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Consultative Committee

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REPORT OF THE STUDY GROUP ON LONG-FINNED PILOT WHALES

Cambridge, United Kingdom

22 - 26 April, 1996

International Council for the Exploration of the Sea

Conseil International pour l'Exploration de la Mer

Palægade 2–4 DK–1261 Copenhagen K Denmark

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1 INTRODUCTION

1.1 List of Participants

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* Attended for part of the meeting only

Cherry Allison (International Whaling Commission Secretariat), Solange Brault (USA) and David Borcher (University of St. Andrews, UK) kindly performed some computations during the course of the meeting to assist the Group in its deliberations.

1.2 Terms of Reference

It was decided at the 82nd Statutory Meeting in 1994 that the Study Group on Long-Finned Pilot Whales would meet in Cambridge, UK with the following terms of reference (C.Res 1994/2:4):

a) complete an evaluation of the status of the long-finned pilot whales in as many regions of the North Atlantic as possible (i.e. population size and trends, population dynamics parameters), including the importance of behavioural factors and accounting for multi-species interactions;

b) identify key information gaps and critical long-term information needs.

The meeting took place at the Sea Mammal Research Unit in Cambridge from 22-26 April, 1996.

1.3 Working Papers

Working papers presented at the meeting are listed in Section 10, together with references to other documents cited in this report.

1.4 Terminology

The words "pilot whales" in this report refer to long-finned pilot whales, (*Globicephala melas*) unless otherwise indicated. Groups of animals swimming in synchrony are referred to as "schools". Several such schools are frequently seen in close association, and these larger groups of schools are referred to here as "pods". Aggregations driven ashore in the Faroes fishery are called "grinds". The size of individual whales in a grind is routinely measured using a non-linear measurement called "skinn" (for further explanation, see Bloch & Zachariassen, 1989). This measurement is used in the allocation of the catches among individuals participating in the harvest. "Significant" means statistically significant at the 5% level.

1.5 Report Structure

This reports summarises deliberations of the previous meeting of the Study Group held in 1993, as reported in document C.M.1993/N:5, and describes the Study Group's discussion and conclusions based on additional information available to it during its April 1996 meeting.

2 POPULATION IDENTITY AND SEASONAL MOVEMENTS

A number of the working papers were relevant to the discussion of the Study Group under this item (WP-1, 2, 3, 9, 10, 11). As in 1993, the discussion was structured into distributional, genetic, morphometric and other evidence.

2.1 Distributional Evidence

The information provided at the 1993 meeting led the Group to conclude that:

At the large scale, the distribution data provided no direct evidence for there being more than one population in the North Atlantic. The species occurs broadly from roughly 35 to 65° N in the western Atlantic and 40 to 75° N in the eastern Atlantic, with no indication of breaks in the distribution.

At the local scale there was, however, uncertainty as to whether all-year-round occurrence of pilot whales in some areas and seasonal occurrence in others could be used as evidence of more than one stock.

There was a major gap in information on distribution throughout the western North Atlantic from the shelf break east to 42° N.

There was some discussion on whether a direct proportionality would be expected between abundance and the number of strandings in a given area. The Group agreed that, although this might be true in some areas, in general mechanisms other than local abundance might be important. The Group recommended further research to be carried out on the following points:

Additional sighting survey data should be collected to fill the gap in coverage in the offshore waters south of Greenland.

The sighting data should be presented with some form of effort and weather adjustment, hopefully to reveal gradients in abundance.

WP-1 presented at this meeting, was a revision of a paper presented at the 1993 meeting. It describes the distribution of pilot whales in the North Atlantic based on published and unpublished data from sightings and strandings. The general distribution pattern remained unchanged. The approximate southern limit in the western Atlantic is at 35° N, and that in the east is 42° N. At the southern boundaries of the area the congeneric species, the short-finned pilot whale (*Globicephala macrorhyncus*) is also known to occur. Separation of the two species is not possible at sea. The northern limit of the long-finned pilot whale is at 65 to 67° N, as observed in the NASS surveys. The sightings data presented suggested a gap in distribution in the Channel and the North Sea and west of Scotland and Ireland (55 to 60° N), which could have indicated a gap in distribution, at least in some seasons.

The Group was made aware of a paper by Evans (1992) in which opportunistic sightings and strandings of pilot whales were reported in the North Sea and the Channel. During an extensive sightings survey concluded in July 1994 (Hammond *et al.*, 1995), however, no sightings were made in these two areas. The group concluded that although the species occurs in the Channel and the North Sea, its presence might be seasonal. Evans' (1992) paper also reported numerous sightings by weather ships west of the British Isles.

WP-9, 10, and 11 presented sighting survey data from the 1995 Icelandic and Faroese North Atlantic Sighting Surveys (NASS-95). The geographical distribution of the sightings agreed with the known distribution of the species. The group noted, however, that the distribution of the sightings varied over the years 1987, 1989 and 1995. Øien reported that data from a 1995 Norwegian survey confirmed the northern distribution limit of the species in the Lofoten area, but with relatively low densities in the Norwegian and Barents Seas.

The Study Group noted also that although the NASS-95 survey brings new information on the abundance of the species, it does not fill the gap in effort in offshore waters south of Greenland, from the shelf break east to 42° W, which had been evident at the 1993 meeting. The Group noted that it was unfortunate that the longitudinal coverage could not have been extended in the NASS 95 survey to provide comprehensive coverage of the range of the species.

The distribution of sightings of pilot whales in the North Atlantic is shown in Figure 2.1.1. All areas to the east of the dashed line between Cape Farewell and Spain have been covered in some seasons by systematic sighting surveys, as have the areas enclosed by heavy solid lines in east Greenland and eastern North America. The area enclosed by the dashed line delineates the area covered in the North Atlantic Sighting Surveys. The Group concluded that distributional evidence had not allowed it to delineate any stock boundaries, and noted again that the area south of Greenland should be surveyed to determine if the gap in sightings data represents an actual gap in distribution.

2.2 Genetic Evidence

At the 1993 meeting, the results from mtDNA analyses (sequence data from the D-loop and restriction enzyme analysis) indicated low levels of mitochondrial genetic variation. Results from allozyme studies showed a large variability but did not detect any significant genetic differences between pilot whales from the western Atlantic, Iceland and the eastern Atlantic. There was agreement that the results presented were not inconsistent with the hypothesis of a single North Atlantic stock of pilot whales, but they were too limited to substantiate such a conclusion.

In 1993, the Study Group recommended that further research be carried out on the following points:

The possibility that the low mtDNA variability compared to that in other delphinid species is related to the cohesive social structure.

Further genetic analyses using methods other than analysis of mtDNA to determine reproductive relationships within and among different groups, and to compare animals from different regions.

No further genetic work had been carried out since the 1993 meeting, and no papers related to this topic were presented. The Study Group discussed the currently available information on the genetic variability of the long-finned pilot whale, and noted the low reported variability in mtDNA (Siemanns, 1993). An explanation by B. Amos (Cambridge University) forwarded to the Group was that if pilot whales live in strong matrilineal schools, as he suspects, then the genetically effective population size is the number of genetically-related groups of animals, referred to here as pods. Small effective populations might be expected to have low mtDNA variability. The number of such related groups is not known, but may be relatively small. For example, the total population size divided by the average grind size is of the order of several thousand. Amos also indicated that recent results for another social toothed cetacean, the sperm whale, suggested very little mtDNA heterogeneity among animals from the Galapagos and the Atlantic.

Amos suggested that more information on population structure could be obtained from further genetic studies on nuclear DNA, particularly highly variable micro-satellite DNA, by comparing the within-grind variability between different areas and seasons.

The Study Group recommended that before further genetic studies are initiated, a forum of geneticists should review the available knowledge and methods with special reference to stock structure and social behaviour in order to facilitate planning of future work in this area.

2.3 Morphometric Evidence

At the 1993 meeting, a comparison was presented of body part measurements between pilot whales caught in the Newfoundland and the Faroese drive fishery. The analysis showed significant differences between flipper length relative to body length for males, and the length of the skulls and torsos for both females and males between the two areas. The Group agreed that since the conclusion regarding population structure hinges on the morphometrics analysis, the following comparative studies should be carried out:

Comparison of the measurement methods used in the two areas;

Analyses of potential changes in body size proportions during growth;

Evaluation of potential problems due to the time between the collection of the Faroese data in the 1980's and the Newfoundland data in the 1950s.

In connection with the third point it was noted that comparable morphometric measurements exist from pilot whales stranded on Cape Cod, and recommended that these be compared to the other morphological data.

D. Bloch reported that the geographical comparison of skull morphology which had been recommended at the 1993 meeting was not feasible because different ways of preparing and storing the skulls would lead to a different distortion of the skulls. There was also the problem of very low potential sample sizes.

The Study Group noted with appreciation the effort of the New England Aquarium to make the Cape Cod measurement data available for analysis (WP-3). This preliminary paper summarized the morphometric measurements which were collected from mass strandings between 1982 and 1991 on Cape Cod. An inspection of the data suggested that the Cape Cod animals were characterized by a shorter absolute eye-to-anus length compared with the Faroese animals. The Group noted that there was apparently considerable variability between the measurement for two of the strandings shown in detail, and it was confirmed that in none of the other strandings were all of the animals measured. Further analyses conducted during the meeting compared measurements from all of the strandings to those from the Faroe Islands and Newfoundland stratified by length categories. These analyses confirmed the earlier conclusion that Faroese pilot whales were different from the western North Atlantic pilot whales.

The Study Group agreed that the issues raised at its previous meeting regarding the morphological comparison between eastern and western specimens had been addressed. Collaboration between the individuals collecting the data had revealed that the methodology used in the Newfoundland study and that in the Faroes were similar and that the data were comparable. The problem of allometric growth had been resolved by treating body length as a covariate in the published analysis (Bloch and Lastein 1993). The potential problems which might have arisen from the different timing of sampling between the two sets of data, 1950's for Newfoundland and 1980's for the Faroese, had been addressed by analysis of the contemporaneous Cape Cod data.

The group concluded that there are significant differences in morphology between the Faroese pilot whales and the Cape cod and Newfoundland pilot whales. The simplest interpretation of this conclusion is that there is more than one population of long-finned pilot whales in the North Atlantic.

2.4 Other Evidence

2.4.1 Pollutants and parasites

At the 1993 meeting, the convergent results from studies on organochlorines, heavy metals and parasite loads, with significant inter-pod variation, indicated that although pods occur in the same area, they have spent different portions of their time in different areas. These data negated the hypothesis of just one resident Faroese population.

No further work pertinent to this matter had been carried out since the 1993 meeting.

2.4.2 Isotopes

Results presented at the 1993 meeting showed that the stable isotope ratios of nitrogen from tissue samples from the west coast of the US and the Faroe Islands were different. These results were consistent with animals being resident for extended periods on either side of the Atlantic, but suggest that animals sampled in close proximity can have different longer-term diets. One problem in the interpretation, however, was that the turnover rates for different tissues are unknown (Abend and Smith 1995).

No further analyses were reported and the Study Group reiterated its previous recommendation that any further analyses should take account of the differences in pollutant and parasite loads in the selection of specimens.

Teeth

At the 1993 meeting, it was reported that the patterns of dentine deposition and the easiness of age reading was different between two Icelandic schools and one Faroese school, perhaps indicating differences between grinds. The factors underlying these differences are not known, but could be based on physiological differences, genetic differences or local environmental effects. It was recommended that more Faroese grinds were investigated to determine if these observed differences in deposition and readability are part of a general pattern.

No further studies had been carried out, however, and the Group did not discuss this issue further.

2.4.3 Tagging

No data were available at the 1993 meeting, and no further studies had been carried out since. WP-5 and 6 reported on the recent developments in satellite tracking of other cetacean species, and the Study Group reiterated its previous recommendation that movements of animals in the Faroes could usefully be studied by this methodology.

2.5 Other

WP-2 analysed the latitudinal and monthly changes in length measurements made of the Faroese pilot whale catches since 1950. The measurements are in "skinn" units, a non-linear scale that relates to weight and is used in the distribution of the catches. The results indicate that:

> the main driving season was May to September in the southern region, and June to August in the north,
>
> mean skinn values did not change seasonally in either of the regions, and
>
> mean skinn values were significantly smaller in the southern region (ca. 5 skinns) than in the northern region (7 skinns).

The authors attributed the skinn difference to a latitudinal migration of pilot whales coupled with the timing of calving.

The Group considered that such a difference in the mean skinn value could be due to various factors, such as age composition or sex ratio differences between catches, and believed that further analyses were necessary before any definitive conclusion could be drawn.

2.6 Overall Conclusions

At the 1993 meeting, three hypotheses were finally formulated and examined:

1. There is only one North Atlantic population of long-finned pilot whales,
2. There is more than one such population,
3. There is only one stock in the near vicinity of the Faroe Islands, which is restricted to these waters.

The Study Group had not been able to choose between the first two hypotheses, although the morphological evidence supported the second. The Group had recommended that the resolution of the remaining uncertainties in the analysis of those data should be given high priority because of their potential importance in distinguishing between these two hypotheses.

