12.5	14.6	16.0	17.0	18.0
0.30	10.0	12.5	14.7	16.2	17.4	19.1
0.35	10.0	12.5	14.7	16.3	17.5	19.7
0.40	10.0	12.5	14.7	16.3	17.6	20.1

	Standard deviation of yield (million lbs.)					
	Catch ceiling					
HR	10	12.5	15	17.5	20	None
0.00	0.0	0.0	0.0	0.0	0.0	0.0
0.05	1.1	1.2	1.2	1.2	1.2	1.2
0.10	0.6	1.6	2.0	2.0	2.0	2.0
0.15	0.0	0.8	1.9	2.7	2.9	2.9
0.20	0.0	0.3	1.3	2.4	3.3	3.8
0.25	0.0	0.2	1.1	2.2	3.3	4.7
0.30	0.0	0.1	1.1	2.3	3.4	5.7
0.35	0.0	0.1	1.1	2.3	3.5	6.6
0.40	0.0	0.1	1.0	2.3	3.5	7.1

	Average spawning biomass (fraction of HR=0.00 biomass)					
	Catch ceiling					
HR	10	12.5	15	17.5	20	None
0.00	112.20	112.20	112.20	112.20	112.20	112.20
0.05	0.65	0.65	0.65	0.65	0.65	0.65
0.10	0.51	0.46	0.45	0.45	0.45	0.45
0.15	0.49	0.40	0.35	0.33	0.33	0.33
0.20	0.49	0.39	0.32	0.28	0.25	0.24
0.25	0.49	0.39	0.30	0.25	0.22	0.19
0.30	0.49	0.39	0.30	0.25	0.20	0.16
0.35	0.49	0.39	0.30	0.24	0.20	0.14
0.40	0.49	0.39	0.30	0.24	0.20	0.13

	Yield ³ 90% of catch ceiling (million lbs.)					
	Catch ceiling					
HR	10	12.5	15	17.5	20	None
0.00	0	0	0	0	0	0
0.05	2	0	0	0	0	0
0.10	83	47	12	1	0	0
0.15	100	83	55	34	10	0
0.20	100	98	75	55	39	0
0.25	100	99	89	67	52	0
0.30	100	100	91	75	61	0
0.35	100	100	92	77	64	0
0.40	100	100	93	78	65	0

	Spawning biomass reaches threshold (percent of years)					
	Catch ceiling					
HR	10	12.5	15	17.5	20	None
0.00	0	0	0	0	0	0
0.05	0	0	0	0	0	0
0.10	0	0	0	0	0	0
0.15	0	0	0	0	0	0
0.20	0	0	0	0	0	0
0.25	0	1	7	12	14	15
0.30	0	1	13	27	34	41
0.35	0	1	14	30	40	58
0.40	0	1	15	31	41	81

	Female % of yield by weight (percent)					
	Catch ceiling					
HR	10	12.5	15	17.5	20	None
0.00						
0.05	79	79	79	79	79	79
0.10	77	78	77	77	77	77
0.15	77	76	76	76	75	75
0.20	77	76	75	75	74	74
0.25	77	76	75	74	74	73
0.30	77	76	75	74	73	72
0.35	77	76	75	74	73	72
0.40	77	76	75	74	73	71

Table 7. Same as Table 1, but showing effect of dropping the 81 cm minimum size limit for IPHC Area 2C.

Average annual yield (million lbs.)

HR	Catch ceiling 10	12.5	15	17.5	20	None
0.00	0.0	0.0	0.0	0.0	0.0	0.0
0.05	6.6	6.6	6.6	6.6	6.6	6.6
0.10	9.8	10.8	11.0	11.0	11.0	11.0
0.15	10.0	12.3	13.6	14.2	14.3	14.3
0.20	10.0	12.5	14.5	15.8	16.6	16.9
0.25	10.0	12.5	14.8	16.5	17.7	18.9
0.30	10.0	12.5	14.9	16.7	18.1	20.3
0.35	10.0	12.5	14.9	16.8	18.2	21.2
0.40	10.0	12.5	14.9	16.8	18.3	21.9

Standard deviation of yield (million lbs.)

HR	Catch ceiling 10	12.5	15	17.5	20	None
0.00	0.0	0.0	0.0	0.0	0.0	0.0
0.05	1.0	1.0	1.0	1.0	1.0	1.0
0.10	0.5	1.4	1.7	1.7	1.7	1.7
0.15	0.0	0.5	1.6	2.3	2.5	2.5
0.20	0.0	0.1	0.9	2.0	2.8	3.3
0.25	0.0	0.0	0.7	1.7	2.7	4.3
0.30	0.0	0.0	0.6	1.8	2.9	5.4
0.35	0.0	0.0	0.6	1.7	2.9	6.5
0.40	0.0	0.0	0.5	1.7	2.9	7.3

Average spawning biomass (fraction of HR=0.00 biomass)

HR	Catch ceiling 10	12.5	15	17.5	20	None
0.00	130.90	130.90	130.90	130.90	130.90	130.90
0.05	0.69	0.69	0.69	0.69	0.69	0.69
0.10	0.56	0.51	0.51	0.50	0.50	0.50
0.15	0.55	0.46	0.41	0.39	0.39	0.39
0.20	0.55	0.45	0.38	0.33	0.31	0.30
0.25	0.55	0.45	0.37	0.31	0.28	0.24
0.30	0.55	0.45	0.37	0.31	0.26	0.21
0.35	0.55	0.45	0.37	0.30	0.26	0.18
0.40	0.55	0.45	0.37	0.30	0.26	0.17

Yield ³ 90% of catch ceiling (million lbs.)

HR	Catch ceiling 10	12.5	15	17.5	20	None
0.00	0	0	0	0	0	0
0.05	1	0	0	0	0	0
0.10	90	47	8	0	0	0
0.15	100	92	58	33	7	0
0.20	100	100	86	59	42	0
0.25	100	100	96	77	56	0
0.30	100	100	97	83	68	0
0.35	100	100	97	85	71	0
0.40	100	100	98	86	72	0

Spawning biomass reaches threshold (percent of years)

HR	Catch ceiling 10	12.5	15	17.5	20	None
0.00	0	0	0	0	0	0
0.05	0	0	0	0	0	0
0.10	0	0	0	0	0	0
0.15	0	0	0	0	0	0
0.20	0	0	0	0	0	0
0.25	0	0	6	11	13	14
0.30	0	0	8	22	31	37
0.35	0	0	8	24	36	51
0.40	0	0	8	25	37	68

Female % of yield by weight (percent)

HR	Catch ceiling 10	12.5	15	17.5	20	None
0.00						
0.05	78	78	78	78	78	78
0.10	76	76	75	75	75	75
0.15	76	75	74	74	73	73
0.20	76	74	73	72	72	72
0.25	76	74	73	72	71	71
0.30	76	74	73	72	71	69
0.35	76	74	73	72	71	69
0.40	76	74	73	72	71	68

Table 8. Same as Table 1, but showing effect of dropping the 81 cm minimum size limit for IPHC Area 3A.

Average annual yield (million lbs.)

HR	Catch ceiling 30	35	40	45	50	None
0.00	0.0	0.0	0.0	0.0	0.0	0.0
0.05	14.0	14.0	14.0	14.0	14.0	14.0
0.10	25.1	25.4	25.5	25.5	25.5	25.5
0.15	29.5	32.7	34.4	35.3	35.7	35.8
0.20	30.0	34.8	38.6	41.3	43.2	45.9
0.25	30.0	35.0	39.8	44.0	47.2	55.4
0.30	30.0	35.0	40.0	44.8	48.9	63.5
0.35	30.0	35.0	40.0	44.9	49.3	69.3
0.40	30.0	35.0	40.0	44.9	49.5	73.4

Standard deviation of yield (million lbs.)

HR	Catch ceiling 30	35	40	45	50	None
0.00	0.0	0.0	0.0	0.0	0.0	0.0
0.05	2.1	2.1	2.1	2.1	2.1	2.1
0.10	3.6	4.3	4.4	4.4	4.4	4.4
0.15	1.1	3.1	4.8	6.1	6.8	7.1
0.20	0.0	0.8	2.6	4.4	6.0	9.5
0.25	0.0	0.0	0.7	2.3	4.0	11.5
0.30	0.0	0.0	0.1	1.1	2.7	14.2
0.35	0.0	0.0	0.1	0.8	2.3	17.9
0.40	0.0	0.0	0.1	0.8	2.3	21.6

Average spawning biomass (fraction of HR=0.00 biomass)

HR	Catch ceiling 30	35	40	45	50	None
0.00	281.10	281.10	281.10	281.10	281.10	281.10
0.05	0.75	0.75	0.75	0.75	0.75	0.75
0.10	0.59	0.59	0.59	0.59	0.59	0.59
0.15	0.55	0.51	0.49	0.48	0.48	0.48
0.20	0.54	0.49	0.45	0.42	0.41	0.39
0.25	0.54	0.49	0.44	0.40	0.37	0.32
0.30	0.54	0.49	0.43	0.39	0.36	0.27
0.35	0.54	0.49	0.43	0.39	0.35	0.23
0.40	0.54	0.49	0.43	0.39	0.35	0.21

Yield ³ 90% of catch ceiling (million lbs.)

HR	Catch ceiling 30	35	40	45	50	None
0.00	0	0	0	0	0	0
0.05	0	0	0	0	0	0
0.10	34	10	2	0	0	0
0.15	93	70	42	24	13	0
0.20	100	98	84	64	43	0
0.25	100	100	99	90	75	0
0.30	100	100	100	98	90	0
0.35	100	100	100	99	95	0
0.40	100	100	100	99	96	0

Spawning biomass reaches threshold (percent of years)

HR	Catch ceiling 30	35	40	45	50	None
0.00	0	0	0	0	0	0
0.05	0	0	0	0	0	0
0.10	0	0	0	0	0	0
0.15	0	0	0	0	0	0
0.20	0	0	0	0	0	0
0.25	0	0	0	1	1	1
0.30	0	0	0	3	8	17
0.35	0	0	0	4	12	37
0.40	0	0	0	4	13	51

Female % of yield by weight (percent)

HR	Catch ceiling 30	35	40	45	50	None
0.00						
0.05	77	77	77	77	77	77
0.10	74	74	74	74	74	74
0.15	73	72	72	71	71	71
0.20	72	71	70	70	69	69
0.25	72	71	70	69	68	67
0.30	72	71	70	69	68	65
0.35	72	71	70	69	68	64
0.40	72	71	70	69	68	64

Table 9. Percentage change in performance statistics resulting from dropping the 81 cm size limit for Areas 2B, 2C, and 3A combined. Positive values indicate an increase over having an 81 cm size limit.

Average annual yield (million lbs.)

HR	Catch ceiling 50	60	70	80	90	None
0.00	-	-	-	-	-	-
0.05	4	4	4	4	4	4
0.10	4	6	6	6	6	6
0.15	0	3	6	7	8	8
0.20	0	1	3	5	7	9
0.25	0	0	1	3	5	10
0.30	0	0	1	2	3	9
0.35	0	0	0	2	3	9
0.40	0	0	0	1	2	8

Standard deviation of yield (million lbs.)

HR	Catch ceiling 50	60	70	80	90	None
0.00	-	-	-	-	-	-
0.05	8	8	8	8	8	8
0.10	-6	12	11	13	13	13
0.15	-63	-22	-1	10	14	15
0.20	-	-57	-25	-9	5	16
0.25	-	-67	-40	-20	-8	18
0.30	-	-50	-38	-20	-12	19
0.35	-	-100	-44	-20	-10	19
0.40	-	-100	-43	-23	-10	18

Average spawning biomass (fraction of HR=0.00 biomass)

HR	Catch ceiling 50	60	70	80	90	None
0.00	0	0	0	0	0	0
0.05	1	1	1	1	1	1
0.10	3	2	1	1	1	1
0.15	6	6	3	2	2	2
0.20	7	9	8	6	3	2
0.25	7	9	11	10	8	2
0.30	7	9	12	12	10	1
0.35	7	9	12	12	12	0
0.40	7	9	12	13	13	0

Yield ³ 90% of catch ceiling (million lbs.)

HR	Catch ceiling 50	60	70	80	90	None
0.00	-	-	-	-	-	-
0.05	-	-	-	-	-	-
0.10	24	100+	-	-	-	-
0.15	0	24	59	100+	100+	-
0.20	0	2	22	41	85	-
0.25	0	0	5	22	33	-
0.30	0	0	3	11	19	-
0.35	0	0	2	7	14	-
0.40	0	0	1	7	11	-

Spawning biomass reaches threshold (percent of years)

HR	Catch ceiling 50	60	70	80	90	None
0.00	-	-	-	-	-	-
0.05	-	-	-	-	-	-
0.10	-	-	-	-	-	-
0.15	-	-	-	-	-	-
0.20	-	-	-	-	-	-
0.25	-	-	-50	-67	-33	-33
0.30	-	-100	-63	-29	-20	-9
0.35	-	-100	-56	-38	-16	-3
0.40	-	-100	-56	-36	-22	0

Female % of yield by weight (percent)

HR	Catch ceiling 50	60	70	80	90	None
0.00	-	-	-	-	-	-
0.05	-4	-4	-4	-4	-4	-4
0.10	-5	-5	-5	-5	-5	-5
0.15	-4	-5	-5	-5	-5	-5
0.20	-4	-4	-4	-5	-5	-5
0.25	-4	-4	-4	-4	-4	-5
0.30	-4	-4	-4	-4	-4	-5
0.35	-4	-4	-4	-4	-4	-4
0.40	-4	-4	-4	-4	-4	-4

Table 10. Same as Table 9, but showing the effect of dropping the 81 cm minimum size limit for IPHC Area 2B.

Average annual yield (million lbs.)

	Catch ceiling					
HR	10	12.5	15	17.5	20	None
0.00	-	-	-	-	-	-
0.05	6	6	6	6	6	6
0.10	2	5	7	8	8	8
0.15	0	3	4	6	8	8
0.20	0	1	2	4	6	7
0.25	0	0	1	3	3	7
0.30	0	0	1	1	2	6
0.35	0	0	1	2	2	5
0.40	0	0	1	1	2	5

Standard deviation of yield (million lbs.)

	Catch ceiling					
HR	10	12.5	15	17.5	20	None
0.00	-	-	-	-	-	-
0.05	10	20	20	20	20	20
0.10	-25	0	11	11	11	11
0.15	-100	-20	-5	8	16	16
0.20	-	-40	-13	-8	6	15
0.25	-	0	-8	-4	0	18
0.30	-	-50	-15	-4	-3	16
0.35	-	-50	-15	-8	-3	16
0.40	-	-50	-17	-8	-5	11

Average spawning biomass (fraction of HR=0.00 biomass)

	Catch ceiling					
HR	10	12.5	15	17.5	20	None
0.00	0	0	0	0	0	0
0.05	-1	-1	-1	-1	-1	-1
0.10	1	-1	-3	-3	-3	-3
0.15	4	3	1	-3	-4	-4
0.20	4	5	3	2	-2	-5
0.25	4	6	5	4	2	-6
0.30	4	6	7	7	5	-6
0.35	4	6	7	7	7	-5
0.40	4	6	7	7	7	-3

Yield ³ 90% of catch ceiling (million lbs.)

