Strontium in fin whale baleen: a potential tracer of mysticete movements across the oceans?

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***Highlights (for review : 3 to 5 bullet points (maximum 85 characters including spaces per bullet point)**

Highlights

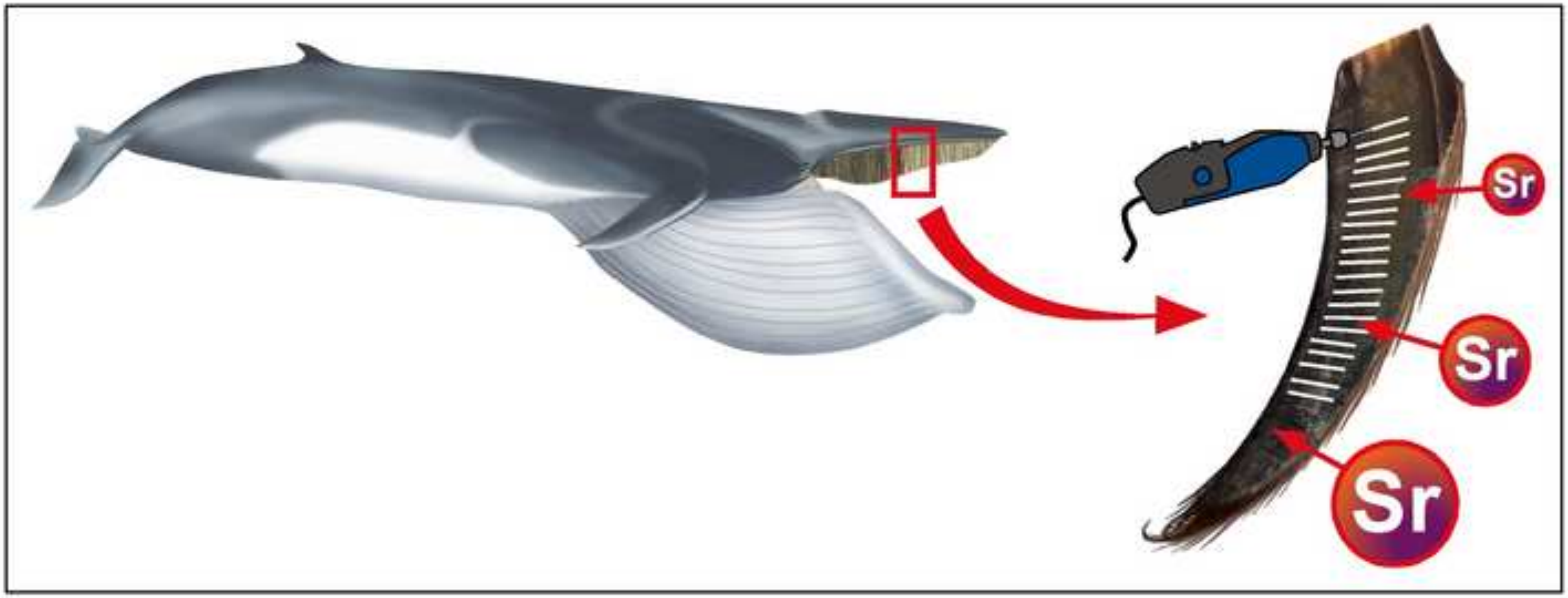
1. Sr concentrations were determined in baleen plates from North Atlantic fin whales
2. Concentrations increased from proximal to distal samples on each plate
3. Trends were similar in all plates, with regional differences in overall Sr levels
4. Some plates showed fluctuations in Sr levels, indicative of whale migrations
5. We suggest Sr is adsorbed from seawater, reflecting regional baseline variations

Abstract

Strontium is a metal broadly distributed in oceanic waters, where its concentrations follow gradients mainly driven by oceanographic and biological factors. Studies on terrestrial vertebrates show that Sr can accumulate in mammalian hair in amounts mainly related to the external environment, a property that has been scarcely investigated in aquatic mammals. Cetaceans are marine mammals whose skin is generally hairless, but the species belonging to the mysticete group feed through a filtering apparatus made of keratinous baleen plates that, like hair, grow continuously. During their annual latitudinal migrations, mysticetes cross water masses with variable chemo-physical characteristics that may be reflected in these tissues. In the present study, baleen plates were sampled from 10 fin whales obtained from NW Spain (N = 5) and SW Iceland (N = 5) to investigate Sr concentrations along the plates growth axis. Samples were taken longitudinally at regular 1cm - intervals on each plate. Sr concentrations, determined through mass spectrometry, ranged from 5 to 40 mg Kg^{-1} and increased from proximal to distal positions along plates. These results suggest a progressive adsorption of Sr on the plate surface, a process that also occurs in mammalian hair. Increasing trends were similar in the two regions but overall concentrations were significantly higher in NW Spain, reflecting different Sr baseline concentrations in the two areas and indicating isolation between the two whale populations. Some oscillations in Sr longitudinal trends were also detected, likely indicating that whales migrate across water masses with different Sr baselines. These results suggest that Sr concentrations in keratinous tissues of marine mammals can be used as ecological tracers of their migrations and habitat use.

Keywords: Sr; *Balaenoptera physalus*; keratin; North Atlantic Ocean; marine mammals; baleen plates.