The Group had agreed that the third hypothesis was unlikely to be true on small spatial scales based on variability in pollutant and parasite loads observed for animals in the Faroese catches. Further, large differences in inter-annual distribution patterns could be seen in the sighting survey data, supporting movements over larger spatial scales than the survey blocks.

Based on the new information presented to this meeting, the Group agreed that the first hypothesis can be ruled out by the morphological differences seen between the eastern and western Atlantic animals.

Further, the Group confirmed its previous conclusion that the third hypothesis is probably false at the scale of the survey blocks; that is, the animals in the Faroes do not form a discrete localized population. The high inter-annual variability in distribution patterns that this conclusion was in part based on was confirmed by the data from the NASS 1996 survey.

The group recommended that a complete statistical analysis of the morphological data be completed and that the data in WP-1 be updated to include Evans' data and the French sighting and stranding data.

3 SOCIAL STRUCTURE AND BEHAVIOURAL FACTORS

Genetic studies based on samples of complete grinds collected from the Faroese fishery suggest that pilot whales occur in genetically related groups, referred to here as pods (Andersen 1993, Amos *et al.*, 1993), and further that mitochondrial DNA from animals across the Atlantic showed very low levels of variability (Siemanns 1993). The Study Group reviewed this information at its previous meetings, and, although it was unsure how to interpret it in part due to the sample sizes used for some of the studies, recommended that the implications of this apparent group structure for the ability of the population to support different levels of mortality should be investigated.

The genetic evidence is based on three methods of analysis: protein polymorphisms, DNA fingerprinting and micro-satellite polymorphisms. Allele frequencies of three polymorphic allozyme loci for thirty-one grinds, totalling 1948 individuals, were heterogeneous among schools, and within schools by age. These data were interpreted to imply that animals within pods were more closely related, that mature females compose the core of the pods, and that males breed outside their pods.

Genetic differentiation among animals from different grinds was confirmed by DNA fingerprinting of 100 individuals from two pods (Amos 1993). Further analyses of these data revealed that the proportion of animals accompanied by their mother was 46%, and declining with age. A low proportion not significantly different from zero were estimated to be accompanied by their fathers. An index of genotype frequency was shown to increase with age for both male and female animals from one grind, further confirming the hypothesis that females compose the core of the group and that, while males remain in their natal pod, they do not breed with females in that pod.

Low mitochondrial DNA variability was demonstrated from animals sampled in Canada, the US, the Faroes and the United Kingdom, with most animals being identical (Siemanns 1994). Although this comparison was made to test for population discreteness, the interpretation of its unexpectedly low variability was of interest to the Group.

Since the last meeting of the Group, one new paper has been published (Andersen and Siegismund, 1994), further exploring the potential for movement of males among pods. No other working papers were presented on this topic. Because again no individuals with genetic expertise participated in the meeting, the Group was unable either to adequately review the new paper adequately or to evaluate its earlier concerns about the inferences being made from earlier genetics studies. The Group strongly recommended that a review of the available genetic information be conducted, with an eye to determining priority for subsequent analyses.

The Group also noted that the average size of the grinds and the average size of schools of animals sighted during surveys was markedly different. Pilot whales have frequently been observed to occur in several small groups dispersed over several kilometres, but the Group was unaware of any systematic attempts to estimate the total number of animals in an area. Determining the causes of the difference between the grinds and schools sighted during surveys had been recommended as a high priority.

Desportes (WP-7) reported a preliminary attempt to determine spatial structure of pilot whale schools during the 1995 Faroese sighting survey. She adopted a novel procedure of conducting a 360° scan of the area in the vicinity of a school sighted during the sighting survey to identify other schools of animals. She then closed on each of the other schools seen in turn, mapping their relative locations. This study indicated that estimates of the size of schools tended to increase with closer inspection, and that schools were spread out over several kilometres. The total number of animals in the aggregations investigated were, however, still less than the average grind size (this matter is discussed further in Section 4.1).

The implications of the harvested groups of animals being genetically related were explored in WP-16 and in Zabow and Butterworth (1994). Kasuya (WP-16) reviewed social factors which should be considered. He noted information on killer whales, and suggested that pods may split so that the age structure would not differ between the two resultant pods. He noted the potential for adverse and beneficial effects of pod splitting in per capita food availability, in decrease in information and experience within the smaller pods, and in the potential for decreased survival rates with smaller pod size. He identified possible density-dependent mechanisms in terms of both the number of individuals and number of pods in the population, and the number of animals within pods.

Zabow and Butterworth (1995) explored the impact of cohesive social structure on the dynamics of cetacean populations. They hypothesized that small groups of younger animals split from their parent groups once these exceed a certain size, and that per capita growth rates are less for these smaller groups as they are less successful in protecting their young from predators. They found that this effect, coupled to an exploitation pattern which removes only the larger groups, led to lesser sustainable yields than could be taken from an equivalent population without such group structure, but the difference was at most a few percent for the parameter values investigated.

The Group discussed some aspects of this topic in the context of other discussions, but did not have sufficient time to address this agenda item in sufficient detail. However, it was noted that there does not appear to be sufficient information available about the specifics of the social processes involved in pod formation and creation, and their ecological implications, to allow the concerns about the implications of these processes on the ability of pilot whales to support harvesting mortality to be completely addressed.

4 ESTIMATES OF ABUNDANCE

4.1 Eastern Atlantic

Line-transect estimates of abundance, based on the 1987 and 1989 North Atlantic Sightings Surveys (NASS-87 and NASS-89) were presented in the report of the Study Group's 1993 meeting and in Buckland *et al.*, (1993). The NASS-89 survey covered the greater area. When the Icelandic, Faroese and Spanish data are combined, they result in a total abundance estimate of 778,000 whales (CV=0.295). The area of the eastern Atlantic to which this estimate applies is indicated in Figure 2.1.1. The abundance estimates for all survey blocks in both 1987 and 1989 are given in Tables 4.1.1 to 4.1.3 and the localities to which they correspond are shown in Figures 4.1.1 to 4.1.4. The Norwegian contribution to these joint international surveys covered the remaining parts of the Norwegian Sea and the Barents Sea in the far north, but resulted in no pilot whales being observed in 1987 and only five sightings in the 1989 survey. The 1989 abundance estimate may be biased downward somewhat as smaller schools may be missed on the trackline.

WP-7, WP-9 to 11, and WP-19 presented pilot whale observations from the NASS-95 surveys conducted by the Faroe Islands and Iceland making use of three survey vessels and one aircraft during July-August 1995. As in earlier years, the Norwegian component of the NASS-95 confirmed scarcity of the species in the Norwegian and Barents Seas with only two sightings (six sub-groups) made (Oien, pers.commn.).

WP-9 provided results of an experiment to estimate g(0) (the probability of detection on the trackline), and indicated that g(0) is near unity when two sightings platforms are used. Furthermore, a study was conducted to address a problem identified in earlier surveys relating to the representative position and total school size of sightings. This arises because, upon the vessel approaching the sighted school, it usually becomes evident that more whales are present, either through the school itself being larger than initially thought, or because other schools are seen in close proximity. It was concluded that this problem could be resolved to a large extent by regular closing on sighted schools (rather than closing on an opportunistic basis) and by mapping positions of subgroups. Furthermore, this experiment demonstrated that regular closing on pilot whale sightings is a necessity on surveys that otherwise are planned to be conducted in passing mode, since estimates of school sizes when the animals are first sighted were shown to be seriously biased downward. These observations also explain to some degree the apparent discrepancy between the average grind size at the Faroe Islands, and the mean school size reported from sighting surveys.

In the light of these results obtained by the 1995 Faroese survey, the Study Group discussed whether there remained reasons to continue to suspect that pilot whale school sizes developed from Icelandic vessels in NASS-89 were under-estimated. However, since the Icelandic vessels had employed a delayed-closing mode rather than passing mode, particularly in areas of low baleen whale abundance (baleen whales were the primary target of the survey), this was not considered a cause for concern. It was noted (WP-19) that the analysis of the Icelandic 1995 sightings data gave higher estimates of abundance when restricted to survey in conditions of less than Beaufort 3. The potential source of negative bias in abundance estimates through surveying in poor conditions (high Beaufort) when pilot whales are more difficult to see requires further study.

As evident from Figures 4.1.1 to 4.1.4, the coverage of the three surveys (NASS-87, 89, and NASS-95) was not identical. When abundance estimates for comparable areas in 1987 and 1989 were compared, no significant differences were evident. However, when abundance estimates for the Faroese blocks 10, 40, and 50 in 1989 and 1995 (WP-9, Table 4.1.2) were compared, there appeared to be a significantly lower density in 1995. Both surveys were conducted comparably - passing mode but with regular closing. Densities in comparable Icelandic blocks in the 1995 (WP-19) and the 1989 surveys (blocks 36, 93, 94, 95, and parts of 40 and 70, see WP-19 and Tables 4.1.1 and 4.1.4) are not significantly different. Comparable blocks in the 1987 and 1995 surveys (i.e. blocks 2, 36, 88, 93-95 in 1987; blocks 2, 3, 8 and 9 in 1995) show similar estimates of abundance (WP-19). Although the combined estimates from these surveys are similar, between-year shifts in densities across survey blocks were observed. Given the mobility of the species, the apparent between-year shifts in distribution, and the relatively thorough and extensive coverage of NASS-89, the Study Group considered the estimate derived from the joint surveys in 1989 to be the most appropriate.

4.2 Western Atlantic

In the western North Atlantic, no synoptic view of the distribution and abundance of pilot whales based on systematic sightings surveys is available. Past surveys for pilot whales in this region have had very limited area coverage (see Figure 2.1.1), with the result that the associated abundance estimates give little indication of the abundance for the whole region. Off Newfoundland, Hay (1982) reported an estimate of abundance in the range of 13,000 animals. Mercer's (1975) estimated initial population size for the stock harvested off the Newfoundland coast is in the range of 50-60,000 animals, while Mitchell (1974) using cumulative catch data (1950-60's) arrived at an initial population size (lower bound) of 54,000 whales. Further south at the shelf and shelf edge waters off the US Atlantic coast, the CeTAP survey conducted during 1978-1981 (CeTAP, 1982) gave an estimate of 11,120 (CV=0.29) animals, while more recent aerial surveys conducted in 1991 (WP12) gave a figure of 5,377 (CV=0.53) animals.

5 ESTIMATES OF TRENDS IN ABUNDANCE

5.1 Eastern Atlantic

The Study Group noted that although Hoydal and Lastein (1993) had failed to detect significant changes in the mean size of pilot whales caught over the last 50 years, which could indicate a stable stock, the slow growth rate of older animals probably meant that the statistical power of such measures to detect changes was low.

The Group discussed the possiblity of inferring trends in abundance from information on the number of natural strandings. It noted that there was no evidence for a relationship between stock abundance and the rate of occurrence of such strandings. It considered that the ratio of natural strandings to removals by the fishery was not likely to cast light on the actual fishing mortality since, as an extreme example, a high stranding rate could simply reflect an epidemic occurring in a depleted population, rather than a large stock of whales. While Hoydal and Lastein (1993) found some long-term correlations between temperature and catch levels of pilot whales in the Faroe Islands during the period 1709-1992, the reversal in the sign of the correlation around 1920 weakens the usefulness of this relationship in understanding and predicting trends in abundance.

A relationship was found between squid catches in the area and pilot whale drives, and between the timing of pilot whale catches and in the occurrence of blue whiting in their feeding area in the Norwegian Sea. The migration of blue whiting in the Faroe area differs from year to year between the Faroe-Shetland Channel, the Faroe Bank Channel and east of Faroe Bank and is correlated with the position of the fronts between the currents in the area. There seems to be a relationship between the blue whiting migration route in a particular year and the location of the pilot whale catches in the Faroes.

One aspect of the pilot whale drives in the Faroe Islands that had not been discussed earlier by the Study Group was trends in the sex ratio with time, which could relate to population size trends (Bloch and Lastein, 1995). Bloch (1992) reported a significant difference in the sex ratio between the periods 1870-1872 (33.6% males) and 1952-1985 (40.0% males). No such difference was detected between this more recent Faroese sample and the samples collected from the Newfoundland fishery in the 1950s to early 1970s. In Bloch and Lastein (1995) relationships were sought between the long-term catch series and the Faroese valuation of whales (in "skinn"), the observed differences in sex ratio with time and the maturity distributions from studies in the 1980s. A long-term oscillation with time in the mean size of pilot whales seemed to be related to long-term climatic variations. These seem to influence the food sources in the Faroes area, as has also been shown in other long-term studies of the occurrence of guillemots, puffins, cod and herring in this area (Reinert, 1976).

5.2 Western Atlantic

Mercer (1975) used a DeLury model to estimate initial pilot whale population off Newfoundland of less than 60,000, with the number remaining at the end of the catch period (1972) of less than 19,000 animals. However, this analysis makes a number of key assumptions that may not be justified relating, for example, to constancy of fishing effort, an availability correction related to squid landings, and an absence of distributional shifts. No new evidence on trends in abundance from this area was available to the Study Group.

