

Analysis of PIT tag recoveries through 2005

William G. Clark

Abstract

Tag recoveries in 2005 resulted in very little change in estimates of fishing mortality and migration rates based on 2004 recoveries in last year's analysis. Except in Area 2C, the mark-recapture estimates of fishing mortality are dramatically lower than the estimates in this year's stock assessment.

Introduction

In 2003 the Commission staff marked with PIT tags and released all fish caught on three skates of gear at all setline survey stations coastwide, totaling almost 44,000 fish (Kaimmer and Geernaert 2004). The release was repeated in 2004 in Areas 2B and 3A, totaling another 23,000 fish (Williams et al. 2005). In 2003, 2004, and 2005 samplers in the ports scanned a substantial part of the landings to recover tags (Forsberg 2004).

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, rates of migration between areas, and in principle the rate of natural mortality. This paper reports preliminary estimates based on recoveries in 2004 and 2005.

Raw data

Recoveries in the year of release from both releases were too few to be meaningful. Table 1 shows recoveries from the 2003 release in 2004 (1a) and 2005 (1b), and from the 2004 release in 2005 (1c), counting only fish 70 cm and larger when released. Because of the 81 cm minimum size limit in the commercial fishery, fish smaller than 70 cm at release had almost no chance of being recovered. (One fish tagged at 69 cm was recovered.)

Except for Area 2B, recapture rate patterns are quite similar for both release groups and both recovery years (Fig. 1). In Area 2B, the pattern of recapture rates of fish 90-130 cm length range in 2005 is the same for both release groups but much lower than the recapture rates observed in 2004, suggesting a difference in commercial selectivity between 2004 and 2005.

One would expect the recapture rates of 2003 releases to be lower in 2005 than in 2004 because of mortality during 2004. This is mostly the case in Areas 2B and 2C. In Area 3A the 2005 recapture rates of 2003 releases are about the same as the 2004 rates, and in Area 3B they are mostly higher, suggesting that some recaptured tags were not detected and recovered when scanned in 2004. This was suspected at the end of 2004 (Clark 2006) and numerous careful seeding experiments were carried out in 2005 to check detection rates (Forsberg 2006), so we are reasonably confident that close to 100% of recaptured tags were detected in 2005.

In both 2004 and 2005, there is a strong east-to-west trend in recapture rates. In Areas 2B and 2C, the recapture rate of fish around 100 cm was about 10%, dropping by half to about 5% in Area 3A, again by half to 2-3% in Area 3B, then down to under 1% in Area 4A and to practically nil in Area 4B. In Areas 3 and 4 these rates are dramatically lower than the commercial fishing mortality rates at length estimated in the stock assessment (Clark and Hare 2006).

Except for the significant number of Area 3A tags recovered in Area 3B, recoveries outside the release area mostly occurred to the east of the release area, consistent with the notion of an eastward migration from nursery areas to adult summer feeding areas. But there is no indication of higher migration rates among smaller fish. Out-of-area recoveries amounted to 10-20% of total recoveries in all length groups, with no discernible differences among areas.

Length interval at release (cm)	Total recoveries	Out-of-area recoveries	Proportion out-of-area
70-79	76	12	0.16
80-89	324	54	0.17
90-99	321	45	0.14
100-109	222	37	0.17
110-119	135	22	0.16
120-129	88	7	0.08
130+	106	14	0.13

Recovery model

The raw recapture rates are somewhat lower than the true commercial harvest rates because they do not account for fishing and natural mortality in the time before recovery, or for the effects of growth and migration. To properly account for those things, and to estimate the rates of migration and natural mortality, we have to formulate and fit a recovery model.

As in the stock assessment, we use the Baranov catch equation to predict recoveries. This facilitates comparisons of the two kinds of estimates, and it allows for a straightforward treatment of tag recaptures in unsampled fisheries (sport catch, bycatch etc.). Different treatments are required for legal-sized and sublegal fish.

