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Regional variation of caesium-137 in minke whales *Balaenoptera acutorostrata* from West Greenland, the Northeast Atlantic and the North Sea

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Abstract Levels of radioactive caesium (^{137}Cs) were determined in minke whales (*Balaenoptera acutorostrata*) from West Greenland, the Northeast Atlantic region and the North Sea. The sample consisted of muscle tissue from 135 minke whales caught in 1998 in 7 different areas: West Greenland, $n=44$; East Greenland, $n=4$; Jan Mayen, $n=22$; Svalbard, $n=14$; Barents Sea, $n=20$; Vestfjorden/Lofoten, $n=14$; the North Sea, $n=17$. Mean ^{137}Cs levels in whales ranged from 0.298 (SD=0.083) Bq kg $^{-1}$ wet weight around Svalbard to 1.319 (SD=0.587) Bq kg $^{-1}$ wet weight in the North Sea. The finding of the highest caesium concentration in minke whales from the North Sea is in accordance with previous findings that ^{137}Cs levels in the marine environment of the North Atlantic region decrease with increasing distance from major point sources (i.e. nuclear-fuel reprocessing plants in the UK and France, and outflow from the Baltic Sea containing ^{137}Cs from the 1986 Chernobyl accident). The mean ^{137}Cs levels in minke whales from Svalbard and the North Sea differed significantly from mean levels in the

other areas. This difference supports the indications from other studies that groups of minke whales are resident for some time at their feeding grounds in the North Atlantic and may occur in separate stocks during summer.

Introduction

Currently, North Atlantic minke whales (*Balaenoptera acutorostrata*) are subject to hunting by Greenland and Norway (Witting 2000) for human consumption (e.g. Pars et al. 2001).

Information on population sub-structure, or identification of “stocks”, is a prerequisite for adequate management of animals that are exploited. For the purposes of this paper, a “population” can be defined as a group of interbreeding individuals showing limited genetic exchange with individuals outside the group (Pianka 1978, 1988). Populations are empirically characterised by genetic analysis. A “stock”, however, is a management unit that can be defined as a group of animals that interacts with humans separately and can be exploited and managed independently from other groups (Royce 1972; Wang 2002). Because human interaction with exploited wild species usually occurs in geographically discrete hunting areas, the definition of stocks in this context has an intrinsic geographic component to it. Thus, here the concept of “stock” is used in a resource management, rather than population biology, perspective.

Various methods have been used to study the population (e.g. Danielsdóttir et al. 1992, 1995; Bakke et al. 1996; Martinez and Pastene 1999) and stock (Larsen and Øien 1988; Christensen et al. 1990) structure of North Atlantic minke whales. However, their stock structure remains unclear. For example, it is unknown how many discrete stocks exist in the North Atlantic Ocean, what the stock boundaries are, and the extent to which stock inter-mixing occurs.

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About a decade ago, the International Whaling Commission (IWC) defined a number of “small areas” for minke whale management in the North Atlantic based largely on the distribution of the whales at their summer feeding grounds (Anonymous 1992, 1993). North Atlantic minke whales feed predominantly during summer in fertile polar and sub-arctic waters to which they migrate from winter breeding grounds in warmer, possibly sub-tropical, latitudes. Virtually no food is consumed during winter (Mackintosh 1965; Jonsgård 1966; Horwood 1990; Ballance 2002). There is no single predominant prey species of minke whales that is common across the North Atlantic. This diversity of prey can at least partly be attributed to the complex bathymetry and water conditions of the region (Mackintosh 1965). Although minke whales may occur over relatively deep waters (Anonymous 1997), they tend to feed in shallow, continental shelf areas where they concentrate on traditional summer feeding grounds: (1) Newfoundland-Labrador, (2) West Greenland, (3) East Greenland, (4) Iceland, (5) Jan Mayen, (6) Svalbard, (7) the Barents Sea, (8) northwestern Norway, and (9) the North Sea (Horwood 1990; Anonymous 1997) (Fig. 1). The ecological conditions at these summer feeding grounds