*Graphical Abstract



1. Introduction

Strontium (Sr) is an alkaline metal that makes up, approximately, the 0.02-0.03% of the Earth's crust. In nature, it never occurs free because its metallic form oxidizes to Sr^{2+}, which is the form available in soil and water (Pors Nielsen, 2004). In seawater, Sr^{2+} is the fifth most abundant cation, occurring naturally along with other abundant cations such as those of sodium, magnesium, calcium and potassium. Sr concentrations in the oceans are estimated to range approximately 7-8 mg l^{-1} (Angino et al., 1966; Bernat et al., 1972), with some basin-scale variability: reported average concentrations are 8.07 ± 0.06 in the Atlantic Ocean, 7.58 ± 0.04 in the Pacific Ocean, and 8.3 ± 0.06 mg l^{-1} in the Mediterranean Sea (Uddin et al., 2013).

Oceanic Sr derives mainly from wind deposition, suspended particulate from river inputs, weathering of the continental crust, and, to some extent, the dissolution of carbonate litho-facies (Uddin et al., 2013). Several authors (Stoll and Schrag, 1998; Tripati et al., 2009) underline the importance of planktonic organisms in regulating Sr concentrations in the sea. Large amounts of Sr are incorporated into coralline aragonite (De Villiers, 1999) or, to a lesser extent, into coralline calcite (Stoll and Schrag, 1998), where Sr is incorporated together with carbonates. Environmental parameters including salinity and temperature regulate the rate of incorporation of Sr into planktonic organisms and that of its dissolution into the environment. Phenomena such as seawater acidification have also an effect over these rates, accelerating the dissolution of carbonates and, consequently, of carbonate-bound Sr. Thus, concentrations of soluble Sr in seawater vary regionally according to oceanographic and biological factors, including: continental weathering, oceanic crust alterations, riverine inputs, variations in salinity (Bernat et al., 1972), and temperature, which, in turn, can influence the distribution of specific planktonic organisms and/or affect sea water acidification processes.

Despite the fact that Sr concentrations in oceanic seawater and planktonic organisms are well known, Sr amount and pace of absorption and its tissue concentrations in marine vertebrates have been scarcely studied (Kunito et al., 2002; Vighi et al., 2017; Wise et al., 2011). Indeed, most of the knowledge on Sr physiology in vertebrates derives from studies on terrestrial mammals and humans. Sr intake in these organisms derives mostly from food and fluids, and concentrations are regulated by gastrointestinal absorption, renal excretion, placental transfer, and mammary secretion (Comar and Bronner, 1969). Sr concentrations in soft tissues are generally negligible. The largest amount of retained Sr is deposited in bone apatite (99%), where it can substitute Ca thanks to their similar chemical properties (Fourman et al., 1968; Vaughan, 1981). However, most of the ingested Sr is not absorbed because it is excreted through urine, faeces and sweat (Walser, 1969; Font et al., 2012), or it is transferred to keratinous tissues (Font et al., 2012). Thus, experiments of Sr exposure through injection or controlled diet using Sr isotopic markers showed a substantial accumulation of Sr in the hair of mammals (Hopkins et al., 1963), where it was observed to remain for a long time after ceasing experimental exposure (Della Rosa et al., 1966).

Microscopic studies on hair show that environmental Sr is not only physiologically accumulated but can also adsorb to the hair cuticle from the external environment (Gellein et al., 2008; Kempson and Skinner, 2005; Kempson et al., 2006). Similar to Ca, Sr is incorporated in both the outer and the inner hair structure by different mechanisms. Sr concentrations have been reported to increase from the proximal to the distal segments of hair, indicating continuous adsorption from the environment (Kempson et al., 2006). These findings suggest that keratinous tissues may be useful to assess environmental exposure to Sr and other elements and, to some extent, investigate the metabolic history of the individual (Moon et al. 1988).

In cetaceans, skin is generally hairless except for a few vibrissae on the rostrum and mouth in some species (Yochem and Stewart, 2017). This makes the investigation of temporal trends of elements accumulation in cetaceans challenging. Analyses of elements in these animals have been traditionally carried out on skin biopsies of live animals or on tissues of dead animals (*e.g*. Borrell et al., 2015; Sanpera et al., 1993, 1996; Vighi et al., 2015). Although baleen plates of mysticetes received only marginal attention in this respect, they can fit for this purpose, due to their structural similarity to hair despite their different function. Baleen plates are keratinous structures that grow on the upper jaw of mysticetes and jointly form the filtering apparatus that allows whales to filter-feed on planktonic organisms and fish. The structure of a baleen can be outlined as a series of longitudinal tubules kept together by a keratinized matrix, which leaves the inner edges of the tubules exposed to the water to act as food filters. As shown by both X-ray and elemental analyses, plates are mainly composed of keratin (both organized as α-keratin and amorphous keratin, in amounts ranging 47 – 87 % of the baleen dry weight), and calcium salts (mainly hydroxyapatite), plus small amounts of elements such as manganese, copper, boron, and iron (Aubin et al., 1984). Fibers can also contain small quantities of lipids (1.5 – 6.7 % of the baleen dry weight), but not collagen (Aubin et al., 1984). Similarly to hair, baleen plates have a continuous growth. However, the keratin they are composed of is metabolically inert and, once formed, does not undergo any turnover. As a result, the elements that are deposited from the marine environment during the whale -and plate- growth are 'recorded' along the plate growth axes, allowing investigation of movements and geographical destinations of baleen whales (Aguilar et al., 2014; García-Vernet et al., 2018, Lee et al., 2005; Matthews and Ferguson, 2015; Roubira et al., 2015). The few elemental concentration studies conducted on baleen plates took advantage of this principle and investigated the accumulation and trends of various elements in species such as the common minke whale, *Balaenoptera acutorostrata* (Born et al., 2003; Hobson et al., 2004); the North Atlantic right whale, *Eubalaena glacialis* (Wilcox et al., 2009), and the bowhead whale, *Balaena mysticetus* (Shao et al., 2004). However, trends of Sr elemental accumulation have never been investigated in this tissue.

