Sei whale (*Balaenoptera borealis*) discovery markings in the Central Atlantic

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ABSTRACT
Markings of sei whales off Iceland took place mainly in late August and September 1979 to 1981 southwest of Iceland on the whaling grounds over or west of the Mid Atlantic Reykjanes Ridge. In total 66 whales were reported marked and 10 of these were later recovered in the catch taken on the grounds west and east of the Ridge in the autumn from the single land station in Hvalfjörður, South West Iceland where the density and arrival time of the sei whales was highly irregular. The last catches were taken in 1988. In addition two whales were marked at East Greenland in 1981 but neither recovered. Sei whale sightings in the autumn in 0-group surveys 1990-95 are not concentrated in the marking area (whaling area) but have a relatively uniform distribution south west of Iceland over to South East Greenland. Surveys in the North Atlantic in mid summer show a continuum of sightings in the wider area south of Iceland and even highest densities at the southern most limit at 50°N in 1989 in July to early August. Canada marked 30 sei whales 1966 to 1971 but none of these was recovered in the catch off Iceland. The markings farthest north on the grounds have the highest rate of recoveries which are absent from markings farthest south and in the catches taken farthest east on the grounds south of Iceland. The rate of recovery falls quickly with time though mortality is accounted for. These results are similar to those from more numerous fin whale markings in this area. These markings are clearly at the northern limit of the distribution range of the species and must be gradually diffusing into and diluted by incoming animals from the larger stock estimated roughly 10,000 animals in the midsummer surveyed area, but possibly significantly larger.

INTRODUCTION

The sei whale (*Balaenoptera borealis*) is one of three species commercially exploited by Iceland until the IWC Moratorium took effect after the 1985 whaling season. During 1948-1985 the average annual catch of sei whales taken by the Icelandic fleet was 68 animals. Catches fluctuated between 0 and 240 per year during this period (Sigurjónsson 1988). Abundance of sei whales in the whaling area west and southwest off Iceland is generally highest in late summer and fall (Sigurjónsson and Víkingsson 1997) although they sometimes arrive earlier. In addition to the commercial catches, 70 sei whales in total were taken during 1986-1988 as a part of a research programme. In 1991, Iceland proposed a so-called "Comprehensive Assessment" (CA) of North Atlantic sei whales under the auspices of the IWC and suggested an analysis of Discovery-type marking data as a part of that process (Sigurjónsson *et al.* 1991). The CA process was, however, never initiated as Iceland left the IWC the following year. In this paper this undertaking is picked up on and the available Discovery-type marking data in the Central North Atlantic summarized .

Unbiased population estimates can be obtained from mark recapture data independent of where the marking or recapture takes place, if the population mixes randomly between the time of marking and recapture. This is an unfounded assumption for whale stocks and not supported by the data presented here. Either the markings or recaptures need to be randomly placed throughout the range of a group of animals to obtain an unbiased abundance estimate of a relatively consistent group which does not mix randomly. If some areas are underrepresented in the markings and recoveries, the estimates will be negatively biased. This is definitely the case with these data. A time series of markings and recoveries in a limited area could however, provide some information on the mixing into the area over time, in particular if the age structure of the catches can be obtained, which is the case with these data, but the markings took place in just a few years and the whaling operation was terminated soon there after. In spite of these limitations there are still some interesting observations to be made from the data, and in particular a comparison to more extensive data from fin whales in the same area.

MATERIAL

There have been four successful marking efforts of sei whales on the whaling grounds off West Iceland conducted from whaling vessels by experienced gunners. These markings took place in late August and September 1979 to 1981. In addition a single whale was marked in late June 1982 and two whales were

marked at East Greenland in July 1981. All the marks were placed over or west of the Mid Atlantic Reykjanes ridge (Fig. 1). A summary of individual marking cruises is given in Table 1. The Discovery marks fired into the whales had visible streamers that were used to judge if the marking was a success (Hit) and to identify multiply marked whales.

These marks are recovered when caught whales are processed. A single land station operated in Iceland during the marking period in Hvalfjörður which is inside the Faxaflói bay on South-West Iceland. The operational range of the station was limited (Fig. 2) by the need to keep the sailing time short to bring in the meat while fresh for processing. The sei whales were taken mainly in the autumn south and south west of Iceland (from west of the Vestfirðir peninsula in the north to south of the Vestmanna Islands in the south) after the fin whale season which was mainly to the west and sperm whales were taken farther north. The seasons terminated due to short days and poor weather in the autumn and in general may not indicate a lack of sei whales within reach at that time. The last seasons terminated early because of low quotas. Sei whales were rarely caught in waters cooler than 7° off Iceland.

