North Atlantic fin whale stock structure hypothesis IV fit with modified Implementation Simulation Trials

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ABSTRACT

The Scientific Committee has recommended that further analysis of the Discovery Marking data be carried out within the framework of the *Implementation Simulation Trials*. Minimal modifications were made to the trial programs to allow the parameters for both the tag reporting rate and tag loss to be estimated separately within and between areas. When a mixing model (hypothesis IV) is applied to a dispersal scenario these parameters will act as proxy for the dispersal rate and local abundance. The fit of the hypothesis IV mixing model is significantly poorer than the fit to the hypothesis III dispersal model. However, with the reporting rate estimated significantly larger than 1 and some tag loss the fit to Hypothesis IV becomes better, and estimating these parameters only within area results in further significant improvements of the fit, indicating dispersion as the culprit. In the trial set-up the Canadian markings and catches are all modelled within one area. The returns from the markings in the two Canadian operations off Nova Scotia and Newfoundland are similar to the West Iceland – East Greenland situation and modelling these on a finer scale would apparently add strength to these results.

STOCK STRUCTURE, CPUE, DISCOVERY MARKING, POISSON, NEGATIVE BINOMIAL

INTRODUCTION

At the last IWC SC meeting Gunnlaugsson (2011) presented an analysis of fin whale mark recapture events in the North Atlantic WI *small area* that originated from markings from WI and EG *small areas*. The author concluded that the observed time trend in the markings, which differed in the two areas, contradicted the assumptions in stock structure hypothesis IV. Gunnlaugsson (2011) demonstrated that a model with dispersion fits the data significantly better than a model based on the assumptions of said hypothesis.

The SC RMP sub-committee **agreed** that while the results were suggestive that hypothesis IV can be rejected given the available information, the analyses were not conducted within the context of the *Implementation Simulation Trials* (IWC 2011). It therefore **recommended** that the analysis of Discovery Marking data be integrated within the existing *Implementation Simulation Trials.* In making this recommendation, the sub-committee noted the analysis had shown that the marking data are not comparable with the abundance estimates for the entire stock, which suggests that the component of the stock which is marked is much smaller than the whole population. This needs to be accounted for and will require that the *Implementation Simulation Trials* (IST) be modified accordingly for the analysis suggested.

As a response to the request of the subcommittee, minimal modifications were made to the trial program that allowed both the tag loss and the reporting rate for within area recaptures to be estimated separately from between area recaptures. These are used as a proxy for estimating the component that is immediately available to the catch operation, and to demonstrate the trend with time.

The IST program had been set up such that the tag loss and tag reporting rate parameters could be estimated. The reporting rate was however estimated greater than 1 in the trial runs and therefore this parameter had been fixed at 1 for the WI recoveries. Reporting rate might differ by catch operation but should be independent of the marking area. If the true marked and recaptured population abundance (N) is smaller than the assumed population abundance (obtained from surveys) that is being fitted to, there will be apparently too many recoveries and it will show up in the same way as if reporting rate was greater than 1. When the whole population is considerably larger than just the whales on the whaling grounds that are targeted during any single season, with dispersal, the subsequent thinning of the marks on the grounds will show up as tag loss. With tag loss though, in the limit, there will be no tags left even in the component of the population that is of sufficient age, but with dispersal there is a levelling off when the marks have dispersed through the whole population. However with time this marked component also tends to zero due to mortality. As the bulk of the markings happened shortly before the cessation of whaling, the difference of tag loss and dispersal would hardly be detectable in this case.

The North Atlantic fin whale trials specification is given in SC/60/AnnexD (IWC 2008). The tag recapture data are there assumed to be negative-binomially, rather than Poisson distributed. This was meant to account for possible non-randomness in the tagging / recapture process. The formulation of the negative-binomial likelihood function was presented in SC/60/Annex D and requires an extra parameter *Lambda* (λ).

The IST program had been set up such that this parameter could be estimated, however *Lambda* was in all trial runs fixed at the constant value of 2. Documentation as to why this value was chosen could not be located.

Marking experiments are conducted in many fisheries and in general several fish are marked from one trawl or at a single station. Several marked fish may also be recovered in one trawl or at one location. It has been observed that recoveries from one marking event tend to be lumped by recovery events (e.g Hannesson *et. al* 2008 and reverences therein). This has led to assumptions of non-Poisson distributions or models with station random effects. In the whale marking surveys off Iceland the vessel continued some distance on its track immediately after marking a whale, or a small number of whales, at one location to avoid inadvertently double marking a whale. That would otherwise be fairly likely to happen, as the number of whales is in general orders of magnitude smaller than fish. The catches were then taken as single whales or a pair of whales per trip to the whaling grounds. There is thus little room for lumping, i.e. correlation, in the whale markings.