In this study, Sr concentrations were determined in fin whale (*Balaenoptera physalus*) baleen plates. The fin whale, like most mysticetes, performs annual migrations between high latitude summer feeding grounds and low latitude winter breeding grounds (Aguilar and García-Vernet, 2017). In the North Atlantic, the fin whale is one of the most abundant mysticetes, with a broad distribution that extends from the equator to at least 80ºN and includes the Mediterranean and Baltic Seas (Aguilar and García-

Vernet, 2017). Based on results obtained from the application of various techniques, the North Atlantic fin whale has been classified in several stocks and sub-stocks that purportedly occupy segregated geographical ranges (Figure 1; International Whaling Commission, 2009, 2017). The definition of these stocks is mainly based on the location of the feeding grounds where whales concentrate during summer, while the location of winter breeding grounds, as well as the migration routes and the level of mixing between stocks, are still largely unknown. However, during their latitudinal migration, fin whales cross water masses characterized by distinctive temperature, salinity, productivity and other chemical characteristics, some of which may be detected through elemental analyses in their tissues (e.g. Sanpera et al., 1993; 1996; Vighi et al., 2017). In the present study, Sr concentrations were analyzed in subsamples taken at regular intervals along the longitudinal growth axis of each baleen plate to investigate the potential similarity between baleen plates and mammalian hair in accumulating Sr over time through both endogenous and exogenous processes. Analyses were performed on fin whales sampled off SW Iceland and NW Spain: the feeding grounds used by two stocks that, according to previous research, do not intermingle (Bérubé et al., 1998; Lockyer, 1982; Sanpera et al., 1996; Víkingsson and Gunnlaugsson, 2005; Vighi et al., 2016, 2017). The ultimate aim of the study was to investigate the potential of Sr concentrations in baleen plates for providing further evidence on the isolation between the two fin whales stocks, and for assessing individual variations induced by migrations through changing baselines.

2. Materials and methods

2.1. Sample collection and composition

Ten baleen plates were analyzed: five from individuals from NW Spain and five from individuals from SW Iceland. Samples from NW Spain were obtained from the biological tissue bank of the University of Barcelona (BMA Tissue Bank), which preserves biological material from fin whales caught by the IBSA whaling company during the 1983 - 1984 summer whaling seasons off the Galicia Bank. Samples from

SW Iceland were obtained from fin whales caught by the Hvalur H/F whaling company during the summer of 2013. Sampling areas and land stations are shown in figure 1. Biological information was only available from Icelandic individuals and is summarized in Table 1.

2.2. Ethics statement

Samples from NW Spain derived from whales caught when commercial exploitation was legal in Spain. Samples from SW Iceland were obtained from whales legally caught under Icelandic regulation and were legally imported in Spain (CITES permit ES-BB-00150/13I). No samples were donated or purchased and all sampled whales were caught with purposes other than research.

2.3. Sample preparation

Each baleen plate was cleaned with a chloroform:methanol (2:1) solution to remove surface oils and adhered material. Powdered subsamples of keratin were obtained along the plate using a Dremel $_R$300 series equipped with engraving cutter bits made of high-speed steel, which do not feature any Sr component and thus cannot cause any sample contamination.

As the growth rate of baleen plates in *B. physalus* is approximately 20 cm (± 2.16) per year (Aguilar et al., 2014; Bentaleb et al., 2011), 30-40 subsamples were taken longitudinally along each plate at 1 cm-intervals to include in the analyses a record of at least one complete year before the whale death. The first subsample of each plate was extracted from the point where the plate emerged from the gum (Figure 2), and following subsamples were taken proceeding regularly towards the distal portions of the plate.

2.4. Sr analysis

Sr analysis was performed as described in Vighi et al. (2017). Approximately 0.1 g of each powdered keratin sample was acid-digested in clean Teflon reactors using 3 ml of HNO_3 (70%) and 1 ml of H_2O_2 (30%). After 12 h incubation at 90ºC, digested samples were diluted in 30 ml distilled water. 10 ml subsamples of each diluted sample were analyzed with an ICP-MS (Induction Coupled Plasma-Mass Spectrometer) Perkin Elmer Optima 6000. One H_2O_2 blank, one replicate, and one certified reference material (Bovine liver 1577a) every 10 samples were analyzed to validate analyses. Replicates differed less than 10% and the recovery percentage ranged 90-100%. Results are expressed as mg kg^{-1} dry weight.

Analyses were performed at the *Centres Científics i Tecnològics* (CCiT-UB) of the University of Barcelona, Spain.