6 HISTORICAL CATCH ESTIMATES, POPULATION DYNAMICS PARAMETERS AND POPULATION MODELS

6.1 Historical Catch Estimates

At the previous meeting of the Study Group, available information on directed fisheries, strandings and bycatches of pilot whales in other fisheries were tabled by nation. This information was updated at this meeting (Table 6.1.1).

6.2 Population Dynamics Parameters

6.2.1 Age at First Ovulation and at First Lactation

At its previous meeting the Study Group had considered a range of estimates of age at first ovulation based on an analysis of material collected from grinds in the Faroe Islands between 1986 and 1988. In WP-14 and WP-15 the identical material (from 7 grinds) was used to allow comparable estimation of age at maturity (8.2 years) and age at first lactation from an analysis of the histological structure of mammary gland samples. Depending on the criteria used to decide whether an animal had begun to lactate, age at first lactation (equivalent to age at first parturition) was estimated at 11.2 years or 14.4 years. If the sample from one 19 year old female which had never lactated was excluded, then mean age at first parturition was estimated at 10.6 years, and a mean number of ovulations at 1.2. The difference between the age at first ovulation and even the lowest estimate of age at first parturition is greater than the estimated length of gestation (now accepted as 12 months, see Martin and Rothery, 1993). This implies that some females do not give birth to a live calf after their first ovulation. The higher estimate for the age at first parturition implies that some females ovulate for the first time several years before they give birth to their first calf. The Study Group noted that inhibition of reproduction in sexually mature females is not uncommon in social mammals (I. Boyd, pers. comm.). It therefore recommended that values for age at first parturition ranging from 10 to 14 years should be used in population model analyses, though considered that the lower end of this range was the more likely.

6.2.2 Pregnancy Rates and Inter-birth Interval

The Study Group had experienced some difficulty in interpreting the results of estimates of inter-birth interval (the inverse of the fertility rate) during its 1993 meeting. It had recommended further analysis of this material which was provided in WP-17. A logistic regression had been fitted to data on the proportion of sexual mature females at age using data from Faroese grinds collected in 1986-88. Age-specific fertility rates were then calculated by multiplying the estimated pregnancy rate for each age by the proportion of mature animals in that year class. This analysis indicated that the highest fertility rates occurred in 10 year old animals and that fertility declined with age. Animals over 32 years old were classified as reproductively senile, even though there was evidence that they continued ovulation and were still lactating. These results are broadly in line with those found by Martin and Rothery (1993), and the Group accepted them as the best available estimates of age-specific fertility rates. Production of female young was estimated by multiplying estimated fertility rates by 0.7 to allow for the higher proportion of female calves which has been observed in pilot whale populations (Desportes *et al.*, 1994).

6.2.3 Age-specific Survival Rates

At its 1993 meeting, the Study Group had reviewed estimates of age-specific survival rates based on analyses of the age structure of complete grinds. However, because in general observed age structure depends not only on age-specific survival rates, but also on age-specific fishing selectivities, the rate of increase of a population, and the history of recruitment to that population, the Group had recommended further analysis of these samples. WP-17 reported on further analyses of these data and addressed some of these concerns. Age-specific survival rates for females had been estimated from the ratio of points along a smooth function fitted to the age structure using the LOESS method. This assumes that the age structure is stable and that the population is stationary. When the estimates of survival and fertility were combined in a Leslie matrix model, it was clear that they implied that the population was increasing at roughly 5.7% per annum. However, the observed age structure is incompatible with this. In particular there is almost no difference between the number of animals in age classes 10-25, which is impossible for a steadily increasing population. This implies either a very high survival rate in a population with a low (or zero) rate of increase, or that the animals from this part of the age structure were born during a period of declining recruitment. An examination of the skinn data suggested that the latter possibility is unlikely, although it cannot be ruled out. To render the results from the Leslie matrix model compatible with the observed age structure, a term for intra-uterine mortality was introduced. Intra-uterine mortality is known to occur in many large vertebrates, and occurs in pilot whales leading to the observed skewed sex ratio at birth (Desportes *et al.*, 1994). The intra-uterine mortality which results in a zero population growth rate is 0.62.

6.2.4 Maximum Population Growth Rate

The Study Group agreed that the value of roughly 5.7% obtained in WP-17 as the growth rate of a pilot whale population with zero intra-uterine mortality was a plausible upper bound on that growth rate. In principle, this bound could be higher if survival or fertility rates increase in response to density dependence, but the values for both of these factors used in the calculations seem close to biological maxima.

6.2.5 Input Values for HITTER

The HITTER procedure which is used in Section 6.3 to examine the effects of catch histories and growth rates on population trajectories is based on a simple age-structured model. Parameter estimates obtained in WP-17 and WP-15 were adopted for use in this procedure, as indicated below.

Age specific natural mortality: WP-17 indicates that female pilot whales can be conveniently classified into five categories (two categories of juvenile animals, two of mature animals, and senescent animals). Estimates obtained from WP-17 for annual natural mortality for these categories were as follows:

1. juvenile (ages 0.5 to 8): roughly constant at 0.05
2. first mature stage (ages 9 to 20): 0.02
3. second mature stage (ages 21 to 31): 0.06
4. senescent stage (ages greater than 31): 0.15 on average.

Age at maturity: Values of 9 and 13 years were used, corresponding to the range of estimates of 10-14 years estimated for age at first parturition with a gestation period of about one year. Model results were, however, insensitive to the choice between these two values, so that results are reported for the lower value only.

Age at recruitment: It is believed that the Faroese drive fishery is non-selective, and thus all animals are subject to the same fishing mortality. HITTER cannot, however, operate with an age at recruitment less than 1 year, so that knife-edge recruitment at that age was assumed. The model results would be insensitive to ignoring the calves in this way.

Effects of senescence: WP-17 indicates that fertility declines with age and that some older animals do not reproduce at all. HITTER calculates an average fertility rate for all mature animals which is compatible with a pre-specified maximum sustainable yield rate (MSYR). MSYR is related directly to the maximum population growth rate. This analysis, therefore, does not account for age-specific fertility which could influence the population trajectory - although such effects are unlikely to be large in a fishery which is not age selective.

MSYL: The population size which gives maximum sustainable yield (MSY) was assumed to be 60% of carrying capacity, based on the value which has been used by the Scientific Committee of the International Whaling Commission for modelling the dynamics of baleen whales. Although the predictions of HITTER are generally relatively insensitive to this value (Allison 1989), the Group noted that this value may well be greater for a highly social species like the pilot whale. Both MSYL and MSYR (=MSY/MSYL) can be expressed in terms of different components of the population (e.g. mature animals or animals one year old and older) selected by harvesting; the Group used the animals one year old and older for this computation.

6.3 Population modelling

The Study Group decided to use a simple population model to investigate the implications of three sources of information on the pilot whale population in the eastern North Atlantic. These are the possible range of maximum growth rates for the species (implied by biological parameter values as discussed in Section 6.2), recent estimates of abundance (see Section 4.1) and historical series of catches (see Section 6.1). In the absence of new information, no modelling of the pilot whale population in the western North Atlantic was attempted.

The Group elected to use the "HITTER" procedure (de la Mare, 1989; Punt and Butterworth, 1991) for this purpose. This procedure makes use of an age-structured population model with density dependence in fecundity to compute population trajectories which pass through a particular estimate of population size. Pilot whales exhibit sexspecific natural mortality. The HITTER procedure cannot model differences in natural mortality between the sexes. The analysis was therefore conducted for the female component of the population only under the assumption that the population is 60% female (as indicated by data from recent Faroese grinds, and supported by information from mass strandings in other areas). Technical aspects of the HITTER computations are detailed in a footnote to Table 6.3.1. The justification for the choice of specific demographic parameter values has already been described in Section 6.2. The output from HITTER is generally relatively insensitive to the choices of biological and technological parameter values (see, for example, Allison 1989). The trajectories calculated by HITTER are, however, critically dependent on the estimate of population size through which the trajectory is constrained to pass and the maximum growth rate assumed for the population, as discussed below.

The NASS-89 surveys provided an estimate of 778,000 pilot whales in the eastern North Atlantic (see Figure 4.1.1). However, all of these animals do not necessarily belong to the population impacted by catches in the Faroes. It was therefore decided to carry out computations for population estimates corresponding to a series of progressively larger areas adjoining the Faroes. The smallest such area chosen was block 17 for NASS-1987, the "Faroe Islands Area." Other areas chosen were: blocks 10, 88 and 20 from NASS-89, the "Rockall-Iceland Area"; blocks 10, 88, 20, 36, 40 and 50, "Mid-Atlantic Ridge-Faroes Area", and finally the total area covered by NASS-89 (see Figure 6.3.1). The respective population estimates for these four Areas are 55,000, 110,000, 420,000 and 778,000.

The Group had agreed (see Section 6.2) that 5.7% is a plausible upper bound for the annual growth rate of a pilot whale population. However, this rate may not be achieved in practice, so that computations were also carried out with maximum growth rates of 0%, 1.4%, 2.8% and 4.3%, corresponding to 0, 25, 50, and 75% of this upper bound. The first of these levels (0%) is included only as a baseline to show the effect of accumulating catches.

The Faroe Islands Area is probably unrealistically small. The estimate of abundance from the 1995 survey (WP-9), which surveyed a larger block, is significantly lower than that for block 17 in NASS-87. This suggests that at least some of the pilot whales which occur around the Faroe Islands move on a spatial scale larger than that of block 17. This interpretation is supported by variations in the pollutant and parasite burden between different schools caught in the Faroe Islands.

The model used requires estimates of historical catches. The Group assumed that all of the catches recorded in Table 6.1.1 from Greenland eastward came from one population. The Group did this because information to allocate the catches spatially was not readily available. Alternative assumptions would not, however, substantially affect the results presented below because the non-Faroese catches are small by comparison. Catches remained relatively stable between 1840 and 1930; they rose sharply around 1940 and have fluctuated since then (Figure 6.3.2).

HITTER computations assume the population to be in equilibrium at carrying capacity at the time of the first catches in the time series of historical catches input. It is known that catches were taken before the first year chosen for the series used (1709), but the catch data are less reliable before this year. Failure to account explicitly for such earlier catches is not, however, seen as likely to introduce a serious bias in results (except, of course, when the maximum population growth rate is assumed to be zero) because, for the other growth rates considered, the trajectories have essentially stabilized under the effect of earlier levels of catch by the mid-1800's; results are provided only for subsequent years.

The Study Group attempted to identify some summary statistics which captured the important features of the population trajectories. The results of this attempt are shown in Table 6.3.1. However, the Study Group concluded that the qualitative features of the trajectories are more reliable than the quantitative ones. Trajectories from 1840, for all combinations of Area and maximum population growth rate, are shown in Figure 6.3.3.

The Group stressed that the quantitative results shown in Table 6.3.1 and Figure 6.3.3 should be interpreted with caution because:

a) of the necessary assumption of invariance of parameters (including, in particular, carrying capacity) and density dependent behaviour over a period of centuries;

b) the HITTER procedure used does not properly account for the known reproductive senescence in female pilot whales;

c) of the absence of any possible effects of social structure in the population model.

7 MULTI-SPECIES INTERACTIONS

The terms of reference for the Study Group indicate that multi-species interactions are to be taken into account in evaluating the status of pilot whales in the North Atlantic. At its previous meeting the group noted that information pertinent to multi-species interactions was limited. Pilot whales appear to prefer squid of several species, but also consume a wide variety of fish species. There are commercial fisheries on several of the prey species on both sides of the Atlantic. Differential retention of hard parts of these prey items in pilot whale stomachs makes quantitative comparison of dietary preference difficult from the available stomach samples. The level of overall consumption of prey also harvested by man is difficult to evaluate based on the information on fishery resource distribution and pilot whale distribution, and available models to integrate this information such as multispecies VPA and the Norwegian cod-capelin model MULTSPEC may be of limited utility in application to multi-species aspects of pilot whales.

Shortage of time precluded a detailed discussion of this topic by the Group, but the following new information was noted. Abend and Smith (WP-4) presented results of the application of stable isotopes of nitrogen and carbon to western Atlantic pilot whales and their prey. These results confirm the preference for squid, but suggest a seasonal variation between squid and Atlantic mackerel. Bloch reported that an analysis of historical changes in abundance of several harvest species in the Faroe Islands was completed earlier, with the unpublished manuscript written in Faroese (Reinert, 1976). That analysis suggested that there have been substantial contemporaneous changes in availability of several fish, bird and cetacean species in the past. The Group recommended that this paper be translated into English.

8 STATUS EVALUATION

The Study Group agreed to consider the pilot whales from the eastern and western North Atlantic as two stocks for the purpose of evaluating status. This agreement was based on analyses conducted since the Group's last meeting, which have confirmed significant morphological differences between animals from the Faroes and those from Newfoundland and Cape Cod. The Group accepted the estimate of 778,000 for the number of pilot whales in a large portion of the eastern North Atlantic provided in its previous report (C.M. 1993/N:5, see also Buckland *et al.*, 1993). There is no comprehensive estimate for the western part of the North Atlantic. No direct information on trends in the abundance of pilot whales in the North Atlantic was available to the Group. Information on population dynamics parameters is given in Section 6.2. The Group attempted to obtain indirect information on trends in abundance in the eastern North Atlantic by means of the population model described in Section 6.3.

