**Supplementary material from “Stable isotopes reveal winter feeding in different habitats in blue, fin and sei whales migrating through the Azores”**

**Methods**

***Potential range and seasonal movements of whale species***

The summer feeding range of North Atlantic blue whales extends from the Scotian Shelf to Davis Strait in the west, and from Denmark Strait to Svalbard in the east [1]. Fin whales co-occur with blue whales in most of this range but on the eastern Atlantic their feeding grounds extend further south to the British islands, Bay of Biscay and Iberian coast [2]. Additionally, there is evidence that part of the fin whale population wintering in the western Mediterranean migrates towards the Atlantic during the summer months [3]. Satellite telemetry studies indicate that blue and fin whales seen in the Azores migrate to central Atlantic waters, between Greenland and Iceland [4]. A recent photo-identification match between the Azores and the Gulf of St. Lawrence indicates that blue whales seen in the Azores may spend the previous summer on either side of the North Atlantic basin [5]. All sei whales instrumented with satellite tags in the Azores migrated to the Labrador Sea, off Canada [6,7]. Still, two individuals were apparently heading east of Greenland when their signals were lost, suggesting individuals may use feeding grounds on both sides of the Atlantic [7].

The wintering grounds of these species remain unknown. Fin whales were acoustically detected along the Mid-Atlantic Ridge (16°-50° N, 24°-50°W) from late autumn through early spring, with higher detection rates north of 32°N during winter months [8]. Whaling records and historic and contemporary winter sightings of sei whales along the West African coast (from Morocco down to Senegal) [9,10] and of blue whales between Cape Verde and Mauritania [10-12] suggest part of the population may winter off the Northwest Africa coast.

Based on the above, we considered that blue and sei whales seen in the Azores may summer in the Northeast Atlantic (NEA) and Northwest Atlantic (NWA), and spend the 3-4 months preceding sampling in lower-latitude pelagic waters (Azores (AZ), North Africa,-NAF) or closer to the Northwest African coast (NAF-UPW). In the case of fin whales, we also considered the Iberia (IB), Bay of Biscay (BB) and western Mediterranean (MED) as plausible winter-spring habitats.

**Table S1.** Mean and standard deviation (SD) δ15N and δ13C values of potential prey taxa from the literature used to estimate the isotopic composition of prey groups in different regions, by season. Only studies that accounted for lipid through chemical extraction or mathematical correction and provided data for both δ15N and δ13C values, along with a descriptor of the variance and number of samples analysed, were included. Regions are: AZ-Azores, IB-Iberia, BB-Bay of Biscay, NAF-North Africa, NAF-UPW-North Africa Upwelling, NEA-Northeast Atlantic, NWA-Northwest Atlantic, MED-Mediterranean.