2.5. Statistical analysis

A preliminary data exploration was performed by investigating the distribution of Sr concentrations and presence of extreme outliers in each individual. Ranges of Sr concentrations were calculated for all the data set and each sampling area separately. Mean Sr concentrations and relative standard deviations were calculated at each sampling position along plates for the two sampling areas and all data together. To investigate overall trends and differences in Sr concentrations, the normality of distribution and homogeneity of variances were tested (through Shapiro Wilk and F tests) in four selected positions (cm 1, 10, 20 and 30) along plates, and Sr concentrations in these positions were compared through adequate tests (Student's and Welch's *t*-tests, Wilcox tests).

Individual variations of Sr concentrations along the longitudinal sampling positions of each baleen plate (hereinafter referred to as position) were then modeled using general additive models (GAMs) to investigate possible individual trends. Model performance was evaluated according to R^2 and AIC (Akaike's Information Criterion) values.

A level of significance $p = 0.05$ was used for all statistical analyses.

Calculations were carried out with the programming environment *R* (R Development Core Team, 2010).

3. Results

A total of 344 subsamples were extracted and analyzed from the ten baleen plates examined: 150 from SW Iceland and 194 from NW Spain. All samples were successfully processed and analyzed except one, which was probably damaged during processing and thus did not produce any analytical result.

Distribution of Sr concentrations was extremely variable: overall concentrations ranged approximately 35 mg kg^{-1} from minimum to maximum values; when samples from NW Spain and SW Iceland were examined separately, corresponding ranges were 30 and 25 mg kg^{-1}, respectively (Table 2, Figure 3).

The distribution of Sr concentrations was normal in all four positions analyzed, except in the position 30 of baleen plates from SW Iceland ($p < 0.05$, Shapiro Wilk test). Variances were homogeneous in all positions, except position 1 ($p < 0.05$, F test). In all the four positions considered Sr concentrations were significantly higher in the plates of whales from NW Spain than in those of whales from SW Iceland ($p < 0.05$ in all cases; Welch's *t*-test in position 1, Student *t*-test in positions 10 and 20, Wilcox test in position 30, Table 2, Figure 3). Significantly higher Sr concentrations were also found in position 30 than in position 1 ($p < 0.05$, Wilcox test, Figure 3) in the two sampling areas. The difference between samples taken in position 30 and those taken in position 1 along the plates was similar in the two sampling areas and averaged 14.9±1 mg kg^{-1} (Figure 3).

GAMs were fitted to model longitudinal variations of Sr concentrations along plates in each individual separately to examine possible non-linear fluctuations and individual variations. Figure 4 shows the individual trends sorted by sampling area. Sr concentrations increased longitudinally from proximal to distal samples in all individuals, and showed marked longitudinal fluctuations in some of them: "peaks and valleys" could be observed in plates GA, GE, IA, IB, IE (Figure 4).

4. Discussion

In the present study, Sr concentrations were determined along the longitudinal growth axis of fin whale baleen plates, providing the first evidence of time-related Sr accumulation in this tissue. The analyses of plates sampled from different individuals from two separate areas provided a new insight into the accumulation process of this element and can be summarized in three main findings.

a) Sr concentrations increase from proximal to distal segments of baleen plates.

The baleen plate has a continuous growth and its distal tip erodes progressively to facilitate the production of the filaments that constitute the filtering apparatus of mysticetes. The growth rate of baleen plates in the fin whale averages 20 cm per year (Aguilar et al., 2014; Bentaleb et al., 2011). Thus, to examine trends of Sr accumulation during the year that preceded the whales' death, concentrations of Sr were determined in subsamples spaced regularly along the proximal 30-40 cm segment of the plate. Results revealed a consistent increase of Sr concentrations from proximal to distal subsamples in all individuals. This result is consistent with previous studies on Sr concentrations in hair of terrestrial mammals, which reported higher Sr concentrations in the older segments of the tissue than in the more recently formed ones (*e.g.* Kempson and Skinner, 2005; Kempson et al., 2006).

Studies made using stable isotopes of Sr to ascertain the relative contribution of endogenous *vs* exogenous sources of this element in hair show that only a small part of Sr is of endogenous origin, derived from Sr metabolism. Indeed, a substantial proportion of Sr derives from environmental exposure and subsequent adsorption of the element on the outer surface of the hair (Gellein et al., 2008; Kempson and Skinner, 2005; Tipple et al., 2013). Here, the proportion of endogenous *vs* exogenous Sr in baleen plates could not be established through Sr isotopic characterization. However, the average Sr concentrations found in the position (cm) 1 of the plates could be a reliable proxy for estimating the endogenous Sr contribution. As this position corresponds to the point where the plate emerges from the gum, samples taken there are not affected yet by exposure to the external environment. The substitution of Ca with Sr in baleen hydroxyapatite, a phenomenon commonly reported in bone, and related to the similar chemical properties of the two elements, is likely to contribute to most endogenous Sr in baleen (Fourman et al., 1968; Vaughan, 1981).

The increment of Sr concentrations observed along plates suggests however a combined endogenous - exogenous origin of Sr. As the keratin forming baleen tissue becomes inert immediately after its formation, any Sr concentration increase observed along the plate suggests that an increasing proportion of the element is adsorbed on the plate's surface from seawater. The observed increasing pattern may also be enhanced by a 'solvent depletion' effect: during the plate growth, the distal segments of the plate are progressively eroded. If some components of the plate deteriorate faster than those where Sr is adsorbed – or incorporated (i.e. hydroxyapatite), an apparent uptake of Sr may be observed, whereas the increase would be determined by the concentration of existing Sr.