It is considered unlikely that any marks went undetected in this operation as all parts of each whale were processed. Some marks were found in boilers so they could not be assigned definitely to individual whales in the catch, but that does not affect the statistic here. The marks were generally found in the muscle surrounded by fibrous tissue and not apparently migrating out. All details were reported to the IWC secretariat where a complete database is held.

Total hits and recoveries by years are given in Table 2a. All marks from known multiply hit whales are included in the numbers in the tables. These are four double markings in 1980 and one double and one triple marking in 1981. Both marks from a double hit whale in 1980 were recovered in 1983 and are included. A possible hit in 1981 was recovered the same day protruding from the tail and is not included here. A second possible hit was recovered in 1983 from a whale double marked in 1980, both marks recovered, the possible hit is not included. No sei whale has been found with double marks not reported as such. There have been in total 21 possible hits and four marks hit protruding none of which are included. The recovery rate (recoveries over total number of trials=catch*marked whales) per year after marking also assuming a 5% natural mortality was computed (Table 2b). The marked whales may not be fully recruited to the catch when they are marked so the recovery rate may increase (or decrease less than expected) in the first years, so no mortality was assumed in the first year (i.e. all caught whales are considered to have been markable the year before).

Recoveries from markings by latitude is presented in Table 3 (there is little longitudinal resolution in the marking data).

RESULTS

The five recoveries up to 1982 were all west of the Reykjanes ridge where also all the marking took place, the five recoveries of six marks since then are all east of the ridge south of the Vestmanna Islands where no marking was conducted. This is likely a function of the autumn operation shifting to the south, after the protection of sperm whales took effect from 1982. Sperm whales were mostly found farther north. During the years of limited research takes (1986-1988) the seasons were generally short and most of the sei whales were taken earlier in the season and in fact no recoveries were made after 1985. In 1980 to 1982 all whales were taken west of Iceland but in 1983 only 11 sei whales were taken west of Iceland, the remaining 89 sei whales were then taken late in the autumn south of Iceland (Fig. 3). In 1984, 32 out of 95 were taken on the western grounds while in 1985 and 1987 all the whales were taken on the southern grounds. In 1986 a part and in 1988 the limited sei whale catch was taken during the fin whale hunt on the western grounds. In total only 80 sei whales out of 301 were taken west of Iceland 1983 to 1988.

The recovery rate by year after marking is given in Table 2b and falls markedly with time. The recovery rate by latitude of marking position is given in Table 3 and is highest for markings farthest north.

DISCUSSION

The recovery rate from different marking operations given in Table 1 is markedly different. There is though no logistic reason to suspect this to be a function of the operation. The same vessels and gunners were involved in several markings, mostly of fin whales, and comparison does not support operational differences.

Recoveries from fin whales marked on the grounds west of Iceland vanish with time and with the distance to the place of marking, but distant markings are relatively more likely to show up after some years.

This has been found consistent with gradual mixing of the whales on the grounds into a larger stock in other areas (Gunnlaugsson and Sigurjónsson 1989). Even within the whaling grounds there is significant short term site fidelity between years (Gunnlaugsson and Víkingsson 2008). Most likely the same applies to sei whales caught off Iceland. The number of marked sei whales and numbers caught are much smaller than for fin whales so they will not stand up to statistical significance tests, but show all the same features as found in the fin whale marking data.

As seen in Table 3 the recovery rate by latitude is highest for markings farthest north (on the grounds west of Iceland) and absent farthest south. The southernmost mark recovered was placed in June 1982. This might suggest a seasonal factor too, with whales marked to the south early in the season to be more likely to be recovered. However, there is little seasonal resolution in the data except for this single marking in June and the two marks placed at East Greenland in July, which have not been recovered and were not expected to, due to the distance. No marks have shown up in the Icelandic catches of the 30 marks placed in the West Atlantic by Canada 1966 to 1971 but three were recovered there (Brown 1977).