Legal-sized fish

The recovery model is:

$$E(Rec_{yik.zjl}) = N_{yik.zjl} \cdot HR_{zjl} \cdot SR_{zj} \cdot DR_{zj}$$

where the notation $yik.zjl$ refers to tagged fish released in year y in area i at length k and recovered in year z in area j at length l , which is equal to k plus $(z - y)$ growth increments (3 cm/yr). $N_{yik.zjl}$ is the number of tagged fish of release group Rel_{yik} that are present at the beginning of year z in area j . The other factors are the commercial harvest rate, sampling rate, and detection rate. For the calculations fish are placed into release groups by 10 cm interval: 70-79, 80-89, ..., 130+. Release groups grow by 3 cm per year.

The commercial harvest rate is calculated with the Baranov catch equation:

$$HR_{zjl} = \frac{F_{zjl}}{Z_{zjl}} \cdot (1 - \exp(-Z_{zjl} \cdot \Delta t))$$

where Δt is the duration of the season (0.5 for the year of release and 1.0 thereafter). Commercial selectivity is represented as a piecewise linear function of the current mean length of a release group. Selectivity is fixed at 0.01 at 70 cm, 1.0 at 100 cm, and estimated at 80, 90, 110, 120, and 130 cm. Selectivity at intervening lengths is interpolated. The instantaneous commercial fishing mortality rate at length F_{zjl} is the product of the computed length-specific selectivity Sel_{jl} and a reference rate F_{zj} that applies where selectivity is one (100 cm):

$$F_{zjl} = Sel_{jl} \cdot F_{zj}$$

The total instantaneous mortality rate at length Z_{zjl} is the sum of commercial fishing mortality F_{zjl} , all other fishing mortality G_{zjl} , natural mortality M , and tag failure rate X :

$$Z_{zjl} = F_{zjl} + G_{zjl} + M + X$$

We can compute the ratio $\left(\frac{G_{zjl}}{F_{zjl}} \right)$ from the ratio of (sport catch + bycatch + personal use catch in number) at length l to commercial catch in number at length l (Table 2). If this ratio is g_{zjl} , the expression for total mortality is:

$$Z_{zjl} = F_{zjl} \cdot (1 + g_{zjl}) + M + X$$

The number of surviving tags at the end of the year is then $N_{yik.zjl} \cdot \exp(-Z_{zjl} \cdot \Delta t)$. Migration occurs instantaneously on January 1, and consists of post-multiplying the matrix containing the estimated distribution of surviving marked fish (by area of release, length at release, and area where presently located) by a matrix of migration rates (by area of origin and destination area.)

Sublegal fish

Some tagged sublegals are taken in non-commercial fisheries but we cannot directly estimate how many because we do not sample those fisheries and there are no commercial landings of sublegal fish. For these fish we have to use the assessment estimates of fishing mortality at length. Fortunately the estimates are all very small, and if the assessment is in fact underestimating stock abundance in western areas the true values are even smaller.

The table below shows the estimates from the 2004 assessment. Nearly all the sublegals tagged were larger than 60 cm, and most were larger than 70 cm. In the 60-80 cm length range bycatch mortality does not vary consistently with length in any area but hook-and-line mortality does. The last column shows a suggested working value for total non-commercial fishing mortality $G_{sublegal}$, arrived at by adding the bycatch mortality plus a hook-and-line rate from the upper end of the range and rounding.

Sport + personal use mortality					
Area	60 cm	70 cm	80 cm	Bycatch mortality	Working value
2A	---	---	---	---	0.03
2B	0	0.001	0.006	0.002	0.01
2C	0	0.002	0.009	0.004	0.01
3A	0	0.001	0.005	0.010	0.01
3B	0	0.000	0.001	0.008	0.01
4A	0	0.000	0.001	0.031	0.03
4B	0	0	0	0.020	0.02
4CDE	---	---	---	---	0.03

We do not have analytical estimates for Area 2A. Relative stock sizes and catch levels imply that sublegal sport plus personal use mortality in Area 2A is about three times the Area 2B value and sublegal bycatch mortality about ten times. A reasonable working value for Area 2A is therefore 0.03. In Area 4CDE we can use the Area 4A value.