The analyses described in Section 6.3 indicate that the effects of documented catches of pilot whales in the eastern Atlantic depend critically on what assumptions are made about the geographic range of the population that is affected by these catches and on the maximum population growth rate. If the whales which are caught in the Faroe Islands come from the *Mid-Atlantic Ridge-Iceland Area* or the area covered by the NASS-89 sighting survey, then catches over the last 150 years have had scarcely any impact on the population trajectory (Figure 6.3.3). However, the qualitative effect of the catches is very different if they have come from a population with a geographic range the size of the *Rockall-Iceland Area* or the *Faroe Islands Area*. For these two Areas, for higher values of the maximum population growth rate (4.3% and 5.7%), the larger catches which have been taken since 1940 cause an initial decline, but population numbers are relatively constant after 1955. For the lower values (1.4% and 2.8%), however, the decline since 1940 is continuous and its magnitude increases as the growth rate decreases.

The Group concluded that it was extremely unlikely that the catches in the Faroe Islands (Figure 6.3.1) came only from a population restricted to the *Faroe Islands Area*, for reasons discussed in Section 6.3. The Group had no information which would enable it to determine which of the other Area boundaries was most appropriate. However, it noted that although there was a relatively small difference between the size of the *Rockall-Iceland Area* and the *Mid-Atlantic Ridge-Iceland Area*, there was a very large difference in the effect of the catches. This observation suggests that much of the uncertainty about the status of pilot whales in the eastern North Atlantic could be resolved by a tagging research programme in this area using satellite tags (WP-5, WP-6). Tags should be attached to a number of individuals in different pods. If tagged animals cross the boundaries of the *Rockall-Iceland Area*, this would imply that catches made in the Faroe Islands are taken from a population whose range is greater than that Area.

Additionally, some of the uncertainty about the status of pilot whales could be resolved by improving estimates of the population growth rate. A comparison of the ratio of the number of calves to the number of mature females in individual grinds with the estimates of fertility provided in WP-17 would allow the combination of intra-uterine and neo-natal mortality to be estimated. This would allow direct estimation of current population growth rate for the population of whales exploited by the Faroese fishery.

Despite having insufficient time to address the matters of behavioural factors and multi-species interactions (Sections 3 and 7) adequately, the Group judged that current knowledge on these topics is not yet sufficiently extensive to have affected its conclusions above. The Group therefore agreed that it had successfully addressed its terms of reference to complete an evaluation of status as well as possible at present.

9 FUTURE RESEARCH REQUIREMENTS

The Study Group noted that its identification of some 22 research needs during its previous meeting had proven useful in that many of those had been addressed in the intervening period. Various published papers and working papers to this meeting documented the results of those investigations. In addition, members reported verbally on some items which did not prove as useful as hoped upon further investigation. Referring to the numbering sequence in the previous report (C.M. 1993/N:5, pages 11-13), the items which have been partially or completely addressed include: 1, 2, 3, 4, 6, 7, 8, 10, 11, 12, 14, 15, 17, 19, 20, 21. Those items for which further work is still warranted are included below.

Understanding of the status of the long-finned pilot whale in the North Atlantic has improved substantially as a result of research conducted in recent years, especially in the eastern Atlantic. The major **uncertainties in population status advice** given in Section 8 are in the potential and actual population rates of increase and the geographic areas over which pilot whales range. In the western Atlantic, where the Group was unable to provide any advice on population status, major uncertainties in population size and distribution, and on the geographic areas over which whales range remain. The Group recommended that to resolve the issues of status of pilot whales in the North Atlantic, those areas of research described below should be given highest priority.

In addition, the Group noted that it had been unable to include several additional aspects of the biology of pilot whales in the evaluation of population status attempted above. For example, behavioural factors and multi-species interactions have not been sufficiently evaluated. Further, there are several areas where further research is required to develop a reliable long-term monitoring programme for the Faroese fishery. Research addressing several other **uncertainties about population status** are described below. The Group agreed that three among these should be given highest priority. One is that previous genetic analyses be reviewed, with a goal of developing priorities for further genetic studies related to population discreteness and social structure. The second is that a long-term research and population monitoring strategy be developed related to the Faroe Island fishery, based on an in-depth review of previous and current fishery monitoring procedures and the extensive research conducted in the Faroe Islands since the mid-1980's. The third is that to understand the geographic ranges of the affected whales better, a systematic programme of further laboratory and statistical analyses be conducted focusing on those schools sampled in the Faroe fishery which appear most distinctive, for example in pollutant and parasite burdens and size composition.

The Study Group noted that the ICES forum has played an important role in organizing research needs over its duration, in providing a valuable dialogue among researchers in the member nations, and in providing the stimulus to get work completed in a timely manner. Based on this experience, members agreed that to carry out the research described above adequately will require a multi-national effort among all countries bordering the range of pilot whales, and an international scientific forum for coordination and review. They also judged that further review of the status of pilot whales in the North Atlantic would be useful only after substantive additional information becomes available from such research.

9.1 Research Related to Uncertainties in Population Status Advice Given

9.1.1 Information on the size of the population subject to the Faroese fishery

The dependence of the inter-annual variability in distribution patterns reflected in the data from the several sighting surveys conducted in the same area in successive years should be evaluated over varying spatial scales. This would improve indirect information on the ranges of pilot whales in the area.

Movements of individual pods of pilot whales that approach the Faroe Islands should be monitored by use of satellite tags. Several animals within a pod should be tagged, perhaps with tags designed to be active over varying time periods.

9.1.2 Information on abundance and distribution in the western North Atlantic

Sighting surveys covering wider areas especially longitudinally, are required to better determine the range and distribution patterns of the species.

Spatially comprehensive abundance estimates are needed, especially covering the regions of the North American continental shelf seaward to the extent of the species distribution.

Additional monitoring of movements of animals rehabilitated from strandings using satellite tags is needed to determine the spatial area occupied by animals in populations subject to by-catch in commercial fishing operations.

9.1.3 Population modelling

Improved estimates of fecundity and survival rates should be developed based on the samples of grinds collected from the Faroese drive fishery. Issues of particular concern are the details of the reproductive cycle, ages of first successful calving and of reproductive senescence, age-specific mortality rates, and intra-uterine mortality rates through comparison with the observed proportion of calves in the samples. Such estimates at the population level, and potentially at the genetically-related group level, would improve understanding of population growth rates.

The individual size measurements available from the Faroese drive fishery statistics should be analysed to estimate the numbers and proportions of younger animals present in the population over time.

Population models tailored to the specifics of pilot whale life history should be used to estimate time series of population sizes using the overall catch data and the time series of younger animals in the catch.

The estimates of a pilot whale life table described above would be used to determine potential levels of population rates of increase to aid evaluation of the previous and current impact of catches and by-catches in the eastern and western North Atlantic.

9.2 Research Related to Other Uncertainties About Population Status

9.2.1 Review of genetic studies

The Study Group strongly recommends that the several previous genetic analyses of the Faroese biological samples be reviewed by appropriate groups of experts in the fields of genetics, behavioural ecology and cetacean biology, with a goal of developing priorities for further genetic studies related to population discreteness and social structure. Future genetic analyses as recommended by this review, should take into account possible seasonal mixing of groups, genetically-based social structure, and between-school genetic variability.

9.2.2 Monitoring programme

The Study Group strongly recommends that a long-term research and population monitoring strategy be developed related to the Faroe Islands fishery, based on an in-depth review of previous and current fishery monitoring procedures and the extensive biological sampling and abundance research conducted in the Faroe Islands since the mid-1980s. While periodic collection of such data is to be encouraged, optimal allocation of resources should be determined to ensure that most value is obtained from collection of data using all three of these approaches. The Group recommended that the goals of such a programme should include both longer-term monitoring which would help improve understanding of the status of the harvest animals, and shorter-term monitoring to detect more rapid changes as might occur.

9.2.3 Distinctive grinds

The Study Group also recommended that to better understand the geographic ranges of pods, a systematic programme of further laboratory and statistical analyses be conducted focusing on those schools sampled in the Faroe Islands fishery which appear most distinctive, for example in pollutant and parasite burdens and size composition. Specific characteristics of some of the 43 pods sampled in the Faroe Islands have been identified using a variety of techniques, including enzyme electrophoresis, animal size at age, pollutant levels, and parasite loads. A systematic comparison using all of these, and potentially other measurements such as distinctive markers in teeth and stable isotope ratios, between these specific schools and representative samples from those schools which have not been identified as distinctive would potentially provide useful information on population spatial distribution patterns and structure.

9.2.4 Spatial distribution data

The Group noted data from some additional sources relating especially to the eastern Atlantic not reflected in WP-1, including some collected subsequent to the preparation of that document and others not included. Incorporation of those additional data in this document would be useful, and members agreed to provide the appropriate references and/or data to Smith for inclusion in the published version of this paper.

Sighting survey data from the central Atlantic are needed to resolve the apparent gap in distribution south of Cape Farewell. To be useful in addressing uncertainties in stock identity, however, biological samples such as morphological measurements or biopsy samples from entire pods (but see above on genetics data) from this region would also be required.

9.2.5 Morphological data

Further comparison of the morphological measurements newly available for pods stranding on Cape Cod, Massachusetts since the 1980's are needed. Completion of preliminary comparisons of Cape Cod animals to Faroese animals used during the meeting are required to confirm the conclusion that the animals stranding on Cape Cod are morphologically different from those in the Faroese fishery.

Comparisons of the Cape Cod animals to those from the Newfoundland fishery should be made to determine possible differences within the western North Atlantic population.

9.2.6 Information on social structure

The cohesive social structure suggests that the dynamics of the population must be considered in terms of the growth and formation of genetically related groups of animals, as well as the growth and reproduction of the individual animals as is done traditionally. Specific analyses of potential value include:

a) Further statistical analyses of differences among the pods, for example by estimating parameters of simpler population dynamics models (e.g. WP-17).

b) Selected genetic measurements made for animals from all groups sampled.

c) Estimation of numbers and sizes of pods, as well as numbers of individuals, in the population, for example by use of alternative survey procedures (e.g. WP-7).

d) Further exploration of alternative models of pod and population dynamics, along the lines of Zabow and Butterworth (1995), especially considering alternative methods of pod formation, the vital rate implications of pod size and possible density-dependent mechanisms associated with strong pod structures (WP-16 and WP-17).

e) Further development of data collection and analysis methods which better handle the schooling patterns of pilot whales is needed, especially to estimate numbers of animals in the vicinity of groups of animals sighted during line transect surveys.

9.2.7 Multi-species interactions

The Study Group made little progress on multi-species interactions because of lack of information on the several prey resources and on the seasonal distribution patterns of pilot whales. It could not identify how further progress might be made here, but noted two approaches worth considering further:

a) A Faroese paper documenting simultaneous changes in abundance of resource species from historical records should be translated into English.

b) Comparison of measurements of stable isotope ratios for samples of different tissues from pilot whales and of their prey should be undertaken to determine long-term predation patterns.

9.2.8 By-catch data

The Study Group was aware that the catch history data available to it is incomplete in some regions, although this lack was unlikely to affect its evaluation of the status of the population. The Group felt that efforts should be made to complete the record of the catches as far as possible. Specific areas of concern include:

a) Estimates of by-catch were thought to be available for some fisheries for which no such indication had been available to the Group. Any such estimates should be obtained.

b) By-catch is known in fisheries for pelagic species such as Atlantic mackerel and squids using pelagic trawls and in those for large fish such as swordfish and tuna using drift gillnets. Estimates of by-catch rates and of levels of present and historical fishing effort should be examined to determine likely levels of by-catch in these fisheries throughout the North Atlantic.

10 REFERENCES

Abend, A., Smith, T. 1995. Differences in ratios of stable isotopes of nitrogen in long-finned pilot whales (*Globicephala melas*) in the western and eastern North Atlantic. ICES J. Mar. Sci., 52: 837-841.

Allison, C.A. 1989. Sensitivity tests for modelling of the bowhead population. Paper SC/41/PS13 presented to the IWC Scientific Committee, May 1989 (unpublished). 9 pp

Amos, B., Bloch, D., Desportes, G., Majerus, T.M.O., Bancroft, D., Barrett, J., and Dover, G.A. 1993. A review of molecular evidence relating to social organisation and breeding system in the long-finned pilot whale. Rep. int. Whal. Commn (special issue 14): 209-217.

Andersen, L.W. 1993. Further studies on the population structure of the long-finned pilot whale, Globicephala melas, off the Faroe Islands. Rep. int. Whal. Commn (special issue 14): 219-231.

Andersen, L.W. and Siegismund, H.R. 1994. Genetic evidence for migration of males between schools of the long-finned pilot whale Globicephala melas. Marine Ecology Progress Series 105: 1-7.

Bloch, D. 1992. Studies on the long-finned pilot whale in the Faroe Islands, 1976-86. Fróîskaparrit 38-39 (1989-90): 35-61.

Bloch, D. and Lastein, L. 1993. Morphometric segregation and long-finned pilot whales in eastern and western North Atlantic. Ophelia, 38 (1): 55-68.

