

Analysis of PIT tag recoveries through 2009

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Abstract

This was the final year of scanning for PIT tag recoveries. Patterns of recoveries were consistent with recent years. This year we fitted some new models to the data, and the best fitting model allowed emigration probability to be a linear function of halibut length on the logistic scale. Under this model, quite different relationships were estimated for each regulatory area, with smaller fish being more likely to migrate from Areas 4A and 3B, and larger fish having greater, albeit imprecisely estimated, migration rates from eastern areas. Estimates of net migration in terms of exploitable biomass are also presented in this report. These show that relative to their area's biomasses, Area 2B is the greatest net recipient and Area 4A the greatest net exporter.

Introduction

In 2003 the International Pacific Halibut Commission (IPHC) 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 each year from 2003 to 2009, samplers in the ports scanned a substantial part of the landings to recover tags (Forsberg this volume).

The primary purpose of this large project was to estimate the harvest rate of fully selected halibut by the commercial fishery, but the tag-recovery data also permit estimates of length-specific selectivity schedules, rates of migration among regulatory areas, and, in principle, the rate of natural mortality.

This report updates the analyses of the PIT tag recovery data to include recoveries in 2009, the final year of portside scanning for tags. All models discussed in the 2008 report (Webster 2009) were again fitted, along with three additional models allowing migration rates to be functions of either halibut length or year.

PIT tag recovery data for 2009

PIT tag recoveries for 2009 are discussed in detail in Forsberg (2010). In total, 322 tags were recovered, 100 fewer than in 2008, with 187 from the 2003 releases and 135 from the 2004 releases. Total recoveries over the duration of the study are close to 3200 tagged fish (Table 1), representing approximately 5% of all tags released. Table 2 shows recoveries of tagged fish from the 2003 and 2004 releases in 2009 for comparison with the corresponding tables from previous years (Webster 2009, Webster and Clark 2008). The overall pattern of recoveries is similar to recent years.

Tag-recovery modelling

The recovery data were analysed by fitting tag-recovery models, adapted from the migration models of Brownie et al. (1993) and Schwarz et al. (1993) to allow fishing mortality rates to vary with length. Natural mortality was fixed at a rate of 0.15, tag-loss was taken to be 3% per year, and

based on previous seeding work, we assumed 97% of scanned tags were detected. Other sources of fishing mortality – sport catch, wastage, personal use, and bycatch – were accounted for as components of total fishing mortality in the models.

Models were fitted using maximum likelihood estimation. We fitted a sequence of plausible models to the recovery data from Areas 2B-4A. Data from other regulatory areas were omitted due to sparse recoveries. The first four models were also fitted in 2008 (Webster 2009), while the other three are new models.

1. Fishing mortality varies with length, and area, but not with year; migration rates are constant over time.
2. Fishing mortality varies with length, area, and year; migration rates are constant over time.
3. Fishing mortality varies with length, area, and year; migration rates are constant over time but a different for fish under 90 cm and with length greater than or equal to 90 cm, assuming a 3 cm/year growth rate since release.
4. Fishing mortality varies with length, area, and year; migration rates in the year following release differ from those in subsequent years.
5. Fishing mortality varies with length, area, and year; migration rates are a continuous function of year.
6. Same as 5, but migration rates differ among years without assuming a functional relationship.
7. Fishing mortality varies with length, area, and year; migration rates are a continuous function of current fish length.

The models are parameterised so that fishing mortality at length l cm is a proportion (the selectivity), Sel_l , of fishing mortality of 100 cm fish, F_{100} :

$$F_l = F_{100} Sel_l.$$

In models that allow fishing mortality to vary with year, F_{100} is allowed to vary while the selectivities stay constant over time. Thus, relative differences in commercial fishing mortality, F , among years were constrained to be the same for all lengths so that the shape of the relationship of F with length stays the same over time. This approach avoids fitting models with extremely high numbers of fishing mortality parameters.

In Models 5-7, we had to be careful to avoid over-parameterisation, and we therefore sought a model structure that avoided fitting full migration matrices for each length class or study year.