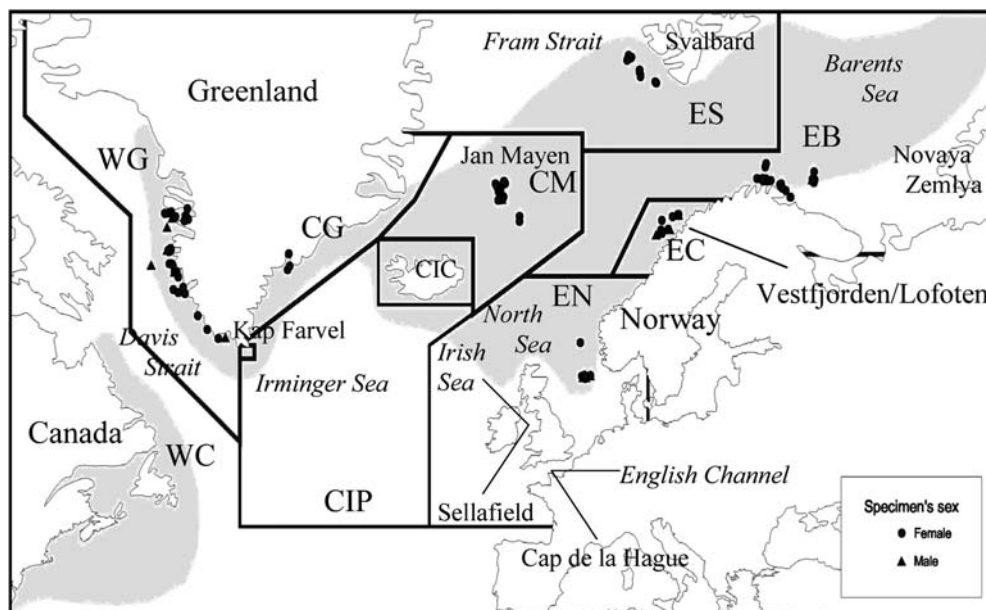
differ substantially (e.g. Anonymous 2002). The summering grounds formed the basis for the IWC “areas”, which have since formed the basis for harvesting of the species and therefore, by definition, for the currently understood stock structure.

The present study employs a relatively new approach to investigation of minke whale stock structure by examining the geographical variation in levels of ^{137}Cs in minke whale muscle tissue. The approach is based on the rationale that whales accumulate in their tissues ^{137}Cs via food and water from their environment. Groups of minke whales exploiting habitats with different ambient ^{137}Cs levels may reflect those differences in their own tissues, which can then be used to infer the existence of “ecological separation” or management stocks.

^{137}Cs (physical half-life = 30.17 years) is a useful biomarker because it accumulates in muscle tissue due to its chemical similarity to potassium (Dahlgard et al. 1994).

Significant sources of ^{137}Cs in the marine environment of the North Atlantic region are: (1) radioactive waste discharged into coastal waters of the Irish Sea from a nuclear fuel reprocessing plant at Sellafield, United Kingdom (since 1952), and to a lesser extent into the English Channel from the Cap La Hague plant in France (since 1966) (Fig. 1); (2) releases into air and sea during the 1986 Chernobyl (Ukraine) power-plant accident. Seawater from the Baltic Sea carrying significant amounts of ^{137}Cs released during the 1986 Chernobyl power-plant accident mixes in the North Sea with waters from the aforementioned areas; (3) global fallout from atmospheric nuclear-weapon testing (Livingston 1988; Herrman et al. 1995; Kershaw and Baxter 1995). In recent years, the most significant sources of anthropogenic nuclides to the marine environment of the North Atlantic are (1) and (2) (Aarkrog 1998; Strand et al. 1998; Brungot et al. 1999; Grøtheim 2000) but global fallout