There is also some mortality of discarded sublegals in the commercial fishery. Survey selectivity is about 0.15 for sublegal fish near 81 cm, and about 15% of sublegal discards die, so $F_{sublegal} \approx 0.15 \cdot 0.15 \cdot F_{zj} \approx 0.02 \cdot F_{zj}$, which is negligible.

With these working values, the mortality of tagged sublegals is $Z_{sublegal} = G_{sublegal} + M + X$.

Treatment of recoveries in the year of release

Recoveries in the year of release have been few and spotty. Because of that, the fishing mortality rates at length in the year of release (commercial and non-commercial) are simply computed from the raw recoveries and applied to the release numbers to estimate the number surviving to the beginning of the next year. The removals in the year of release are therefore fully accounted but have no influence on the estimates of selectivity, fishing mortality, natural mortality, and migration.

Model fits and estimates

At present we have two full years (2004 and 2005) of recoveries from the coastwide 2003 releases and one full year (2005) from the 2004 releases in Areas 2B and 3A. Recoveries in Areas 2A, 4B, and 4CDE were too few to provide any meaningful estimates, so all releases and recoveries in those areas were left out of the modeling work.

The recovery model can be parameterized to estimate a different selectivity schedule and reference fishing mortality rate in each year in each area, and a single migration matrix and natural mortality rate. When fitted to deterministic (artificially generated) recovery data, the model matches the recoveries and estimates all the parameters exactly. When the model is fitted to the actual recovery data, the predictions do not match the recoveries exactly because there are not enough selectivity and migration parameters to do so. Still the predictions are good and tests with randomly chosen initial parameter vectors (shotgun tests) show that the parameter estimates are unique.

Variances were estimated by bootstrapping the data. Initial trials showed that the natural mortality rate is very poorly determined. It can be estimated by fitting the model to the entire

data set, or just to the data from Area 2B or 3A where two releases were done. The point estimates and standard deviations were:

Data set	Point estimate	Bootstrap standard deviation
All areas	0.12	0.09
Area 2B only	0.13	0.21
Area 3A only	0.15	0.10

All of the estimates are similar and all are close to the working value of 0.15 used in the assessment. But in view of the large variances, the conclusion for the time being is that the data are not informative as regards the natural mortality rate. In all of the fits reported below the natural mortality rate was fixed at 0.15.

Fits of the full model showed that except for a couple of length groups in Areas 2B and 2C, estimates of fishing mortality at length were not significantly different in 2004 and 2005. This was expected, because fishing effort in 2005 was almost the same as in 2004 in every area except Area 2C where it was about 15% higher. Estimated fishing mortality in Area 2C in 2005 was about 30% higher than in 2004 but the difference was not significant. In Areas 3A and 3B the 2005 estimates were 40-50% higher than the 2004 estimates. While the differences were not significant, they may indicate lower detection rates in 2004 than in 2005. But since all of the estimates of fishing mortality at a length of 100 cm in Areas 3A and 3B fall between 0.03 and 0.06, the effect of any incomplete detection in 2004 on the model calculations and estimates is very small in absolute terms.

For the reported fits, the model was parameterized to estimate a single selectivity schedule and fishing mortality rate for each area in both recovery years. To the extent that there were differences between years, the reported estimates are average values. The estimates of fishing mortality rates (Table 3) and migration rates (Table 4) are quite similar to those reported last year (Clark and Chen 2005).

Comparison with assessment estimates

Because of the lower recapture rates of larger fish in Area 2B in 2004, the mark-recapture estimates of fishing mortality are now substantially lower than the assessment estimates for fish larger than 100 cm (Fig. 2), whereas in the 2004 analysis they were about the same. In Area 2C the two kinds of estimates are still in approximate agreement. In Area 3A the mark-recapture estimates are still much lower than the assessment estimates, but the pattern now looks quite similar to the one in Area 2B. In Areas 3B and 4 the two sets of estimates still differ by an order of magnitude.