Although there is little longitudinal resolution in the markings there is an apparent lack of returns from markings in deeper waters (farther west) and there is a striking lack of returns in the catches farthest east (east of the Vestmanna Islands) where 141 whales are caught since 1983, while there are 6 recoveries (in five whales) farther west in a catch of 162 whales.

The fall in recovery rate with time after marking (Table 2b) need not come as a surprise. Sei whale sightings in the autumn in 0-group surveys with cetacean observers 1990-95 (Fig 4) are not confined to or even concentrated in the marking area (whaling area) but have a relatively uniform distribution south west of Iceland over to South East Greenland. NASS surveys in the North Atlantic in mid summer show a continuum of sightings in the wider area south of Iceland. The 1989 survey was later in the season (July to early August) and stretched farthest south (Sigurjónsson et al. 1991) and found even highest densities at the southern limit (at 50°North) during the latter part of the survey (Fig 5). Occurrence in the other NASS surveys (1987, 1995 2001 and 2007) and autumn 0-group surveys (also in 1983, 1984 and 1986) varied a lot and there were no observations of sei whales in spring surveys 1991-1994 around Iceland (Gunnlaugsson et al. 2004). Although the recovery rate dwindles with time, the recovery rate is still higher than what would be expected given the abundance estimates in the area. In 1989 the estimate was 10.300, CV. 0.268 (Cattanach et al. 1993) for an area down to 50°N and east of 42°W and in 1995 the estimate was 9.249 (Borchers and Burt 1997) for a smaller area. North of 54¨N There is no need to hypothesize a significant mark shedding in these operations, which is not supported by several recoveries from double marked whales, where both the marks were found (Gunnlaugsson and Sigurjónsson 1989). A high recovery of double marked whales and a recovery of a whale with two marks that were believed to have been fired into different whales, does not support high mark mortality.

The findings from mark returns are in concordance with the general knowledge of this stock. The Icelandic catch is from the northern limits of the stock and therefore the occurrence on the grounds is fluctuating in time and space with ocean currents, temperature and food availability. The sex composition of the catch in Iceland was greatly varying (Martin 1983) and genetic studies (Daníelsdóttir 199) have shown high degree of heterogeneity between years which has also been confirmed by morphometric studies (Víkingsson 1988).

CONCLUSION

The sei whale marking data in the Central Atlantic, where the highest returns between years come from markings closest to the catch position, farthest north, and soon after marking, are in accordance with progressive dispersal between years of the animals marked on the whaling grounds to other areas. Similarly, whales from other areas would be increasingly more likely to occur on the grounds during the whaling season. According to the sighting surveys these other areas must be in warmer waters, out of reach to the station, south of Iceland, over the Reykjanes ridge and over to South-East Greenland. Survey effort south of Greenland west of 42°W is very limited but there might be a continuum over to Newfoundland, but dispersal over such long distances must be very gradual and slow, given the lack of recoveries from East-Greenland and Canadian markings.

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Table 1. Classified hit marks(whales) and recovered marks(whales) from different marking operations.

Recov.	Markings	Vessel	Time	Marking area
0(0)	8(8)	#7	1979, Sep. 13-14	West Iceland south of 63°09N.
7(6)	17(15)	#7	1980, Aug. 28-30	West Iceland between 64°09 and 65°00N
2(2)	23(21)	#8	1980, Sep. 9-13	West Iceland north of 63°45
1(1)	17(14)	#9	1981, Sep. 29	West Iceland south of 63°55
0	2	Ljósf	1981, July 18	East Greenland 61°N, 36°W
1	1	AF100	1982, June 24	West Iceland 63°38N 27°W

Table 2a. Markings classified as hit marks(whales) and recovered marks(whales) by years up to 1989. No recoveries after 1985. Also given in parenthesis is the maximum number of whales marked where this is known to be different. Not included are two marks placed at East Greenland in 1981. Landed catch is given by year up to 1985, but was for 1986 40; 1987 19; 1988 9; and no sei whale catches in 1989.

		Recoveries								Marks
Markings		1979	1980	1981	1982	1983	1984	1985	Total	remaining
1979	8	0	0	0	0	0	0	0	0	8
1980	40(36)		0*	4	1	3(2)	0	1	9(8)	31(28)
1981	17(14)			0	0	1°	0	0	1	16(13)
1982	1				0	0	1	-	1	0
Total	66(59)	0	0	4	1	4(3)	1	1	11(10)	55(49)
Catch		84	100	100	71	100	95	38		

* One same year recovery of a possible hit not included.
° Both the hit and a possible hit mark were recovered two years after a possible double marking, only hit is included.