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Region | Location | Prey group | Lowest taxonomic ID | Year | Season | δ15N | | δ13C | | Nº | References |
|  |  |  |  |  |  | Mean | SD | Mean | SD | samples |  |
| AZ | Azores | Copepods | Copepods | 2009 | Spring | 5.16 | 0.63 | -20.45 | 0.56 | 52 | 13 |
| AZ | Azores | Euphausiids | Euphausiidae | 2009 | Spring | 6.39 | 0.66 | -19.94 | 0.66 | 27 | 13 |
| BB | Bay of Biscay | Euphausiids | *Meganyctiphanes norvegica* | 2001-10 | Autumn | 8.30 | 0.20 | -19.80 | 0.20 | 15 | 14 |
| IB | Iberia | Euphausiids | *Meganyctiphanes norvegica* | 2001 | Spring | 6.35 | 0.56 | -20.93 | 0.31 | 6 | 15 |
| IB | Iberia | Euphausiids | *Meganyctiphanes norvegica* | 2001 | Autumn | 7.55 | 0.57 | -21.10 | 0.20 | 6 | 15 |
| NAF | Cape Verde | Copepods | *Undinula vulgaris* | 2012 | Autumn | 4.68 | 0.31 | -19.49 | 0.38 | 3 | 16 |
| NAF | Cape Verde | Euphausiids | Euphausiid | 2012 | Autumn | 3.04 | 0.32 | -18.60 | 0.16 | 3 | 16 |
| NAF | Guinea Dome | Copepods | *Undinula vulgaris* | 2012 | Autumn | 4.95 | 0.85 | -19.14 | 0.13 | 6 | 16 |
| NAF | Guinea Dome | Copepods | *Calanoides* sp. | 2015 | Spring | 8.28 | 1.10 | -19.37 | 0.80 | 13 | 17 |
| NAF | Guinea Dome | Euphausiids | Euphausiacea | 2015 | Spring | 7.79 | 1.06 | -19.70 | 0.40 | 11 | 17 |
| NAF | Guinea-Bissau - Liberia | Copepods | *Undinula vulgaris* | 2012 | Autumn | 6.07 | 0.15 | -19.97 | 0.06 | 3 | 18 |
| NAF | Guinea-Bissau - Liberia | Euphausiids | Euphausiid | 2012 | Autumn | 4.45 | 0.26 | -19.90 | 0.24 | 4 | 18 |
| NAF | Western Tropical Atlantic | Copepods | *Undinula vulgaris* | 2012 | Autumn | 4.46 | 1.75 | -19.47 | 0.90 | 23 | 16 |
| NAF | Western Tropical Atlantic | Copepods | *Calanoides* sp. | 2015 | Spring | 6.19 | 1.16 | -19.50 | 0.60 | 19 | 17 |
| NAF | Western Tropical Atlantic | Euphausiids | Euphausiid | 2012 | Autumn | 4.23 | 1.60 | -18.78 | 0.67 | 10 | 16 |
| NAF | Western Tropical Atlantic | Euphausiids | Euphausiacea | 2015 | Spring | 6.60 | 0.96 | -19.22 | 0.73 | 24 | 17 |
| NAF | Western Tropical Atlantic | Euphausiids | *Meganyctiphanes norvegica* | 2015 | Spring | 8.00 | 0.81 | -19.17 | 0.05 | 2 | 17 |
| NAF | Western Tropical Atlantic | Euphausiids | *Thysanoessa* sp. | 2015 | Spring | 8.15 |  | -20.54 |  | 1 | 17 |
| NAF-UPW | Saharan bank | Copepods | *Calanoides* sp. | 2015 | Spring | 5.57 | 1.15 | -17.93 | 1.35 | 7 | 17 |
| NAF-UPW | Saharan bank | Euphausiids | Euphausiid | 2012 | Autumn | 5.98 | 0.31 | -21.30 | 0.20 | 4 | 18 |
| NAF-UPW | Saharan bank | Euphausiids | Euphausiacea | 2015 | Spring | 6.25 | 1.58 | -18.16 | 1.53 | 14 | 17 |
| NAF-UPW | Senegal-Mauritania | Copepods | *Calanoides carinatus* | 2012 | Autumn | 6.80 | 0.91 | -17.70 | 0.45 | 8 | 18 |
| NAF-UPW | Senegal-Mauritania | Copepods | *Undinula vulgaris* | 2012 | Autumn | 4.62 | 0.52 | -19.06 | 0.41 | 19 | 16, 18 |
| NAF-UPW | Senegal-Mauritania | Copepods | *Calanoides* sp. | 2015 | Spring | 8.30 | 1.09 | -18.34 | 1.18 | 27 | 17 |
| NAF-UPW | Senegal-Mauritania | Euphausiids | Euphausiid | 2012 | Autumn | 6.14 | 1.59 | -19.16 | 0.49 | 10 | 16, 18 |
