# Recent changes in biological parameters of North Atlantic fin whales

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ABSTRACT

The resumption of whaling of fin whales west of Iceland provides an opportunity to compare the biology of the stock after three decades of no whaling to the stock after continuous whaling for over 4 decades that ended in four years of extensively studied scientific permit catches. The comparison shows some drastic changes in the stock. As expected there were more large whales after the pause, but these whales have a lower pregnancy rate and a higher maturity age. The sex ratio is reversed and there are very few young whales in the recent catch and signs of stunted growth. This implies that there has already been a density response in the stock. This would not be expected if the stock was severely depleted with a low msyr as assumed in some IST scenarios.

## INTRODUCTION

The fin whale stock exploited west of Iceland has a long catch history (Sigurjonsson 1989) and stock trajectory calculations are therefore particularly sensitive to the assumed msyr. According to a few scenarios included in the *Implementation Simulation Trials* (IWC 2010a) the present stock was still severely depleted after three decades with no whaling (IWC 2010b). Under these scenarios the stock should still be increasing (IWC 2010b) and dominated by young animals as productivity would be still high. The resumption of commercial whaling in the autumn of 2006 which was continued in the seasons 2009 and 2010 provides an opportunity to observe the stock at a different level and validate these scenarios. Extensive data sets were available from the pre-moratorium period (before 1986) and biological sampling was intensified during 1986-1989 as a part of a special permit research programme (Anonymous 1990). The earlier biological data has been a subject to several analyses (e.g. Lockyer and Sigurjonsson 1991, Víkingsson 1995, Víkingsson and Gunnlaugsson 2006) and Konradsson *et al.* 1991.

## MATERIAL AND METHODS

Systematic biological sampling has been conducted at the whaling station in Hvalfjörður since 1967 (Lockyer and Sigurjónsson 1991) while basic data on length and sex exist for every landed whale since 1948. Here, we have rounded the body length data to feet for comparability with the earlier data-set. The whaling operation at Hvalfjörður started in 1948, and we have split the data into periods of approximately 10 years with the first period including the years up to 1955. The other periods are 1956-1965, 1966-1975, 1976-1985, scientific permit catches 1986-89 and finally the most recent catches from autumn 2006 and seasons 2009 and 2010. The first biological information is from 1967, 69 and 72-73 and then each year from 1977. Reproductive organs have been weighted and ovaries inspected and corpora counted. Maturity was determined by the presence of some corpus. Age readings were made from ear plug growth layers (Konradsson *et al.* 1990). The readers of the recent data were trained on old earplugs and photographs with assigned ages from the earlier readers for consistency with the earlier data. Aspartic acid racemization measurements from eye lenses (Nielsen *et al*. 2012) were available for the 2006 and 2009 seasons and the age readings were re-evaluated based on these, but the 2010 data has not been finalised and the age readings are preliminary. The data were therefore mainly analysed only by length to exclude the possibility of bias or difference in the age readings.

## RESULTS

### Sex ratio

There were more males caught during the last period than females (48%), whereas females have been around 52% in earlier catches and 58% during the permit catches 1986-1989 which was as similar operation. The change is not due to the recent operation starting rather late in the season as June-July is already only 55 females to 65 males, whereas during the permit catches this was 153 to 108. There is an apparent lack of smaller females (<18 m).

### Distribution by length

In the period 1976-89 male catches (table 1) above 18.44 m (rounded to 61 ft or more) were fewer than 30% (table 1a) while in the recent catches this is over 45% (64/142). The female catches (table 1b) above this size were fewer than 25%, but in the recent catches 88% (115/132). The catch is predominantly medium sized

whales. There is the usual peak in the length distribution at 60 and 62 ft for males and females, but then an unusual second peak at 63 and 65 ft respectively.

**Maturity and productivity by length**
There is no noticeable difference in the female proportion mature by length in the recent catches compared to earlier catches, but as noted there are very few females below 18.44 m (61 ft) in the recent catches (4 sampled 2 mature). This is the size at which the proportion mature exceeds 50%. There was one immature young cow in 2009 of length 21.3 m. This is the only immature animal over 19.5 m on record and will be genetically checked whether is a hybrid. The proportion of mature animals that are pregnant (table 2) is much lower than in any of the previous sampling periods, independent of length. The average number of corpora (table 3) is also lower than in the earlier periods for the largest females (66+ ft), but higher for the smallest females (63 feet or less).