The corresponding estimates of exploitable biomass are shown below, along with the swept-area estimates of total biomass at length from the NMFS trawl survey converted to exploitable biomass. In Areas 2B and 2C the mark-recapture and assessment estimates are comparable. There is no trawl survey value for Area 2B, and the trawl survey value for Area 2C is certainly much too low because of the extent of very rough bottom in that area. In Areas 3A, 3B, and 4A, the assessment and trawl survey values are comparable both in magnitude and in the relative distribution of biomass among areas, while the absolute mark-recapture estimates are much higher and show a much a higher relative abundance in Areas 3B and 4A. This pattern is at odds with all other data on the relative distribution of halibut biomass among areas (Fig.3).

Area	Mark-recapture	Assessment	Trawl survey
2B	80	61	---
2C	45	61	6
3A	292	143	92
3B	364	45	53
4A	372	19	13
3A-3B-4A total	1028	207	158

Discussion

The 2005 recoveries show much the same pattern as the 2004 recoveries, and therefore continue to show a dramatic difference in estimated abundance between the mark-recapture experiment and the analytical stock assessment. A possible reason for the difference is that the stock assessment assumes that the stock in each regulatory area is a closed population, or at least that net migration is negligible. The mark recoveries have shown higher than expected migration rates among fish 65 cm and larger at release, and no apparent relationship between size and migration rates. If net migration (out or in) is significant in some areas, that would affect the stock assessment estimates because net migration is effectively included in the estimate of fishing mortality.

The annual rate of emigration from each regulatory area is just the sum of the emigration rates to other areas that are estimated and reported above. The rate of immigration to a given area depends on both the emigration rates from other areas and the abundance of fish in those areas. It is not an output of the model fit but it is available from the model prediction of the distribution in 2004 of the fish tagged and released in 2003. The estimated rates of emigration and calculated rates of immigration for each area are:

Area	Emigration rate	Immigration rate	Net migration
2B	0.03	0.23	+0.20
2C	0.12	0.10	-0.02
3A	0.10	0.10	0
3B	0.11	0.10	+0.01
4A	0.11	0	-0.11

These estimates show a large immigration into Area 2B, of which about half is due to a significant migration rate from the comparably-sized Area 2C stock and the other half due to very low rates of migration from the much larger Area 3A and 3B stocks. Of the 22 tags released in Area 2C and recovered in Area 2B, nine had been released in statistical areas on the regulatory area boundary and the remainder farther north. For the purpose of this analysis, the disputed part of Dixon Entrance was treated as being in Area 2B.

Area 4A shows a substantial net emigration rate. But in Areas 2C, 3A, and 3B estimated net migration is in fact negligible, so it does not appear that a proper treatment of migration in the stock assessment would resolve the disagreement with the mark-recapture estimates.

References

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Table 1a. Recoveries in 2004 of fish 70 cm and larger released coastwide in 2003.

Area of release	Releases in 2003	Recoveries by area in 2004									Total
		2A	2B	2C	3A	3B	4A	4B	4C	4D	
2A	278	1	1	0	0	0	0	0	0	0	2
2B	2518	0	56	3	0	0	0	0	0	0	59
2C	3430	1	10	81	2	0	0	0	0	0	94
3A	15462	0	1	6	116	14	0	0	0	0	137
3B	13485	0	3	0	10	65	0	0	0	0	78
4A	3075	0	1	1	2	1	6	0	0	0	11
4B	1070	0	0	1	0	0	0	1	0	0	2
4C	0	0	0	0	0	0	0	0	0	0	0
4D	943	0	0	0	0	0	0	0	0	0	0
Total	40261	2	72	92	130	80	6	1	0	0	383

Table 1b. Recoveries in 2005 of fish 70 cm and larger released coastwide in 2003.

Area of release	Releases in 2003	Recoveries by area in 2005									Total
		2A	2B	2C	3A	3B	4A	4B	4C	4D	
2A	278	0	1	0	0	0	0	0	0	0	1
2B	2518	1	39	0	0	0	0	0	0	0	40
2C	3430	0	8	75	1	0	0	0	0	0	84
3A	15462	0	2	2	160	20	0	0	0	0	184
3B	13485	0	3	7	28	95	0	0	0	0	133
4A	3075	0	2	2	3	2	6	0	0	0	15
4B	1070	0	0	0	1	0	0	0	0	0	1
4C	0	0	0	0	0	0	0	0	0	0	0
4D	943	0	1	0	1	0	0	0	0	2	4
Total	40261	1	56	86	194	117	6	0	0	2	462

Table 1c. Recoveries in 2005 of fish 70 cm and larger released in Areas 2B and 3A in 2004.