	Catch ceiling					
HR	10	12.5	15	17.5	20	None
0.00	-	-	-	-	-	-
0.05	-	-	-	-	-	-
0.10	17	42	100+	-	-	-
0.15	0	14	20	100	100+	-
0.20	0	3	12	20	56	-
0.25	0	0	9	14	18	-
0.30	0	1	3	7	15	-
0.35	0	1	3	5	8	-
0.40	0	1	3	5	7	-

Spawning biomass reaches threshold (percent of years)

	Catch ceiling					
HR	10	12.5	15	17.5	20	None
0.00	-	-	-	-	-	-
0.05	-	-	-	-	-	-
0.10	-	-	-	-	-	-
0.15	-	-	-	-	-	-
0.20	-	-	-	-	-	-
0.25	-	0	40	71	75	88
0.30	-	-50	-19	4	10	21
0.35	-	-50	-22	-9	-2	16
0.40	-	-50	-21	-9	-9	19

Female % of yield by weight (percent)

	Catch ceiling					
HR	10	12.5	15	17.5	20	None
0.00	-	-	-	-	-	-
0.05	-2	-2	-2	-2	-2	-2
0.10	-3	-2	-3	-3	-3	-3
0.15	-3	-2	-3	-3	-3	-3
0.20	-3	-3	-2	-2	-3	-3
0.25	-3	-2	-2	-2	-2	-3
0.30	-3	-2	-2	-2	-2	-3
0.35	-3	-2	-2	-3	-2	-3
0.40	-3	-2	-2	-2	-2	-3

Table 11. Same as Table 9, but showing the effect of dropping the 81 cm minimum size limit for IPHC Area 2C.

Average annual yield (million lbs.)

	Catch ceiling					
HR	10	12.5	15	17.5	20	None
0.00	-	-	-	-	-	-
0.05	2	2	2	2	2	2
0.10	1	3	4	4	4	4
0.15	0	1	2	4	5	5
0.20	0	0	1	3	4	6
0.25	0	0	1	2	3	7
0.30	0	0	1	2	3	7
0.35	0	0	1	2	2	7
0.40	0	0	1	1	2	7

Standard deviation of yield (million lbs.)

	Catch ceiling					
HR	10	12.5	15	17.5	20	None
0.00	-	-	-	-	-	-
0.05	0	0	0	0	0	0
0.10	0	0	6	6	6	6
0.15	-	-17	-6	10	14	14
0.20	-	0	-18	-5	4	18
0.25	-	-100	-22	-11	-7	16
0.30	-	-100	-25	-10	-6	15
0.35	-	-	-25	-15	-6	16
0.40	-	-	-29	-15	-6	16

Average spawning biomass (fraction of HR=0.00 biomass)

	Catch ceiling					
HR	10	12.5	15	17.5	20	None
0.00	0	0	0	0	0	0
0.05	1	1	1	1	1	1
0.10	3	3	2	2	2	2
0.15	4	6	5	3	3	3
0.20	4	7	8	8	5	3
0.25	4	7	9	9	9	3
0.30	4	7	9	10	10	2
0.35	4	7	9	10	11	1
0.40	4	7	10	10	11	0

Yield ³ 90% of catch ceiling (million lbs.)

	Catch ceiling					
HR	10	12.5	15	17.5	20	None
0.00	-	-	-	-	-	-
0.05	0	-	-	-	-	-
0.10	6	24	100+	-	-	-
0.15	0	5	14	83	100+	-
0.20	0	0	9	13	50	-
0.25	0	0	3	12	14	-
0.30	0	0	3	8	11	-
0.35	0	0	2	8	11	-
0.40	0	0	3	8	9	-

Spawning biomass reaches threshold (percent of years)

	Catch ceiling					
HR	10	12.5	15	17.5	20	None
0.00	-	-	-	-	-	-
0.05	-	-	-	-	-	-
0.10	-	-	-	-	-	-
0.15	-	-	-	-	-	-
0.20	-	-	-100	-100	-100	-100
0.25	-	-100	-40	-31	-24	-22
0.30	-	-100	-33	-21	-14	-5
0.35	-	-100	-38	-23	-12	-4
0.40	-	-100	-43	-22	-12	-3

Female % of yield by weight (percent)

	Catch ceiling					
HR	10	12.5	15	17.5	20	None
0.00	-	-	-	-	-	-
0.05	-5	-5	-5	-5	-5	-5
0.10	-4	-4	-4	-4	-4	-4
0.15	-4	-4	-3	-3	-4	-4
0.20	-4	-3	-3	-4	-3	-4
0.25	-4	-3	-3	-3	-4	-4
0.30	-4	-3	-3	-3	-4	-4
0.35	-4	-3	-3	-4	-4	-4
0.40	-4	-3	-3	-3	-3	-4

Table 12. Same as Table 9, but showing the effect of dropping the 81 cm minimum size limit for IPHC Area 3A.

Average annual yield (million lbs.)

HR	Catch ceiling 30	35	40	45	50	None
0.00	-	-	-	-	-	-
0.05	7	7	7	7	7	7
0.10	7	8	9	9	9	9
0.15	3	6	8	9	10	10
0.20	0	3	5	7	9	11
0.25	0	1	3	5	7	11
0.30	0	0	1	3	5	11
0.35	0	0	0	1	3	9
0.40	0	0	0	1	2	8

Standard deviation of yield (million lbs.)

HR	Catch ceiling 30	35	40	45	50	None
0.00	-	-	-	-	-	-
0.05	11	11	11	11	11	11
0.10	-3	5	7	7	7	7
0.15	-50	-24	-13	-5	0	3
0.20	-100	-64	-38	-25	-18	0
0.25	-	-100	-72	-48	-35	-1
0.30	-	-	-91	-63	-45	4
0.35	-	-	-80	-60	-41	10
0.40	-	-	-75	-53	-32	13

Average spawning biomass (fraction of HR=0.00 biomass)

HR	Catch ceiling 30	35	40	45	50	None
0.00	0	0	0	0	0	0
0.05	1	1	1	1	1	1
0.10	2	1	1	1	1	1
0.15	6	4	3	2	2	1
0.20	8	7	6	4	3	2
0.25	8	9	9	7	6	2
0.30	8	9	10	10	8	1
0.35	8	10	11	12	10	1
0.40	8	10	11	12	12	1

Yield ³ 90% of catch ceiling (million lbs.)

HR	Catch ceiling 30	35	40	45	50	None
0.00	-	-	-	-	-	-
0.05	-	-	-	-	-	-
0.10	70	100	100	-	-	-
0.15	19	40	45	60	100+	-
0.20	0	17	31	42	43	-
0.25	0	1	15	29	36	-
0.30	0	0	3	17	27	-
0.35	0	0	0	6	19	-
0.40	0	0	0	3	12	-

Spawning biomass reaches threshold (percent of years)

HR	Catch ceiling 30	35	40	45	50	None
0.00	-	-	-	-	-	-
0.05	-	-	-	-	-	-
0.10	-	-	-	-	-	-
0.15	-	-	-	-	-	-
0.20	-	-	-	-	-	-
0.25	-	-	-	0	0	-50
0.30	-	-	-100	-50	-27	-11
0.35	-	-	-100	-56	-29	-3
0.40	-	-	-100	-67	-38	-4

Female % of yield by weight (percent)

HR	Catch ceiling 30	35	40	45	50	None
0.00	-	-	-	-	-	-
0.05	-6	-6	-6	-6	-6	-6
0.10	-5	-5	-5	-5	-5	-5
0.15	-4	-5	-5	-5	-5	-5
0.20	-4	-4	-4	-4	-4	-5
0.25	-4	-4	-4	-4	-4	-4
0.30	-4	-3	-4	-4	-4	-4
0.35	-4	-3	-3	-3	-3	-3
0.40	-4	-3	-3	-3	-3	-3

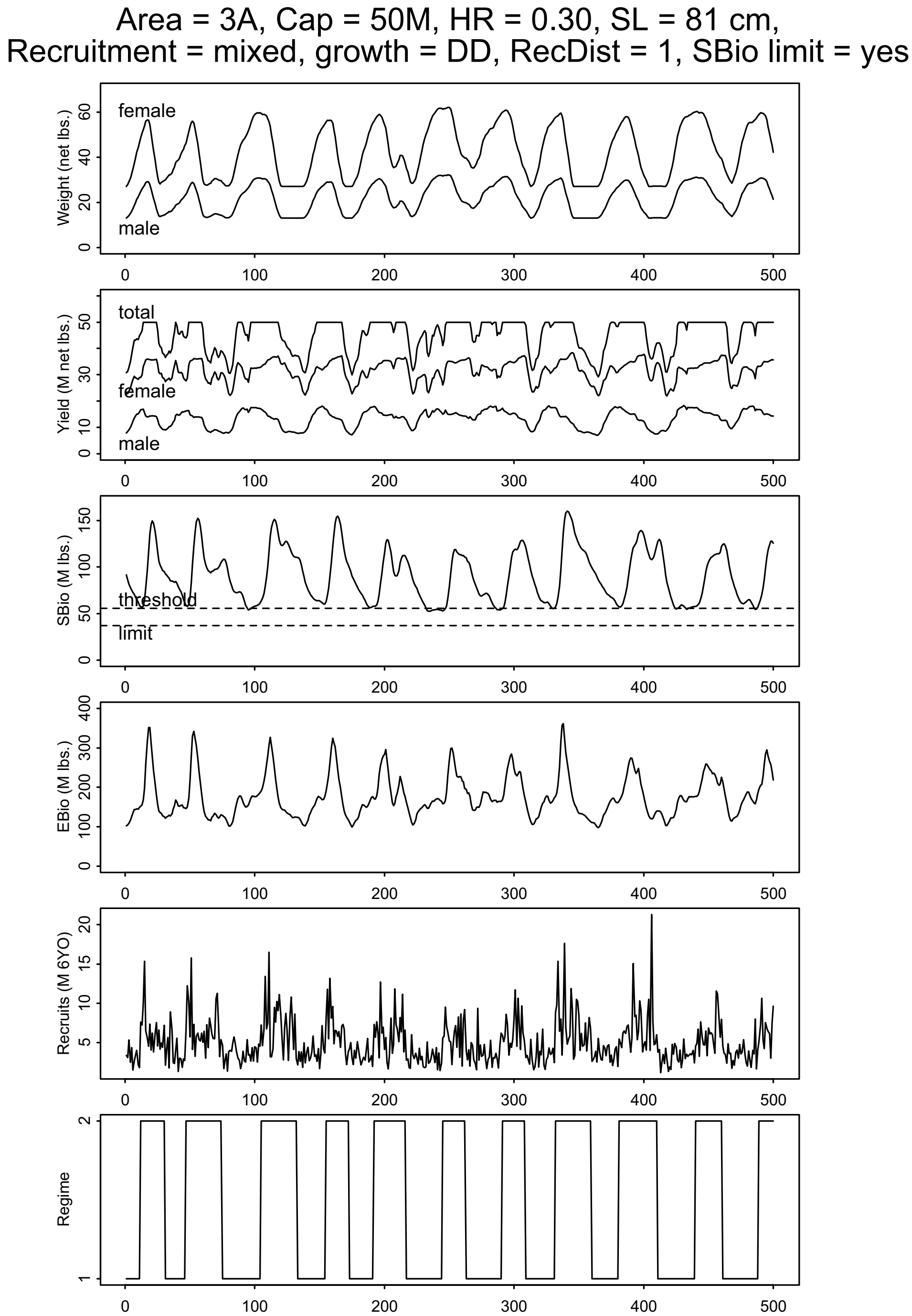

Figure 1. An illustration of the simulations conducted to test the CCC policy. The x axis in all plots is years. The bottom plot shows the duration of alternating regimes. Above that is shown total age 6 recruits, next is exploitable biomass (EBio), next is Spawning Biomass (SBio, females only, threshold and limit biomass reference levels shown as horizontal lines), next is yield (male, female and total) and top plot is average weight of a 14 year old fish (male and female). These simulations are for Area 3A, with a harvest ceiling of 50 million pounds and a ceiling harvest rate of 0.30.

Yield per recruit analysis for a sex specific halibut assessment model

Steven R. Hare and William G. Clark

Abstract

In 2003, for the first time, sex-specific estimates of halibut abundance were produced. A number of other significant changes were also made in the assessment model. In support of these changes a yield per recruit analysis (YPR) was conducted. Spawning biomass per recruit and proportion female in older age groups were found to decline rapidly with harvest rate. The results suggest that harvest rates should be maintained in the range of 0.15-0.20. No change to the current harvest policy is recommended until a full dynamic analysis is completed.

Introduction

For the past 20 years, a constant harvest rate policy has been used to set annual halibut catch limits. A harvest rate of 0.20 – applied to the exploitable biomass - has been used for the past seven years, with higher rates of 0.35 and 0.30 used in the mid 1980s and early 1990s, respectively. Exploitable biomass is defined as number of halibut times their average weight times their selectivity to the fishing gear. Commercial selectivity is strongly affected by the minimum size limit, currently 81 cm. Prior to 1974, the minimum size limit was 65 cm. The change from a minimum size limit of 65 cm to 81 cm was done to increase sustainable yields (Myhre 1974). Since 1974, growth rates of halibut have decreased markedly (Clark et al. 1999) and this trend has continued to the present (Clark and Hare 2004b). Despite the change in size at age, subsequent yield per recruit analyses have supported maintaining the 81 cm minimum size limit (Clark and Parma 1995, Parma 1998).

This year a new, sex-specific, assessment model for halibut was introduced which provides estimates of numbers at age and mean length at age for both sexes. On the basis of several lines of evidence, selectivity is now modeled as a length-determined process. The sex specific differential size at age of halibut therefore implies very different selectivity at age by sex, with males experiencing much lower selectivities. The expected result of a persistent difference in sex-specific selectivities is a higher harvest of one sex, lower harvest of the other, and an over accumulation of one sex in the population remaining in the sea. In fact, this has been the case as IPHC survey catches show a preponderance of females. One would anticipate that as a result of this, that there would be increasingly fewer older females in the population.

Another recent change that potentially affects the harvest rate policy is that all halibut are now aged via the break and burn method. This has had the effect of “aging” the halibut population relative to our view prior to five years ago when almost all halibut were surface aged. The new age distribution may affect estimates of annual growth rates and maturity at age.

In this paper we conduct a yield per recruit (YPR) analysis using the most recent estimates of growth, maturity and selectivity. We examine yield per recruit and spawning biomass per recruit given all the new stock parameters. We further consider the effect of removing the current 81 cm size limit. In all analyses we also examine the sex ratio among older fish.