Fig. 1 Map showing locations of samples of minke whales (*Balaenoptera acutorostrata*) in 1998 with boundaries of the International Whaling Commission management units and their acronyms (Anonymous 1992). Samples in the present study were collected in WG (West, Greenland), CG (Central, eastern Greenland), CM (Central, Jan Mayen), ES (East, Svalbard), EB (East, Barents Sea), EC (East, Coastal Norway) (Vestfjorden/Lofoten), EN (East, North Sea). No samples from CIC (Central Iceland Coastal), CIP (Central Iceland Pelagic) and WC (West, Canada) were included. Grey shading indicates the approximate distribution of minke whales in the North Atlantic region during summer based on Stewart and Leatherwood (1985) and Anonymous (1997). It is not known whether or not the distribution is continuous between Canada and western Greenland



still constitutes a significant background level (Dahlgard 1994; Dahlgard et al. 1994, 1995).

The ^{137}Cs is distributed in the North Atlantic region by ocean currents. From the North Sea, ^{137}Cs is transported north along the western coast of Norway with the Norwegian Coastal Current. At about 70°N, this current splits into an eastern branch that extends into the Barents Sea region and a larger northwestern branch – the West Spitsbergen Current (WSC) – that enters the Arctic Ocean and Fram Strait between Svalbard and NE Greenland (Fig. 1). In the Fram Strait, the WSC waters mix with waters coming from the Arctic Ocean and then flow as a surface current – the East Greenland Current – south along the continental shelf of eastern Greenland. After having mixed with Atlantic waters from the Irminger Sea, the East Greenland current flows around Kap Farvel at the southern tip of Greenland and enters the Davis Strait and the West Greenland marine ecosystem (Kershaw and Baxter 1995; Aarkrog 1998; Gregor et al. 1998).

There is a general decrease in ^{137}Cs levels in seawater en route from northwestern Europe to West Greenland (Kershaw and Baxter 1995; Grøtheim 2000; Ólafsdóttir et al. 1999). For example, ^{137}Cs in seawater in the Irish Sea averaged 0.0505 Bq l⁻¹ in 1993 (Berrow et al. 1998) whereas it was between 0.0023 and 0.0071 Bq l⁻¹ in East Greenland in 1990–1997 (highest in the northern part), and between 0.0036 and 0.0045 Bq l⁻¹ in West Greenland (lowest to the north) (Aarkrog et al. 2000). Although this geographical trend was more pronounced in the late 1970s and early 1980s (cf. Fig. 8.7 in Strand et al. 1998), when the discharge from Sellafield was at its highest (Aarkrog 1998), it still persists (Grøtheim 2000).

Osterberg et al. (1964) suggested that radionuclides could be used to track the migration of marine mammals. Variation in ^{137}Cs levels in harbour porpoises (*Phocoena phocoena*) sampled at different distances from Sellafield indicated ecological separation among groups of this small odontocete in British and Irish coastal waters (Berrow et al. 1998). A similar fall-off with distance from sites of discharge was found by Watson et al. (1999) in harbour porpoises, harbour seals (*Phoca vitulina*) and grey seals (*Halichoerus grypus*) around the United Kingdom, and by Tolley and Heldal (2002) in harbour porpoises along the western coast of Norway – indicating ecological separation of groups of animals.

We determined regional variation in ^{137}Cs levels to study potential ecological separation – or the presence of different stocks – during summer in North Atlantic minke whales. Minke whales, which are widely distributed in the North Atlantic during summer (Fig. 1), attain a total body mass of about 6 tonnes (e.g. Folkow et al. 2000). Allometric relationships in Mailhot et al. (1989) predict that the biological half-life of ^{137}Cs in a minke whale this size is likely to be at least half a year. We hypothesized that if minke whales are philopatric during summer, the ^{137}Cs levels in their muscle tissue will generally reflect the ^{137}Cs level at their summer foraging grounds. We therefore anticipated that the

samples from the North Sea and from western Norway would contain the highest ^{137}Cs concentrations. Alternatively, if the highly mobile minke whales (Blix and Folkow 1995) move frequently between different feeding areas during summer within the region explored in the present study, one would not expect any regional difference in ^{137}Cs levels in the whales.