Area of release	Releases in 2004	Recoveries by area in 2005									Total
		2A	2B	2C	3A	3B	4A	4B	4C	4D	
2B	2703	2	46	3	0	0	0	0	0	0	51
3A	19214	0	4	10	222	9	0	0	0	0	245
Total	21917	2	50	13	222	9	0	0	0	0	296

Table 2. Sport + personal use catch + bycatch, as a fraction of commercial catch at length, by 10 cm length interval (2004 data).

10 cm interval	2A	2B	2C	3A	3B	4A	4B	4C	4D
80-89	1.13	0.11	1.15	0.87	0.10	1.01	0.18	2.27	2.27
90-99	0.70	0.08	0.37	0.31	0.02	0.23	0.06	0.69	0.69
100-109	0.93	0.09	0.22	0.22	0.02	0.11	0.05	0.48	0.48
110-119	0.89	0.10	0.18	0.18	0.01	0.08	0.04	0.44	0.44
120-129	0.93	0.15	0.19	0.17	0.02	0.06	0.17	0.49	0.49
130+	0.93	0.15	0.19	0.17	0.02	0.06	0.17	0.49	0.49

Table 3. Estimates (\pm one standard deviation) of average instantaneous fishing mortality rates at length in 2004 and 2005. The estimate is of fishing mortality at the length shown, not for a 10 cm length interval.

Length	Area 2B	Area 2C	Area 3A	Area 3B	Area 4A
80 cm	0.06 \pm 0.01	0.02 \pm 0.01	0.00 \pm 0.00	0.01 \pm 0.00	0.00 \pm 0.00
90 cm	0.09 \pm 0.02	0.09 \pm 0.02	0.03 \pm 0.00	0.03 \pm 0.00	0.01 \pm 0.01
100 cm	0.12 \pm 0.03	0.18 \pm 0.04	0.05 \pm 0.01	0.03 \pm 0.01	0.01 \pm 0.01
110 cm	0.10 \pm 0.04	0.28 \pm 0.06	0.06 \pm 0.01	0.03 \pm 0.01	0.01 \pm 0.01
120 cm	0.07 \pm 0.04	0.18 \pm 0.05	0.07 \pm 0.01	0.01 \pm 0.01	0.00 \pm 0.00
130 cm	0.08 \pm 0.02	0.16 \pm 0.03	0.08 \pm 0.01	0.01 \pm 0.01	0.00 \pm 0.00

Table 4. Estimates (\pm one standard deviation) of annual migration rates between areas.

Release area	Probability of migrating from release area to:				
	Area 2B	Area 2C	Area 3A	Area 3B	Area 4A
Area 2B	0.97 \pm 0.01	0.03 \pm 0.01	0.00 \pm 0.00	0.00 \pm 0.00	0.00 \pm 0.00
Area 2C	0.10 \pm 0.03	0.88 \pm 0.03	0.02 \pm 0.01	0.00 \pm 0.00	0.00 \pm 0.00
Area 3A	0.01 \pm 0.00	0.01 \pm 0.00	0.90 \pm 0.02	0.09 \pm 0.02	0.00 \pm 0.00
Area 3B	0.01 \pm 0.00	0.01 \pm 0.00	0.09 \pm 0.02	0.89 \pm 0.02	0.00 \pm 0.00
Area 4A	0.02 \pm 0.01	0.01 \pm 0.01	0.05 \pm 0.02	0.03 \pm 0.02	0.89 \pm 0.04