Maturity at age

Halibut maturity at age has been examined several times, most recently by Parma (1998). All previous analyses were conducted using halibut ages determined by surface readings. For this analysis, we examined maturity at age in Areas 2B and 3A during several times periods to look for time trends. For comparison we also examined maturity at length. The time periods were grouped as follows: 1963-1966, 1976-1983, 1992-1996, 1997-2001, 2002-2003. To estimate maturity at age/length, logistic functions were fit to the data for each period and region. The form of the function was as follows:

$$p = \frac{1}{1+e^{(-k \bullet (A-A_{50}))}} \qquad \text{or} \qquad p = \frac{1}{1+e^{(-k \bullet (L-L_{50}))}}$$

where k is a slope parameter and A_{50} is the age, and L_{50} is the length, at which 50% of the females are mature. To avoid mixing ages from different reading techniques, only surface ages were used for the periods prior to 2001 and only break and burn ages were used for 2002-2003.

The results are illustrated in Figure 1 and maturity function parameter estimates are given in Table 1. Despite the differences in time periods and aging techniques, female maturity at age has been remarkably consistent over time and between Areas 2B and 3A. These time periods capture the extreme in changing growth rates over time and show that maturity is likely determined more by age and not by size. The age at which 50% of females attain maturity varies from a low of 10.47 in 2B in the early 90's to a high of 12.27 in 2B in 2002-2003. In Area 2B, the higher age at 50% maturity might be attributed to the new aging technique but a similar increase in A_{50} was not found in Area 3A. The difference in assigned ages is not appreciable until after approximately age 15 and this accounts for why there is no systematic difference between the different aging types. For our YPR analyses, we use a single maturity schedule with the parameter estimates from the logistic model fitted to all 2002-2003 data for both areas (A_{50} = 11.59, k = 0.563)

As was first shown by Parma (1998), there has been a highly significant change in maturity at length. Length at 50% maturity ranged from a high of 120 cm in the 1960s to a low of 94 cm in the late 1990s in Area 2B and from a high of 126 cm in the 1970s to a low of 85 cm in the late 1990s in Area 3A. As shown by the 2002-2003 break and burn data, the declining trend in maturity at length has stopped and even rebounded slightly in Area 2B.

Growth and size at age

In their analysis of halibut growth rates, Clark and Hare (2002) concluded that growth was likely a density dependent process related to the number of adult (age 10+) animals in the stock. The new assessment model of halibut has produced new estimates of both population size and coincident growth rates. Clark and Hare (2002) devised a model for estimating the density dependent effect which was altered slightly for harvest policy analyses in 2001 and 2002 (Hare and Clark 2002, 2003). A similar growth model has been developed for this analysis which contains three parameters: mean size at age 6, an annual growth increment between ages 6 and 20, and an annual growth increment between ages 21 and 30. Growth in weight is therefore linear from age 6 to 20 at one rate and then linear at a different (and lower) rate from ages 21 to 30. There are separate parameter estimates for each area (Area 2B, 2C, 3A and all three regions combined), sex and fishery (survey and commercial). For each area, sex and fishery type, there are high and low values for the two annual growth increments and these are related to the number of adult animals in the stock. Size at age 6 varies by sex, region and fishery but is constant across population size. The parameter estimates, along with minimum and maximum mean weight at age for ages 20 and 30 are given in Table 2.

For the yield and spawning biomass per recruit analyses, two different growth schedules were used. To approximate present day weight at age we used the minimum estimates for the three parameters and to approximate size at age 20 years ago when fish were considerably larger, we used the maximum estimates.

Length at age (L_a) is computed from the inverse of mean weight at age (W_a), as follows:

$$L_a = \sqrt[\frac{1}{3.24}]{\frac{W_a}{0.00000692}}$$

In general, this method underestimates mean length compared to the usual method of integrating across length using the observed mean length at age and standard deviation. An analysis of survey data showed that the underestimate of mean length computed in this manner is at most 2%. The advantage of using this method is that it allows us to use the mean weights at age generated by our growth model rather than having to choose particular years to represent current and past growth rates. Figure 2 shows the computed mean lengths at age for both areas, both sexes and both growth rates.

Selectivity at age

Selectivity at age is computed by combining the fixed selectivity at length schedules estimated in the assessment with estimates of length at age. Two coastwide selectivities are used, one for survey selectivity, and another for commercial selectivity. The survey selectivity schedule is used in the YPR analysis to approximate selectivity in the absence of a size limit. The survey selectivity (S) schedule is as follows:

$$\begin{aligned} S &= 0 && L \le 70 \\ S &= \frac{(L-70)}{60} && 71 \le L < 130 \\ S &= 1 && L \ge 130 \end{aligned}$$

Commercial selectivity schedule assumes the current 81 cm size limit and is as follows:

$$\begin{aligned} S &= 0 && L \le 80 \\ S &= \frac{(L-80)}{40} && 81 \le L < 120 \\ S &= 1 && L \ge 120 \end{aligned}$$

Results

Under current growth rates and using a single coast wide selectivity at length schedule, there are sizable differences in both spawning biomass per recruit (SBPR) and yield per recruit (YPR) between Areas 2B and 3A (Figure 3). SBPR drops off more rapidly in 2B than in 3A. Conversely, YPR is higher in 2B than in 3A. The effect of dropping the size limit would be to increase YPR on the order of 5-7% for harvest rates between 0.15 and 0.25. The concomitant reduction in SBPR, however, is on the order of 30%. This would not appear to be a strong argument in favor of dropping the size limit. Under old growth rates, the drop off in SBPR with harvest rate is even more steep than under the current growth rates, with little difference between Areas 2B and 3A. YPR is considerably larger in 3A because fish grew to much larger sizes in 3A than in 2B 20 years ago. Dropping the size limit has little effect on SBPR but has a strong negative effect on YPR in Area 3A but not in Area 2B. When fish grow to large sizes, there are large benefits in having a minimum size limit.

A number of fisheries along the Pacific Coast of the U.S. employ harvest strategies that are based on maintaining a certain level of SBPR. Three common reference points are F_{30}, F_{35}, and F_{40}, i.e., fishing at a rate that reduces SBPR to 30, 35, or 40% of its level absent of fishing. Another common reference point, one based on yield considerations, is $F_{0.1}$. Under this harvest policy, the target harvest rate is that where the nominal increase in YPR drop to 10% of its increase at very low harvest rates. The harvest rates that meet these criteria are illustrated in Table 3. Under current growth rates, Area 3A appears able to tolerate higher harvest rates than 2B. Harvest rates between 0.19 and 0.29 in Area 3A cover the three SBPR reference points while the range in Area 2B is 0.15-0.21. Dropping the size limit would lead to substantially lower recommended harvest rates, dropping to 0.13-0.18 in Area 3A and 0.12-0.16 in Area 2B. Under the old growth rate schedules, all recommended harvest rates are lower, generally on the order of 20-30%.

As we noted earlier, the differential growth rates between the sexes combined with our new view that selectivity is length-based rather than age-based gives cause for concern that females may be over harvested relative to males and underrepresented in the remaining population in the ocean. In Table 4, we summarize the proportion female at ages 10, 15, 20, 25, and 30 under a variety of harvest rates ranging from 0.15-0.30. As expected, the proportion of females does decrease with age. The proportion female also declines sharply with harvest rate. The proportion female declines more rapidly in Area 2B than 3A both with and without a size limit and for both current and old growth rates. By age 20, the proportion of females in the ocean population is less than 0.30 for all harvest rates greater than 0.15 By age 25, the proportion of females in less than 0.20. Dropping the size limit does increase the proportion females at older ages, with as much as 50% improvement, however the actual proportions are still quite low. Under the old growth rates, proportion female is higher for both areas, with and without a size limit. In fact, in Area 3A the proportion female at age stops declining after age 15 since under the old growth schedule males were fully selected by that age. Proportion females does still decline with harvest rate.

Discussion

This YPR analysis provides a new perspective on target harvest rates. Past YPR analyses differed in many ways from the current analysis: pooled sexes, higher natural mortality rate, age-based selectivities, and so on. There are several overall conclusions from this analysis.

1. Harvest rates should be in the range of 0.15 to 0.20 if SBPR is to remain above F_{35}.
2. Given current growth rates, Area 3A can withstand a slightly higher harvest rate than Area 2B.
3. There is little yield benefit to dropping the size limit and SBPR drops substantially at all harvest rates.
4. Female proportion at age always decreases with increasing harvest rate.

There are a number of very strong and influential provisos for any YPR analysis, including this one. Specific to this analysis, we used a single coastwide selectivity schedule. In the assessment model, selectivity is always steeper in Area 2B than in 3A. Using a different selectivity curve for 2B would likely narrow the differences between the two areas. YPR analysis assumes a state of equilibrium which is clearly not appropriate for halibut. For instance, with higher harvest rates, density dependent effects would result in increased growth and this may well temper the decline in SBPR and increase in YPR. Such changing conditions cannot be implemented in a YPR analysis. Variable recruitment is also likely to strongly affect the results as there would be alternating pulses of large numbers of small animals following smaller pulses of large animals. These concerns must be analyzed in a dynamic context as was done for the conditional constant catch (CCC) harvest policy (Hare and Clark 2003, Clark and Hare 2004a). Such an analysis is currently underway and no change to the harvest policy should be implemented until such results have been analyzed.

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Table 1. Time periods, sample sizes, and parameter estimates for logistic function fits to Pacific halibut maturity data at age (A) and length (L).

Area	Years	n	A_{50}	k	L_{50}	k
2B	1963-1966	647	11.96	0.515	119.71	.111
2B	1976-1983	753	10.99	0.772	111.14	.100
2B	1992-1996	3581	10.47	0.674	97.60	.093
2B	1997-2001	5419	10.78	0.583	93.65	.099
2B	2002-2003	2124	12.27	0.555	101.36	.107
2B	All years	12528	10.97	0.592	98.15	.089
3A	1963-1966	2538	10.45	1.043	119.59	.169
3A	1976-1983	3514	11.62	0.887	125.98	.129
3A	1992-1996	4389	10.91	1.002	92.09	.122
3A	1997-2001	5508	10.66	0.789	85.44	.095
3A	2002-2003	2222	10.83	0.527	85.25	.091
3A	All years	18175	10.93	0.822	96.53	.060
						.
All areas	2002-2003	4347	11.59	0.563	97.63	.070
All areas	All years	30704	10.91	0.711	93.37	.093

Table 2. Growth parameters used to establish current and past weight at age by area, sex, fishery and age. See text for details on model.

Area	Sex	Min Max	Age 10+ fish in population	Age 6 weight (net lbs)	7-20 growth increment (net lbs)	21-30 growth increment (net lbs)	Age 20 wt (net lbs)	Age 30 wt (net lbs)
	Survey fishery parameters							
2B	F	Min	1	9.0	3.0	2.0	51.0	71.0
	F	Max	6	9.0	5.2	2.5	81.8	106.8
	M	Min	1	6.0	1.0	0.5	20.0	25.0
	M	Max	6	6.0	1.7	1.0	29.8	39.8
2C	F	Min	1	7.0	4.0	1.5	63.0	78.0
	F	Max	6	7.0	6.5	2.5	98.0	123.0
	M	Min	1	5.5	1.3	1.0	23.7	33.7
	M	Max	6	5.5	2.5	1.0	40.5	50.5
3A	F	Min	2	7.0	2.5	2.0	42.0	62.0
	F	Max	25	7.0	8.0	2.0	119.0	139.0
	M	Min	2	7.0	1.0	0.5	19.0	24.0
	M	Max	25	7.0	4.0	2.0	61.0	81.0
All	F	Min	4	8.0	3.0	2.5	50.0	75.0
	F	Max	37	8.0	6.5	2.5	99.0	124.0
	M	Min	4	5.5	1.0	1.0	19.5	29.5
	M	Max	37	5.5	3.0	1.0	47.5	57.5
	Commercial fishery parameters							
2B	F	Min	1	15.0	2.3	2.0	47.2	67.2
	F	Max	6	15.0	4.8	2.5	82.2	107.2
	M	Min	1	13.0	0.5	0.6	20.0	26.0
	M	Max	6	13.0	1.2	0.9	29.8	38.8
2C	F	Min	1	13.0	3.0	2.4	55.0	79.0
	F	Max	6	13.0	6.3	2.4	101.2	125.2
	M	Min	1	14.0	0.7	1.0	23.8	33.8
	M	Max	6	14.0	2.0	1.0	42.0	52.0
3A	F	Min	2	13.0	2.0	1.0	41.0	51.0
	F	Max	25	13.0	7.5	4.0	118.0	158.0
	M	Min	2	13.0	0.5	0.5	20.0	25.0
	M	Max	25	13.0	3.5	2.0	62.0	82.0
All	F	Min	4	13.0	2.5	1.5	48.0	63.0
	F	Max	37	13.0	6.3	3.0	101.2	131.2
	M	Min	4	13.0	0.5	0.6	20.0	26.0
	M	Max	37	13.0	2.0	1.3	43.8	56.8

Table 3. Harvest rates that achieve four common management targets under current and old growth rates. The first three columns show the harvest rate that reduces female spawning biomass to 30/35/40% relative to no fishing. The fourth column shows the harvest rate at which the nominal gain in yield is 10% of the gain in yield at very low harvest rates.

Area	Size limit	F_{30}	F_{35}	F_{40}	$F_{0.1}$
	Current growth rates				
2B	81 cm	0.21	0.18	0.15	0.30
3A	81 cm	0.29	0.23	0.19	0.35
2B	0 cm	0.16	0.14	0.12	0.21
3A	0 cm	0.18	0.15	0.13	0.23
	Old growth rates				
2B	81 cm	0.15	0.13	0.11	0.21
3A	81 cm	0.14	0.12	0.10	0.17
2B	0 cm	0.13	0.11	0.10	0.16
3A	0 cm	0.13	0.11	0.09	0.14

Table 4. Proportion female at age in the population by area, size limit and harvest under current and old growth rates.