Table 2b. Number of recovered marked whales by year after marking. Also given is the sum of the product of catch and remaining marked whales and in the second last column the recovery rate per year and in the last column with assumed 5% natural mortality after the first year and years with zero returns are accumulated. Not included are two marks placed at East Greenland in 1981.

Year after marking	Catch x marked	Recovery number	rate by year	M=5% with zero years
0	-	0	-	
1	5494	4	1/1373	ditto
2	4567	3	1/1522	1/1446
3	4506	2	1/2253	1/2033
4	4049	0	0	+ 1/3779
5	2363	1	1/2363	1/1925
6	1671	0	0	+ 1/3217
7	969	0	0	+ 1/3929
8	404	0	0	+ 1/4211
9	72	0	0	+ 1/4259
10	0	-		

Table 3. Markings by latitude and recoveries on the grounds off West Iceland; no of whales (no of animals)

Position	Latitude	Hit	Recovered
West Iceland	North of 64°20N	26(22)	7(6)
West Iceland	64°15' - 63°35N	20	4
West Iceland.	South of 63°30N	20(21)	0
East Greenland	61°N, 36°W	2	0
Total		68(61)	11(10)

FIGURES

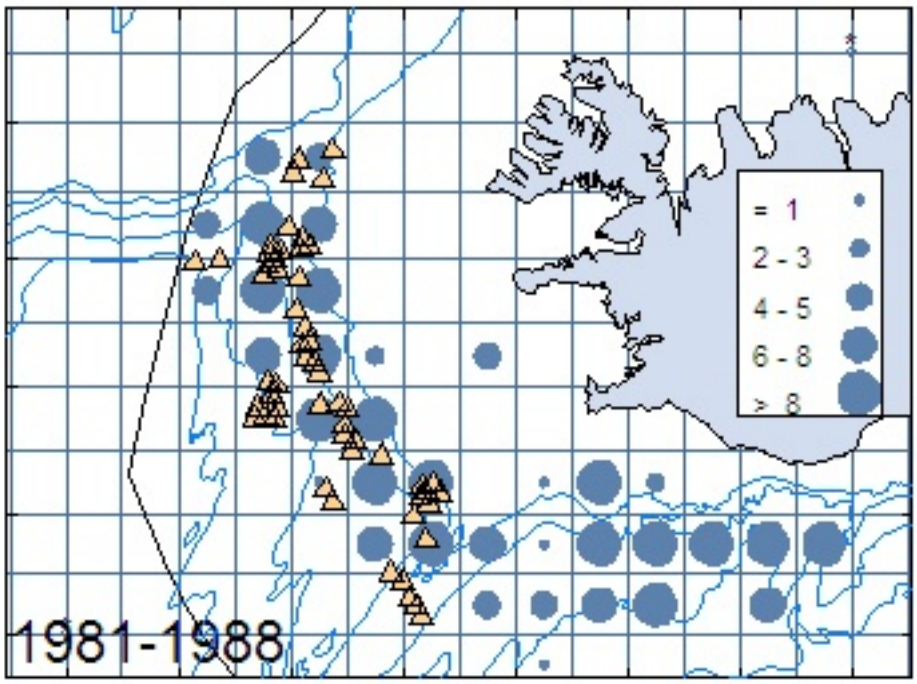

Fig 1. Sei whale markings 1979-82 (triangles) and catch positions 1981-88 (gray dots)