Let $\phi_{rs}(x)$ be the probability that a fish in area r in year $i-1$ is in area s in year i for a given value of the variable x (either length or year). Then the probability a fish does not move in a year is specified to be a linear function of x on the logistic scale, where the slope and intercept depend on the regulatory area:

$$\text{logit}(\phi_{rr}(x)) = \alpha_r + \beta_r x$$

We now need to estimate the other migration parameters, $\phi_{rs}(x)$ for r not equal to s . We begin by doing this explicitly for one particular value of x , x^o say (set to be 100 cm for Model 7, and the year 2004 for Model 5). For other values of x , $\phi_{rs}(x)$ is defined to be:

$$\phi_{rs}(x) = \frac{\phi_{rs}(x^o)}{1 - \phi_{rr}(x^o)} (1 - \phi_{rr}(x))$$

Under this parameterisation, we assume only that the magnitude of the migration probabilities vary with length or year: the pattern of migration stays the same. For example, suppose we have five areas in our model labelled 1-5, and at $x^o=100$ cm, we have $\phi_{11}(100) = 0.9$ (the probability a 100 cm fish does not migrate), $\phi_{12}(100) = 0.05$, $\phi_{13}(100) = 0.03$, $\phi_{14}(100) = 0.01$ and $\phi_{15}(100) = 0.01$. Then $1 - \phi_{rr}(100) = 1 - 0.9 = 0.1$, and $\phi_{12}(100)/0.1 = 0.5$, $\phi_{13}(100)/0.1 = 0.3$ etc., so that whatever the length, 50% of the fish that emigrate from Area 1 will move to Area 2, 30% to area 3 and so on. While the assumption that the pattern of migration does not vary with length or year is certainly a simplification of reality, estimating a full migration for each year or length class would require a very large number of parameters. Such complex models would not be possible to fit with our often sparse recovery data. The specification of Model 6 was only slightly different: for year x , we fit $\text{logit}(\phi_{rr}(x)) = \alpha_{rx}$. Other migration rates are estimated as described above for Models 5 and 7.

Results

The fits of the models were compared using Akaike's Information Criterion (Akaike 1973), which is given by

$$AIC = -2\log(L) + 2p,$$

where L is the likelihood, and p the number of parameters. The first term decreases as the fit improves, while the second term is a penalty for model complexity. The "best" model of those being considered will have lowest the AIC . The values of ΔAIC show differences in AIC between a given model and best model.

Model	$-2\log(L)$	parameters	AIC	ΔAIC
1	2797.9	50	2897.9	108.4
2	2683.1	75	2833.1	43.6
3	2636.4	95	2826.4	36.9
4	2621.2	95	2811.2	22.7
5	2640.2	80	2800.4	10.9
6	2629.3	100	2829.3	39.8
7	2629.5	80	2789.5	0.0

Of the fitted models, Model 7 had the lowest AIC and was the best fitting model of those we considered. Under this model, migration rates vary with length in different ways for the five regulatory areas included in the model. In last year's report (Webster 2009) we looked at the results of Model 3, which estimates a different migration matrix for fish above 90 cm in length

than those under 90 cm. Model 7 produces migration rates for fish of any length in an area by assuming a particular functional form (logistic-linear), and does so using fewer parameters than Model 3. Models 5 and 6 are particularly difficult to fit, because information about migration rates in a given year gets progressively poorer as time since release increases. Thus, we have very good information about the annual migration rate from 2003 to 2004, but since out of area recoveries in later years include fish that moved 1, 2, 3, or more years ago, it becomes difficult for the model to distinguish when the movement actually occurred. For example, estimates of migration rates beyond the first two years for Model 6 (not presented here) made little sense and were likely very poor representations of actual migration rates for those years.