Materials and methods

Sampling in the field

Tissue samples were available from a total of 135 minke whales, which were taken during Norwegian and Greenland whaling operations in 1998 in 7 IWC management units (Anonymous 1992) in the North Atlantic (IWC acronyms in parentheses): West Greenland (WG), East Greenland (CG), Barents Sea (EB), Jan Mayen (CM), Svalbard (ES), Vestfjorden/Lofoten (EC) and the North Sea (EN) (Fig. 1, Table 1). The character of the whaling operations determined the sampling areas, and the aggregate locations within the areas exploited by Norwegian whalers.

The Greenland samples (muscle, kidney, liver, blubber, stomach contents) were collected by hunters with a licence to take minke whales. Similar samples were collected by scientific staff during the Norwegian pelagic and coastal whaling operations. The Greenland whale hunters were instructed how to take the samples and requested to provide information on special forms about date and location of the kill plus information on sex, total body length, and the presence or absence of a foetus, and its length. Similar data were reported for the Norwegian samples plus information on the presence or absence of a *corpus luteum* in the ovaries.

Each sample usually consisted of 100–200 g of somatic muscle tissue collected by the hunters during the flensing from an unspecified part of the whale body.

The samples from CM, ES, EB and EN were collected relatively early in the season and during a relatively short period of time, whereas those from WG and EC were collected over a longer time span (Table 1). Overall, the seasonal and spatial distribution of the samples in the present study was representative of the Greenland (cf. Witting 2000) and Norwegian catches in 1998 (N. Øien, unpublished data).

All samples were stored at –20°C until processed in the laboratory at the Risø National Laboratory, Roskilde, Denmark.

Table 1 Locations and number of samples, periods of sampling and mean levels (\pm SD) of ^{137}Cs (Bq kg⁻¹ w.w.) in skeletal muscle tissue from 135 minke whales that were sampled in 7 areas in West Greenland, the Northeast Atlantic and the North Sea in 1998

Location	<i>n</i>	Period of sampling	^{137}Cs
West Greenland (WG)	44	6 May – 31 Oct.	0.543 \pm 0.252
East Greenland (CG)	4	12 Jul. – 16 Oct.	0.589 \pm 0.122
Jan Mayen (CM)	22	7 Jun. – 1 Jul.	0.448 \pm 0.123
Svalbard (ES)	14	15 May – 31 May	0.298 \pm 0.083
Barents Sea (EB)	20	23 May – 25 Jun.	0.569 \pm 0.144
Vestfjorden/Lofoten (EC)	9 ^a	28 May – 14 Aug.	0.655 \pm 0.232
North Sea (EN)	17	15 May – 8 Jun.	1.319 \pm 0.587
Total	130		

^aThere was muscle tissue from 14 individual whales from EC, but samples from 10 of the individuals were pooled to obtain 5 specimens with enough tissue for the analyses (see Laboratory analyses)

Laboratory analyses

^{137}Cs was analysed by measurement of the gamma radiation from its short-lived daughter ^{137}Ba (2.55 min) on low-background high-purity semiconductor detectors (HP-Ge) shielded with 10 cm low-active lead. In the laboratory, aliquots of 19–1,630 g muscle were freeze-dried, partly ashed at 450°C, homogenized, and filled into different calibrated gamma-counting geometries depending on the amount of ash. For the smallest samples, a 2 ml geometry for a well-type detector was used, whereas larger samples were counted in petri-dish geometries of sizes 5, 10 or 15 cm³. Each sample was counted for 1–8 days. The volume reduction by ashing and the long counting times were necessary because of the low level and the small amount of material available for most samples. All values have 1 sigma counting uncertainties in the range 2–30%. ^{137}Cs concentrations of about 0.4 Bq kg⁻¹ were found in the smallest samples, well above the detection limit of 0.2 Bq kg⁻¹.