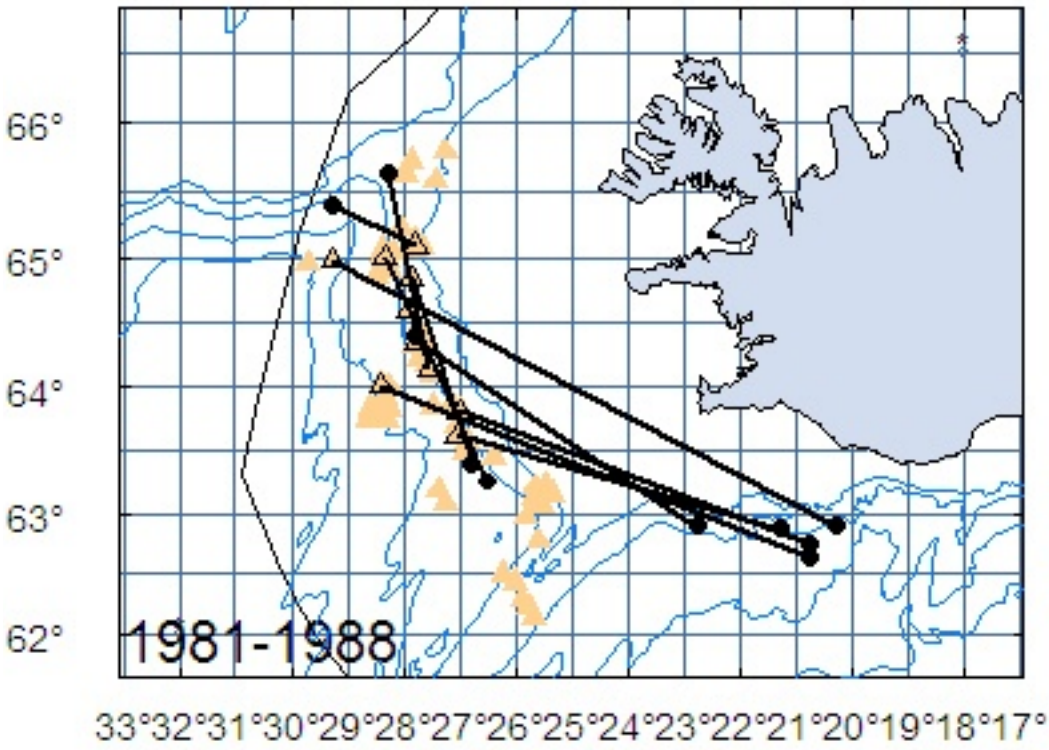

Fig 2. Sei whale mark recovery positions (black dots) connected with black lines to marking positions (black triangles) and all marking positions (yellow triangles)