**Testis weight by length and season**
Total testis weight for a given body length shows some increase over the season (table 4) for the largest males (64+ ft), but June and July may not differ at all, while September may differ already for a body length of 60 ft. Testis weight is heaviest during the last (recent) period for length up to 61 ft. At 63 ft the last period is also heaviest, but a large proportion of the males at this length were caught in September during this period, while that does not explain the difference for the shorter males.

**Age**
The age at 50% maturity (based on corpus observation) is 8 years in all the earlier periods but 14 in the recent catches, but there are only 10 animals with 0 corpora in the recent data of the age 15 or under. There are 7 animals with 0 corpora aged 18 to 34 (all from 2010). The mean age by length is given in table 6. The mean age of the largest animals is a few years higher than during the earlier periods, but the difference is greater for the medium sized animals (18-19 m).

## DISCUSSION

**Length based analysis**
Time budget has not been analyzed for the recent catch period (late autumn 2006, 2009 and 2010), but most of the time whales were taken shortly after the vessels came onto the traditional grounds going straight west from the station. There was apparently no shortage of whales which may have resulted in more time used to select larger whales now. More emphasis on meat quality results in that the whales are brought in quickly after being caught and rarely a second whale is taken per trip. In earlier periods the whalers would frequently bring in 2 to 4 whales per trip. This may partly explain the very low proportion of small whales in the recent catch. There is however a significant catch of males 57 to 60 ft while there is very low catch of females of this size in the last period. The whalers can not tell the sex of whales at sea so the conclusion must be that there were very few females of this size in the area. It has been suggested that the selection for large whales resulted in the higher proportion of females, as they grow to a larger size than the males, and this had led to females (in particular large mature females) being more depleted than the males. After the pause in whaling this should not be the case and there should be an easy selection of the large females, but this is not observed in the low female ratio.

The high number of corpora, during the last period, observed in the smaller (young) females, in spite of the low pregnancy rate, and for the smaller males the heavier testes, points to stunted growth in these animals. That is, these animals are not as young as their length implies. This supports that the differences observed between the recent and earlier age readings are real and not due to some reader bias. The reverse (few corpora, low testis weight) for the largest (oldest) animals agrees with the low pregnancy rate in the recent years. Although maturation would take longer now the proportion mature by length appears little affected due the slower growth, but the proportion mature by age is much lower now. The bulk of the catches are animals born at around the pause in the whaling as reflected in the second peak in the length distribution. The low fertility and apparent low survival (few young animals) since can best be explained by a density response on the grounds soon after the cessation of whaling. A low msyr (1-2%) is then incompatible as it would predict a stock not having rebounded.

Other explanations could be accumulated dispersal into the grounds during the pause in whaling from areas of less productivity, which would require significant dispersal into the grounds (Gunnlaugsson *et al*. 2012). Or animals with less productivity could have entered due to a shift in the distribution. In these scenarios a more even distribution by size would be expected. Similarly if environmental changes (global warming) had lead to poor conditions and a declining population in the area, which was not apparent during the recent catch operation, one would expect such changes to get reflected in sighting surveys.

**Age based analysis**

The 7 cows with 0 corpora aged 18 or higher in the recent data are very unexpected as there are no cows aged 15 or more with 0 corpora in the earlier data. It is possible that in the earlier data such instances were considered unreadable or outliers due to possible mix up of samples. Errors are also possible in the handling of these recent samples. Since these animals were all from 2010 this awaits further inspection once the racemization measurements become available. The average age in the recent catches is 8 to 16 years higher than during the earlier periods which is not surprising. The preliminary ages from the 2010 catches are on average 6 years higher than in 2006 and 2009. Both differ most strikingly from the earlier periods in the large number of animals of high age that are only medium sized. Considering that the catchers continuously removed recruited animals during the earlier periods and possibly selected for the larger animals, the difference is even more striking.

The high age of the recent samples implies that a relatively large proportion of the recent catches might have had a parent caught in the earlier period. Relatedness studies have been presented on the old (Skaug *et al.* 2009) and on the recent catches (SC/65a/RMP1), but the data have yet to be calibrated for comparative analysis of and between these periods. In the earlier data set 11 parent-offspring pairs were detected or 1 in 6,060 pairs while only 3 were detected in the recent sample or 1 in 11,653 pairs. This is in support of a larger population recruiting to the recent catches in spite of a smaller effective catch area, rather than more offspring per individual in the area.