Figure 1 shows the estimated relationships between the annual probability of emigration and current length for each area in the selected model. Area 4A has the strongest relationship, with small fish estimated to be almost certain to emigrate, and the largest fish almost certain to remain in this regulatory area. Emigration from Area 3B follows a similar pattern, but with generally lower probabilities of movement. The model estimates that larger fish are more likely to move for other areas, although precision is very poor due to small numbers of large fish recovered.

Estimates of commercial fishing mortality from the 2009 modelling do not differ greatly from previous years (see Webster 2009), and are not presented in this report. Standard errors and interval estimates of migration rates were estimated by refitting the selected model using a Bayesian approach with non-informative priors. Parameter estimates obtained from Bayesian modelling were close to the maximum likelihood estimates.

Net migration of biomass

The tag-recovery modelling leads to estimates of annual rates of emigration from each regulatory area. In Webster (2009), we estimated net annual migration rates for numbers of fish by applying model estimates of migration to estimates of the number of legal-sized fish from the stock assessment. In this report, we estimate movement of exploitable biomass among the five regulatory areas in the model.

Estimates of numbers of fish in each regulatory area from ages 6 and above for females and males are available from the stock assessment (Hare 2010), along with mean weights for each age and both sexes in each area. Using the IPHC length-weight curve, we can estimate migration probabilities by age and sex from the migration-length relationships estimated in the modelling. These probabilities are applied to estimates of biomass by age, sex and area to estimate an annual change in biomass for each area by age and sex. Total changes in exploitable biomass come from summing the age and sex-specific values, excluding any ages with mean lengths less than 81.3 cm (U32). This gives us the estimates of net migration of biomass among the five areas in Table 4.

The estimates in Table 4 are similar to those presented in Webster (2009), which were calculated assuming a single migration matrix for all lengths. Differences between the two estimates reflect differences in the length distribution of tagged halibut and estimates of the length (or age) distribution calculated from the stock assessment. Consistent with last year's estimates, the results show Area 2B as the largest net receiver of biomass, and Area 4A as the only area with large net outward migration. Tables 5 and 6 decompose the estimated immigration and emigration rates by their sources and destinations respectively. In each table, the values are percentages of the beginning of year biomass in the areas listed on the left.

Natural mortality

We refitted the selected model including natural mortality, M , as a parameter rather than fixing it at 0.15. M was estimated at 0.124. The fit of the model was only marginally improved, with $-2\log(L)=2629.1$ compared to 2629.5 for the model with M fixed, and with an AIC of 2791.1, there is no evidence that a model with M estimated is better than one with M fixed at 0.15.

Discussion

Results from modelling the relationship between migration rate and length confirm previous observations that migration is an ongoing process that can occur for all sizes (and ages) of halibut. While our estimates show particularly high probabilities of migration of smaller fish from Areas 4A and 3B, emigration from these areas continues for fish of larger sizes. The relationships between migration and length for other areas are more poorly estimated. The estimated trend for eastern areas is in the opposite direction, with larger fish more likely to move, but with little data for larger fish, precision is poor and evidence for these relationships is weak. The results for Area 3A in particular appear to show very large migration rates for larger fish. Although the relationship is not precisely estimated due to sparse data, it is no doubt influenced by the unique pattern of movement out of Area 3A: most Area 3A tags recovered elsewhere are recovered just over the boundary in Area 3B. This result, therefore, may be due to large fish moving quite short distances back and forth across the boundary rather than a true migration process, although it is unclear why this would affect larger fish more than smaller fish. Estimates of net migration in terms of biomass confirm that Area 2B is a net recipient and Area 4A a net exporter of exploitable biomass.

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Table 1. Summary of commercial PIT tag recoveries by release and recovery year

Release year	Recovery year							Total
	2003	2004	2005	2006	2007	2008	2009	
2003	86	383	463	429	293	261	187	2102
2004	0	45	297	251	193	161	135	1082
Total	86	428	760	680	486	422	322	3184

Table 2a. Recoveries in 2009 of fish released coastwide in 2003.