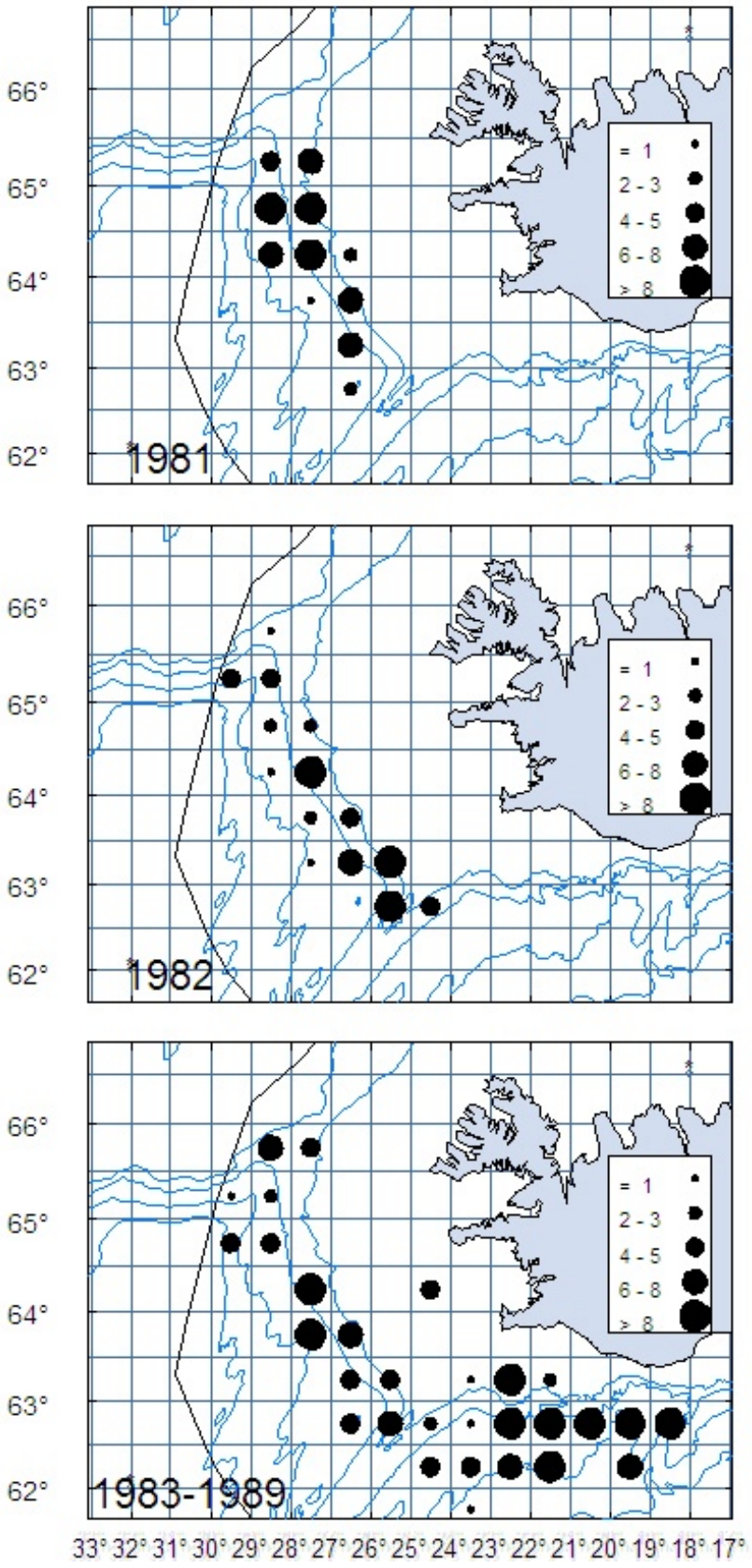

Fig. 3. Sei whale catch positions 1981 (top), 1982 (middle) and 1983-1988 (bottom).

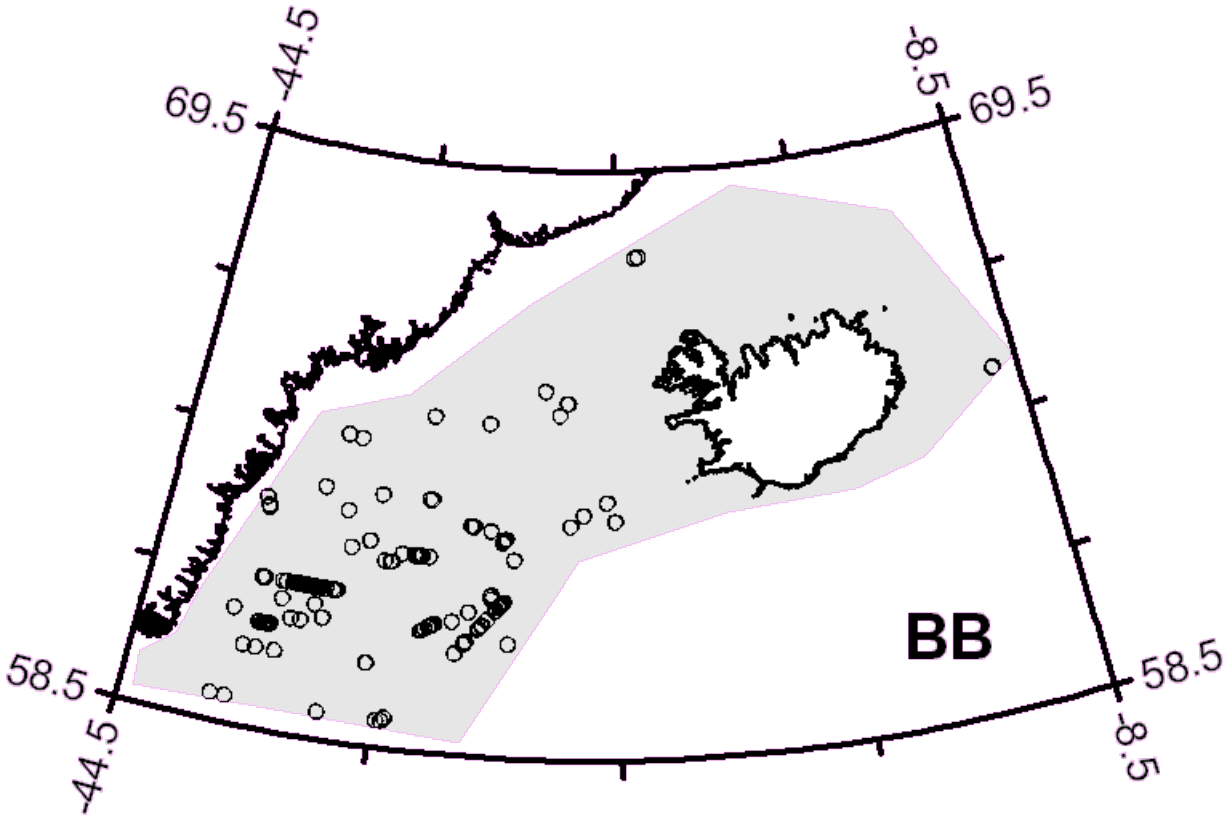

Fig 4. Sei whale sightings in 0-group autumn surveys 1990-95.