The detectors have efficiencies in the range 25–40% relative to a 3"×3" NaI(Tl) detector, and their gamma-ray energy resolutions at 1.33 MeV range from 2.1 to 2.5 keV. For each spectrum, 2,000 channels are used at a gain of 0.7 keV per channel. The systems are calibrated with standard radionuclide liquid solutions placed in geometries similar to those used for the samples. Quality assurance of the analytical results is achieved through regular participation in international inter-calibration and inter-comparison programmes that have demonstrated that the analytical accuracy is better than 10%. This is documented through regular participation in the inter-comparisons organised by the IAEA (International Atomic Energy Agency) laboratory in Monaco since 1970.

For a sub-set of 125 individuals, there was sufficient muscle tissue to allow for determination of ^{137}Cs . However, this was not the case for 10 individuals (< 100 g tissue each) from Vestfjorden/Lofoten (EC). Therefore, the samples from these ten whales were pooled pair-wise in the following manner to obtain five specimens for analysis: (1) two adult F (females) from May and August, (2) two adult F from August, (3) two adult M (males) from August, (4) two immature F from July, and (5) two immature M from June and August. Hence, the total number of samples for ^{137}Cs analyses became 130 (Table 1). Results were expressed in Bq kg⁻¹ wet weight (w.w.).

The sex of each individual was validated genetically (Andersen et al. 2002) according to the methods of Berubé and Palsbøll (1996).

Statistical methods

The ^{137}Cs data were not normally distributed (Shapiro-Wilk *W* test) and were therefore base-e logarithmically transformed to meet the assumptions of normality and homoscedasticity in parametric tests.

The asymptotic body length of male minke whales is smaller than that of females (e.g. Christensen 1981). In the present study, length was used synonymously with age due to a lack of tissues such as *bullae* that could be used for determination of individual age (see Christensen 1981). Information on body length was not available for all whales. Regressions of log-transformed ^{137}Cs levels on body length were analysed in the two genders separately, and for each area separately and combined. Analysis of variance (ANOVA) with the factors "sampling area" and "gender", and their interaction was performed to test for differences in mean ^{137}Cs concentrations among areas and between sex. The ANOVA was successively reduced for factors that were not significant at the 5% level according to Type III Sum of Squares. Differences in mean ^{137}Cs concentrations among areas were tested by Tukey's post hoc tests. SAS 8e (SAS 1999) was used for the statistical analyses.

Results

Among the 135 minke whales, 102 were females (75.6%) and 33 (24.4%) were males.

Table 2 Sampling areas arranged in decreasing order according to mean ^{137}Cs levels in muscle samples of 135 minke whales from West Greenland, the Northeast Atlantic and the North Sea. Continuous underlining indicates that caesium mean levels were not significantly different among the respective areas (Tukey's post-hoc test, $P > 0.05$). For explanation of area acronyms, see Fig. 1 and Table 1

EN	EC	CG	EB	WG	CM	ES
—	—	—	—	—	—	—

Within each sampling area, there was no significant correlation between caesium levels and body length in either gender (r^2 values ranged between 0.03 and 0.68 with corresponding P values of 0.78 and 0.39, respectively). When samples from all areas were pooled, there was a positive but *non*-significant correlation between caesium concentrations and body length in both males ($r^2 = 0.16$, $P = 0.06$, $n = 21$) and females ($r^2 = 0.03$, $P = 0.15$, $n = 77$).

The levels of ^{137}Cs in minke whales of both sexes ranged from 0.298 (SD = 0.083) Bq kg⁻¹ w.w. at Svalbard (ES) to 1.319 (SD = 0.587) Bq kg⁻¹ w.w. in the North Sea (EN) (Table 1). Dry matter constituted on average 29.24% (SD = 4.87, range: 15.42–48.75%, $n = 130$) of wet weight.

"Sampling area" was the only significant ($P < 0.05$) factor influencing ^{137}Cs levels. The mean ^{137}Cs level in whales from the North Sea was significantly higher than in other areas, whereas the mean level in whales from Svalbard was significantly lower than in other areas. Although the mean ^{137}Cs level was relatively high in minke whales from the western coast of Norway (EC) (Table 1), the ^{137}Cs concentrations did not differ among other areas (Tables 1, 2).