For unbiased results the marking and recovery effort must be uncorrelated, such as by randomly marking (or capturing) the whales. When compared to the distribution of fin whales from sighting surveys the whale markings have not been randomly distributed through the areas that the abundance estimates refer to. Nor have the catches been distributed over the whole WI area.

A failure to fit the marking data with a Poisson distribution is unlikely to be some feature of the mark-recovery process, but rather a sign that the model does not capture the spatial-temporal nature of the marked population. This should not be downplayed, as has been the case in the trial runs, by using the negative-binomial distribution.

MATERIAL

All recoveries are either from the Canadian operations that ceased in 1972 (last markings 1979) or the whaling grounds in the WI area (no catches 1990-2005). The 187 markings (1965-83) in the WI *small area* were all well within the reach of the operation (farthest south 62°20N) and all (except 3 that were further east along the south coast with no recovery) concentrated in the general area of the operation. The 93 markings (1967-84) in the EG *small area* either took place just west of the boundary between the WI and EG *small areas* or along the ice edge and shelve edge off Greenland where density was believed to be highest and the marking-sighting cruises were thus conducted. In sighting surveys that started after the marking episode the observed distribution is however rather even also over the deep waters. Although densities decline to the South (south of 60°N), the area there is also large so a large part of the total abundance comes from there. There were a few markings north-east of Iceland and at the Faroe Islands in the IEF *small area* with no recovery.

The included data are given in full detail in the trial specifications (IWC 2008). The Canadian markings and recoveries are given in greater detail in tables 1 and 2. Figure 1 shows the marking and recovery positions of recovered marks .

One Discovery mark placed at Canada in 1979 (total 299, 1965-1979) was recovered at West Iceland in 1988 (Gunnlaugsson and Sigurjónsson 1989). This WI recovery from Canada was 9 years after marking and fits well with a gradual dispersal between neighbouring areas. No interchange, direct or indirect, is assumed between these areas under Hypothesis IV so this recovery can not be included.

Two instances have been observed of within season movement between WI and EG areas. One is a radio tagging experiment in 1980 (Watkins *et al*. 1984) where a whale was followed for 10 days from west off Iceland to East Greenland in the course of a week. Only one other such experiment was conducted (Watkins et al. 1996) when a whale was satellite tagged in the autumn 1994 and signals received for 45 days. In the last day it had moved west of 30°W. The second observation is the reverse movement where one Discovery mark placed at coastal East Greenland (out of a total of 65 markings there) and found in the catch in Iceland a week later in 1968 (Sigurjónsson and Gunnlaugsson 1985). As same season recoveries are generally not included in mark-recapture analysis, neither of these observations have been included in the IST model test fits, but would support higher rates of mixing.

METHODS

The full stock dynamics model used in the IST is given in the trials specifications (IWC 2008).

The tag recovery likelihood (L_2) was changed to Poisson:

$P[X = x] = e^{-m}m^x/x!$

where *m* is the expected number of recoveries ($U_t^{k,k'}$) in year *t* in area *k* from area *k*' and *x* the observed number. The likelihood contribution L_2 is then the negative sum of the logarithms over all *t*, *k*, *k*'. The constant term *ln*(*x*!) was left out.

The program was modified such that tag loss and tag reporting could be estimated separately for the EG markings. Tag reporting was not limited to be less than one, but when updating the marks the upper bound is 1, so that the recovered marks are always fully subtracted.

The conditioning run of NF04-1 (Hypothesis IV with MSYR 0.01) was performed with the mixing estimated within the trial framework and additional runs where the parameters for tag reporting and tag loss were estimated separate for within and between areas. As comparison to the results from the conditioning run of NF04-1, also NF03-1 (Hypothesis III) was run.

RESULTS

The deviance (calculated as -2*ln*(likelihood)) is in hypothesis III (with dispersion) lower by 12.8 than in hypothesis IV with the mixing estimated (it comes out as 8%). The number of parameters is in this comparison the same for both hypotheses.

In hypothesis IV with reporting rate for WI allowed to be estimated greater than 1 it comes out as 2.37 and a common tag loss estimated as 0.88, the deviance is lower by 16.4 (two additional parameters). Additional parameters had in all cases little effect on the estimated mixing.

Results in hypothesis IV with the additional parameters separate for within and between area (the only between area events are WI recoveries of EG markings) were that both the parameters for reporting rate and tag loss between area were estimated a little larger than 1 and fixing them at 1 only changes the deviance by 0.2. The deviance is lower by 6.4 (22.8-16.4) when the parameters are estimated only for the within area recoveries (between area fixed at 1) rather than common for all areas.