Bloch, D.and Lastein, L. 1995. Modelling the school structure of pilot whales in the Faroe Islands, 1832-1994. p. 499-508 in: Whales, Seals, Fish and Man (Eds. A.S. Blix, L. Walloe and O. Ulltang), Elsevier.

Bloch, D. and Zachariassen, M. 1989. The "Skinn" Values of Pilot Whales in the Faroe Islands. An Evaluation and a Corrective Proposal. North Atlantic Studies 1: 39-56.

Buckland, S.T., Bloch, D., Cattanach, K.L., Gunnlaugsson, T., Hoydal, K., Lens, S. and Sigurjónsson, J. 1993. Distribution and abundance of long-finned pilot whales in the North Atlantic, estimated from NASS-1987 and NASS-89 data. Rep. int. Whal. Commn (special issue 14): 33-49.

CeTAP. 1982. A characterization of marine mammals and turtles in the Mid-and North Atlantic areas of the U. S. outer continental shelf. Final report, contract AA51-C78-48, Bureau of Land Manage., Washington, D. C., 538 pp.

de la Mare, W.K. 1989. Report of the Scientific Committee, Annex L. The model used in the Hitter and Fitter programs (Programs: Fitter SC 40). Report International Whaling Commission 39:150-1.

Desportes, G., Andersen, L.W. and Bloch, D. 1994. Variation in foetal and postnatal sex ratios in long-finned pilot whales. Ophelia 39: 183-196.

Evans, P. 1987. The Natural History of Whales and Dolphins. Christopher Helm/Academic Press, London. 343 pp.

Evans, P.G.H. 1992. Status review of cetaceans in British and Irish waters. Report to the UK Department of the Environment. Sea Watch Foundation, Oxford. 98 pp.

Hay, K. 1982. Aerial line transect estimates of abundance of humpback, fin, and long-finned pilot whales in the Newfoundland-Labrador area. Rep. Int. Whal. Commn. 32: 475-486.

Hammond, P.S., Benke, H., Berggren, P., Borchers, D.L., Buckland, S.T., Collet, A., Heide-Jorgensen, M.P., Heimlich-Boran, S. Hiby, A.R., Leopold, M.F., and Oien, N. 1995. Distribution and abundance of the harbour porpoise and other small cetaceans in the North Sea and adjacent waters. Final report, LIFE 92-2/UK/027, Sea Mammals Research Unit, c/o British Antarctic Survey, Cambridge, England.

Hoydal, K. and Lastein, L. 1993. Analysis of Faroese catches of pilot whales (1709-1992), in relation to environmental variations. Rep. int. Whal. Commn (special issue 14): 89-106.

Klinowska, M. 1987. Preliminary list of catches, live strandings and sightings of the pilot whale (Globicephala melaena) in the British and Irish islands. Paper SC/39/SM2 presented to the IWC Scientific Committee, June 1987 (unpublished). 26pp.

Martin, A.R. and Rothery, P. 1993. Reproductive parameters of female long-finned pilot whales (Globicephala melas) around the Faroe Islands. Rep. int. Whal. Commn (special issue 14): 263-304.

Mercer, M.C. 1975. Modified Leslie-DeLury population models of the long-finned pilot whale *G. melaena* and annual production of the short-finned squid *I. illecebrosus* based upon their interaction in Newfoundland. Bull. Fish. Res. Board Can. 32:1145-1154.

Mitchell, E. 1974. Present status of northwest Atlantic Fin and other whale stocks, p. 108-169 in: W.E. Schevill, ed.,The Whale Problem. Harvard U. Press.

Punt, A.E. and Butterworth, D.S. 1991. HITTER-FITTER-BOOTSTRAP User's Guide Version 2.0 (April 1991). Paper SC/43/O9 presented to the IWC Scientific Committee, May 1991 (unpublished), 44 pp.

Reinert, A. 1976. Samandrámur av úrslitunum av Lomvigakanningum 1968-1976. Fiskirannsóknarstovan. (Unpuplished report), 1-9.

Siemanns, L. 1994. [Genetical variability in long-finned pilot whales]. PhD Dissertation, Massachusetts Institute of Technology and Woods Hole Oceanographic Institution, Woods Hole, MA.

Zabow, G., and Butterworth, D.S. 1995. Possible implications of cohesive social structure for the dynamics and sustainable yields of cetacean populations - some exploratory calculations. Rep. Int. Whal. Commn. 45: 391-399.

Zachariassen, P. 1993. Pilot whale catches in the Faroe Islands, 1709-1992. Rep. int. Whal. Commn (special issue 14): 69-88.

10.1 LIST OF WORKING PAPERS

WP-1 Abend, A. and Smith, T. Distribution of the long-finned pilot whale (*Globicephala melas*) in the North Atlantic Ocean. NOAA Tech. Mem. NMFS-NE-##, Woods Hole, Massachussetts (in press).

WP-2 Lástein, L. and Bloch, D. Analysis of existence of subpopulations of long-finned pilot whales in the Faroes waters.

WP-3 Brault, S. and Early, G. Pilot whale strandings on Cape Cod: Progress report on Morphology, with addendum by T. Smith

WP-4 Abend, A. and Smith, T. Differences in carbon and nitrogen stable isotopes between female long-finned pilot whales and their primary prey in the western North Atlantic.

WP-5 Vikingsson,G. and Sgurjónsson, J. A note on recent developments in satellite tracking of cetaceans with special reference to the long-finned pilot whale (*Globicephala melas*).

WP-6 Read, A. and Westgate, A. Monitoring the long-term movement patterns of harbour porpoises with satellite-linked radio telemetry.

WP-7 Desportes, G. Super schools.

WP-8 Brown, M R. Summary of information on pilot whale school sizes from IDCR cruises.

WP-9 Borchers, D.L., Burt, M.L., and Desportes, G. Preliminary estimates of abundance of long-finned pilot whales (*Globicephala melas*) from the Faroese component of the NASS-95 survey.

WP-10 Sigurjónsson, J., Vikingsson,G., Gunnlaugsson, T. and Halldórsson, S.D. North Atlantic Sightings Survey 1995 (NASS-95): Shipboard surveys in Icelandic and adjacent waters June-July 1995. Preliminary cruise report.

WP-11 Sigurjónsson, J., Gunnlaugsson, T., Vikingsson, G. and Gudmundsson, H. North Atlantic Sightings Survey 1995 (NASS-95): Aerial survey in coastal Icelandic waters July 1995.

WP-12 NEFSC. 1995. Long-finned pilot whale (*Globicephala melas*): Western North Atlantic Stock.

WP-13 Bravington, M.V. A model framework for estimating relative abundance as a function of covariates, using sightings data.

WP-14 Kasuya, T. Comments on the estimation of time between first ovulation and parturition.

WP-15 Desportes, G. Preliminary comparison between average age at first ovulation and at first lactation in long-finned pilot whales off the Faroe Islands.

WP-16 Kasuya,T. Social factors to be considered on dynamics of exploited cetacean populations.

WP-17Sanders-Reed,C., Brault, S. and Smith,T. Implications of demographic models of long-finned pilot whales.

WP-18 (withdrawn)

WP-19 Gunnlaugsson, T. And Borchers, D. Preliminary density estimation of pilot whales from the Icelandic NASS-95 surveys.

Table 4.1.1 Abundance estimates by block, Icelandic pilot whale data, NASS-87 and NASS-89

Year	Block	Number of sightings, n	Size of block (nm^2)	Abundance estimate, N	CV(N)	95% confidence interval
1987	1	1	2542.1	136	1 079	(24, 763)
	2	1	18926.3	271	0.594	(92, 796)
	7	11	75215.1	4651	0.814	(1149, 18819)
	36	6	44172.5	5753	0.707	(1651, 20051)
	38	12	59848.0	11325	0.577	(3960, 32388)
	93	15	21760.7	17339	0.608	(5774, 52066)
	94	10	46092.4	14147	0.781	(3656, 54744)
	95	1	69396.1	4240	0.778	(1101, 16326)
	All	57	337953.2	57864	0.362	(29074, 115164)
1989	36	16	44172.5	47195	0.408	(21857, 101904)
	40	10	107842.0	74503	0.522	(28484, 194869)
	50	25	99750.0	217950	0.458	(92611, 512923)
	60	3	131458.0	112138	0.777	(29157, 431288)
	70	7	38571.0	42109	0.523	(16052, 110461)
	38	9	59848.0	31889	0.633	(10215, 99549)
	93	2	21760.7	1783	0.597	(604, 5260)
	94	9	46092.4	46786	0.579	(16314, 134171)
	95	9	69396.1	37026	0.550	(13528, 101340)
	All	90	668890.7	611378	0.354	(312023,1197933)

Table 4.1.2 Abundance estimates by block, Faroese pilot whale data, NASS-87, NASS-89, and NASS-95 (preliminary).

Year	Block	Number of sightings, n	Size of block (nm^2)	Abundance estimate, N	$CV(N)$ interval	95% confidence
1987	17	15	29599	55112	0.521	(21108,143895)
	37	1	69394	4275	0.880	(968, 18871)
	47	3	73492	5392	0.732	(1495, 19453)
	All	19	172485	64779	0.454	(27752,151209)
1989	10	5	195560	26122	0.689	(7702, 88593)
	20	6	40625	22887	0.898	(5068,103357)
	All	11	236185	49009	0.614	(16186,148389)
1995		23	341,183	91,440	0.56	(33,107,251.518)

Table 4.1.3 Abundance estimates by block, Spanish pilot whale data, NASS-89.

Year	Block	Number of sightings, n	Size of block (nm^2)	Abundance estimate, N	$CV(N)$ interval	95% confidence
1989	21	15	244390	128080	0.571	(45241,362604)
	22	4	170900	12235	0.633	(3924, 38148)
	All	19	415290	140316	0.541	(52015,378518)

Table 4.1.4 Preliminary density estimates of pilot whales from the Icelandic NASS-95 surveys.

Block	A, sq.nmi.	n	Enc.rate	N(estimated)
2	21,171	0	0	0
3	26,779	0	0	0
4&7	135,416	12	0.0119 (.378)	93,000 (.44)
8	55,472	7	0.0182 (.877)	58,000 (.90)
9	123,957	19	0.0063 (.503)	45,000 (.55)
Total:				196,000 (.36)

Table 6.1.1 Pilot whale catch and stranding data by nation.

Pilot whale catches in the North Atlantic

YEAR	Norway			Great Britain & Ireland		Faroe Islands		Iceland		Greenland		Newfoundland		Northeastern United States		
	Total catc	Males	Females	Total catch	Stranded	Total catc	%females	Driven	Stranded	Catches		Catches		Catches	Bycatch	Stranded
1606								40								
1700						0										
1701						0										
1702						0										
1703						0										
1704						0		37								
1705						0										
1706						0										
1707						0										
1708						0										
1709						1448										
1710						1430										
1711						715										
1712						385										
1713						1090										
1714						635										
1715						625										
1716						728										
1717						720										
1718						409										
1719						726										
1720						803										
1721						905										
1722						317										
1723						1320										
1724						1063										
1725						1359										
1726						688										
1727						835										
1728						236										
1729						1423										
1730						915										
1731						2188										
1732						277										
1733						1186										
1734						696										
1735						559										
1736						391										
1737						350										
1738						214										
1739						313										
1740						0										
1741						1460										
1742						0										
1743						622										
1744						1017										

Table 6.1.1 (Cont'd)

Pilot whale catches in the North Atlantic

1745						0										
1746						100										
1747						647										
1748						165										
1749						212										
1750						0										
1751						0										
1752						194										
1753						0										
1754						172										
1755						0										
1756						0										
1757						0										
1758						0										
1759						0										
1760						0										
1761						0										
1762						0										
1763						0										
1764						0										
1765						0										
1766						0										
1767						0										
1768						0										
1769						0										
1770						16										
1771						0										
1772						0										
1773						0										
1774						0										
1775						0										
1776						743										
1777						0										
1778						0										
1779						0										
1780						0										
1781						434										
1782						50										
1783						0										
1784						0										
1785						0										
1786						0										
1787						262										
1788						0										
1789						0										
1790						0										
1791						0										
1792						152										
1793						148										400

Table 6.1.1 (Cont'd)

Pilot whale catches in the North Atlantic

1794						288										
1795						0										
1796						545										
1797						100										
1798						91										
1799						1370										
1800				0		53			45							
1801				0		154										
1802				0		752										
1803				40		1063										
1804				0		953										
1805				310		206										
1806				50		550										
1807				0		367										
1808				0		1145										
1809				0		226			1000							
1810				0		429										
1811				261		510										
1812				0		834		724	2814							
1813				0		281										
1814				0		261										
1815				0		543										
1816				0		812										
1817				0		652										
1818				0		917		100								
1819				0		1448										
1820				0		787										
1821				0		263										
1822				0		1647										
1823				0		1098										
1824				0		442		550								
1825				0		1935										
1826				0		714										
1827				0		711										
1828				0		725								49		
1829				0		556								40		
1830				0		1149										
1831				300		695										
1832				800		391										7
1833				0		1455								100		
1834				330		1569								600		
1835				0		1338										
1836				380		1183										
1837				20		1221								36		
1838				0		1332										
1839				195		1614								32		
1840				38		2193										
1841				287		1651										
1842				0		645										