It is noteworthy that the increasing pace of Sr was similar in all cases: differences between Sr concentrations in the extreme positions along plates were similar in the two areas, and trends were similar in all individuals. This suggests that, even if each individual had a different history of exposure to environmental Sr and different metabolic Sr baselines, the rate of accumulation during the baleen plate growth - or the rate of erosion and thus depletion of other plate components - is rather constant and is governed by simple physicochemical processes.

b) Sr concentrations vary among whale stocks.

Strontium concentrations in the oceans are related to a combination of different natural processes including the contribution of riverine input, biologic activity, inorganic reactions, and the mixing of water masses (Andersen et al., 1970). Authors such Angino et al. (1966) discouraged the use of "average" concentrations of Sr in sea water, due to the considerable variations of its concentrations in the oceans. Many authors have also highlighted the importance of the zooplanktonic contribution to Sr oceanic concentrations: several species, especially those provided with aragonitic shells, can act as an absorbing medium and incorporate high Sr concentrations (Angino et al., 1966; De Villiers, 1999; Stoll et al., 1998; Tripati et al., 2009). As a consequence, water masses with different proportions of these organisms may show large differences in their Sr concentrations. Some latitudinal variations of Sr concentrations have also been detected: in the Atlantic Ocean, Sr is less concentrated in northern waters than in subtropical waters (Angino et al., 1966); while in the Pacific Ocean Sr concentrations generally increase towards high latitudes (De Villiers, 1999). However, the highest Sr concentrations are generally found in oceanic areas characterized by the presence of upwelling phenomena, high productivity, and low salinity (De Villiers, 1999; Uddin et al., 2013).

In the present study, higher Sr concentrations were observed in the baleen plates from whales feeding off NW Spain than in those from whales feeding off SW Iceland. This suggests that the two fin whale stocks are exposed to different environmental concentrations of Sr. Both feeding grounds are located in areas of high summer productivity. The difference in Sr baselines between the two areas may thus be attributed to a higher abundance of Sr-enriched zooplankton and/or to a higher contribution of Sr-enriched suspended particulate derived from riverine inputs off NW Spain as compared to SW Iceland. During winter, whales from both areas migrate to breeding grounds whose precise location and migration routes are still unknown. Fin whales feeding off Spain likely belong to an isolated stock that in winter would migrate southwards to a breeding ground probably located off the western coast of Africa (IWC 2009; Vighi et al., 2016). Whales belonging to the 'West Iceland' stock may be instead a complex mixture of individuals breeding in the Central – Western Atlantic, and migrating along multiple routes, mainly following a broad corridor along the Gulf Stream (IWC 2009, Silva et al. 2013). The lack of knowledge about the breeding location and migration corridors of the two groups of whales precludes speculation on the origin of the exogenous Sr adsorbed along the plates. However, the difference found between the two whale populations in the position 1 of the plates – that may be reflective of a different endogenous Sr baseline in the two groups (and yet probably related to their exposure to overall different environmental Sr) - is somehow maintained along baleen plates. The similar increasing rate of Sr concentrations along plates in the two whale stocks suggests that Sr is incorporated at a constant pace during migration. Thus, an average baseline gradient of Sr concentrations, probably related to latitude, appears to be maintained. This result is consistent with results from a previous study investigating Sr concentrations in the bone of fin whales from the same stocks (Vighi et al., 2017). Even after a long-term process of metabolic integration such that taking place in bone (Beard and Johnson, 2000), Sr concentrations in whales from NW Spain were higher than in those from SW Iceland, indicating that the overall environmental Sr concentration to which the two stocks are exposed is substantially different. This finding further supports the already well documented isolation of the populations of fin whales summering off NW Spain and SW Iceland (IWC, 2009).

c) Sr concentration trends vary individually, and in some whales show temporal fluctuations.

Despite the overall trends of Sr concentration in baleen plates showed a consistent increase from proximal to distal positions, results of GAMs showed some individual variability. When analyzed separately, each individual showed a different longitudinal pattern of Sr concentration along its plate. Three whales from SW Iceland showed peaks and fluctuation-like trends. In two of them (whales IB and IE), peaks of Sr concentrations appeared at approximately the 5 and 20 cm positions, while in another (whale IA) the trend seemed to be shifted, with peaks at approximately the 15 and 25 cm positions. In the whales from NW Spain, trends were less defined, with the exception of individuals GA and GE, whose Sr concentrations showed respectively a minimum and a maximum close to the 10 cm position. As previously hypothesized, most of the Sr detected in baleen plates would be of exogenous origin and would therefore reflect the differential Sr contribution of the water masses in which the whales move and feed. As baleen plates grow approximately 20 cm per year (Bentaleb et al., 2011; Aguilar et al., 2014), at least one entire annual migration cycle of the whale is included in the analyses. Thus, some fine scale elemental variations in the chemical characteristics of the regions visited by the whales during migration would be reflected along these segments of baleen plates. Ideally, as all whales were here collected during summer, positions 1, 20 and 40 could be reflecting the characteristics of the summer feeding grounds, while positions 10 and 30 would be reflecting those of the wintering grounds.