## CONCLUSION

Among the IST scenarios for the fin whales hunted west of Iceland considered plausible by the IWC SC was a stock with low msyr of 1% and relatively depleted present status. Such a stock should have increased continuously after the pause in whaling up to 2006. Due to steadily increasing cohorts the recent catches would be expected to consist mainly of young animals. This is not observed in the recent catches. Rather there appears to have been a recent sharp negative density response in the population. Other explanations such as environmental changes during this period (a change in K) would need to be severe to have affected the stock in such a way, if it was severely depleted (well below K). Application of an age structured and/or length based model will be considered further. Analysis of relatedness between the recent and earlier Icelandic samples is planned as well as analysis of more types of relatedness within and between periods and areas.

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**Table 1a**. Total number of males caught, per *period* and as percentage by body length in feet. Smaller and larger animals are accumulated in the first and last group.

| Length | | Period (years) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| m | feet | 48-55 | 56-65 | 66-75 | 76-85 | 86-89 | 06-10 | All |
| n: | | 813 | 1238 | 1258 | 981 | 127 | 142 | 4559 |
| ≤16.2 | ≤53 | 16.4 | 10.7 | 6.8 | 10.1 | 6.3 | 0.7 | 10.1 |
| 16.5 | 54 | 4.7 | 4.0 | 2.8 | 3.9 | 3.9 | 2.1 | 3.7 |
| 16.8 | 55 | 3.6 | 5.2 | 5.0 | 5.6 | 2.4 | 1.4 | 4.8 |
| 17.1 | 56 | 4.1 | 6.1 | 6.5 | 8.7 | 8.7 | 2.8 | 6.4 |
| 17.4 | 57 | 4.8 | 8.6 | 6.5 | 8.0 | 7.9 | 7.0 | 7.2 |
| 17.7 | 58 | 7.3 | 8.0 | 8.7 | 8.5 | 11.0 | 14.1 | 8.5 |
| 18.0 | 59 | 6.6 | 8.6 | 10.6 | 12.0 | 12.6 | 12.0 | 9.8 |
| 18.3 | 60 | 11.6 | 9.6 | 12.5 | 13.0 | 13.4 | 14.8 | 11.6 |
| 18.6 | 61 | 10.7 | 11.1 | 10.8 | 10.7 | 7.1 | 14.1 | 10.8 |
| 18.9 | 62 | 8.7 | 9.7 | 10.8 | 7.7 | 8.7 | 8.5 | 9.4 |
| 19.2 | 63 | 7.1 | 8.0 | 7.3 | 5.9 | 7.1 | 12.7 | 7.3 |
| 19.5 | 64 | 5.2 | 4.4 | 5.4 | 3.2 | 1.6 | 2.8 | 4.4 |
| 19.8 | 65 | 3.8 | 3.5 | 3.3 | 1.4 | 3.1 | 4.9 | 3.1 |
| ≥20.1 | ≥66 | 5.0 | 2.1 | 2.5 | | | 2.1 | 2.3 |

**Table 1b.** Total number of females caught and per *period* and as percentage by body *length*.

| Length | | Period (years) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| m | feet | 48-55 | 56-65 | 66-75 | 76-85 | 86-89 | 06-10 | All |
| n | | 1021 | 1245 | 1271 | 1101 | 179 | 132 | 4949 |
| ≤16.2 | ≤53 | 16.4 | 11.5 | 5.1 | 6.6 | 3.4 | 1.5 | 9.2 |
| 16.5 | 54 | 4.0 | 3.9 | 2.6 | 3.1 | 2.2 | 0.8 | 3.3 |
| 16.8 | 55 | 4.6 | 3.3 | 2.4 | 3.9 | 1.7 | 0.8 | 3.4 |
| 17.1 | 56 | 4.9 | 4.0 | 4.1 | 4.5 | 3.4 | 3.0 | 4.3 |
| 17.4 | 57 | 5.0 | 6.5 | 4.2 | 3.8 | 5.0 | 2.3 | 4.8 |
| 17.7 | 58 | 3.5 | 3.9 | 3.9 | 5.4 | 6.1 | 1.5 | 4.2 |
| 18.0 | 59 | 4.1 | 5.8 | 5.4 | 6.5 | 8.4 | 2.3 | 5.5 |
| 18.3 | 60 | 3.8 | 5.6 | 6.3 | 6.8 | 3.4 | 0.8 | 5.5 |
| 18.6 | 61 | 4.6 | 6.6 | 6.1 | 7.5 | 8.4 | 9.1 | 6.4 |
| 18.9 | 62 | 4.5 | 5.7 | 8.0 | 9.0 | 11.2 | 11.4 | 7.1 |
| 19.2 | 63 | 6.0 | 7.1 | 7.9 | 7.5 | 10.1 | 9.8 | 7.3 |
| 19.5 | 64 | 6.6 | 7.0 | 7.9 | 9.9 | 7.3 | 7.6 | 7.8 |
| 19.8 | 65 | 7.0 | 5.3 | 9.5 | 8.4 | 7.8 | 18.2 | 7.9 |
| 20.1 | 66 | 5.7 | 5.3 | 7.8 | 5.4 | 3.9 | 9.1 | 6.1 |
| 20.4 | 67 | 7.0 | 4.9 | 6.1 | 4.6 | 6.7 | 8.3 | 5.7 |
| 20.7 | 68 | 3.7 | 4.7 | 5.3 | 2.8 | 1.1 | 5.3 | 4.1 |
| ≥21.0 | ≥69 | 8.3 | 8.5 | 6.9 | 3.5 | 5.6 | 8.3 | 6.8 |