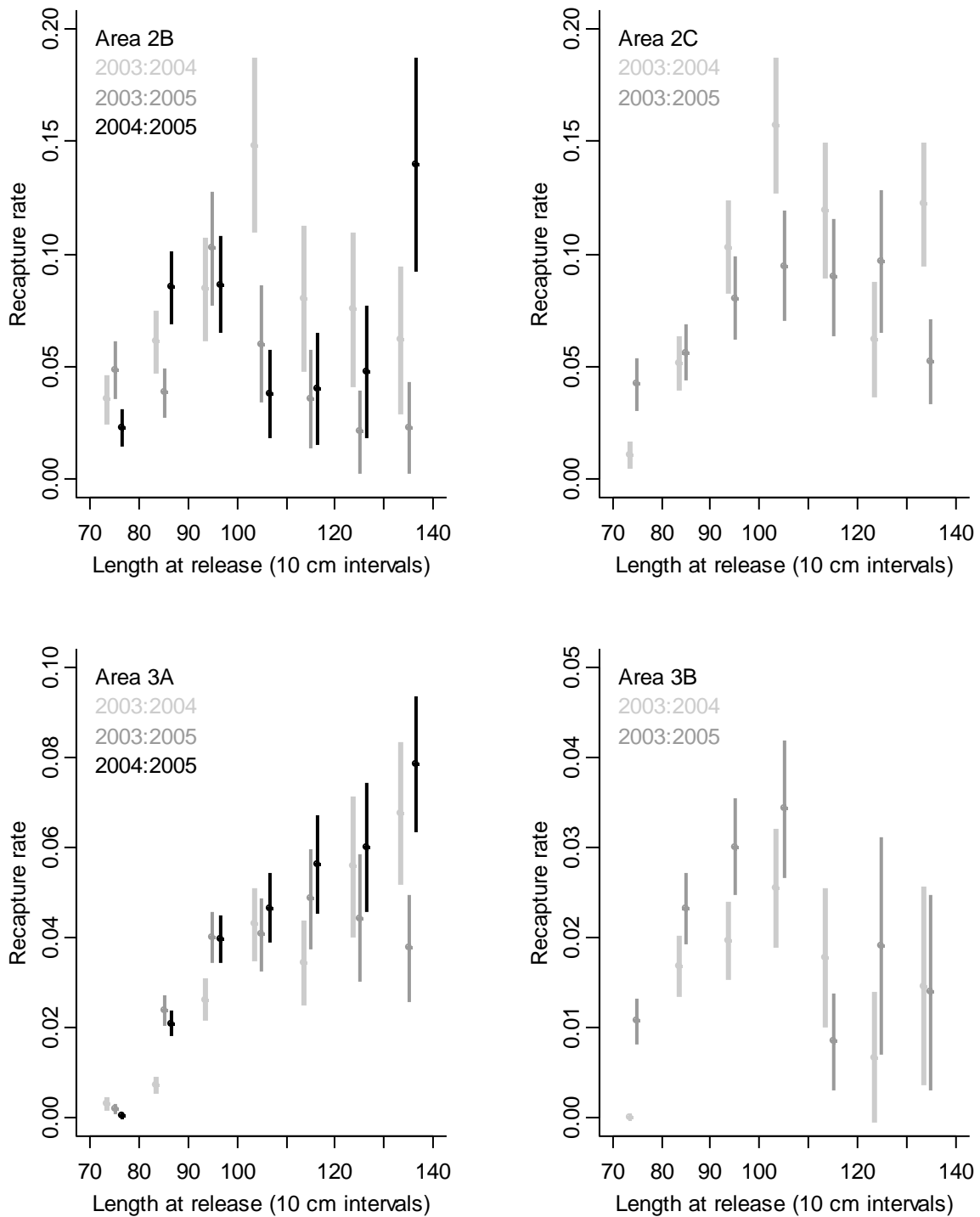


Figure 1. Recapture rates (recoveries as a fraction of releases, adjusted for proportion of landings scanned) by area, release group, and year. The notation “2003:2004” means recoveries in 2004 of fish released in 2003. The vertical bars are 90% confidence intervals. Recoveries from releases in Area 4 were too few to show any meaningful differences among years or length groups.