The fluctuations-like trends observed, although not clearly defined, likely reflect the whales' migration through water masses with different Sr concentrations. These variations may suggest, for example, migration from less productive, warmer or more saline waters, in which Sr concentrations are lower, to more productive, colder or less saline waters, in which Sr concentrations are higher (De Villiers, 1999). As previously stated, our analyses could not distinguish between exogenous *vs* endogenous Sr. Indeed, slight variations in endogenous Sr experienced in the year and a half before the whale death are also likely to have some influence on the concentrations detected in the plates, *e.g.* by smoothing temporal trends and increasing individual variability. The scarce knowledge about the precise migratory routes and destinations of whales prevents yet again correlating the results observed with precise environmental Sr concentrations. However, these findings point to the potential of Sr concentration in baleen plates to be used as chemical tracer not only of stock structure, but also of movements among water masses with distinct elemental composition.

5. General conclusions

Baleen plates of fin whales proved to accumulate substantial amounts of Sr in their structure, with concentrations increasing in the distal positions of the baleen. This suggests that a large proportion of Sr is of exogenous origin and is adsorbed on the outer surface of the plate from the surrounding seawater. Results of this study also confirm that Sr concentration in keratinous tissues of marine organisms (mysticetes baleen plates or pinniped hair or vibrissae) can be used as ecological tracer, like hair Sr concentration has been used to trace movements and migrations of terrestrial mammals (*e.g.*

Bataille and Bowen, 2012; Beard and Johnson, 2000; Font et al., 2012). The coupled analysis of elemental Sr and Sr stable isotope ratios, allowing determination of the exact proportion of endogenous *vs* exogenous Sr in baleen plates, the relative impact of the 'solvent depletion' effect, and the rates of elemental integration in this tissue, would enhance this approach, and provide an alternative insight into the migrations and geographic areas used by whales.

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Figure captions

Figure 1. Sampling areas. The North Atlantic fin whale population stock subdivision as proposed by the International Whaling Commission (IWC, 2017; EC = Eastern Canada + Eastern USA; WG = West Greenland; EG = East Greenland, WI = West Iceland; EI + F = East Iceland + Faroe Islands; N = Norway; S = Spain). Sampling areas and the locations of land stations Caneliñas (Spain) and Hvalfjörður (Iceland), where samples were collected, are marked.

Figure 2. Baleen plate and outline of sampling.

Figure 3. Sr concentrations (mg kg^{-1} dry weight) along the longitudinal growth axis of baleen plates, sorted by sampling area. Means (marked with darker dots) and relative standard deviations of the two areas are shown for every position (cm).

Figure 4. Individual trends of Sr concentrations (mg kg^{-1} dry weight) along the longitudinal growth axis of baleen plates, modeled through GAMs, in the two sampling areas.

Table 1. Biological information from fin whales sampled in SW Iceland.

ID Code	Sampling date	Sex	Length (m)
IA	23/7/13	Female	17.17
IB	23/7/13	Male	18.19
IC	23/7/13	Female	21.25
ID	27/7/13	Male	18.74
IE	29/7/13	Male	20.03

Table 2
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Table 2. Number of samples analyzed; min. and max. Sr concentrations (mg kg^{-1} dry weight) calculated for the two sampling areas and all data together; mean (μ) Sr concentrations and relative standard deviations calculated at positions 1, 10, 20, 30 (cm) along baleen plates. Asterisks (*) indicate significantly higher concentrations according to the statistical tests performed to compare the two areas (1 = Welch's *t*-test; 2= Student *t*-test; 3 = Wilcox test).

	n	**min**	**max**	**cm 1** μ ± **SD**	**cm 10** μ ± **SD**	**cm 20** μ ± **SD**	**cm 30** μ ± **SD**
NW Spain	194	11	41.1	18.6±4.5 *[1]	23.1±5.3 *[2]	28.3±5.3 *[2]	32.5±4.3 *[3]
SW Iceland	149	5.1	30	7.1±1.4	14.3±3.4	19.6±4.1	23±3.5
All data	343	5.1	41.4	12.8±6.8	18.7±6.2	23.9±6.4	27.7±6.2