Table 6.1.1 (Cont'd)

Pilot whale catches in the North Atlantic

1843				0		3142								95		70
1844				300		2171								194		
1845				1800		2541								200		
1846				0		1039								711		189
1847				0		2675								40		
1848				0		1181										
1849				0		769										
1850				0		502								330		75
1851				69		474										
1852				0		2230		65						28		
1853				25		1120								262		82
1854				350		794								100		
1855				0		1368								466		60
1856				0		411										
1857				0		328										
1858				0		757										
1859				128		836										
1860				0		640								846		
1861				660		341								300		100
1862				390		1129										
1863				0		709								234		
1864				0		574										
1865				700		1269								1343		
1866				0		1758								100		
1867				26		398										
1868				0		478										
1869				0		716								63		
1870				0		842	66.4							767		3
1871				780		796	66.4									
1872				0		2315	66.4									
1873				192		1670	66.4							97		160
1874				0		652	66.4							1457		28
1875				0		780								1430		2
1876				75		797								322		
1877				80		383										
1878				0		329		207						261		
1879				108		1930								8		
1880				100		615										
1881				0		390										
1882				154		521										
1883				0		135	66.4									
1884				0		368								3493		
1885				0		977										
1886				60		723										
1887				0		833										
1888				340		476										
1889				0		695										
1890				0		0										
1891				0		0										

Table 6.1.1 (Cont'd)

Pilot whale catches in the North Atlantic

1892				0		34										
1893				0		840										
1894				0		498										
1895				0		542										
1896				0		128										
1897				0		342										
1898				600		1336										
1899				71		2380										
1900				0		797										
1901				0		0										
1902				166		481										
1903				83		212										
1904				0		566										
1905				0		221										
1906				0		414										
1907				0		267								44		
1908				0		1793										
1909				0		735										
1910				0		1324										
1911				50		1650										
1912				0		669								100		160
1913				0		168								32		191
1914				0		291										275
1915					0	1203								103		110
1916					0	397								82		657
1917					0	263										
1918					0	848								268		149
1919					0	153										
1920					0	802										
1921					0	1076				126						
1922					0	473										
1923					0	1047				32				16		
1924					1	0				13						
1925					0	468										
1926					0	347				200						68
1927					0	0		250								
1928					1	480		5	75	185				500		500
1929					500	17		200						350		195
1930					0	266								1300		98
1931					1	2386				415						
1932					8	1282				120						50
1933					0	959		350								
1934					0	178		72								173
1935					0	652		219	225	325						53
1936					0	1633										50
1937					0	886		68		28				250		103
1938	27	20	7		0	2093		140								71
1939	28	21	7		0	3363		190		400						
1940	0	0	0		0	2847										20

Table 6.1.1 (Cont'd)

Pilot whale catches in the North Atlantic

1941	4	4	0		0	4480		524								12
1942	8	8	0		0	1931										150
1943	8	6	2		0	1037			700							320
1944	5	1	4		20	1386										
1945	13	11	2		0	1558										
1946	1	1	0		200	1040										
1947	7	6	1		0	1839						0				
1948	1	1	0		0	587						215				108
1949	6	6	0		450	955						0				11
1950	9	0	9		249	560						172		36		12
1951	8	5	3		0	2794						3102				
1952	2	1	1		0	1242	60					3155				3
1953	3	2	1		0	2100	60					3584				
1954	0	0	0		0	2010	60			28		2298				4
1955	13	10	3		63	885	60			2		6612				
1956	1	0	1		0	1816	60			2		9794				
1957	80	53	27		36	2085	60	105		25		7831				105
1958	225	167	59		0	2619	60	300		48		789				170
1959	224	159	65		0	1787	60			158		1725				
1960	331	228	103		0	1795	60	100		10		1957				
1961	295	224	71		0	1892	60			5		6262				
1962	43	32	11		0	1813	60			12		150				
1963	71	53	18		0	2204	60.2					221				46
1964	54	44	10		0	1364	60.2					2849				
1965	32	21	11		83	1620	60.2			138		1520				2
1966	339	264	75		0	1485	60.2	3		38		887				2
1967	117	111	6		0	1973	60.2					739				
1968	31	27	4		15	1650	60.2			8		204				23
1969	27	22	5		0	1395	60.2					123				
1970	43	32	11		0	388	60.2			10		155				
1971	0	0	0		1	1015	60.2					4				
1972	0	0	0		0	511	60.2					0				
1973	0	0	0		0	1050	57.2			2						
1974	1	1	0		0	679	57.2			16						
1975	0				0	1086	57.2			108						
1976	0				0	532	57.2			50						
1977	0				0	897	57.2			138						
1978	0				1	1192	57.2			100						
1979	0				0	1674	57.2			50						2
1980	0				1	2775	57.2			10						
1981	0				1	2909	57.2			2						30
1982	0				34	2649	57.2		280	2						90
1983	0				104	1685	57.2								59	23
1984	0				0	1926	57.2								30	120
1985	0				36	2596	57.2			25					121	
1986	0				0	1676			148	10					93	87
1987	0				0	1450									46	
1988	0				0	1738									184	
1989	0				0	1260									77	

Table 6.1.1 (Cont'd)

1990	0				0	917			22					316	
1991	0				0	722								30	
1992	0				0	1572								55	
1993	0				0	808				100				31	
1994	0				0	1201									
1995	0				0	228				132					

Table 6.3.1 Statistics of population trajectories (population size in 1840 and ratios of the size in 1840 and 1940 to the assumed valued in 1989) calculated by the HITTER[1] procedure for combinations of assumptions about the area inhabited by the population from which the harvested animals are drawn from and about the maximum population growth rate (%).

		Area (Population assumed for 1989)			
Maximum population growth rate (%)	Statistics	*Faroe Islands* (55000)	*Rockall-Iceland* (110000)	*Mid-Atlantic Ridge - Faroes* (420000)	*NASS-89 Survey Area* (778000)
0.0	1840	231400	286300	596300	954600
	1940/1840	0.59	0.67	0.84	0.90
	1996/1840	0.21	0.36	0.69	0.81
1.4	1840	117200	156200	447600	803000
	1940/1840	0.84	0.92	0.99	0.99
	1996/1840	0.45	0.71	0.94	0.97
2.8	1840	83900	128100	429800	787100
	1940/1840	0.98	1.00	1.00	1.00
	1996/1840	0.67	0.88	0.99	0.99
4.3	1840	71100	118600	424600	782500
	1940/1840	1.00	1.00	1.00	1.00
	1996/1840	0.82	0.96	1.00	1.00
5.7	1840	64200	114600	422800	780900
	1940/1840	0.99	0.99	1.00	1.00
	1996/1840	0.92	0.99	1.00	1.00

[1]Technical specifications for HITTER computations were: annual age specific natural mortality for age ranges 0-8 : 0.05; 9-20 : 0.02; 21-31 : 0.06; 32+ : 0.15; age at maturity (knife edge) = 9 years; age at recruitment (knife edge) = 1 year (the lowest possible for HITTER procedure); first year of simulation = 1709; density dependence on total (1+) population; MSYL(1+) = 0.6K(1+); MSYR(1+) = 0.705 x maximum population growth rate (follows from the Pella-Tomlinson form assumed for density dependence and the value adopted for MSYL).

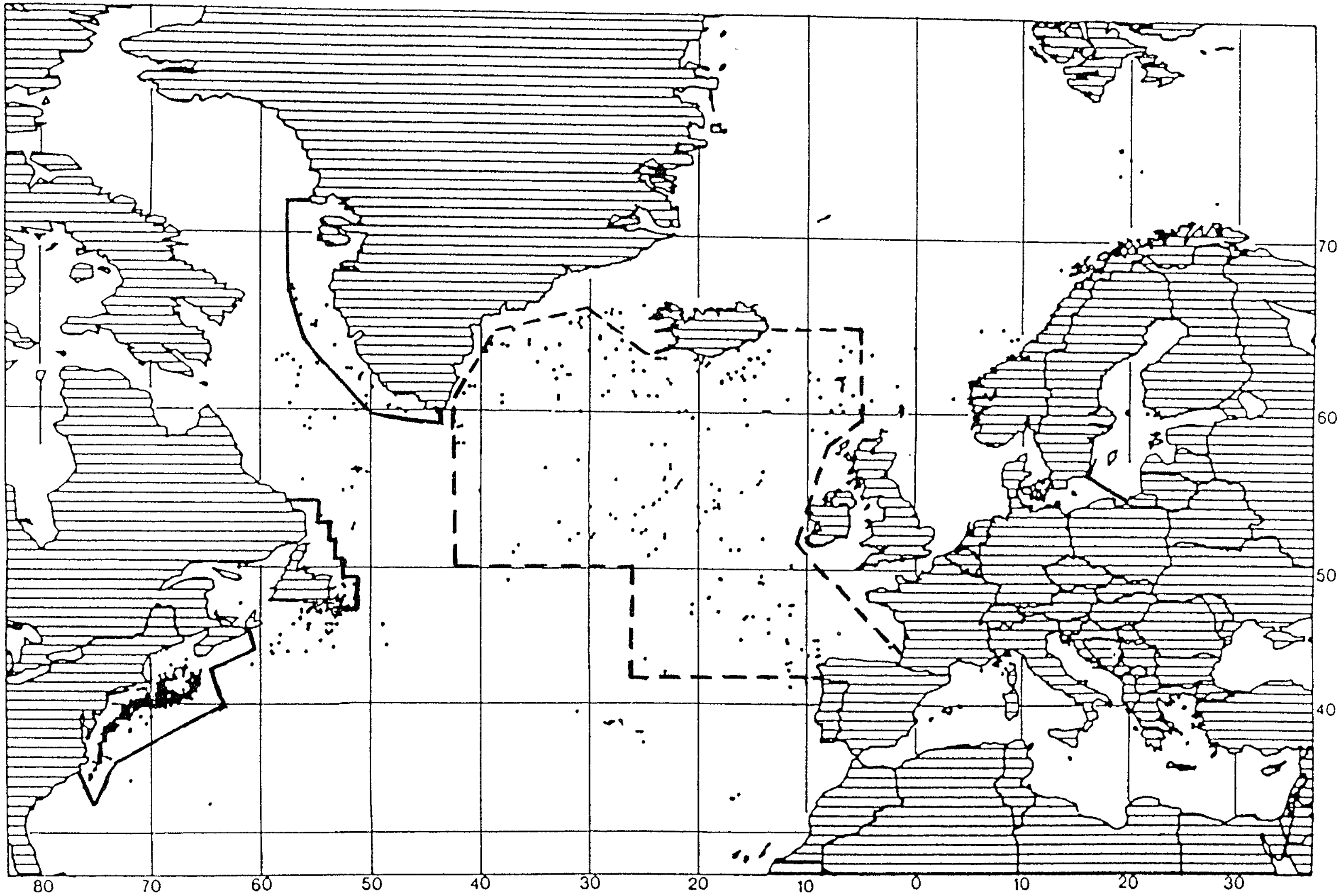


Figure 2.1.1 Distribution of long-finned pilot whales in the North Atlantic and Mediterranean Sea base on sighting data from 1952 to 1992. All the Northeast to the north and east of the dashed line between Cape Farewell and Spain has been covered by systematic sighting surveys (NASS-87, NASS-89, NASS-95, SCANS). The dashed linein the mid-Atlantic indicates the area for which an abundance estimate has been calculated from NASS-87 and NASS-89. The boxes drawn at West Greenland, off Newfoundland and off the US northeast coast indicate areas which have been covered by systematic surveys.

Figure 4.1.1 Survey blocks for NASS-87.