Release area	Release totals	Recoveries by area in 2009									Total
		4D	4C	4B	4A	3B	3A	2C	2B	2A	
4D	979	14	0	0	2	0	0	0	0	0	14
4B	1 128	0	0	3	0	0	1	0	0	0	4
4A	3 452	0	0	0	1	2	7	2	0	0	12
3B	15 282	0	0	0	0	29	29	3	1	0	62
3A	16 413	0	0	0	0	7	51	0	0	0	59
2C	3 675	0	0	0	0	0	0	18	5	0	23
2B	2 717	0	0	0	0	0	0	1	6	0	7
2A	299	0	0	0	0	0	0	1	0	3	4
Total	43 945	14	0	3	1	38	88	25	12	3	185

Table 2b. Recoveries in 2009 of fish released in Areas 2B and 3A in 2004.

Release area	Release totals	Recoveries by area in 2009									Total
		4D	4C	4B	4A	3B	3A	2C	2B	2A	
3A	20 341	0	0	0	0	8	107	1	1	0	117
2B	3 085	0	0	0	0	0	1	0	17	0	18
Total	23 426	0	0	0	0	8	108	1	18	0	135

Table 3a. Recoveries over the duration of the study (2003-09) of fish released coastwide in 2003.

Release area	Release totals	Recoveries by area in 2009									Total	%
		4D	4C	4B	4A	3B	3A	2C	2B	2A		
4D	979	55	0	0	4	0	1	1	2	0	63	6.4
4B	1 128	1	0	8	0	0	4	2	1	0	16	1.4
4A	3 452	0	1	3	37	13	40	13	13	1	121	3.5
3B	15 282	0	0	0	2	344	177	25	11	1	560	3.7
3A	16 413	0	1	0	0	67	686	7	12	0	773	4.7
2C	3 675	0	0	0	0	0	11	294	41	3	349	9.5
2B	2 717	0	0	0	0	0	0	9	194	2	205	7.5
2A	299	0	0	0	0	0	0	1	6	6	13	4.3
Total	43 945	56	2	11	43	424	919	352	280	13	2100	4.8

Table 3b. Recoveries over the duration of the study (2003-09) of fish released in Areas 2B and 3A in 2004.

Release area	Release totals	Recoveries by area in 2009									Total	%
		4D	4C	4B	4A	3B	3A	2C	2B	2A		
3A	20 341	0	0	0	1	51	817	25	9	0	903	4.4
2B	3 085	0	0	0	1	0	3	3	168	4	179	5.8
Total	23 426	0	0	0	2	51	820	28	177	4	1082	4.6

Table 4. Estimates of net annual migration rates (%) of O32 halibut biomass¹.

Area	Immigration	Emigration	Net migration
4A	1.4	22.6	-21.3
3B	11.1	12.4	-1.3
3A	9.9	5.9	3.9
2C	6.3	9.8	-3.4
2B	9.4	1.6	7.8

¹Calculated from estimates of annual emigration rates from tag-recovery modelling for 2004-09 and population numbers for January 1 2010 estimated using the coastwide stock assessment.

Table 5. Annual immigration rates (%) of 032 halibut biomass into each area broken down by source of immigration.

Area	Source of immigration					Total
	4A	3B	3A	2C	2B	
4A		0.6	0.3	0.0	0.5	1.4
3B	2.1		9.1	0.0	0.0	11.1
3A	2.8	6.5		0.5	0.1	9.9
2C	2.2	1.8	1.2		1.2	6.3
2B	2.0	0.8	1.2	5.4		9.4

Table 6. Annual emigration rates (%) of 032 halibut biomass out of each area broken down by destination of emigration.