Discussion

Comparison with previous studies of ^{137}Cs levels

In the present study, ^{137}Cs levels in minke whales were below 0.66 Bq kg⁻¹ w.w. in all areas except the North Sea. The ^{137}Cs values were comparable to those reported in contemporary studies of whales including the piscivorous (Aarefjord et al. 1995) harbour porpoise. For example, Tolley and Heldal (2002), whose samples were from 1999–2000, found an average of 1.255 Bq kg⁻¹ w.w. ($n = 10$) in harbour porpoises taken along south-western Norway (i.e. at the North Sea). This is similar to the average value in minke whales from the North Sea in this study (Table 1). Berrow et al. (1998) presented a mean value of 2.4 Bq kg⁻¹ w.w. (SE ± 0.1) for three harbour porpoises that were sampled in the North Sea in 1989–1993. Comparable values of Tolley and Heldal's and this study were: 0.913 Bq kg⁻¹ w.w. ($n = 7$) for harbour porpoises at Nordland on the midwest coast of Norway (Tolley and Heldal 2002), which is close to the "Vestfjorden/Lofoten (EC)" area in the present study where we found an average value of 0.655

(SD=0.232) Bq kg⁻¹ w.w. in minke whales. In the Barents Sea area, the ¹³⁷Cs value was 0.495 Bq kg⁻¹ in harbour porpoise (Tolley and Heldal 2002), and 0.569 Bq kg⁻¹ (SD=0.144) in minke whale (this study).

Since 1975, the ¹³⁷Cs level in whales from Greenland waters has averaged about 0.75 Bq kg⁻¹ w.w. ($n=15$) with no apparent time trend (Strand et al. 1998, Fig. 8.34). Although the values in Greenland whales in the present study were somewhat lower (Table 1), they were not significantly so. Furthermore, the whale species in Strand et al. (1998) were not specified. Although they were likely to be minke whales, it cannot be excluded that samples from fin whale (*B. physalus*) and small cetaceans like beluga (*Delphinapterus leucas*) and harbour porpoise may have been included, because the species was not stated by the collectors (H. Dahlgaard, unpublished data).

Hence the ¹³⁷Cs levels in minke whales in the present study were basically at the same levels as those found in contemporary studies of other cetaceans from the same areas.

Long-term stability of ¹³⁷Cs and trophic relationships

We studied radiocaesium levels in muscle tissue. Ideally, studies of spatial differences in ¹³⁷Cs levels should use tissues that are not subject to rapid turnover and replacement. The clearance rate of ¹³⁷Cs in marine mammals is not known with certainty. However, inferred from Mailhot et al. (1989), biological half-life in a baleen whale the size of a minke whale is likely to be at least half a year. Furthermore, muscle (meat) is a radiologically very relevant tissue because it is consumed by humans.

We did not find any significant difference in ¹³⁷Cs levels between males and females, which is in accordance with findings in other studies (Calmet et al. 1992; Berrow et al. 1998; Tolley and Heldal 2002). Furthermore, in the present study there were no statistically significant correlations between ¹³⁷Cs levels and body length (synonymous with age), which is in accordance with Tolley and Heldal (2002) who studied harbour porpoises. Berrow et al. (1998), however, found that in a sub-set of male harbour porpoises from the waters around Britain and Ireland, the ¹³⁷Cs concentrations decreased with increasing age, length and body mass. A negative relationship between caesium concentrations and age was also indicated in harp seals (*Phoca groenlandica*) (Samuels et al. 1970).