| NAF-UPW | Senegal-Mauritania | Euphausiids | Euphausiacea | 2015 | Spring | 8.63 | 1.16 | -18.51 | 1.71 | 19 | 17 |
| NEA | Iceland Sea | Euphausiids | *Meganyctiphanes norvegica* | 2007 | Summer | 7.50 | 0.52 | -20.40 | 0.35 | 3 | 19 |
| NEA | Iceland Sea | Euphausiids | *Thysanoessa inermis* | 2007 | Summer | 8.70 | 0.17 | -20.20 | 0.69 | 3 | 19 |
| NEA | Iceland Sea | Euphausiids | *Thysanoessa longicaudata* | 2007 | Summer | 9.00 | 0.17 | -22.10 | 0.17 | 3 | 19 |
| NEA | Spitzbergen | Copepods | *Calanus finmarchicus* | 2007 | Summer | 8.60 | 0.20 | -21.60 | 0.01 | 4 | 20 |
| NEA | Spitzbergen | Copepods | *Calanus hyperboreus* | 2007 | Summer | 6.70 | 1.00 | -22.20 | 0.26 | 4 | 21 |
| NEA | Spitzbergen | Euphausiids | Euphausiidae | 2007 | Summer | 8.30 | 0.10 | -20.00 | 0.11 | 4 | 21 |
| NEA | Svalbard | Copepods | *Calanus hyperboreus* | 2003 | Summer | 8.83 | 0.85 | -23.76 | 1.37 | 104 | 22 |
| NEA | Svalbard | Copepods | *Calanus glacialis* | 2003 | Summer | 8.40 | 1.31 | -22.58 | 1.46 | 146 | 22 |
| NEA | Svalbard | Copepods | *Calanus glacialis* | 2008 | Summer | 9.10 | 0.25 | -20.83 | 0.27 | 9 | 20 |
| NEA | Svalbard | Copepods | *Calanus finmarchicus* | 2008 | Summer | 7.90 | 0.10 | -21.20 | 0.10 | 3 | 20 |
| NEA | Svalbard | Copepods | *Calanus hyperboreus* | 2008 | Summer | 8.44 | 0.42 | -20.66 | 0.27 | 7 | 20 |
| NEA | Svalbard | Euphausiids | *Meganyctiphanes norvegica* | 2003 | Summer | 11.50 | 0.35 | -21.70 | 0.17 | 3 | 22 |
| NEA | Svalbard | Euphausiids | *Thysanoessa longicaudata* | 2003 | Summer | 10.30 | 0.51 | -21.70 | 0.51 | 26 | 22 |
| NEA | Svalbard | Euphausiids | *Thysanoessa inermis* | 2003 | Summer | 9.40 | 1.20 | -22.30 | 1.20 | 16 | 22 |
| NEA | Svalbard | Euphausiids | Euphausiidae | 2008 | Summer | 8.85 | 0.33 | -20.80 | 0.57 | 6 | 20 |
| NWA | Gulf St Lawrence | Copepods | *Calanus finmarchicus* | 2006 | Summer | 8.30 | 0.32 | -22.70 | 0.32 | 10 | 23 |
| NWA | Gulf St Lawrence | Copepods | *Calanus hyperboreus* | 2006 | Summer | 8.00 | 0.22 | -22.40 | 0.22 | 5 | 23 |
| NWA | Gulf St Lawrence | Euphausiids | *Meganyctiphanes norvegica* | 2006 | Summer | 9.20 | 0.49 | -21.10 | 0.24 | 6 | 23 |
| NWA | SW Greenland | Euphausiids | *Meganyctiphanes norvegica* | 2003 | Summer | 8.50 | 0.40 | -19.00 | 0.00 | 2 | 24 |
| NWA | Western Greenland | Copepods | *Calanus* spp. | 2010 | Summer | 8.39 | 1.27 | -20.97 | 0.84 | 38 | 25 |
| NWA | Western Greenland | Euphausiids | *Meganyctiphanes norvegica* | 2010 | Summer | 11.37 | 1.23 | -21.96 | 0.45 | 40 | 25 |
| NWA | Western Greenland | Euphausiids | *Thysanoessa inermis* | 2010 | Summer | 10.04 | 0.95 | -21.71 | 0.67 | 59 | 26 |
| NWA | Western Greenland | Euphausiids | *Thysanoessa longicaudata* | 2010 | Summer | 8.64 | 1.30 | -22.60 | 0.67 | 21 | 26 |
| NWA | Western Greenland | Euphausiids | *Thysanoessa raschii* | 2010 | Summer | 9.26 | 0.66 | -21.49 | 0.54 | 61 | 26 |
| MED | Balearic Sea | Euphausiids | *Meganyctiphanes norvegica* | 2009 | Winter | 6.91 | 0.74 | -19.68 | 0.33 | 5 | 27 |