Within area the tag loss was estimated 0.82 and tag reporting 2.65 with the 22.80 lower deviance (same two additional parameters but only within area). This gives an AIC that is lower by 18.8. For an AIC correction for a finite population (Burnham and Anderson 2002) it is not obvious what *n* to use (most observed tag recoveries are 0), but a correction would in any case be small in comparison to this number.

This implies that first after marking only the proportion 0.38 (1/2.65) of the animal abundance, (as fitted) in the WI area, are available (mixing with the marked whales), but this then increases by -*ln*(0.82) or 20% per year.

DISCUSSION

The results of the runs show that hypothesis IV (with mixing) fits the data significantly worse than hypothesis III (with dispersion). According to hypothesis IV the mixing between areas takes place in the first year and the mixing proportion then does not change with time. It is logical to assume that the same should apply to mixing within the areas, so no time trend can be explained with this hypothesis. The runs with modified hypothesis IV show that it does not explain significant features in the data. This is in addition to the poor fit to the observed decline in the cpue in the early modern whaling period and the impossibility within this hypothesis of the observed recovery at West Iceland of a mark from Canada. Same season recoveries between the areas and the interchange between the areas observed in the short time radio-tracking experiments can also not be included in the trials model.

The two Canadian marking and catching areas Nova Scotia (NS) and the Labrador Sea/Gulf of St. Lawrence (NL) were in the trials model merged, although the interchange there is no greater than between EG and WI, where by hypothesis IV two unrelated stocks are assumed with only limited mixing in the areas. Recoveries in the WI area from the EG area were found to be more likely from those markings there that were close to the WI area and more likely to be recovered close to the EG area (Gunnlaugsson 2008). The delay to recovery is greater for these than for markings and recoveries within the WI area. The Canadian mark from NL recovered in WI was also caught farthest south west on the grounds and 9 years after marking. The Canadian recoveries between areas have similar features as the Icelandic data. Out of the 9 same season recoveries there is one between areas NS to NL. This mark was caught farthest south (closest to NS) of all recoveries in the NL area (fig. 1). There is another between area recovery two years after marking and this one was marked farthest north-east (closest to NL) of all the marks that were recovered from the NS area. There is one opposite (NL to NS) 4 years after marking and was caught farthest north-east (closest to NL) of all the marks recovered in the NS area. There has been no recovery from markings in the Gulf of St. Lawrence at all (table 2). In general all features of the Canadian marking data and the profile in time are suggestive of gradual dispersal. Modelling the Canadian markings in two areas would add some strength to the case for dispersal in the trials. The recoveries from within the WI area between years have also been shown to be more likely closer to the marking position than to the marking positions of other marks there (Sigurjónsson and Gunnlaugsson 1985). Canadian marking positions and dates have only been reported for recovered marks so such comparison is not possible there. Also the number of Canadian recoveries is lower as catches ceased in these areas in 1972 shortly after the markings started. The first large scale making year was 1966 (only 3 fin whales marked before 1966). Recoveries from markings in this year are much higher than from later years (table 1). This might be explained if these first markings were more concentrated on the whaling grounds, but with time disperse from there. The recoveries by year after marking also differ strikingly for the two areas (table 2) and the NL recoveries have considerably greater spread in the NL area, even though no Gulf markings do appear on the plot at all, as there were no recoveries from these. Merging these data in one area is therefore highly questionable. Analysis of catch and marking positions (if made available) might shed light on the questions arising from the tables and fig. 1.

CONCLUSION

The assumption of invariant mixing percentages by different breeding stocks in feeding areas and no dispersion there between, would have to be complicated by assuming dispersion also, but then only within the areas, to fit the data. Adding parameters such as is done here to get a better fit to the data is also not a biologically acceptable variation of hypothesis IV to replace it in trial runs. Rather hypothesis IV should be rejected or given low plausibility. All the available data indicates that land-based whaling stations with a limited range will in the short term only exploit a local part of the total population that recruits to the catches in the long run.

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Table 1. Catches and markings by year and area, and all subsequent recoveries form this years markings within the area + recoveries from the other catch area (Rec.). No catches in, nor recoveries from the Gulf of StLawrence.