Figure 1
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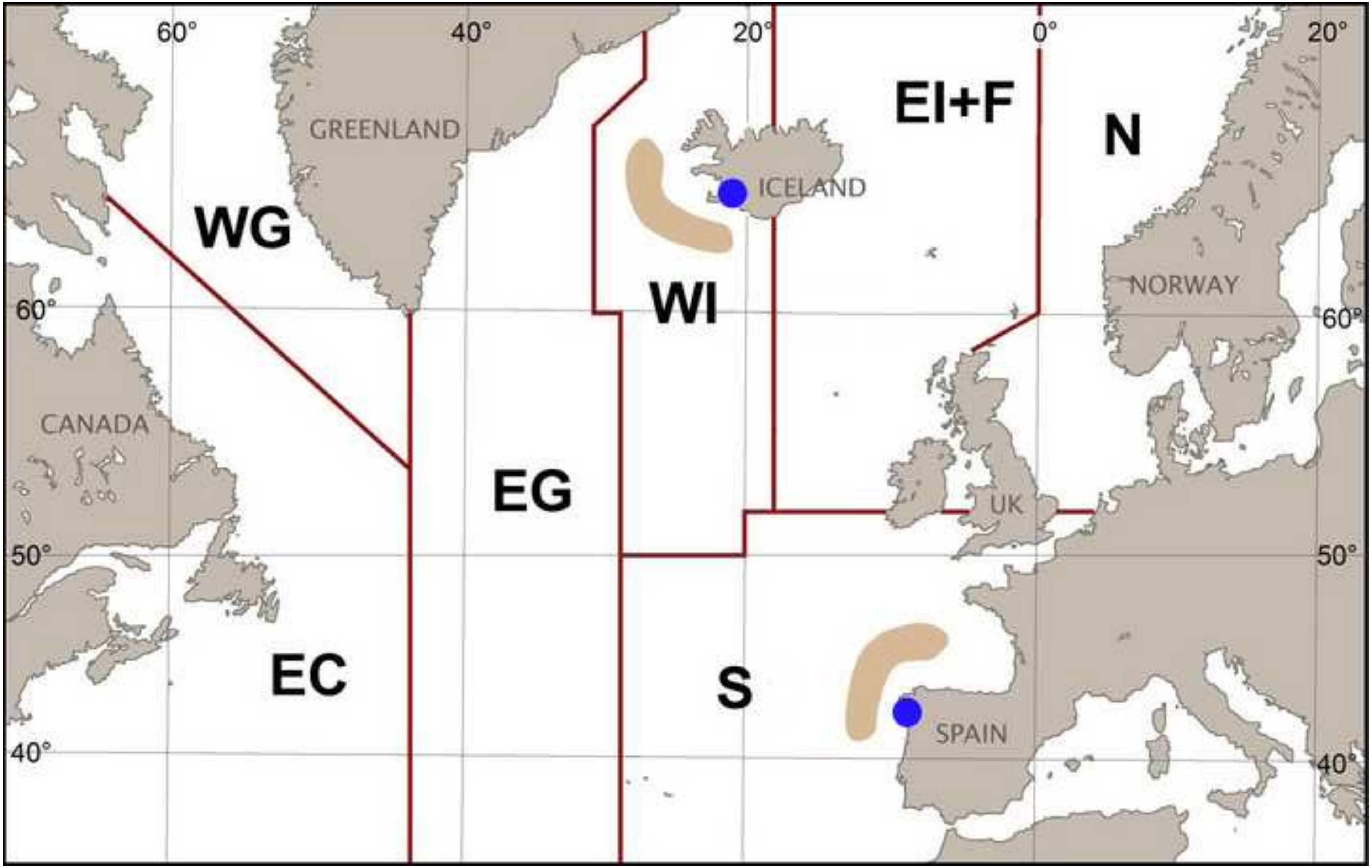

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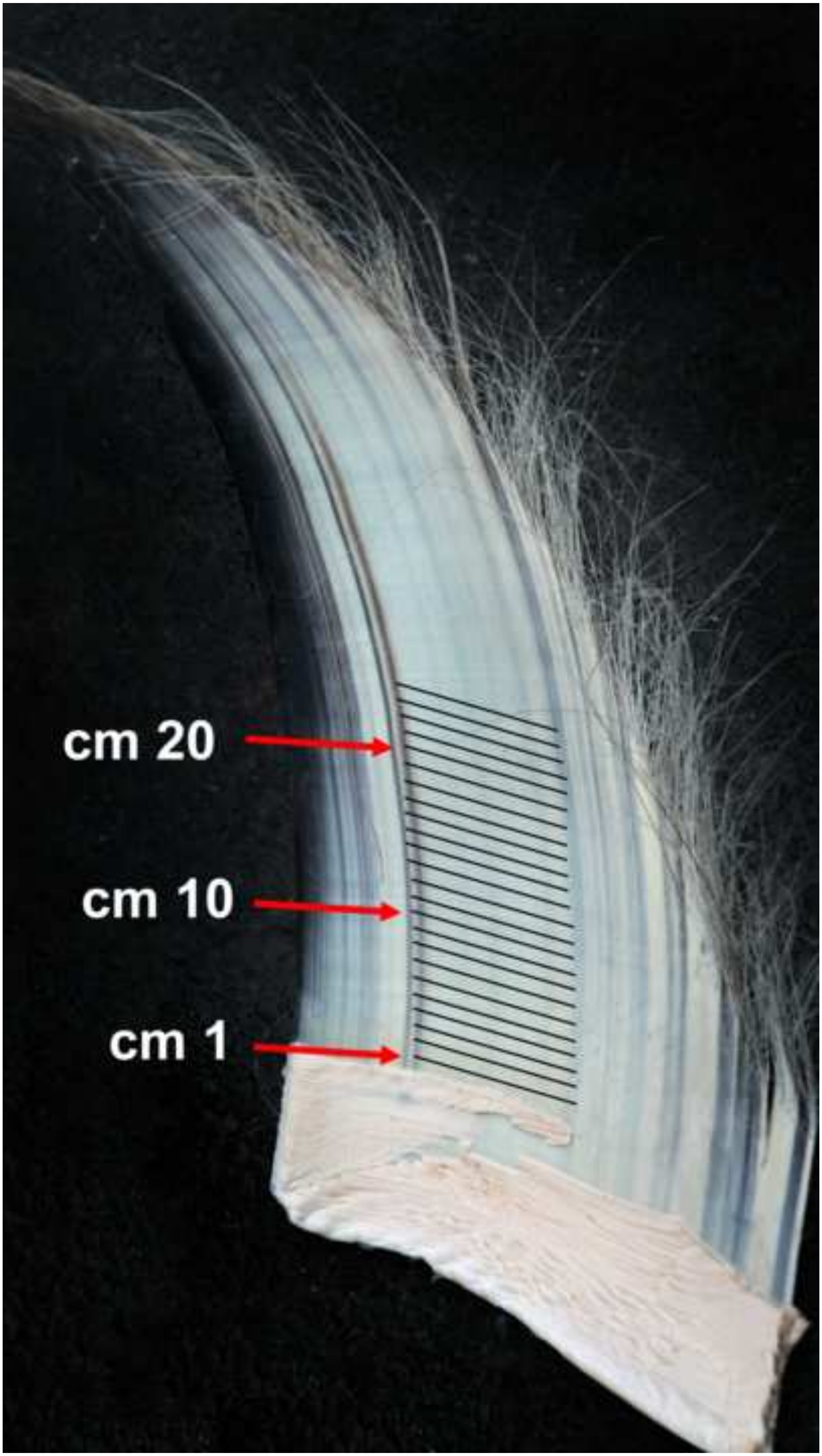