**Table S2.** Estimates of the mean and standard deviation (SD) δ15N and δ13C values of regions used in Bayesian stable isotope mixing models run for blue, fin and sei whales. The model for sei whales included isotopic data from copepods belonging to family Calanidae; the models for blue and fin whales included isotopic data from euphausiids belonging to family Euphausiidae. Regions are: AZ-Azores, IB-Iberia, BB-Bay of Biscay, NAF-North Africa, NAF-UPW-North Africa Upwelling, NEA-Northeast Atlantic, NWA-Northwest Atlantic, MED-Mediterranean.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Regions | Season | Years | δ15N | | δ13C | | N |
| Mean | SD | Mean | SD |  |
| **Blue whale model** | |  |  |  |  |  |  |
| NAF-UPW | Autumn | 2012 | 6.09 | 1.33 | -19.77 | 1.08 | 14 |
| NAF-UPW | Spring | 2015 | 7.73 | 1.69 | -18.76 | 1.02 | 33 |
| NAF | Autumn | 2012 | 4.07 | 1.31 | -19.01 | 0.73 | 17 |
| NAF | Spring | 2015 | 7.06 | 1.12 | -19.39 | 0.68 | 38 |
| AZ | Spring | 2009 | 6.39 | 0.66 | -19.94 | 0.66 | 27 |
| NEA | Summer | 2003, 2007, 2008 | 9.60 | 0.79 | -21.55 | 0.72 | 64 |
| NWA | Summer | 2003, 2006, 2010 | 9.78 | 0.96 | -21.79 | 0.36 | 189 |
|  |  |  |  |  |  |  |  |
| **Fin whale model** | |  |  |  |  |  |  |
| NAF-UPW | Autumn | 2012 | 6.09 | 1.33 | -19.77 | 1.08 | 14 |
| NAF-UPW | Spring | 2015 | 7.73 | 1.69 | -18.76 | 1.02 | 33 |
| NAF | Autumn | 2012 | 4.07 | 1.31 | -19.01 | 0.73 | 17 |
| NAF | Spring | 2015 | 7.06 | 1.12 | -19.39 | 0.68 | 38 |
| AZ | Spring | 2009 | 6.39 | 0.66 | -19.94 | 0.66 | 27 |
| NEA | Summer | 2003, 2007, 2008 | 9.60 | 0.79 | -21.55 | 0.72 | 64 |
| NWA | Summer | 2003, 2006, 2010 | 9.78 | 0.96 | -21.79 | 0.36 | 189 |
| MED | Winter | 2009 | 6.91 | 0.74 | -19.68 | 0.33 | 5 |
| IB | Spring | 2001 | 6.35 | 0.56 | -20.93 | 0.31 | 6 |
| IB | Autumn | 2001 | 7.55 | 0.57 | -21.10 | 0.20 | 6 |
| BB | Autumn | 2001-2010 | 8.3 | 0.20 | -19.80 | 0.20 | 15 |
|  |  |  |  |  |  |  |  |
| **Sei whale model** |  |  |  |  |  |  |  |
| NAF-UPW | Autumn | 2012 | 5.26 | 1.20 | -18.66 | 0.76 | 27 |
| NAF-UPW | Spring | 2015 | 7.71 | 1.56 | -18.35 | 1.09 | 34 |
| NAF | Autumn | 2012 | 4.70 | 1.52 | -19.46 | 0.76 | 40 |
| NAF | Spring | 2015 | 7.04 | 1.53 | -19.45 | 0.68 | 32 |
| AZ | Spring | 2009 | 5.16 | 0.63 | -20.45 | 0.56 | 52 |
| NEA | Summer | 2003, 2007, 2008, 2013 | 8.52 | 1.10 | -22.89 | 1.34 | 277 |
| NWA | Summer | 2006, 2010 | 8.36 | 1.07 | -22.04 | 0.85 | 91 |