Area	Size limit	Harvest rate	Age 10	Age 15	Age 20	Age 25	Age 30
Current growth rates							
2B	81 cm	0.15	.47	.36	.24	.17	.13
		0.20	.46	.31	.17	.11	.07
		0.25	.45	.26	.12	.06	.03
		0.30	.44	.22	.08	.03	.01
3A	81 cm	0.15	.49	.40	.28	.20	.14
		0.20	.48	.36	.22	.13	.08
		0.25	.48	.33	.17	.08	.04
		0.30	.47	.29	.12	.05	.02
2B	0 cm	0.15	.46	.38	.30	.25	.20
		0.20	.45	.34	.24	.17	.13
		0.25	.44	.30	.18	.12	.08
		0.30	.42	.26	.13	.07	.04
3A	0 cm	0.15	.47	.41	.33	.26	.21
		0.20	.46	.37	.27	.19	.14
		0.25	.45	.34	.22	.14	.09
		0.30	.44	.30	.17	.09	.05
Old growth rates							
2B	81 cm	0.15	.45	.33	.26	.24	.23
		0.20	.44	.27	.19	.17	.16
		0.25	.42	.22	.14	.11	.10
		0.30	.40	.17	.09	.07	.06
3A	81 cm	0.15	.45	.40	.40	.40	.40
		0.20	.44	.37	.37	.37	.37
		0.25	.42	.33	.33	.33	.33
		0.30	.40	.29	.29	.29	.29
2B	0 cm	0.15	.46	.37	.32	.30	.30
		0.20	.44	.32	.26	.24	.23
		0.25	.42	.28	.20	.18	.17
		0.30	.41	.23	.15	.13	.12
3A	0 cm	0.15	.46	.43	.43	.43	.43
		0.20	.45	.40	.40	.40	.40
		0.25	.43	.37	.37	.37	.37
		0.30	.42	.34	.34	.34	.34

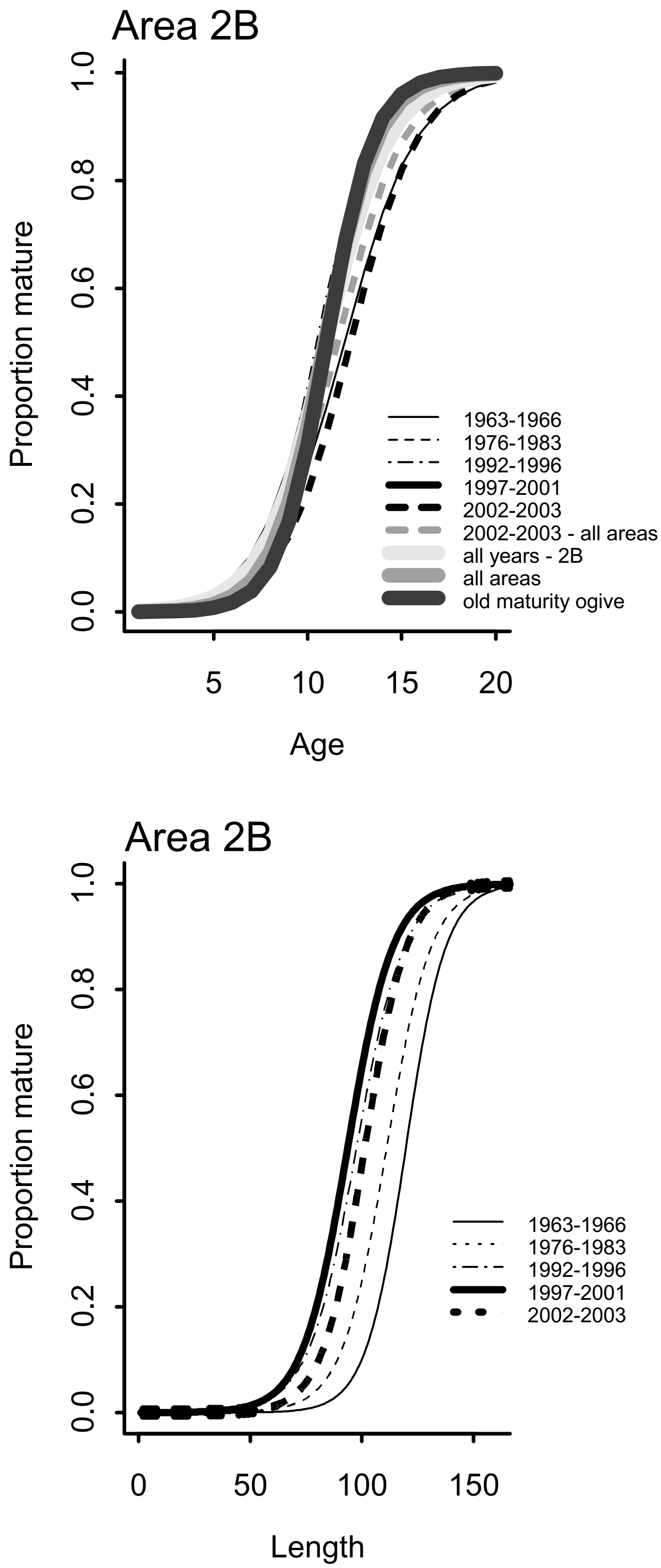

Figure 1. Maturity at age and maturity at length ogives for Pacific halibut in Areas 2B and 3A for a variety of time periods.

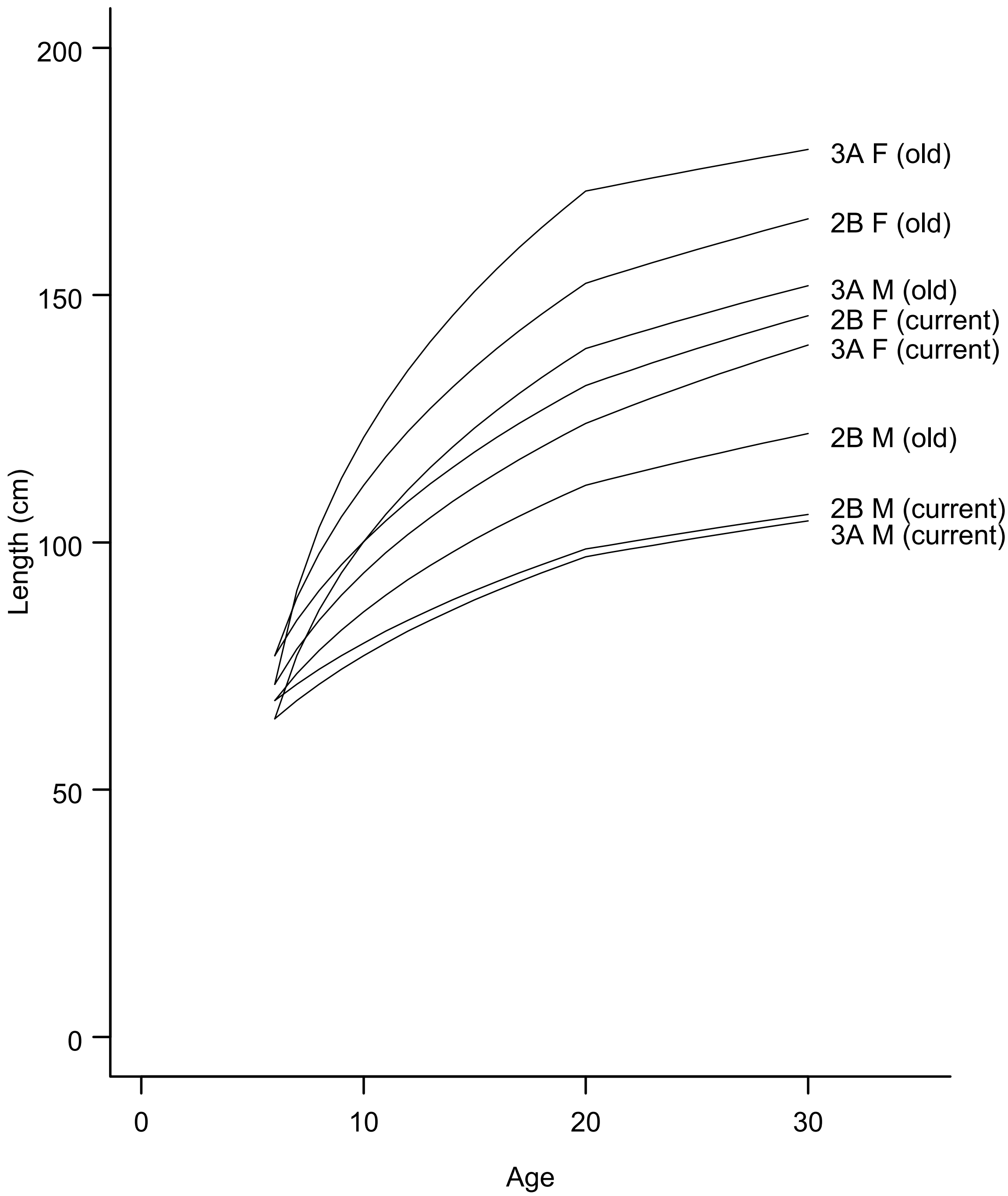

Figure 2. Mean length at age for female and male halibut at current growth rates and old growth rates.

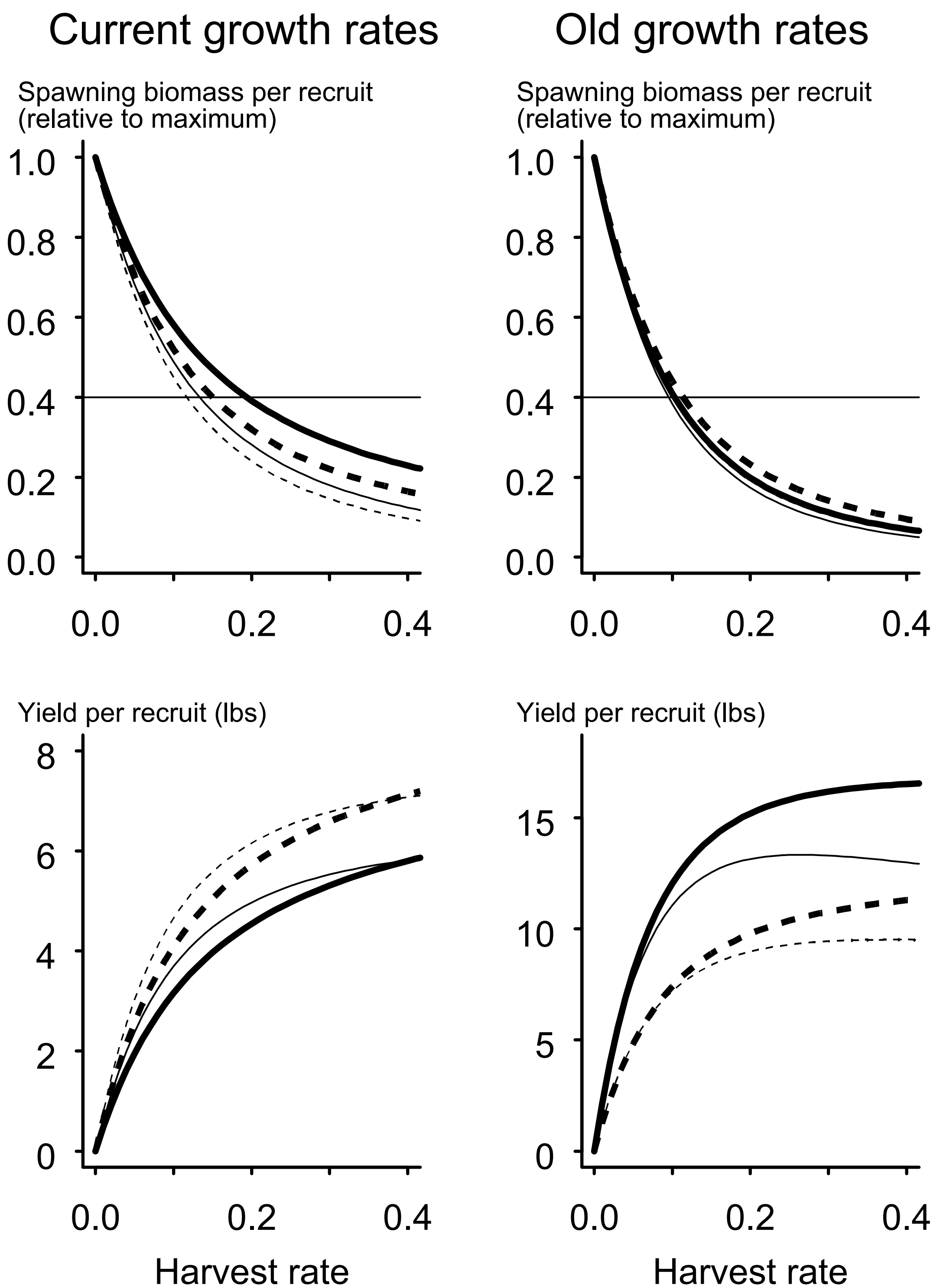

Figure 3. Female spawning biomass per recruit (top panels) and male+female yield per recruit (bottom panels) for Areas 2B and 3A under current growth rates and old growth rates. Solid lines represent 3A, dashed lines represent 2B. Thick lines show results with current 81 cm size limit, thin lines show results with no minimum size limit.

Investigation of the role of fishing in the Area 4C CPUE decline

Steven R. Hare

Abstract

CPUE is Area 4C has declined steadily for the past 20 years. Fishing effort has increased steadily over the same period. Removals – commercial catch and bycatch in the groundfish fisheries – peaked in 2000 and have declined since, despite the increase in fishing effort. It does not appear that Area 4C can sustain the level of removals seen the past several years. A reduction in removals, either commercial catch or bycatch, is recommended as a means of reducing effort.

Introduction

Over the past several years commercial CPUE has steadily dropped in IPHC Regulatory Area 4C (Table 1). The drop is consistent for both fixed hook and snap gear, amounting to a greater than 70% decline over the past 10 years. There has been considerable concern over the reasons for the decline; suggestions have ranged from local depletion, to an increase in water temperatures, to high levels of trawl bycatch and mortality. In this report, I examine the impacts of fishing on commercial CPUE, age, and size structure of the commercial catches. No IPHC surveys have been conducted in Area 4C since 1984. The data available for analysis consist of commercial catches, observer samples aboard groundfish vessels (trawl and longline), and sample data from the annual NMFS Bering Sea trawl survey.

The region currently defined as Area 4C was established in 1986 at the request of the North Pacific Fishery Management Council. The purpose of defining the region was the Council's desire to allocate fishing privileges specifically to coastal villages of the Pribilof Islands. Under several additional management measures, stimulation of the local fishery appeared to be moderately successful up until the end of the open access fishery and implementation of the Individual Fishing Quota system in 1995 (Sadorus and St-Pierre 1995).

Removals from Area 4C

The commercial setline fishery in Area 4C increased from a level of 700,000 pounds in the mid 1990s to a peak of 1.74 million pounds in 2000 (Table 2). The big increase in catches began in 1997 when the Area 4C catch limit was increased from 770,000 pounds to 2.03 million pounds over four years. Most of the increase in Area 4C catches after 1997 was taken by local vessels (Fig. 1). The catch limit was maintained at 2.03 million pounds from 1999 through 2003. The fishery has not taken the full quota since 1998 and catches dropped each year between 2000 and 2003, with the 2003 commercial catch of 886,000 pounds being the lowest since 1996. The catch limit was dropped to 1.72 million pounds in 2004. Initial estimates of the 2004 commercial catch shows a slight increase from 2003 (catch estimated at 955,000 pounds) but still well below the catch limit.