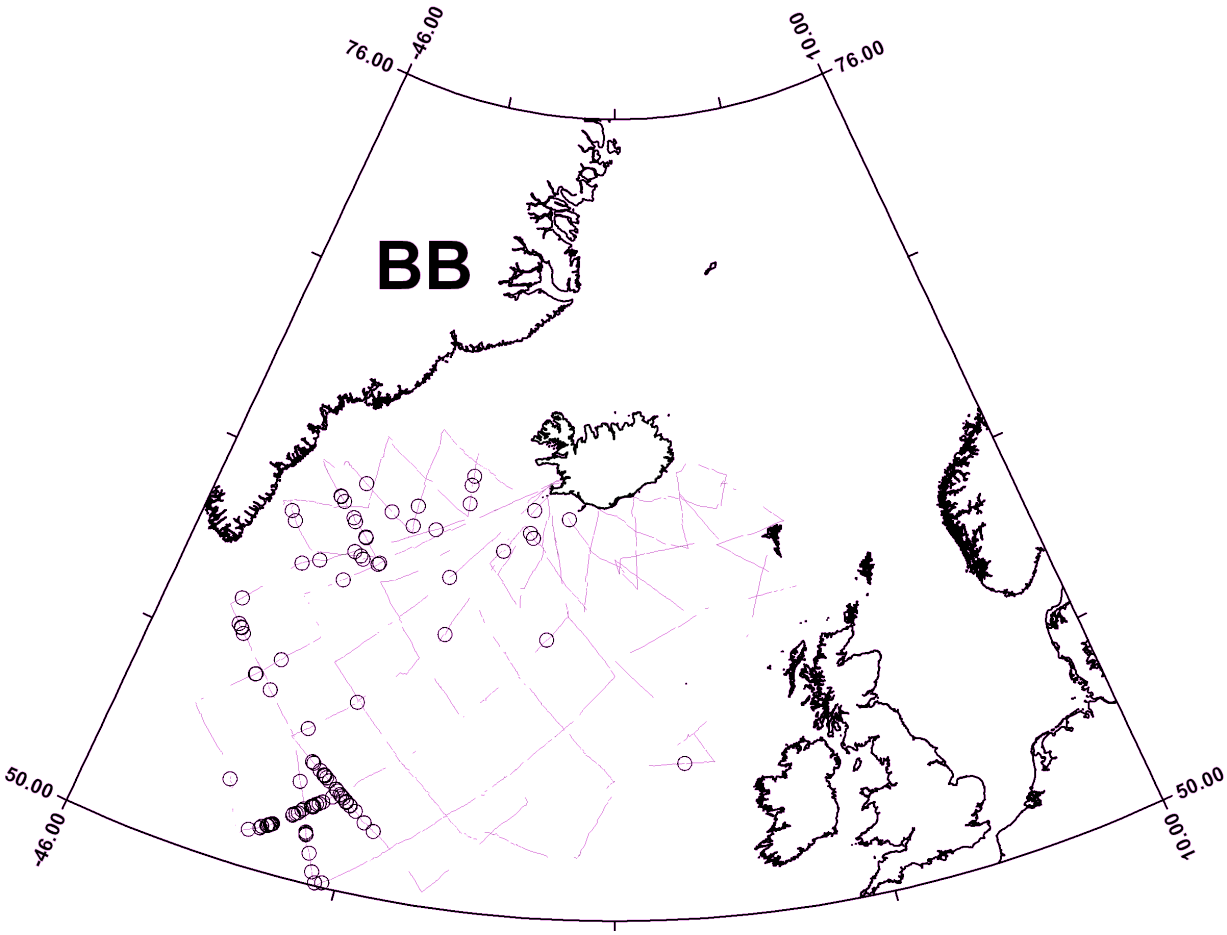

Fig 5. Sei whale sightings in July-August NASS-89