Year	Nova Scotia			Labrador			Gulf
	Catch	Marks	Rec.	Catch	Marks	Rec.	Marks
1960		1			0		0
1965		0			0		2
1966	263	64	22+2	164	14	4	0
1967	309	19	1	436	31	3+1	0
1968	262	1	1	438	0		0
1969	157	20	1	376	2		22
1970	170	1		408	1	1	1
1971	117	16	1	301	0		0
1972	95	5		265	44	2	10
All			26+2			10+1	

Table 2. Total number of tests (∑m*c) for remaining marks (m) in catches (c) and recoveries (Rec.) by year after marking summed over all marking experiments in Nova Scotia (NS) and the Labrador / Gulf of StLawrence (NL) areas.

Delay	NS		NL		interchange	
Years	∑m*c	Rec.	∑m*c	Rec.	∑m*c	Rec.
0	28622	4	39210	4	55472	1
1	28818	4	28849	3	63916	0
2	20661	11	23919	0	49815	1
3	12336	5	23050	0	39509	0
4	9286	2	14377	1	28376	1
5	6465	0	11547	2	21240	0
6	3917	0	3252	0	12085	0
All		26		10		3

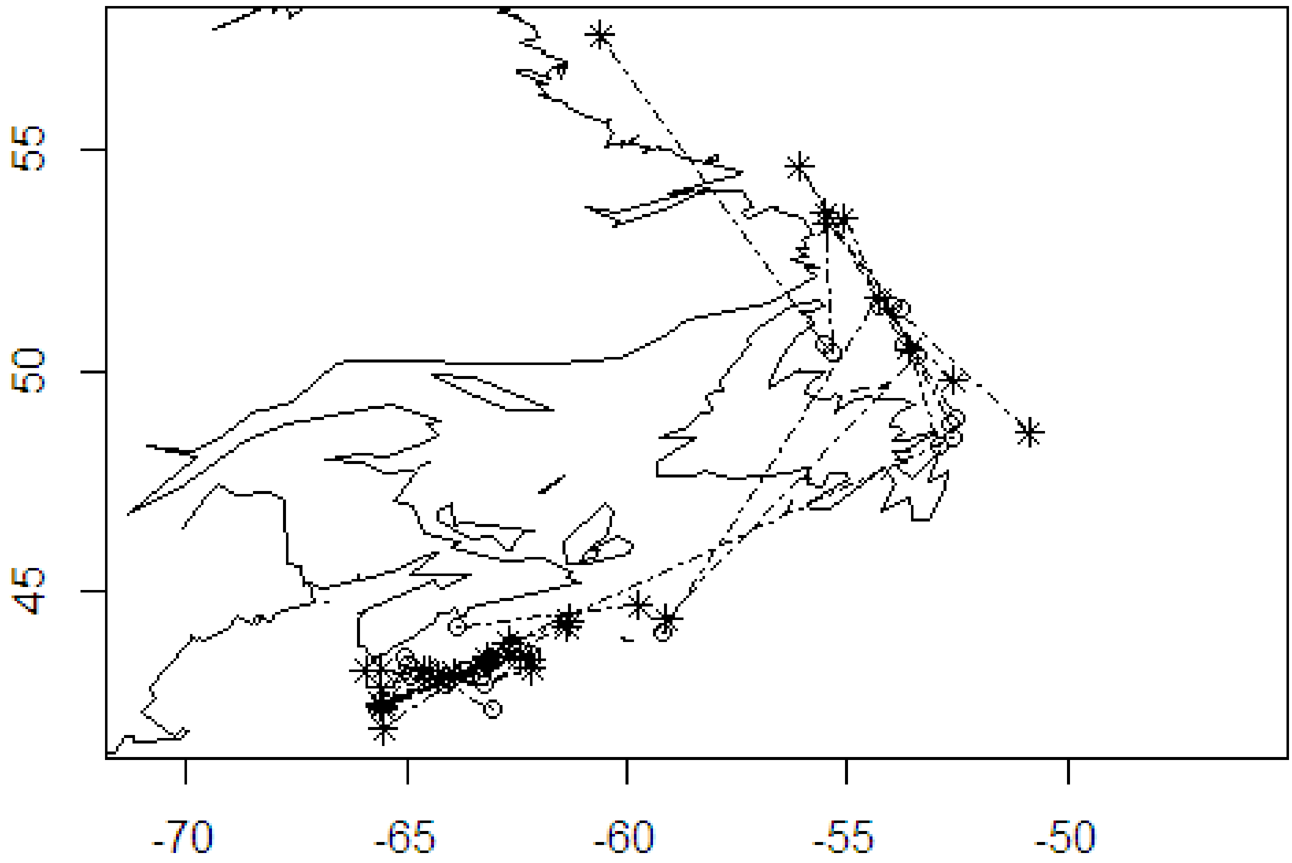

Figure 1. Canadian 1966-1972 fin whale mark recoveries (O) linked to their marking positions (*).