The other major source of removals from Area 4C is bycatch in the groundfish fisheries. Obtaining a precise estimate of the level of removals is not possible due to the mismatch between IPHC and NMFS Regulatory Areas. However, an estimate can be made by leveraging the NMFS observer data on location of halibut bycatch. A total halibut bycatch mortality estimate is determined annually for the combined areas 4CDE (Chen et al. 2004). If the assumption is made that observer coverage levels and bycatch mortality rates are roughly equal among the three areas, then the total mortality can be parsed among the three areas in proportion to observer location records of halibut bycatch. While these assumptions are not perfect they are likely to be within the ballpark as all three areas are generally fished by large vessels that require observer coverage and the high volume target fisheries (flatfish trawl and Pacific cod longline) are found in all three areas. The total mortality can be divided into a legal and sublegal component using the length frequency distribution of halibut in observer samples. These calculations show halibut mortality to have ranged from a low of 320,000 pounds in 1985 to a high of 950,000 pounds in 1992, and averaging 610,000 pounds over the period 1985-2003. The sub-legal component constitutes approximately 58% of the bycatch mortality. Combining the commercial catch and groundfish bycatch shows that total removals from Area 4C were around 1.5 million pounds from the mid 1980s to the mid 1990s, peaked at 2.3 million pounds in 2000, and declined to 1.5 million pounds in 2003

The commercial catch taken in Area 4C is highly concentrated around the two Pribilof Islands (Fig. 2). For commercial catches between 1993 and 2004 with known latitude/longitude locations, approximately 73% of the Area 4C catch was taken within 18 nautical miles of St. Paul Island and 25% within 18 nautical miles of St. George Island. Halibut catches in the commercial groundfish fisheries have a more dispersed pattern (Figure 3). The longline fisheries tend to operate south of both islands and are most concentrated in the southwest corner of Area 4C. The trawl fisheries generally overlap the longline fisheries though with a higher proportion of removals from the southeastern region of Area 4C. The two figures show the pattern of halibut bycatch, not bycatch mortality which is estimated by applying a discard mortality rate (DMR, by target groundfish fishery) to total estimated bycatch. Longline DMRs are generally much lower than trawl DMRs. Over the past 10 years, DMRs in the Bering Sea Pacific cod longline fisheries have ranged from 10% to 14%, while trawl DMRs are generally in the 60-80% range, depending on target fishery (Williams and Chen 2004). With the available data, we cannot apportion the mortality between the longline and trawl bycatch fisheries precisely. The longline fisheries have much higher levels of bycatch but much lower mortality compared to the trawl fisheries so it is likely that both fisheries account for somewhere between 40% and 60% of the total bycatch mortality.

Commercial fishing effort in Area 4C

Most of the commercial catch in Area 4C is taken by vessels using either fixed hook or snap gear. The exact amounts taken by the two gears are unknown because the number of effective skates cannot be determined for anywhere from 20% to 75% of the commercial catch over the past 20 years. The situation is improving: effort could be determined for 83% and 88% of the total commercial catch in years 2001 and 2002, respectively. In those two years, fixed hook catch was approximately twice the snap gear catch. Because of the irregular reporting of effort data, as well as the differing catch efficiencies of the two main gear types, it is not straightforward to determine an estimate of total annual fishing effort. To produce an index of annual fishing effort, I used the fixed gear records to produce a commercial catch CPUE time series (this is the same series used for the stock assessment). This time series of CPUE values was then divided into the annual commercial catch time series, thus producing a "fixed hook equivalent" effort time series (Table 2). Based on this index, commercial fishing effort has doubled over the past 10 years, and increased 800% between 1985 and 2003.

Size and age structure of catches in Area 4C

The age-frequency and length-frequency distributions of Area 4C catches are illustrated in Figures 4 and 5. The same distributions for Area 4A edge catches are included for comparison. From 1993 through 1995, Area 4C catches consisted of a relatively smooth distribution across ages 10 to 17. Beginning in 1996, the 1987 year class dominated catches with fish from that year class comprising half the catch (by number) for several consecutive years. Recruitment of the 1987 year class into the fishery coincided with the increase in quotas and catches beginning around 1997. By the year 2002, the 1987 year class was 15 years old and no longer appeared in dominating numbers in the catch. While Area 4C was very reliant upon the 1987 year class, the same was also true for Area 4A edge. In 1996 and 1997 and then more recently in 2003 and 2004, Area 4A edge catches had relatively higher catches of other age classes than did Area 4C. The length frequency distributions differ little between the two areas indicating a similarity in size at age and dependence on age classes. In addition to the size/age data from the commercial catch, there are also size distribution data from NMFS trawl surveys conducted at stations in Area 4C (Fig. 6). Very few of the collected samples have been aged however. If the assumption is made that the NMFS trawl data are likely illustrative of the size distribution of the groundfish trawl bycatch, the average weight of a trawl bycaught halibut has ranged from 5-10 pounds over the past decade. This contrasts with an average weight in the commercial catch of between 24 and 38 pounds in the commercial catch.

Discussion

Total removals from Area 4C have increased greatly over the past 10 years. CPUE has declined steadily since the beginning of commercial fishing. Catches increased because fishing effort increased, offsetting the decline in CPUE. Beginning in 2002, and now continuing for a third consecutive year, increases in effort are no longer sufficient to attain the higher catches of the past seven years. A plot of CPUE against effort shows a strongly negative relationship (Fig. 7). In fisheries parlance, this type of exploitation pattern is termed a "one way trip" in that there is a continuous pattern of increasing effort and decreasing CPUE.

A basic biomass dynamic model can be fit to CPUE and effort data and provide estimates of maximum sustained yield (MSY), effort levels to achieve MSY, and the maximum rate of exploitation. Such a model for Area 4C generates an MSY estimate of around 1.5 million pounds. This estimate, however, is highly unreliable. It has been widely demonstrated that "one way trip" exploitation histories generate poorly determined estimates (Hilborn and Walters 1992). Further, such a model assumes a closed population and IPHC tagging data (Sadorus and St. Pierre 1995) indicate that Area 4C is part of a much larger management unit – Area 4CDE.

While it appears that we cannot apply a statistical model to estimate productivity within Area 4C, we can critically examine the information provided above and make reasoned conclusions about the impact of fishing on the decline in Area 4C CPUE. Commercial fishing is highly concentrated around the two islands in Area 4C and the level of fishing effort has increased steadily for 15 years.

An additional level of mortality imposed on the population comes from the groundfish fisheries operating in Area 4C. The longline groundfish fishery likely captures halibut somewhat smaller than those taken by the commercial fleet due to the use of smaller hooks for Pacific cod fishing. The trawl fisheries certainly capture much smaller halibut, as evidenced by the size distribution of NMFS survey trawl data. Thus, while the commercial fishery targets the legal component of the population, the bycatch fisheries are impacting the sublegal populations thereby reducing future recruitment to the commercial fishery. Clearly, reducing bycatch mortality in the groundfish fishery would provide larger numbers of halibut to enter the commercial fishery. The extremely large 1987 year class has now essentially passed through the fishery, its numbers greatly reduced by both fishing and natural mortality. At this point it does not appear that there is a dominant year class following in its wake.

The conclusion that I draw from this information is that the level of removals seen the past several years in Area 4C is not sustainable. To fit a more reliable fisheries model – and without survey age data only biomass dynamic type models are feasible – a more variable exploitation history is required. There is little more that can be learned from further increasing effort in Area 4C. However, a great deal can potentially be learned from reducing effort and observing how the stock responds. In particular a reduction of effort and observation of the response in CPUE helps to determine the growth potential of the stock. Because of the low CPUE quotas will have to be reduced substantially, and held low for a period of time, in order to reduce effort.

Besides fishing, the other potential influence on CPUE is the environment. The environment can impact CPUE in a number of ways including altering distributions patterns and impacting recruitment. Investigation of the role of the environment is ongoing here at the IPHC and results will be reported as they emerge. It is too early to determine the results of those investigations, however if the findings were that the environment is responsible for reducing the number of halibut in Area 4C, the resulting management advice – reduce effort – would be the same.

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Table 1. Commercial CPUE (net pounds per efective skate) in IPHC Area 4C for the period 1985-2004. Values are shown for both Fixed gear and snap gear as well as an unweighted combination of the two. Values are not shown for years with fewer than 300 skates of data.

Year	Fixed	Snap	Combined
1985	594	---	663
1986	427	106	366
1987	389	---	395
1988	371	---	371
1989	331	---	337
1990	288	---	300
1991	223	---	223
1992	249	182	239
1993	257	187	246
1994	167	---	167
1995	283	---	283
1996	294	---	294
1997	270	168	233
1998	287	108	207
1999	270	118	189
2000	223	120	176
2001	203	135	176
2002	148	79	114
2003	105	53	86
2004	124	55	92

Table 2. Commercial quotas, catches and an index of effort for Area 4C from 1985 to 2004. Quota and catch values are in millions of net pounds. Effort values are a "fixed hook" equivalent; see text for details.

Year	Quota	Catch	Effort
1985	0.600	0.620	1044
1986	0.600	0.686	1607
1987	0.600	0.878	2256
1988	0.700	0.707	1905
1989	0.600	0.571	1724
1990	0.500	0.529	1838
1991	0.600	0.678	3045
1992	0.800	0.793	3184
1993	0.800	0.831	3239
1994	0.700	0.715	4271
1995	0.770	0.668	2356
1996	0.770	0.680	2313
1997	1.160	1.117	4141
1998	1.590	1.256	4369
1999	2.030	1.760	6516
2000	2.030	1.736	7790
2001	2.030	1.647	8102
2002	2.030	1.210	8170
2003	2.030	0.886	8419
2004	1.720	0.955	NA

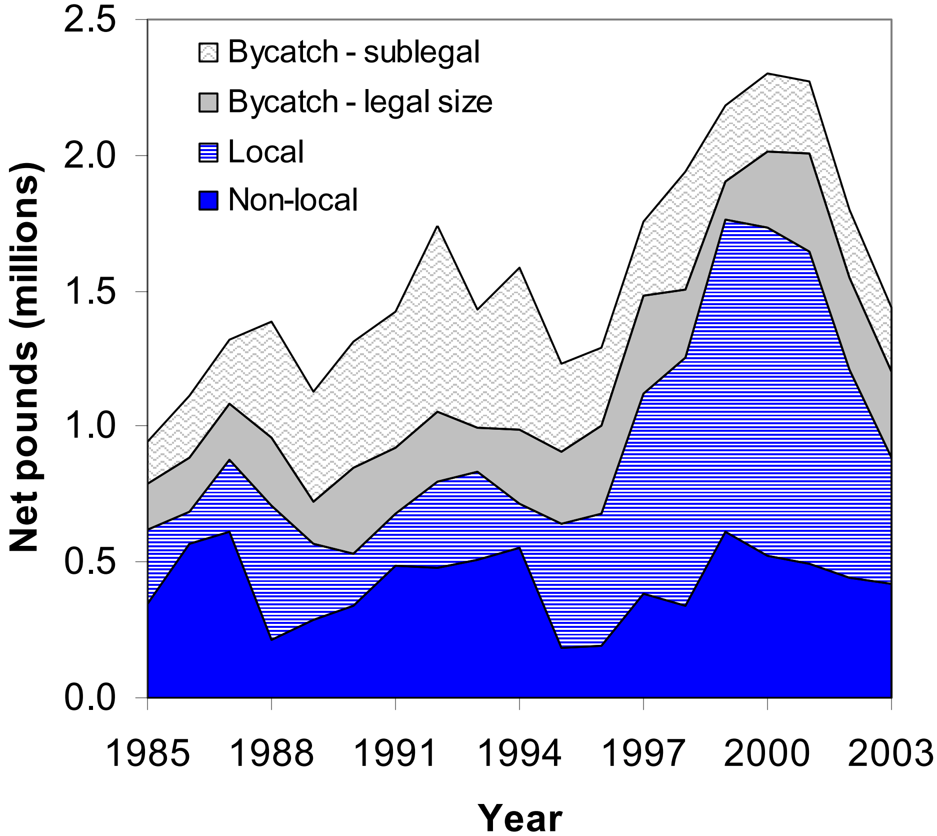

Figure 1. Halibut removals from Area 4C, 1985-2003. The bottom two values are for directed setline fishery where Local refers to the vessels homeported in the Pribilof Islands. The top two values are halibut bycatch mortality in groundfish trawl and longline fisheries.

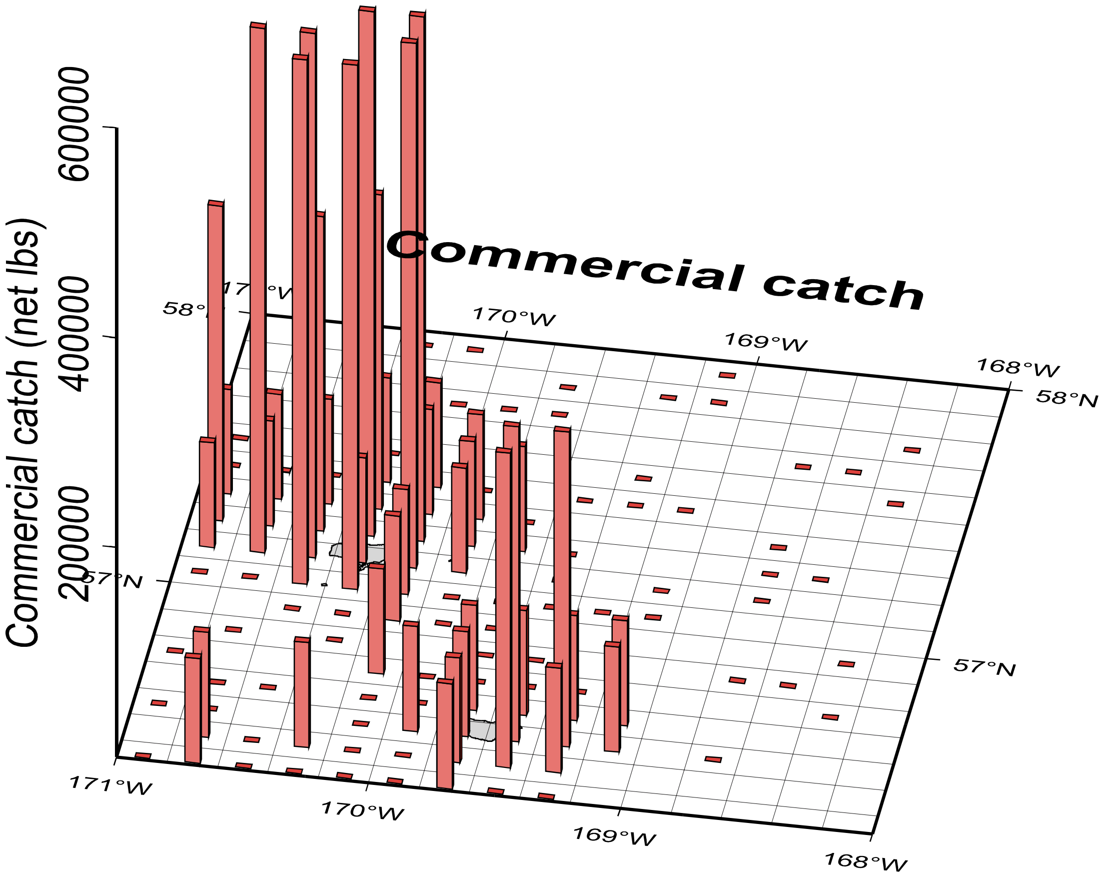

Figure 2. Location of commercial catches summed over the years 1993 to 2004 for logs which had latitude and longitude position. Catches within each grid cell have been binned as follows: less than 10,000 pounds, 10,000-200,000 pounds, 200,000-400,000 pounds, or greater than 400,000 pounds. These catches represent appx. 56% of the total Area 4C catch during this period.