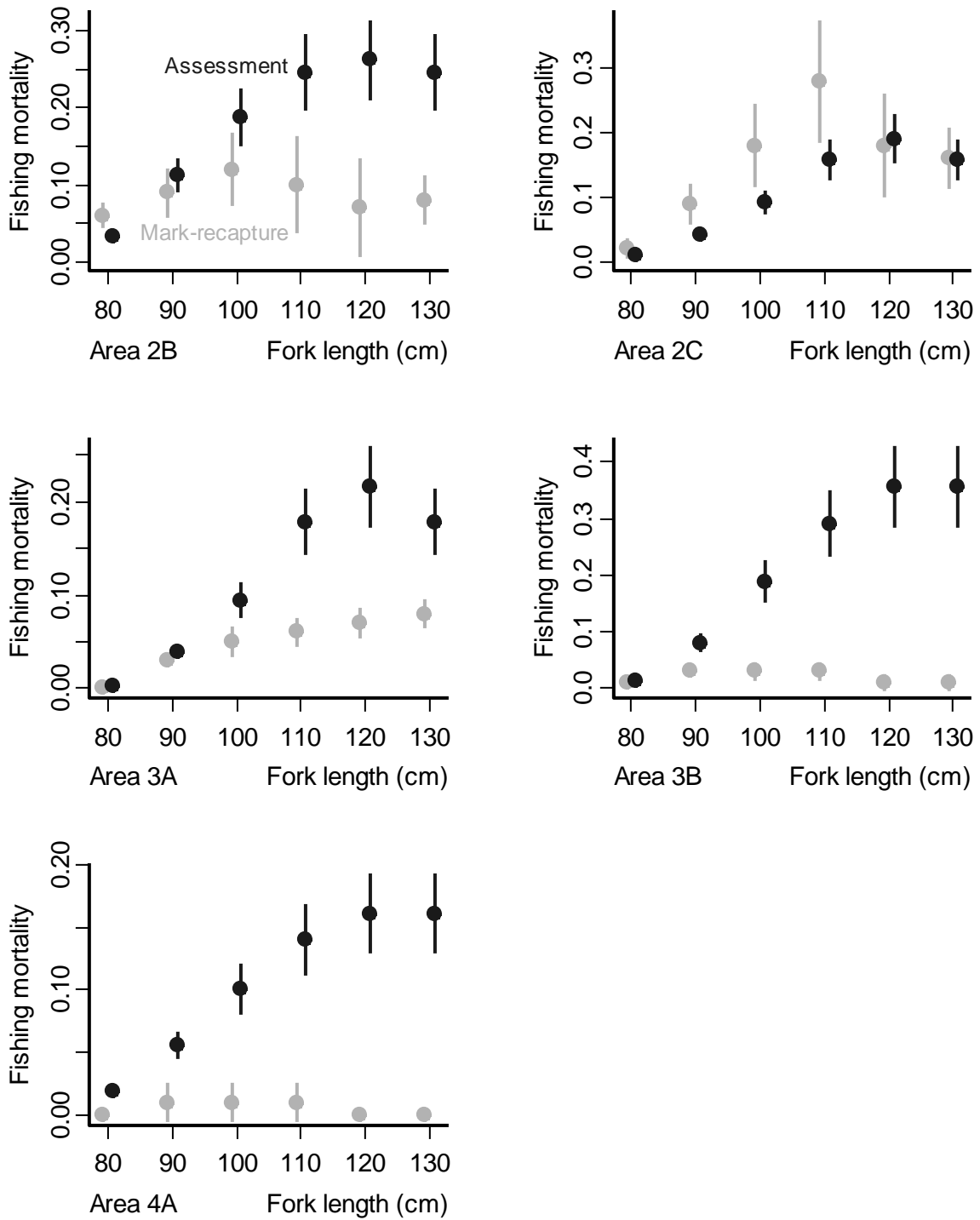


Figure 2. Estimates of fishing mortality from the 2005 stock assessment and the mark-recapture analysis. The vertical bars are 90% confidence intervals.