Although levels of radioactivity in marine organisms reflect the levels in their environment in a general manner, in particular they reflect concentrations in the ingested prey (Rowan and Rasmussen 1994; Kasamatsu and Ishikawa 1997; Zhao et al. 2001). Generally, decapods have lower ¹³⁷Cs levels than fish (Brungot et al. 1999; Aarkrog et al. 2000). Although minke whales are euryphagous, and despite the fact that there may be both inter-annual and inter-seasonal variation in their food

(reviewed by Folkow et al. 2000), it is apparent that their overall food selection is determined by prominent regional differences in the distribution and abundance of various prey types. The regions covered by the present study differ with respect to availability of different prey types and, consequently, also in prey preferences of minke whales. Capelin (*Mallotus villosus*) and sand eel (*Ammodytes* sp.) are important food for minke whales in West Greenland waters whereas polar cod (*Boreogadus saida*) seems to be of relatively greater importance in the East Greenland region (reviewed by Neve 2000). Within the northeast Atlantic region there are regional differences in prey preferences. Consumption of herring (*Clupea harengus*) by minke whales is almost exclusively confined to the Barents Sea and the northwestern coast of Norway, whereas consumption of krill (*Thysanoessa* sp.) is more pronounced in the Svalbard area. In 1999, herring was a predominant food item offshore in the Norwegian Sea (i.e. east of the polar front) whereas sand eel dominated the minke whale food in the North Sea. In this latter area, mackerel (*Scomber scombrus*) and other fish (e.g. whiting *Merlangius merlangus*) constituted the remainder of food items (Olsen and Holst 2001). These regional differences in prey preferences may to some extent influence ¹³⁷Cs levels in minke whales. Analyses of $\delta^{15}\text{N}$ values in muscle of the same whales that were analysed in the present study indicated that at Svalbard (and East Greenland and Jan Mayen) the minke whales are feeding at a lower trophic level (primarily they eat krill) than at the western coast of Norway and in the North Sea, where they mainly feed on fish (Born et al. 2002). Therefore, the relatively low mean ¹³⁷Cs value in minke whales from Svalbard may to some extent be caused by the fact that they feed at a lower trophic level in that area.

We did not detect a difference in mean ¹³⁷Cs levels between West and East Greenland despite indications of the existence of differences in ambient ¹³⁷Cs levels in these two areas. Even though there has been a general decrease in ¹³⁷Cs in the North Atlantic region since the mid-1980s, the levels have remained high in East Greenland biota relative to those in western Greenland (Aarkrog et al. 2000). However, only four samples were available from East Greenland.

Population and stock structure in North Atlantic minke whales

The present study is part of a broader, multi-disciplinary effort to better understand North Atlantic minke whale stock and population structure. Various analyses have been applied to the same suite of samples to detect variation among groups of whales from different areas. Genetic analyses were used for studying population structure (Andersen et al. 2002) whereas stock structure was inferred from regional variation in elemental and stable isotopic composition (Born et al. 2002), persistent organic pollutant (POP) burdens (Hobbs et al. 2002) and

blubber fatty acid (FA) composition (Møller et al. 2002). The study by Andersen et al. indicated the existence of four genetically different groups: West Greenland, a central group (East Greenland and Jan Mayen), a northeastern group (Svalbard, the Barents Sea and Vestfjorden/Lofoten) and the North Sea. It was suggested that these sub-units had developed since the last glaciation (ca. 10,000 years BP) as a response to major differences in ecological conditions (oceanography, ice cover, prey type and availability) in the four regions occupied during summer by the whales. Although the study of regional variation in elemental and stable isotopic signatures (Born et al. 2002) revealed several significant differences among areas, it basically supported the groupings found in the genetic study. Proportions of POP (Hobbs et al. 2002) and FA profiles (Møller et al. 2002) in minke whales did not reveal any major difference among areas except that whales from Greenland waters and the North Sea differed significantly from those from other areas.

Hence, the different analyses grouped the whales somewhat differently. However, this may be expected considering that the various substances and elements studied have different ecological and physiological pathways. However, all analyses indicated that minke whales in the North Sea differ from those in the other areas.

In conclusion, the present study (covering a major part of the North Atlantic region) demonstrated that ^{137}Cs concentrations in minke whales showed regional differences, with highest concentrations close to the areas of discharge. Regional variation in ^{137}Cs levels indicated that minke whales to some extent are ecologically separated and in certain areas are resident during summer.

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