**Table 2**. Apparent pregnancy rate (percentage of mature females with ovarian corpora) by body *length* (in feet rounded) and period (years). Last line gives percentage mature by length.

| *Length* | ≤57 | | 58 | | 59 | | 60 | | 61 | | 62 | | ≥63 | | All | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Years* | % | n | % | n | % | n | % | n | % | n | % | n | % | n | % | n |
| 67-73 | 100.0 | 1 | | | 60.0 | 5 | 50.0 | 4 | 87.5 | 8 | 90.0 | 10 | 72.9 | 85 | 74.3 | 113 |
| 76-85 | 44.4 | 9 | 57.1 | 14 | 60.0 | 20 | 73.5 | 34 | 66.0 | 47 | 59.7 | 67 | 61.8 | 337 | 61.6 | 528 |
| 86-89 | 66.6 | 3 | 40.0 | 5 | 88.8 | 9 | 75.0 | 4 | 66.7 | 12 | 83.3 | 18 | 76.4 | 72 | 75.6 | 123 |
| 06-10 | | 0 | 50.0 | 2 | 100.0 | 1 | | 0 | 30.0 | 10 | 50.0 | 10 | 56.1 | 82 | 51.4 | 105 |
| All | 53.8 | 13 | 52.4 | 21 | 67.6 | 34 | 71.4 | 42 | 63.6 | 77 | 65.4 | 104 | 64.0 | 570 | 64.2 | 861 |
| *Mature* | 1.6 | 191 | 21.7 | 46 | 32.3 | 65 | 44.9 | 78 | 56.0 | 75 | 75.5 | 102 | 88.9 | 118 | 68.6 | 1255 |

**Table 3**. Average number of corpora (*Corp*) of mature females (with corpus) by body *length* (in feet rounded) and period. Last line giving percentage mature by length.

| *Length* | ≤59 | | 60 | | 61 | | 62 | | 63 | | 64 | | 65 | | ≥66 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Years* | Corp | n | Corp | n | Corp | n | Corp | n | Corp | n | Corp | n | Corp | n | Corp | n |
| 67-73 | 1.2 | 6 | 4.5 | 4 | 3.9 | 8 | 5.0 | 10 | 8.0 | 11 | 6.6 | 14 | 6.1 | 19 | 11.5 | 41 |
| 76-85 | 2.0 | 43 | 3.0 | 34 | 3.3 | 47 | 4.1 | 67 | 4.9 | 60 | 7.2 | 93 | 8.0 | 61 | 10.3 | 123 |
| 86-89 | 1.2 | 17 | 1.5 | 4 | 3.5 | 12 | 3.2 | 18 | 4.9 | 15 | 7.8 | 12 | 9.6 | 14 | 12.5 | 31 |
| 06-10 | 2.0 | 3 | | 0 | 4.6 | 10 | 6.5 | 10 | 8.5 | 13 | 6.6 | 10 | 6.8 | 22 | 9.6 | 37 |
| All | 1.7 | 69 | 3.0 | 42 | 3.5 | 77 | 4.3 | 105 | 5.7 | 99 | 7.1 | 129 | 7.67 | 116 | 10.7 | 232 |
| *Mature* | 17.9 | 379 | 56.0 | 75 | 75.5 | 102 | 88.9 | 117 | 92.4 | 106 | 97.7 | 131 | 100 | 116 | 99.6 | 232 |