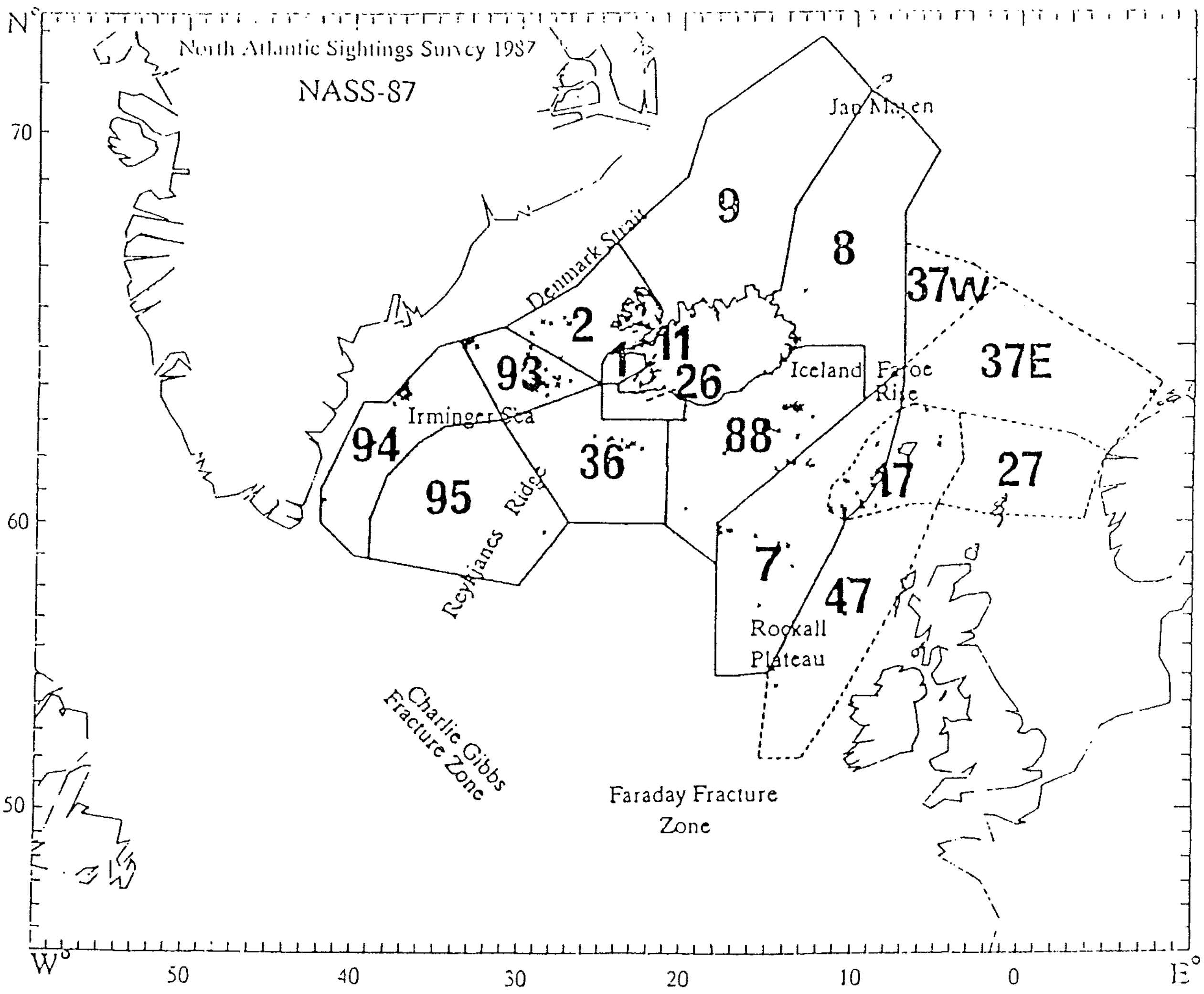
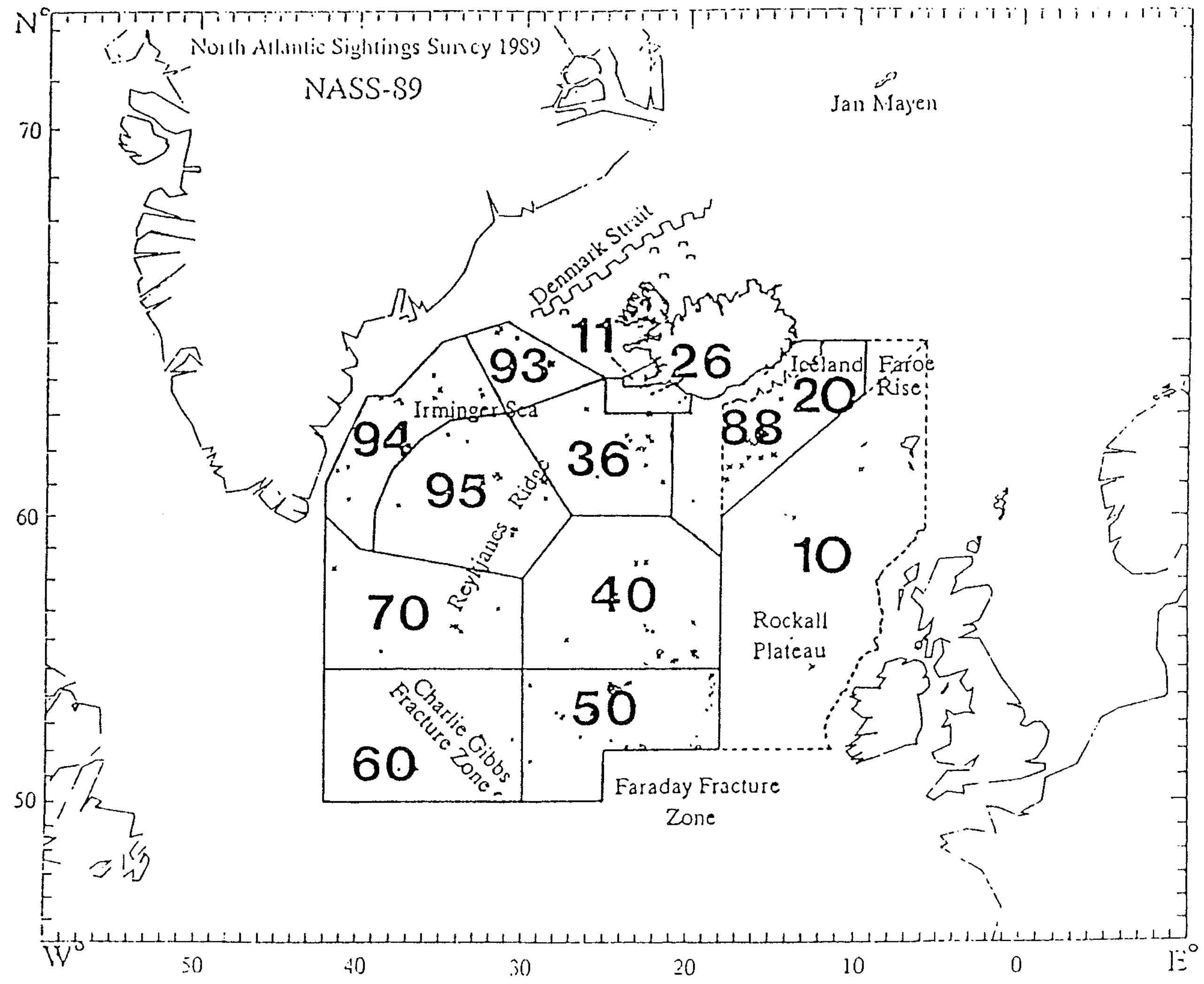


Figure 4.1.2 Survey blocks for NASS-89



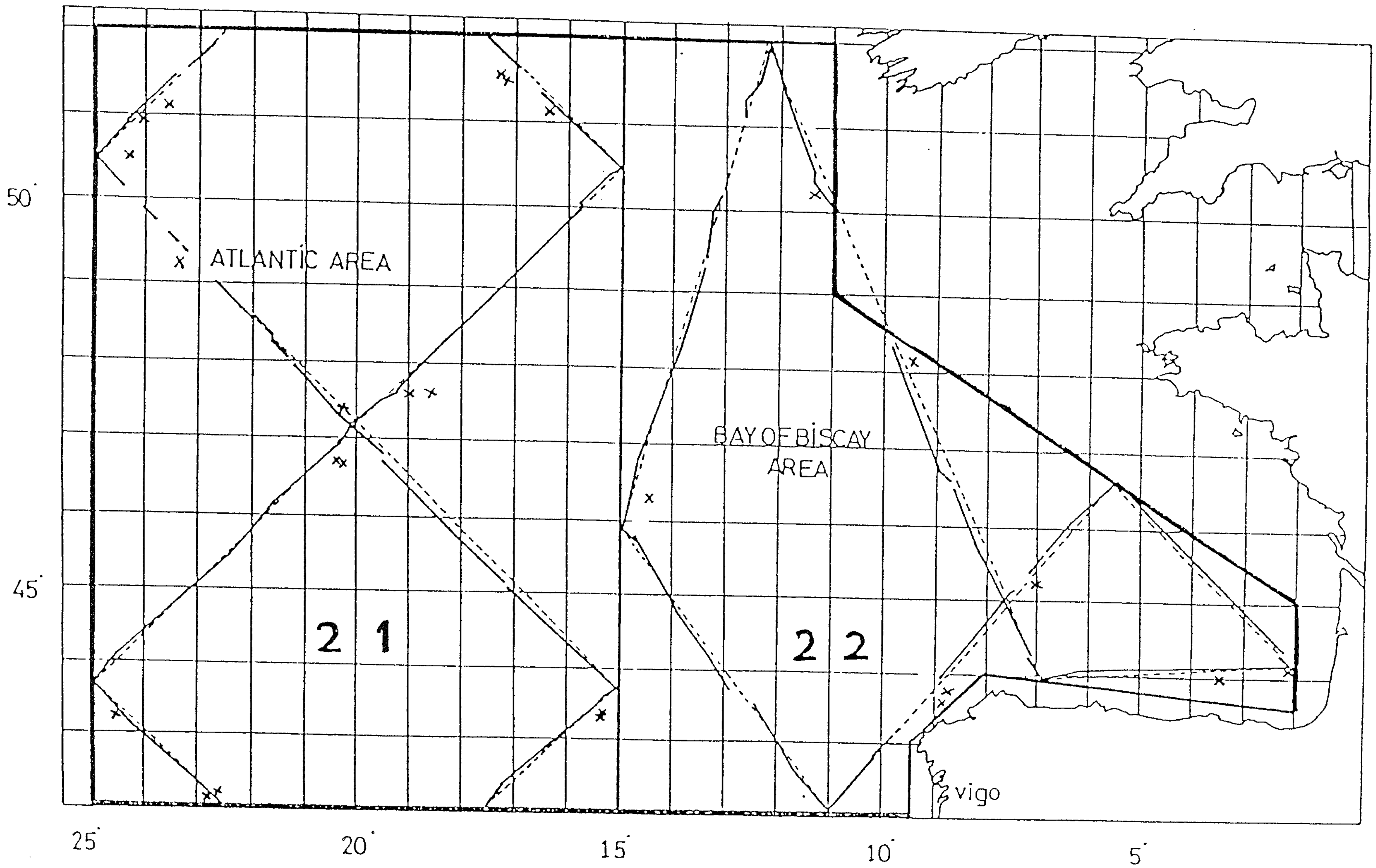


Figure 4.1.3 Survey blocks for the Spanish component of NASS-89

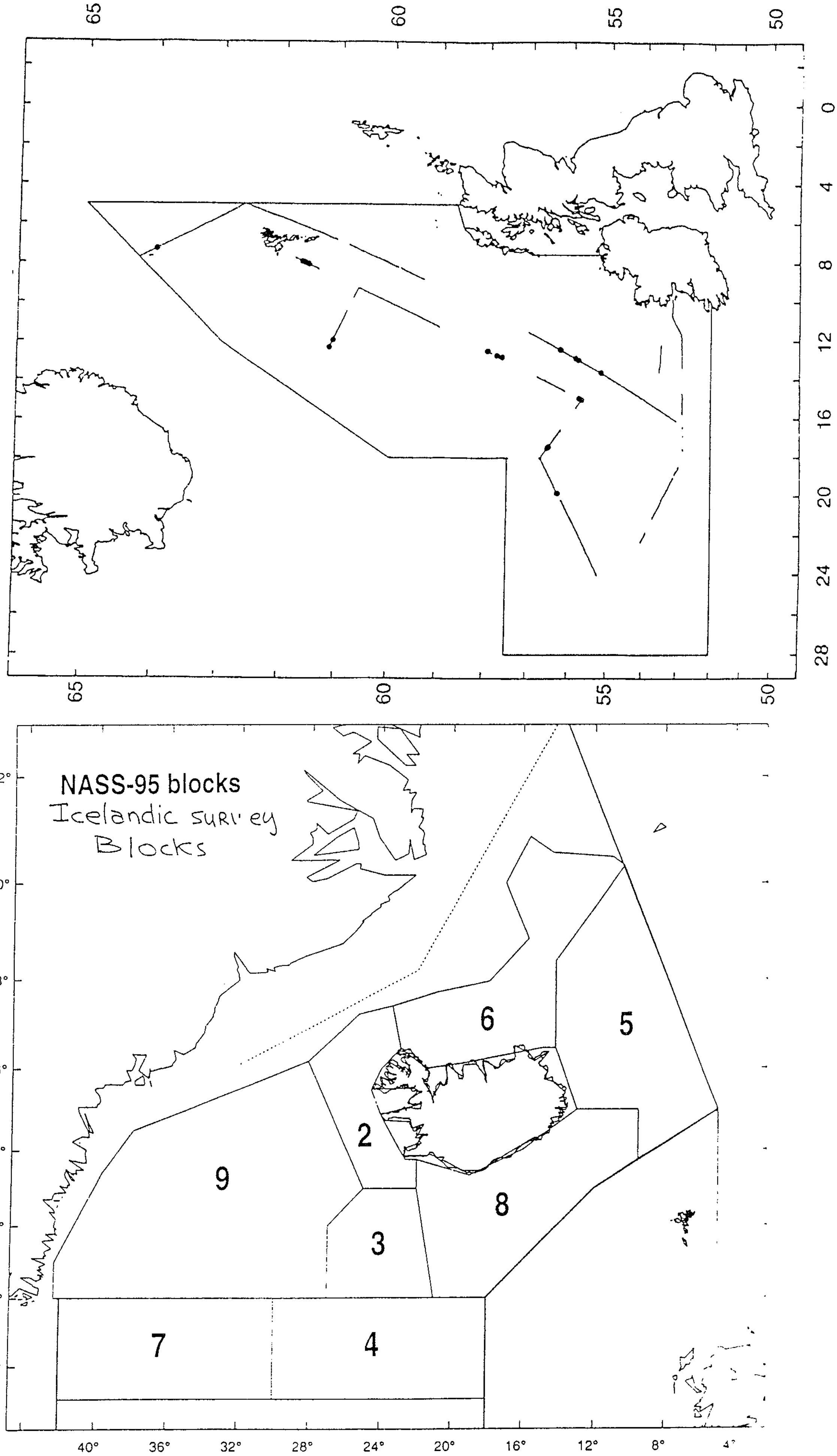


Figure 4.1.4 NASS-95: Faroese and Icelandic survey blocks.