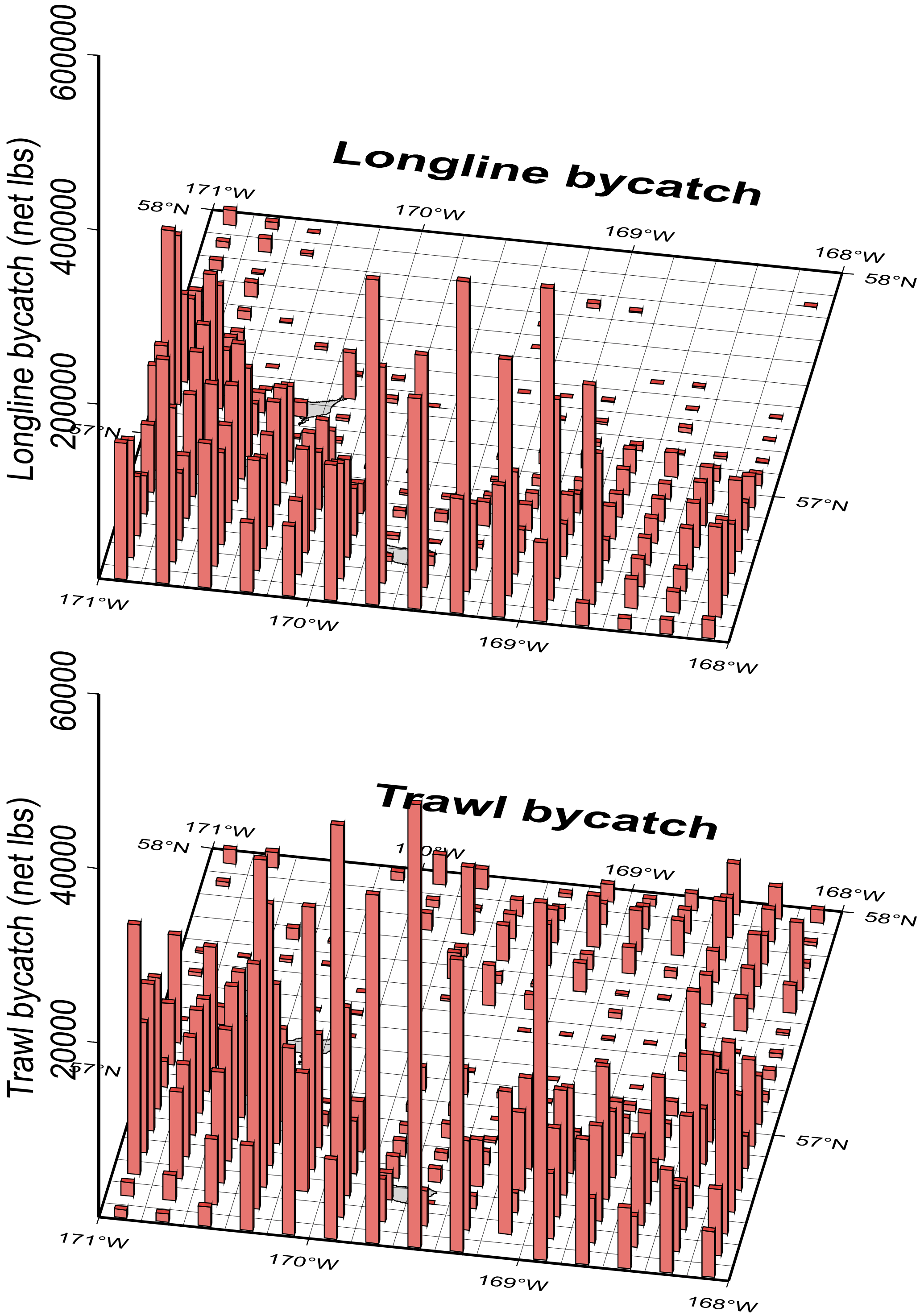

Figure 3. Location of halibut bycatch in longline (top) and trawl (bottom) groundfish fisheries summed over the years 1993-2004. These values are the amounts taken in longline sets or trawl hauls by vessels carrying observers; total bycatch is higher. Further, these values represent incidental catch, not mortality which is computed separately for each target groundfish fishery. Note that the ordinate scale for the longline bycatch is a factor of ten larger than for the trawl bycatch.

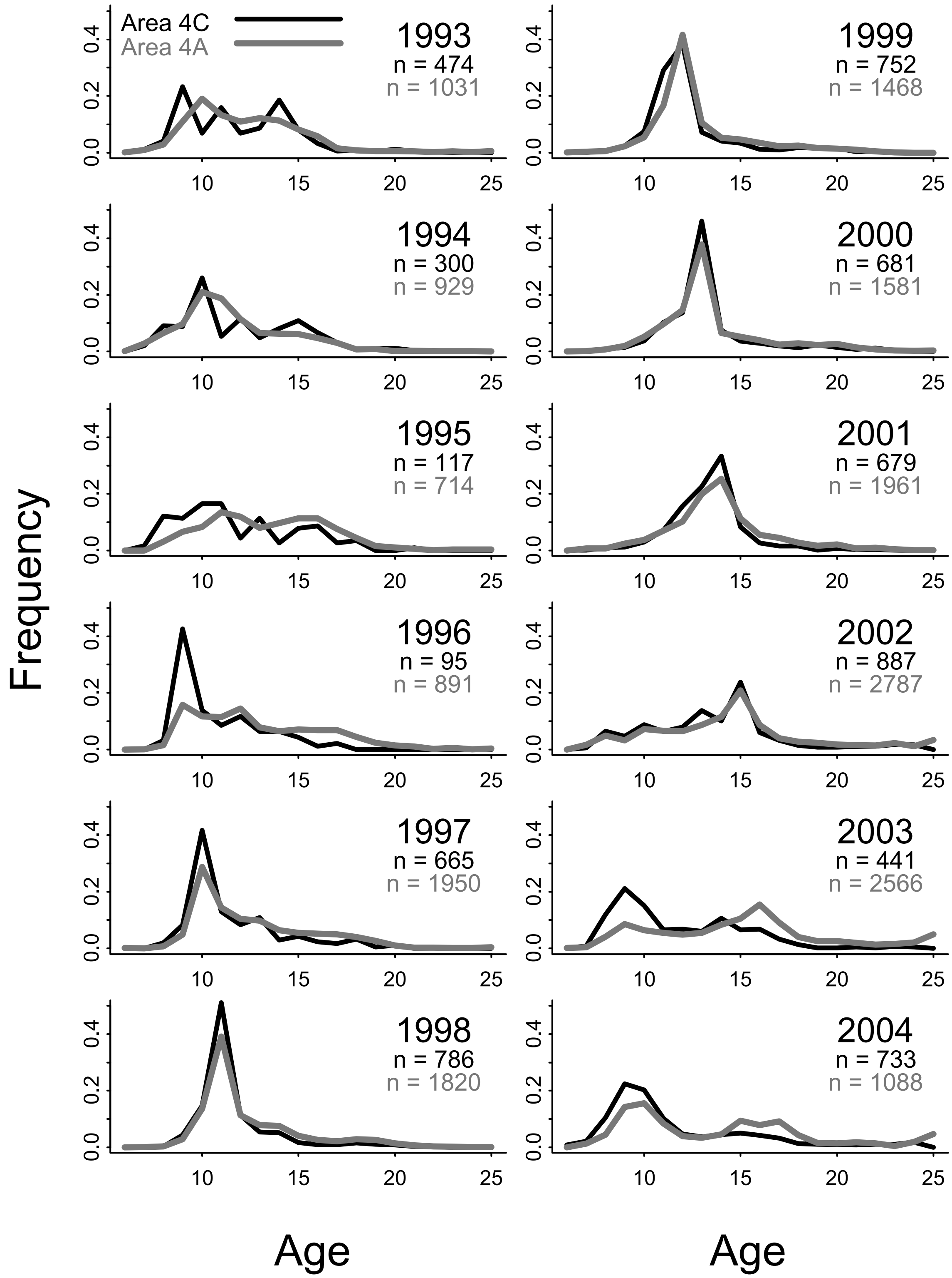

Figure 4. Age frequency distributions in the commercial catch for Areas 4C and 4A edge, 1993-2004.

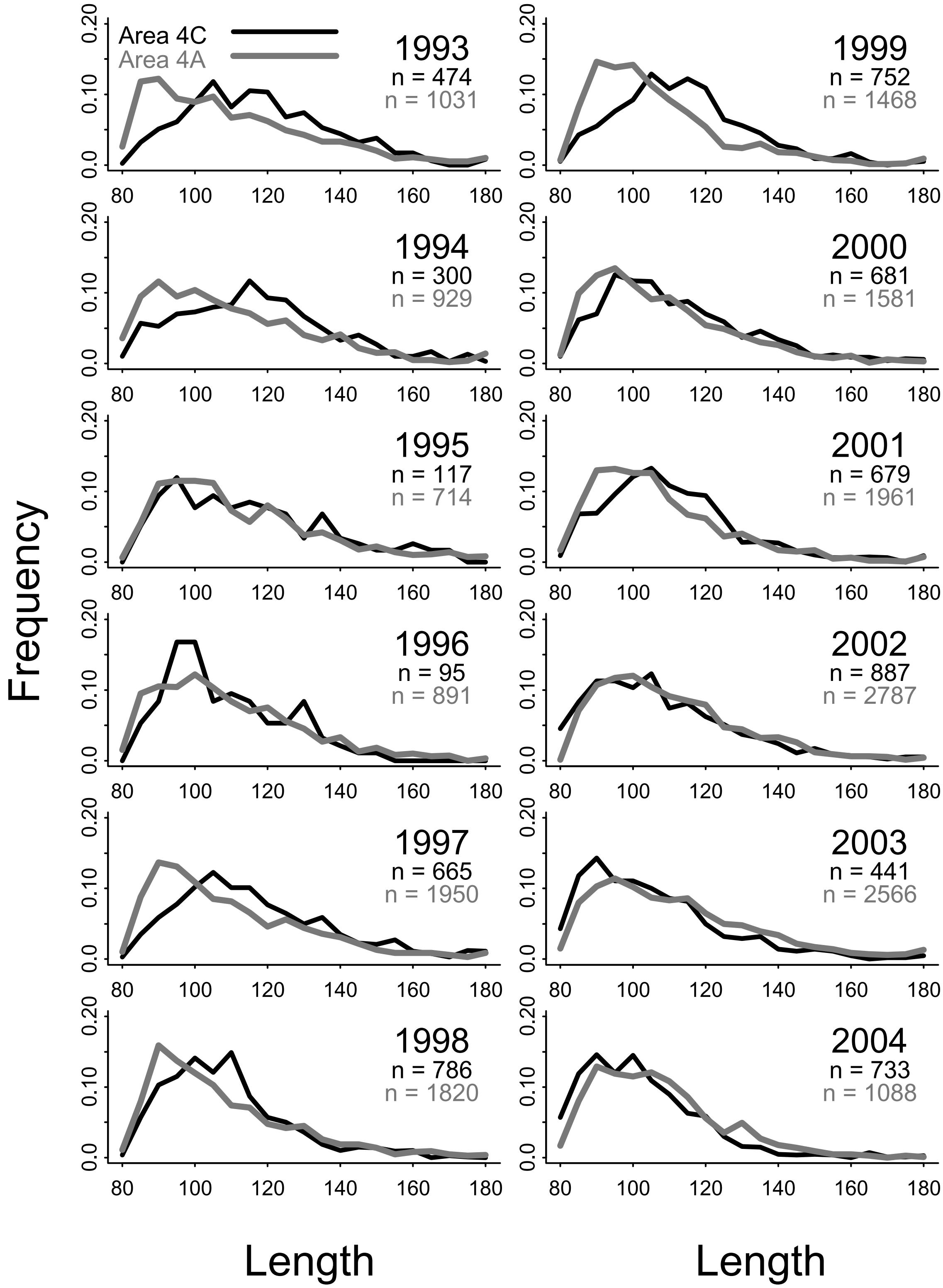

Figure 5. Length frequency distributions in the commercial catch for Areas 4C and 4A edge, 1993-2004.

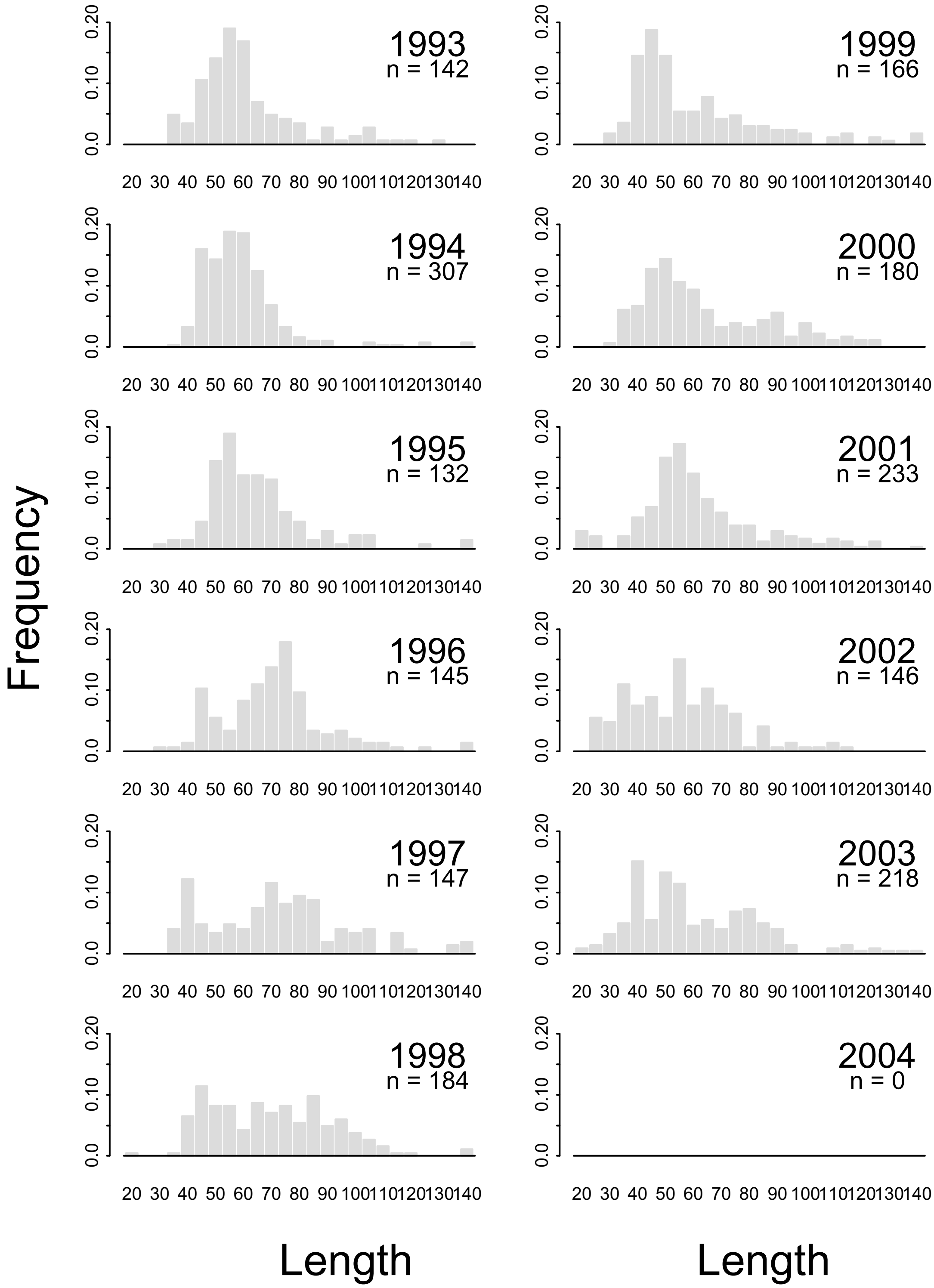

Figure 6. Length frequency distributions in NMFS groundfish trawl surveys in Area 4C, 1993-2004.