Figure 3

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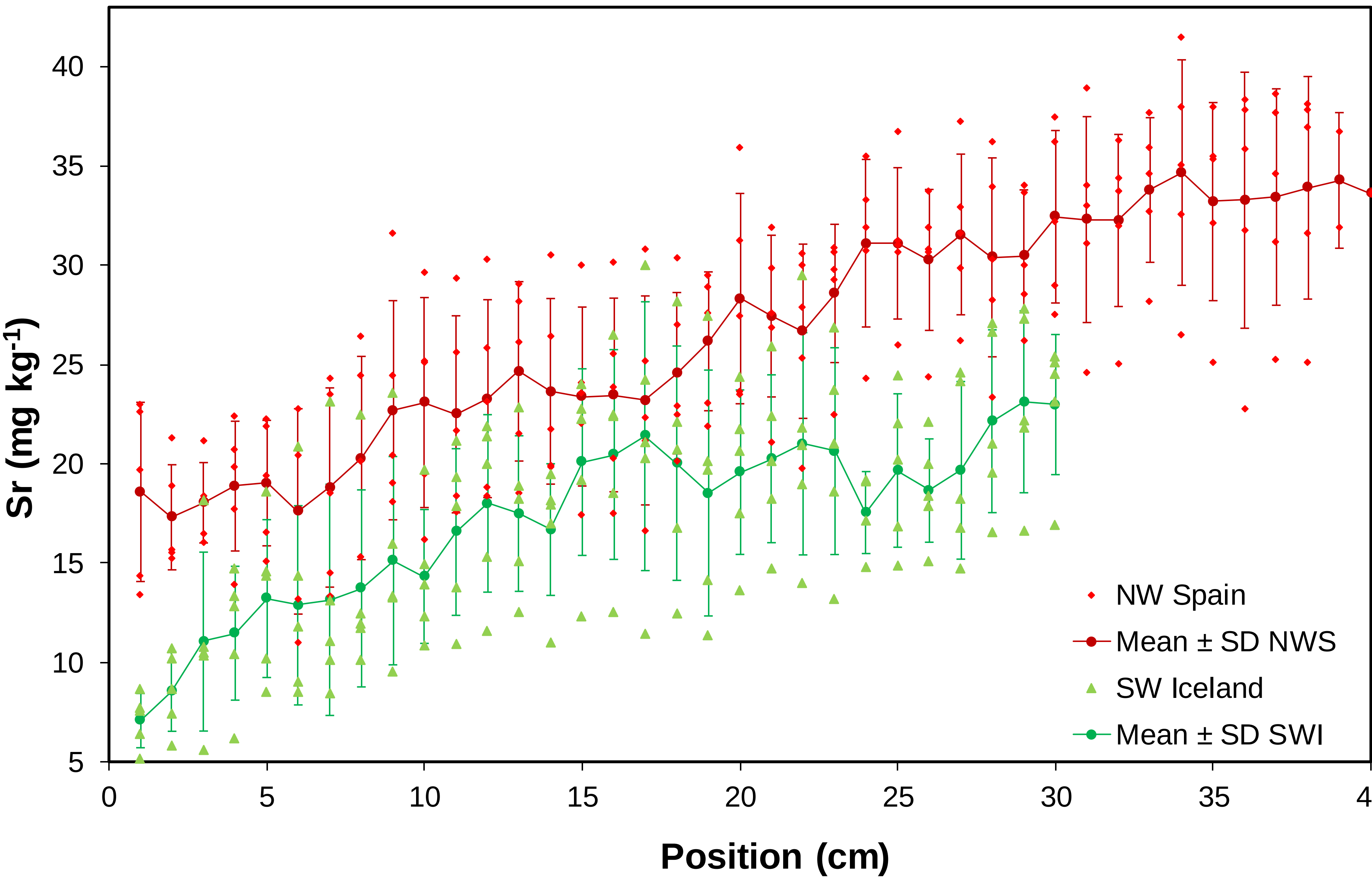

Figure 4
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