**Table 4**. Total testis weight (in kg) averaged by body *length* (in feet rounded) and by month.

| *Length* | 58 | | 59 | | 60 | | 61 | | 62 | | 63 | | 64 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Month* | kg | n | kg | n | kg | n | kg | n | kg | n | kg | n | kg | n |
| June | 12.7 | 35 | 12.8 | 37 | 15.2 | 39 | 18.1 | 39 | 18.8 | 24 | 22.5 | 17 | 20.1 | 15 |
| July | 9.3 | 59 | 13.1 | 73 | 14.7 | 76 | 18.7 | 56 | 20.1 | 45 | 21.7 | 41 | 21.8 | 39 |
| August | 12.0 | 18 | 15.8 | 20 | 16.3 | 20 | 18.5 | 13 | 21.7 | 13 | 21.1 | 13 | 27.1 | 15 |
| Sept. | 11.1 | 11 | 11.8 | 3 | 24.3 | 9 | 19.4 | 10 | 21.4 | 7 | 28.1 | 7 | 32.8 | 2 |

**Table 5.** Total testis weight (in kg) averaged by body *length* (in feet rounded) and by period.

| *Length* | ≤56 | | 57 | | 58 | | 59 | | 60 | | 61 | | 62 | | 63 | | ≥64 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Years* | kg | n | kg | n | kg | n | kg | n | kg | n | kg | n | kg | n | kg | n | kg | n |
| 67-73 | 2.4 | 23 | 9.0 | 9 | 7.6 | 25 | 11.2 | 16 | 14.4 | 19 | 14.4 | 11 | 19.4 | 16 | 20.8 | 14 | 24.4 | 19 |
| 76-85 | 4.2 | 207 | 7.4 | 64 | 11.0 | 65 | 13.5 | 86 | 15.7 | 89 | 18.4 | 80 | 19.8 | 52 | 22.1 | 38 | 23.0 | 32 |
| 86-89 | 3.9 | 27 | 7.5 | 10 | 10.8 | 14 | 12.2 | 16 | 15.3 | 17 | 20.4 | 9 | 21.4 | 10 | 21.5 | 9 | 18.4 | 6 |
| 06-10 | 8.5 | 9 | 14.5 | 10 | 14.6 | 19 | 16.4 | 15 | 16.9 | 19 | 20.5 | 18 | 21.1 | 11 | 24.6 | 17 | 22.6 | 14 |
| All | 4.2 | 266 | 8.3 | 93 | 10.8 | 123 | 13.4 | 133 | 15.6 | 144 | 18.5 | 118 | 20.1 | 89 | 22.3 | 78 | 22.9 | 71 |

**Table 6.** By sex and period (*Years*): mean age (Age) and percentage by *length* (m) and total number (N).

| *Length* | - 17 | | 17- 18 | | 18- 19 | | 19- 20 | | 20- 21 | | 21- | | all |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Years* | Age | % | Age | % | Age | % | Age | % | Age | % | Age | % | N |
| Males | | | | | | | | | | | | | |
| 67-73 | 4.5 | 12.7 | 10.0 | 32.8 | 20.2 | 37.6 | 29.6 | 16.1 | 37.0 | 0.8 | | 0.0 | 378 |
| 76-85 | 5.5 | 21.0 | 11.0 | 38.3 | 18.5 | 31.2 | 26.3 | 9.1 | 33.3 | 0.4 | | 0.0 | 799 |
| 86-89 | 7.3 | 13.6 | 11.1 | 43.2 | 22.2 | 30.5 | 23.3 | 12.7 | | 0.0 | | 0.0 | 118 |
| 06-10 | 14.1 | 4.5 | 22.1 | 36.8 | 27.8 | 36.8 | 34.7 | 19.5 | 25.7 | 2.3 | | 0.0 | 133 |
| Females | | | | | | | | | | | | | |
| 67-73 | 3.4 | 10.0 | 5.2 | 20.3 | 9.0 | 22.2 | 16.0 | 26.8 | 24.1 | 14.9 | 33.2 | 5.9 | 370 |
| 76-85 | 4.9 | 13.7 | 7.0 | 20.7 | 10.8 | 24.6 | 16.6 | 24.9 | 23.0 | 12.5 | 24.3 | 3.6 | 912 |
| 86-89 | 5.4 | 7.3 | 8.4 | 23.0 | 12.3 | 23.6 | 19.3 | 27.3 | 23.4 | 12.7 | 30.9 | 6.1 | 165 |
| 06-10 | 10.1 | 3.2 | 17.4 | 8.7 | 24.7 | 19.8 | 28.1 | 35.7 | 29.1 | 23.8 | 35.3 | 8.7 | 126 |