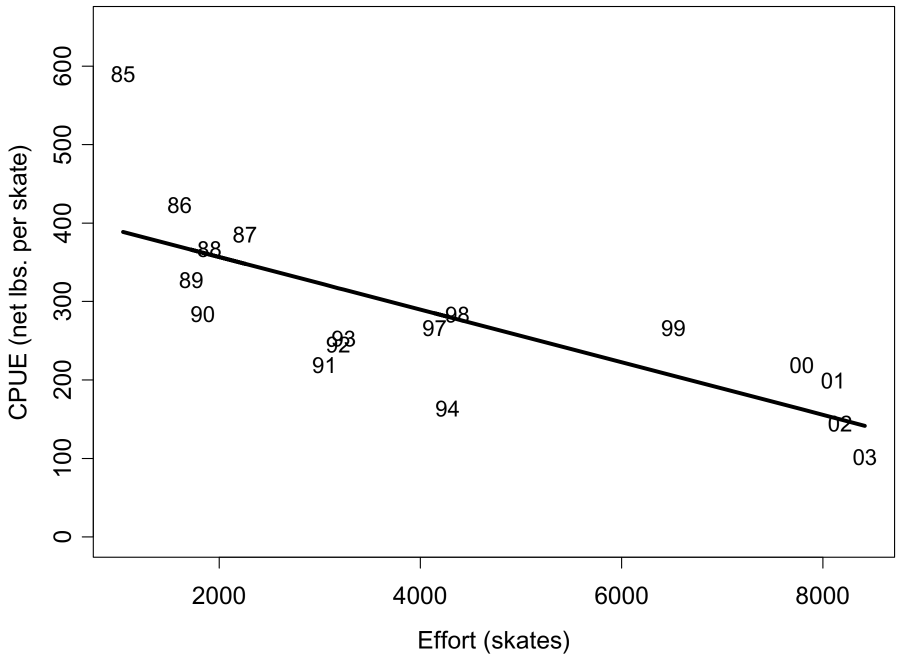

Figure 7. Plot of Area 4C commercial CPUE vs. effort. Two digit values indicate year (between 1985 and 2003) and linear regression fit is illustrated as a straight line.

Preliminary estimates based on 2004 PIT tag recoveries

William G. Clark and Din G. Chen

Abstract

Recoveries in 2004 of tagged fish released in 2003 indicate harvest rates similar to those estimated by the analytical stock assessment in Areas 2B and 2C, much lower in Area 3A, and almost nil in Areas 3B and 4. There was little migration out of Area 2B, but elsewhere 10-20% of legal-sized fish moved from the area of release to another area.

Background

As part of the 2003 coastwide setline survey, the Commission staff released some 44,000 halibut injected with passive integrated transponder (PIT) tags (Kaimmer and Geernaert 2004, Chen 2004). In 2003 and 2004 IPHC scan samplers in ports throughout the Commission area have scanned over a million landed halibut and have recovered several hundred tags.

The primary purpose of this large project is to estimate the harvest rate of fully selected halibut by the commercial fishery, but the mark recaptures also permit estimates of length-specific selectivity schedules and rates of migration between areas. This paper reports preliminary estimates based on recoveries in 2004. (Recoveries in 2003 were too few to be useful.)

Raw data

Of the almost 29,000 legal-sized fish released in 2003, a total of 383 were recovered from commercial landings in 2004 . The great majority of recoveries were made in the area of release, but there was some movement among areas (Table 1).

Recovery rates were expected to vary with length and they did, but not in the expected fashion. The staff has generally assumed that vulnerability to capture (selectivity) is an asymptotic function of length, meaning that it increases with length up to some point and then remains constant. But in Areas 2B and 2C recovery rates increased with length to a maximum at about 110 cm and then declined (Table 2, Fig. 1a). In Area 3A recovery rates increased with length over the entire length range (Fig. 1b). Most surprising was the pattern in Areas 3B and 4, where recovery rates were highest among small fish and very few large fish were recovered (Fig. 1c).

These unexpected patterns prompted a re-analysis of the many marking experiments carried out by the Commission in the 1960s through 1980s (Clark 2005). While not usable for estimating exploitation rates, these data can be used to estimate selectivity, and they in fact showed patterns in Area 2 and 3A quite similar to what we are seeing in the 2004 PIT tag recoveries, so in this analysis selectivity was not required to be asymptotic. There are very few historical marking data from Areas 3B and 4 but what few there are (from Area 3B) show a pattern similar to Area 3A; i.e. increasing selectivity with length rather than decreasing as in the 2004 recovery rates.

Recovery model, point estimates, and variances

The number and distribution of tag recoveries depends on a number of factors. If Rec_{ijl} is the number of recoveries of fish in length interval *l* released in area *i* and recovered in area *j*, then the expected number is:

$$E\left(Rec_{ijl}\right) = Rel_{il} \cdot Surv_{il} \cdot Mig_{ij} \cdot HR_j \cdot Sel_{jl} \cdot SR_j \cdot DR$$

where
Rel_{il} = the number of releases in area *i* of fish in length interval *l*
$Surv_{il}$ = survival rate from 2003 to 2004 of releases in area *i* in length interval *l*
Mig_{ij} = migration rate from area *i* to area *j*
HR_j = harvest rate in area *j* of fish with selectivity = 1
Sel_{jl} = selectivity in area *j* of fish in length interval *l*
SR_j = sampling rate in area *j* (proportion of landed fish that were scanned)
DR = detection rate (proportion of tagged fish that were detected when scanned)

Survivorship from 2003 to 2004 could be calculated by accounting for recaptures in 2003 and natural mortality. Likewise the sampling rate was known and a working value of 90% was used for the detection rate. Migration rates, harvest rates, and selectivities were estimated by numerically locating the fit of the recovery model to the observed recoveries that maximized the binomial likelihood of the observed recoveries. Because of very low recoveries, Area 4 was treated as a unit, and no estimates were attempted for Area 2A.

To fix the scaling of the selectivities and harvest rate in each area, selectivity was defined to be one for fish in the 100-109 cm length interval at release, so values greater than one could occur. (When selectivity is known or assumed to be asymptotic, it is set to one for the largest fish, and that is the maximum.) A single selectivity schedule was estimated for Area 2B and 2C because the empirical schedules were very similar; likewise for Areas 3B and 4.

Variances were estimated by bootstrapping the data, i.e. drawing many random samples of size 29,000 by sampling the release/recovery data with replacement and computing the estimates for each sample.

Table 3 shows the estimates and standard deviations of harvest rate by length interval ($HR_j \cdot Sel_{jl}$), and Table 4 the estimates and standard deviations of migration rates (Mig_{ij}).

Comparison with analytical estimates of harvest rates

The annual stock assessment also estimates harvest rates as a function of length, so these can be compared directly with the mark-recapture estimates (Table 5 and Fig. 2). The assessment estimates shown here were located with a version of the model that fits an empirical rather than the usual asymptotic selectivity schedule. The error bars on the assessment estimates were calculated using a coefficient of variation of 15%, consistent with recent performance.

In Areas 2B and 2C both the level of harvest rates and the pattern of variation with length are similar to the assessment. In Area 3A the pattern is similar but the mark-recapture level is only about half the assessment level, indicating about twice the abundance. In Areas 3B and 4 the harvest levels estimated from the tag recaptures is next to nil while the assessment shows harvest rates similar to the other areas.

References

Chen, D.G. 2004. Preliminary analysis of the IPHC PIT tagging experiment in 2003. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2003:377-390.

Clark, W.G. 2005. Estimates of length-specific commercial selectivity from historical marking experiments. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2004: this volume.

Forsberg, J.E. 2004. Portside sampling for recovered PIT tags in Pacific halibut. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2003:361-376.

Kaimmer, S.M., and Geernaert, T.O. 2004. 2003 PIT tagging: tagging equipment and protocol, and tag shedding studies. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2003:351-360.

Table 1. Releases of legal-sized fish in 2003 and recoveries in 2004, by area.

Area	Releases in 2003	Recoveries in 2004 by area								
		2A	2B	2C	3A	3B	4A	4B	4C	4D
2A	191	1	1	0	0	0	0	0	0	0
2B	1794	0	47	3	0	0	0	0	0	0
2C	2662	1	9	79	2	0	0	0	0	0
3A	11895	0	0	6	113	13	0	0	0	0
3B	9195	0	3	0	10	65	0	0	0	0
4A	2342	0	1	1	2	1	6	0	0	0
4B	916	0	0	1	0	0	0	1	0	0
4C	0	0	0	0	0	0	0	0	0	0
4D	867	0	0	0	0	0	0	0	0	0

Table 2. Releases of legal-sized fish in 2003 and recoveries in 2004, by area and length at release (e.g. "80" is 80-89 cm).

			Recoveries in 2004 by area							
Area	**Length**	**Releases**	**2A**	**2B**	**2C**	**3A**	**3B**	**4A**	**4B**	**4D**
2A	**80**	85	1	0	0	0	0	0	0	0
2A	**90**	42	0	0	0	0	0	0	0	0
2A	**100**	34	0	0	0	0	0	0	0	0
2A	**110**	13	0	1	0	0	0	0	0	0
2A	**120**	13	0	0	0	0	0	0	0	0
2A	**130**	4	0	0	0	0	0	0	0	0
2B	**80**	745	0	16	0	0	0	0	0	0
2B	**90**	371	0	11	0	0	0	0	0	0
2B	**100**	211	0	10	1	0	0	0	0	0
2B	**110**	178	0	4	1	0	0	0	0	0
2B	**120**	151	0	4	0	0	0	0	0	0
2B	**130**	138	0	2	1	0	0	0	0	0
2C	**80**	865	1	0	14	1	0	0	0	0
2C	**90**	538	0	3	17	0	0	0	0	0
2C	**100**	371	0	2	19	0	0	0	0	0
2C	**110**	302	0	2	11	0	0	0	0	0
2C	**120**	223	0	0	4	1	0	0	0	0
2C	**130**	363	0	2	14	0	0	0	0	0
3A	**80**	5219	0	0	1	10	6	0	0	0
3A	**90**	2938	0	0	2	29	4	0	0	0
3A	**100**	1583	0	0	3	26	2	0	0	0
3A	**110**	957	0	0	0	15	0	0	0	0
3A	**120**	550	0	0	0	14	0	0	0	0
3A	**130**	648	0	0	0	19	1	0	0	0
3B	**80**	3783	0	1	0	2	26	0	0	0
3B	**90**	2576	0	0	0	4	19	0	0	0
3B	**100**	1464	0	1	0	4	12	0	0	0
3B	**110**	744	0	1	0	0	5	0	0	0
3B	**120**	328	0	0	0	0	1	0	0	0
3B	**130**	300	0	0	0	0	2	0	0	0

Table 2. (cont'd.)

			Recoveries in 2004 by area							
Area	**Length**	**Releases**	**2A**	**2B**	**2C**	**3A**	**3B**	**4A**	**4B**	**4D**
4A	**80**	810	0	0	0	2	0	1	0	0
4A	**90**	610	0	0	0	0	1	5	0	0
4A	**100**	382	0	1	0	0	0	0	0	0
4A	**110**	237	0	0	1	0	0	0	0	0
4A	**120**	148	0	0	0	0	0	0	0	0
4A	**130**	155	0	0	0	0	0	0	0	0
4B	**80**	206	0	0	0	0	0	0	0	0
4B	**90**	270	0	0	0	0	0	0	0	0
4B	**100**	156	0	0	1	0	0	0	1	0
4B	**110**	100	0	0	0	0	0	0	0	0
4B	**120**	81	0	0	0	0	0	0	0	0
4B	**130**	103	0	0	0	0	0	0	0	0
4D	**80**	127	0	0	0	0	0	0	0	0
4D	**90**	191	0	0	0	0	0	0	0	0
4D	**100**	264	0	0	0	0	0	0	0	0
4D	**110**	149	0	0	0	0	0	0	0	0
4D	**120**	60	0	0	0	0	0	0	0	0
4D	**130**	76	0	0	0	0	0	0	0	0

Table 3. Estimates (± one standard deviation) of commercial harvest rates at length in 2004 based on PIT tag recoveries.

Length at release	**Mean length in 2004**	**Area 2B**	**Area 2C**	**Area 3A**	**Area 3B**	**Area 4**
80-89	88	0.06±0.01	0.08±0.01	0.01±0.00	0.02±0.00	0.01±0.00
90-99	98	0.11±0.02	0.14±0.03	0.04±0.01	0.03±0.01	0.01±0.00
100-109	108	0.20±0.04	0.25±0.04	0.06±0.01	0.03±0.01	0.01±0.00
110-119	118	0.14±0.03	0.17±0.04	0.05±0.01	0.02±0.01	0.00±0.00
120-129	128	0.07±0.03	0.09±0.03	0.09±0.02	0.01±0.01	0.00±0.00
130+	> 138	0.12±0.03	0.15±0.04	0.09±0.02	0.02±0.01	0.01±0.00

Table 4. Estimates (± one standard deviation) of migration rates.

	Probability of migrating from release area to:				
Release area	**Area 2B**	**Area 2C**	**Area 3A**	**Area 3B**	**Area 4**
Area 2B	0.95±0.03	0.05±0.03	0.00±0.00	0.00±0.00	0.00±0.00
Area 2C	0.11±0.04	0.84±0.05	0.05±0.04	0.00±0.00	0.00±0.00
Area 3A	0.00±0.00	0.02±0.01	0.84±0.04	0.14±0.04	0.00±0.00
Area 3B	0.01±0.01	0.00±0.00	0.10±0.03	0.89±0.03	0.00±0.00
Area 4	0.01±0.01	0.01±0.01	0.03±0.03	0.03±0.03	0.91±0.04

Table 5. Estimates of commercial harvest rate at length in 2004 from the 2004 stock assessment.