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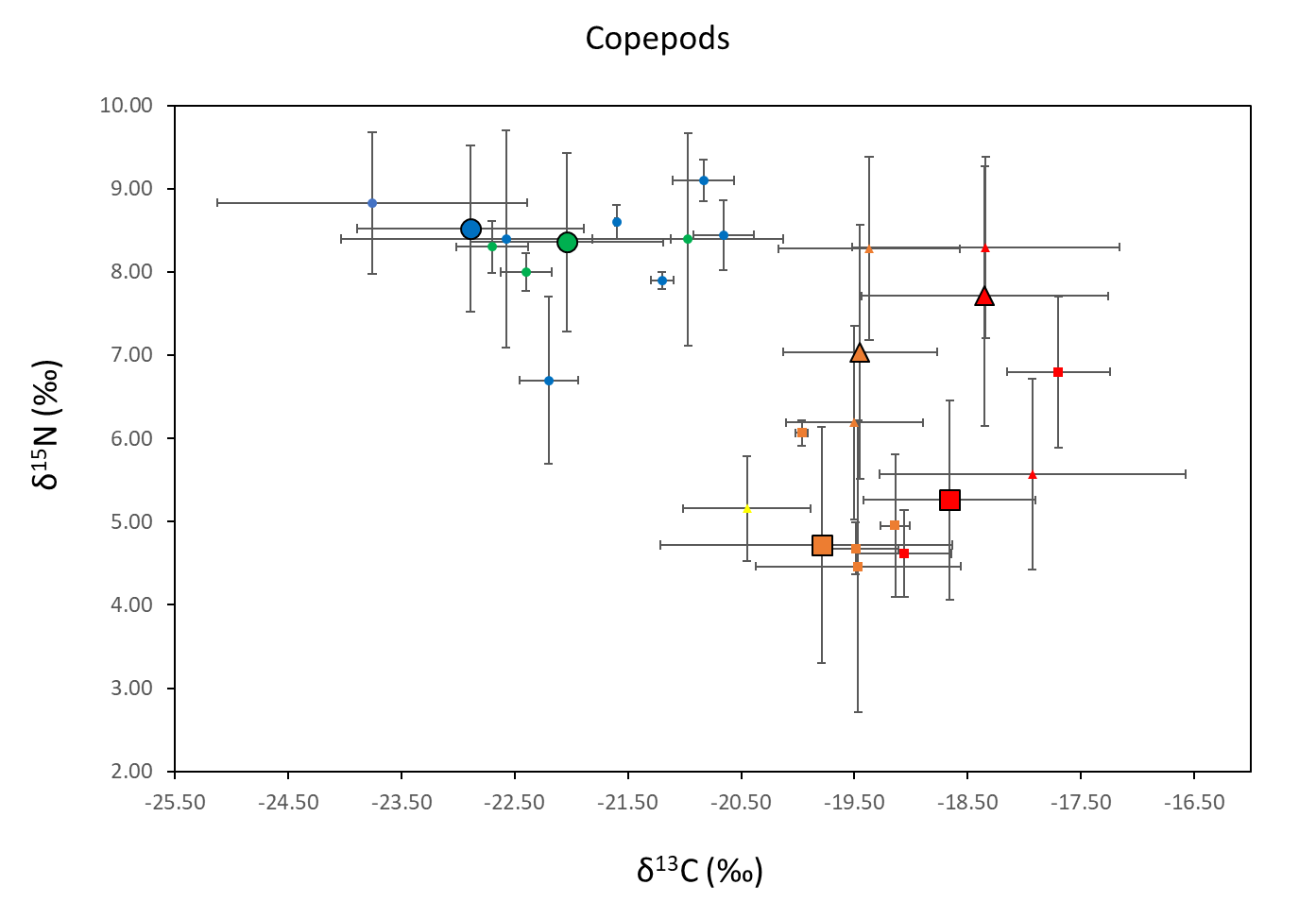
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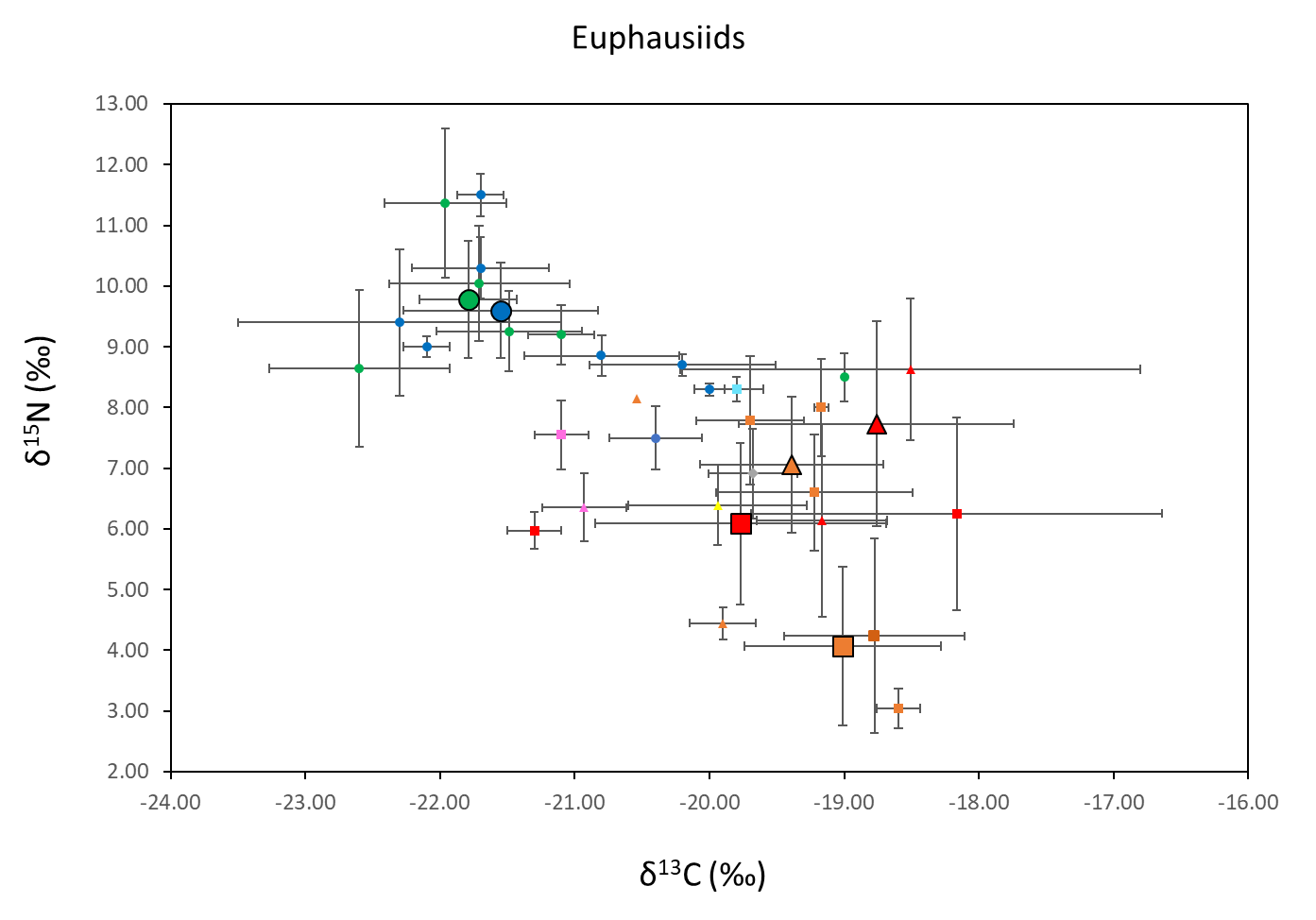
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**Results**