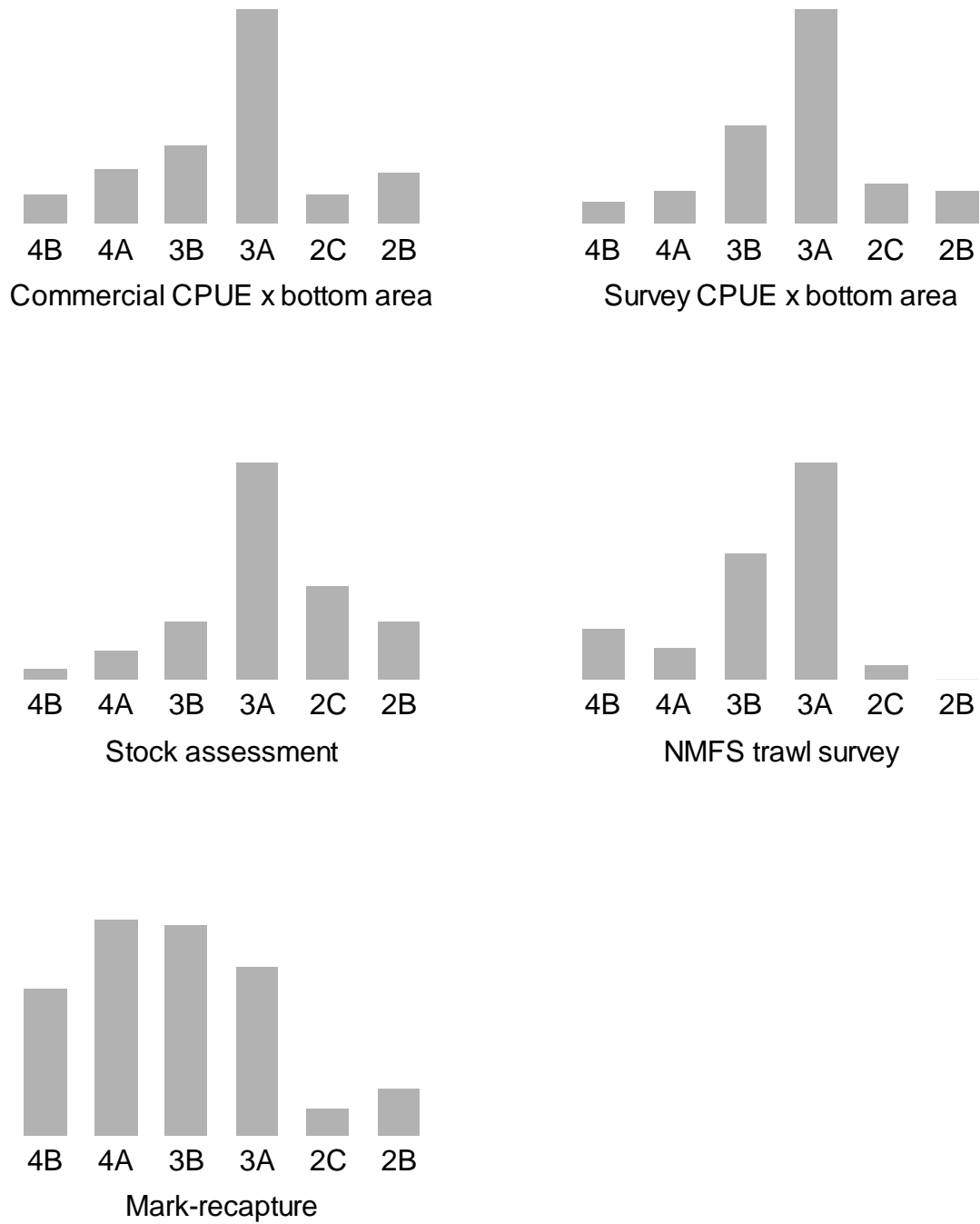


Figure 3. Estimates of the relative distribution of exploitable biomass among regulatory areas based on various data sources. To compute the mark-recapture estimates for length groups with zero recaptures in Areas 4A and 4B, a fishing mortality rate of 0.005 was assumed.