Mean length in 2004	**Area 2B**	**Area 2C**	**Area 3A**	**Area 3B**	**Area 4**
88	0.09	0.03	0.03	0.05	0.05
98	0.16	0.07	0.07	0.13	0.11
108	0.21	0.11	0.14	0.22	0.16
118	0.24	0.14	0.18	0.25	0.17
128	0.23	0.12	0.17	0.24	0.17
> 138	0.18	0.11	0.19	0.23	0.16

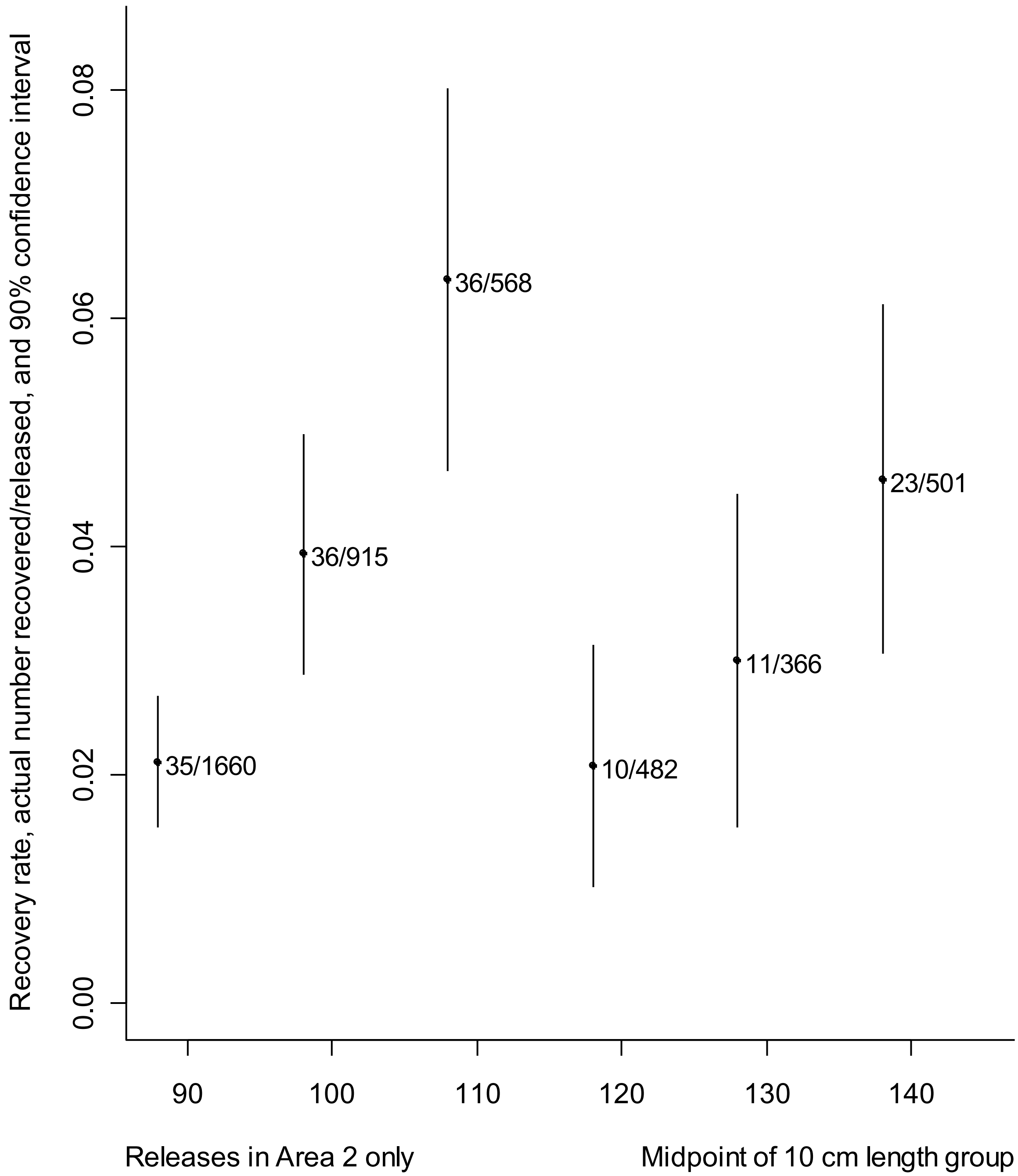

Figure 1a. Raw recovery rate as a function of length at release in Area 2 (2A, 2B, and 2C).

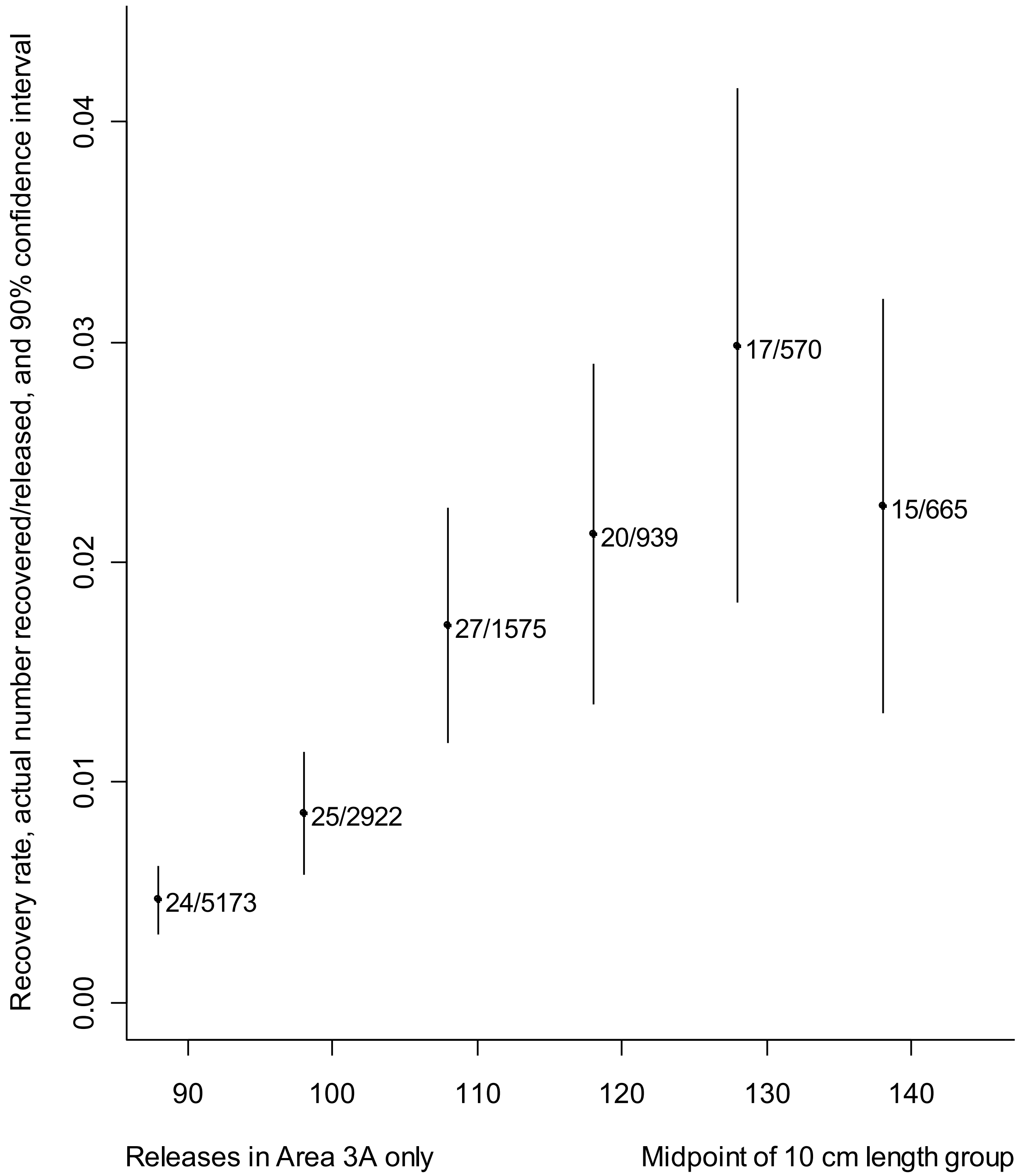

Figure 1b. Raw recovery rate as a function of length at release in Area 3A.

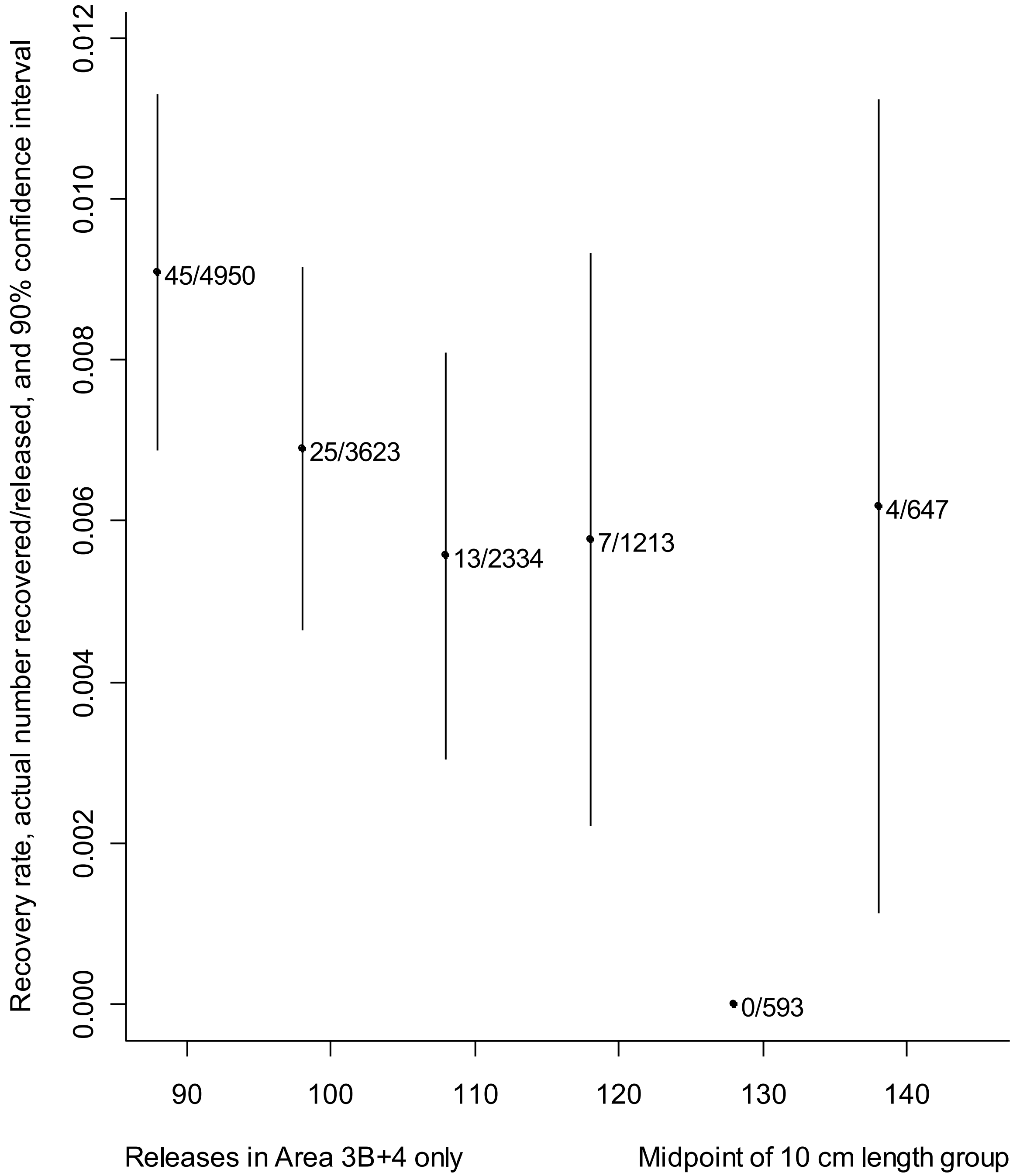

Figure 1c. Raw recovery rate as a function of length at release in Areas 3B and 4.

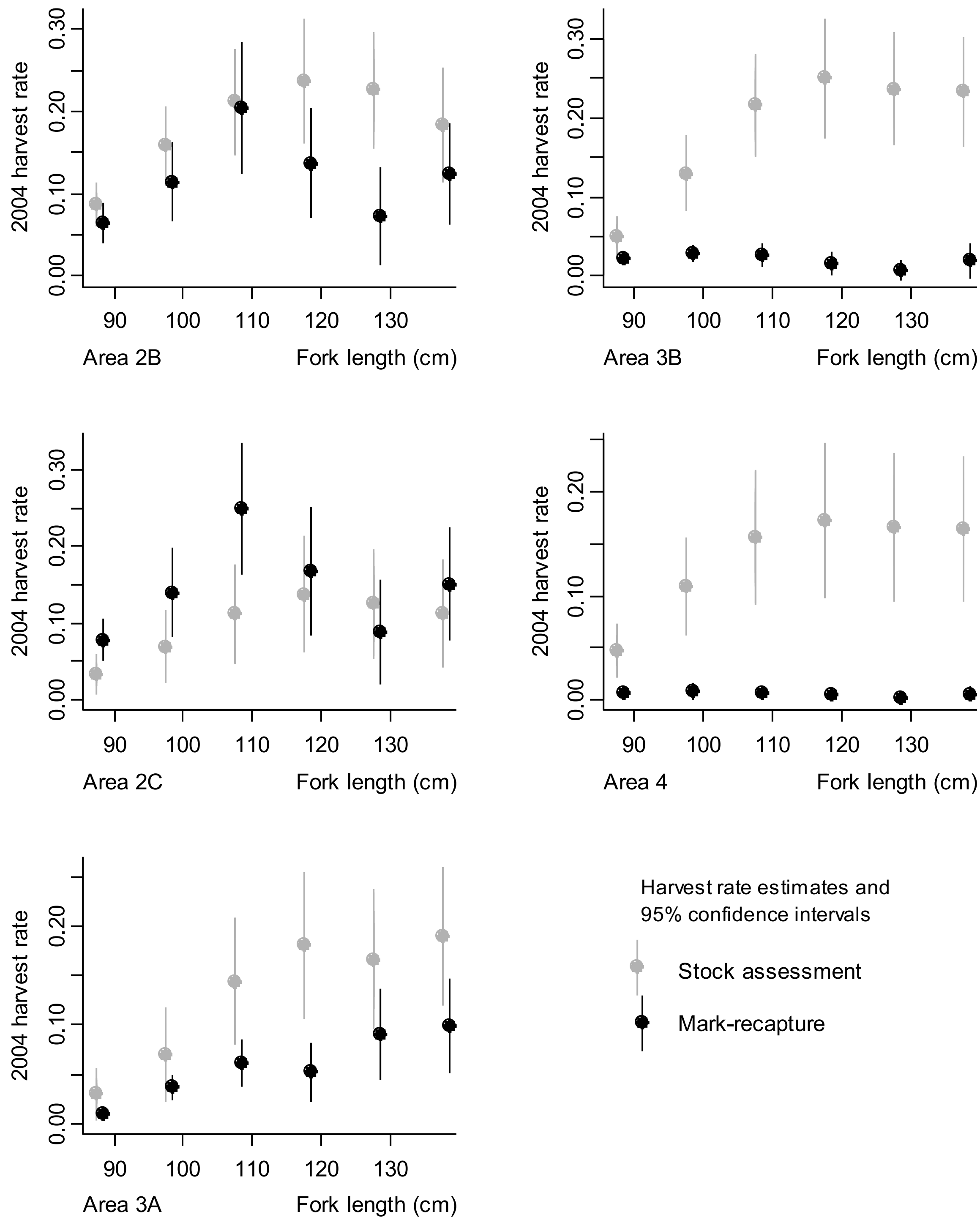

Figure 2. 2004 commercial harvest rates as estimated from the mark-recapture data and the analytical stock assessment.