A = Faroe Islands Area

A+B = Rockall - Iceland Area

A+B+C = Mid-Atlantic Ridge - Faroes Area

A+B+C+D = NASS-1989

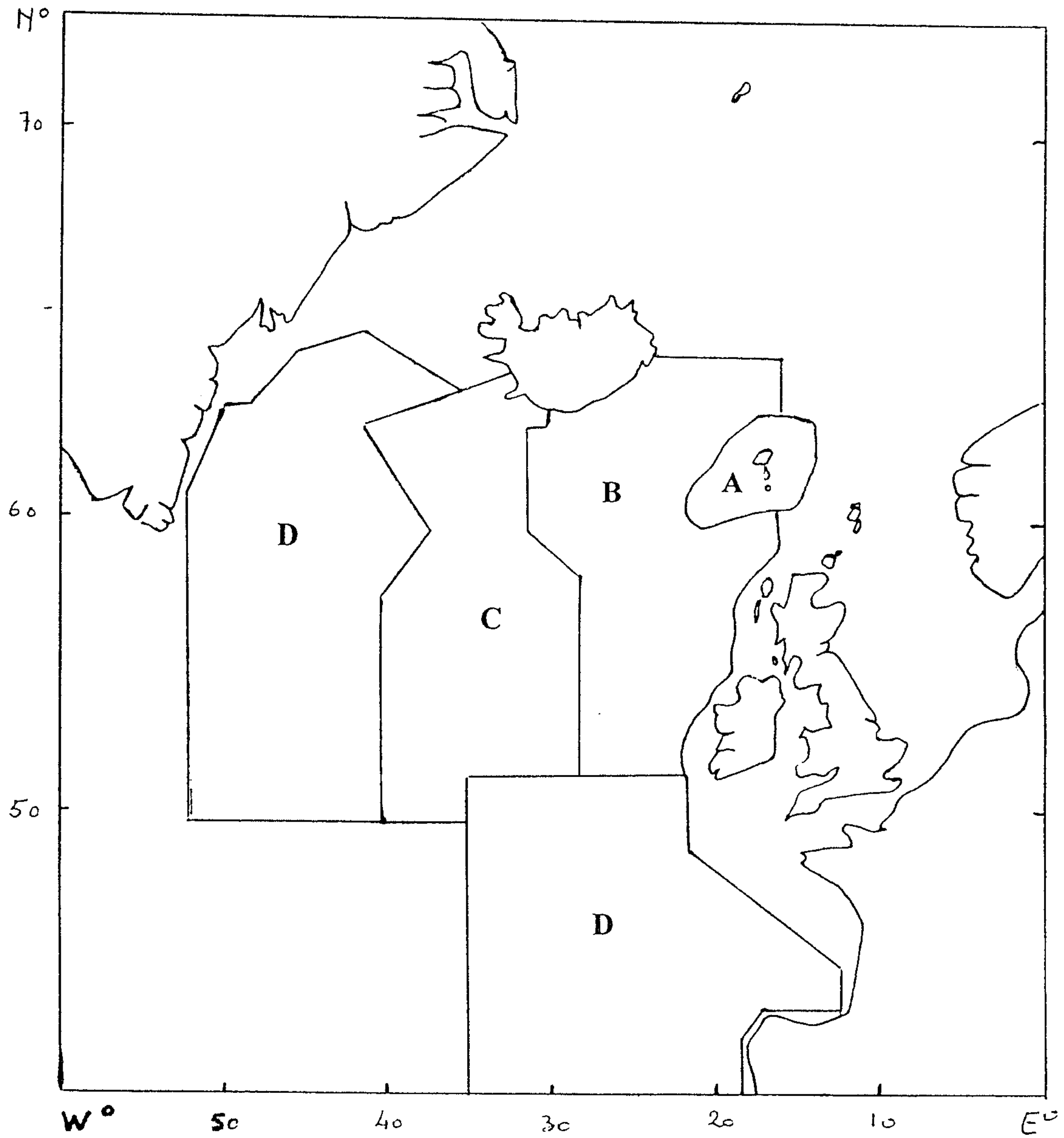


Figure 6.3.1 Areas to which the abundance estimates used in the HITTER runs apply

Ark1 Chart 2

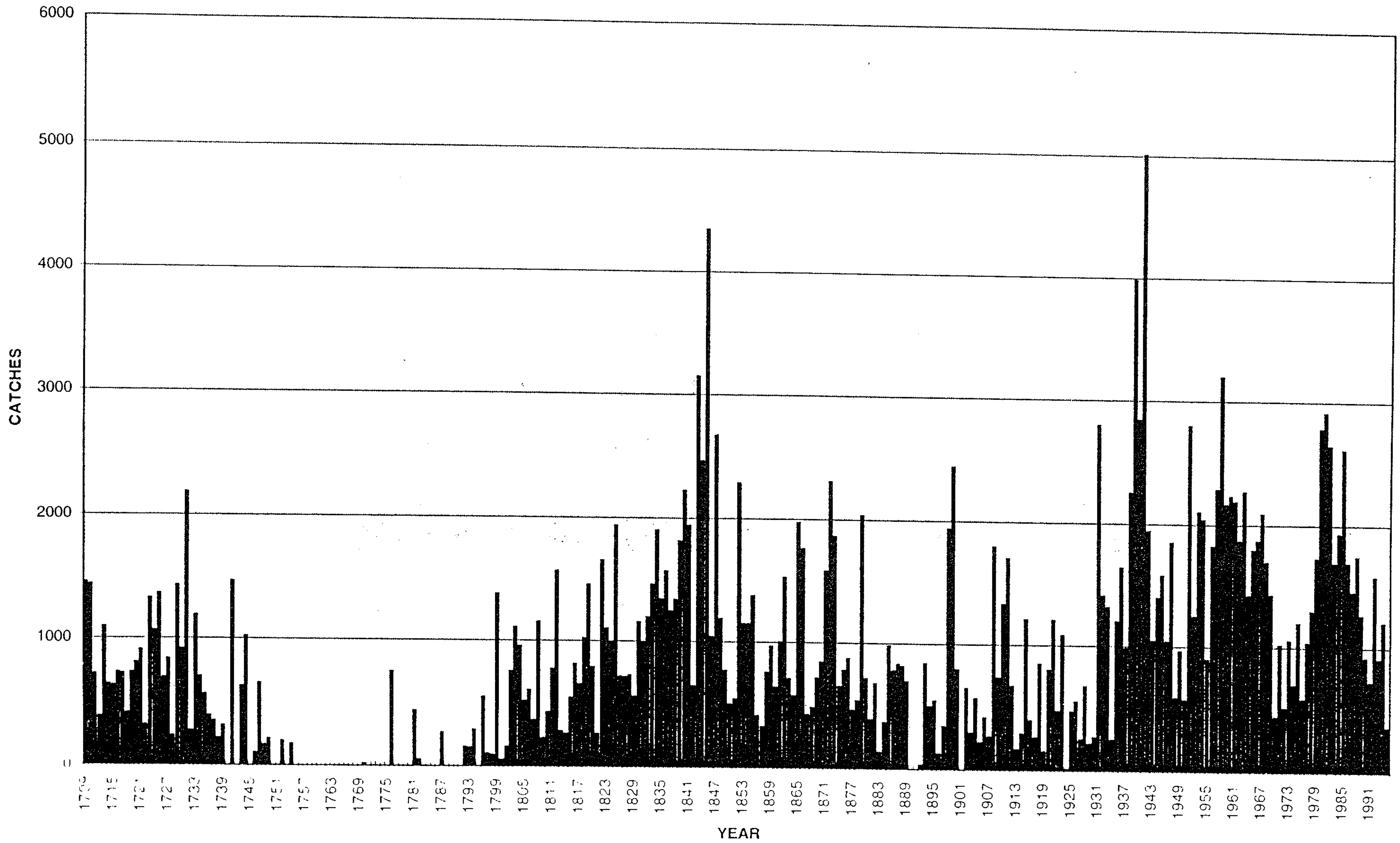


Figure 6.3.2 Catches used in the HITTER runs, 1709-1995

Figure 6.3.3 Relative population trajectories (population size in 1840 divided by population size in 1996) calculated by the HITTER procedure for four possible geographical areas from which the catches may have been drawn, and for five levels of maximum population growth rate. The trajectories are shown from 1840 to 1996, and all are scaled to take the value 1.0 in 1989 (denoted by a triangle). All trajectories are shown completely except that for the combination of 0% population growth rate and the Faroe Islands Area, which is truncated for the higher values by the figure margin.

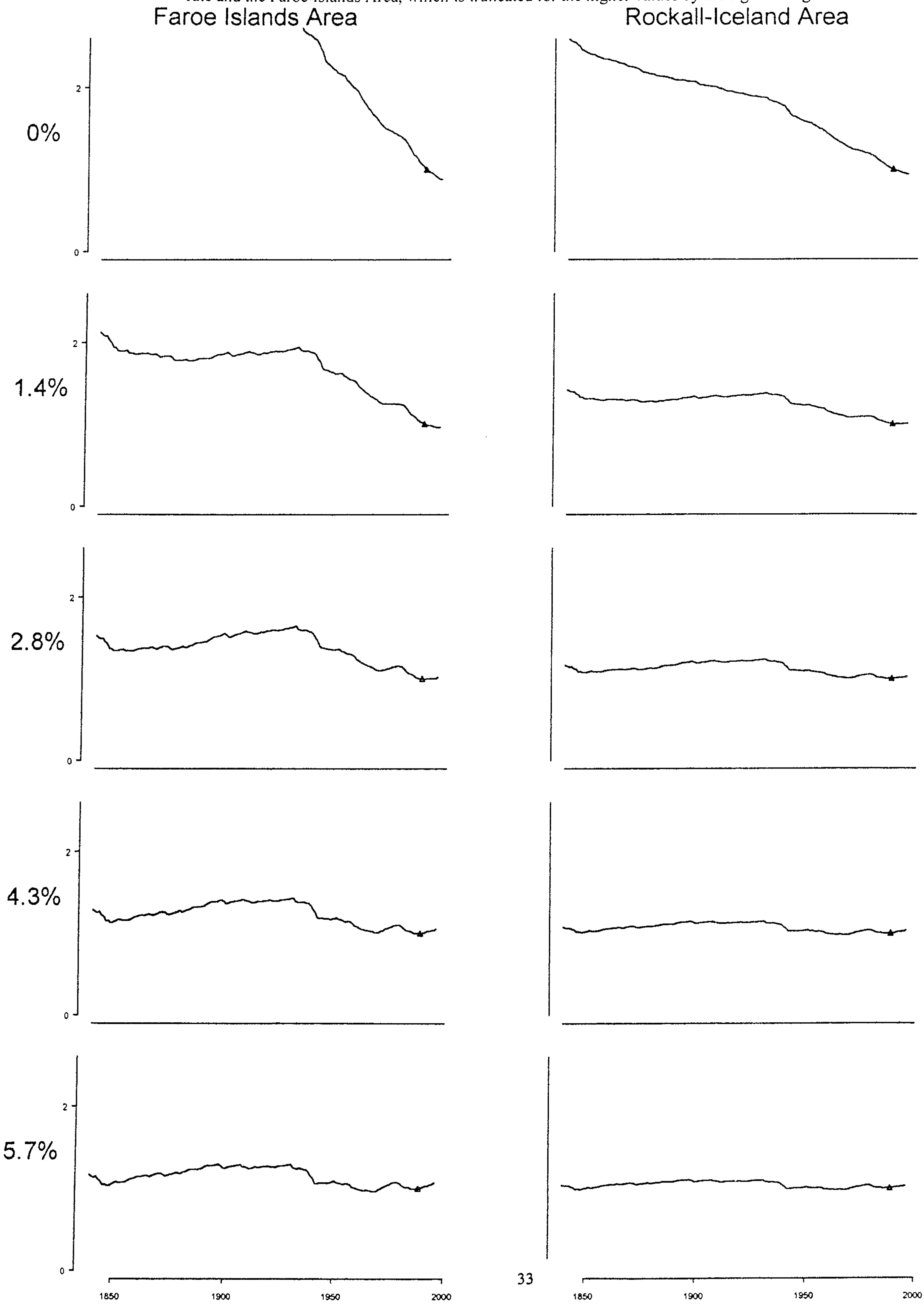


Figure 6.3.3 (Cont'd)