Area	Destination of emigration					Total
	4A	3B	3A	2C	2B	
4A		5.4	12.6	2.0	2.6	22.6
3B	0.2		11.1	0.6	0.4	12.4
3A	0.1	5.3		0.3	0.4	5.9
2C	0.0	0.0	2.2		7.6	9.8
2B	0.4	0.0	0.3	0.9		1.6

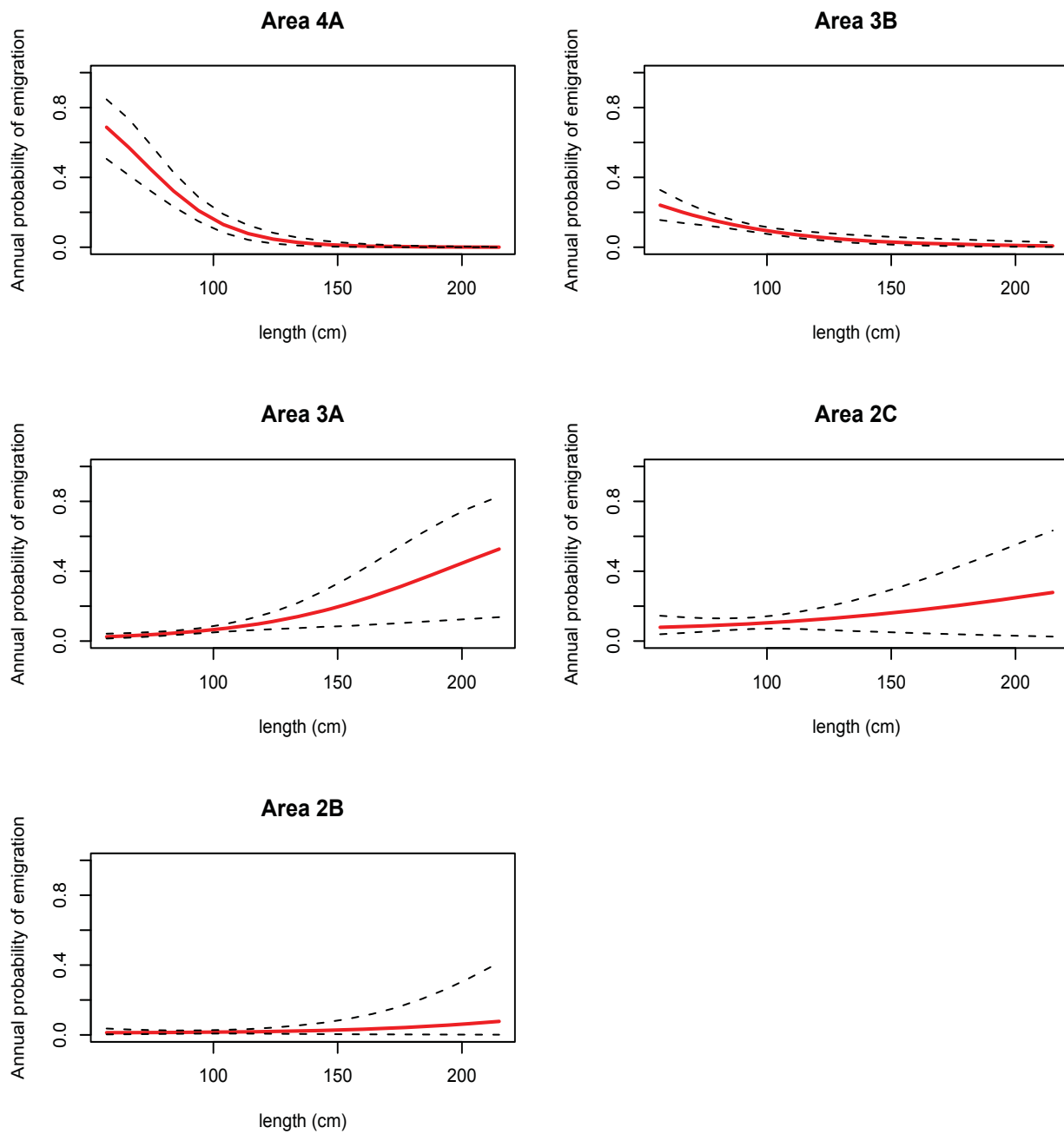


Figure 1. Estimated relationship between rates of emigration from each regulatory area and fish length (solid line), with 95% Bayesian credible intervals (dashed lines).