**Table S3** Summary of results of one-way ANOVAs and Student’s *t*-test assessing differences in δ15N and δ13C values among whale species (blue, fin and sei whales) and among sexes, seasons and years for fin and sei whales. Only factors for which the PERMANOVA indicated a statistically significant effect on stable isotopes were tested with univariate analysis (except for the comparison between spring and summer isotope values for fin whales). Statistically significant (p<0.05) pairwise comparisons based on post hoc Tukey HSD test are shown in the table.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  | δ15N value | | |  | δ13C value | | |
| Analyses | Factor | df | Student’s *t* or ANOVA *F* | *P* | Post hoc Tukey HSD |  | Student’s *t* or ANOVA *F* | *P* | Post hoc Tukey HSD |
| Inter-species |  | 2, 92 | *F*=6.21 | **0.003** | fin–sei |  | *F*=44.61 | **<0.001** | blue–fin, blue–sei, fin–sei |
| Fin whale | Sex | 40 | *t*=0.37 | 0.713 |  |  | *t*=1.60 | 0.118 |  |
|  | Season | 38 | *t*=-0.92 | 0.365 |  |  | *t*=0.81 | 0.423 |  |
|  | Year | 3, 34 | *F*=5.89 | **0.002** | 2008–2010, 2008–2013, 2008–2014 |  | *F*=27.25 | **<0.001** | 2008–2013, 2008–2014, 2010–2014 |
| Sei whale | Season | 2, 27 | *F*=0.32 | 0.731 |  |  | *F*=28.86 | **<0.001** | spring–summer, spring–autumn, summer–autumn |
|  | Year | 5, 27 | *F*=9.74 | **<0.001** | 2005–2014, 2008–2014, 2009–2014 |  | *F*=4.49 | **0.004** | 2008–2012, 2008–2014, 2009-2012 |

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**Figure S1** - Mean and standard deviation (SD) δ15N and δ13C values of potential prey items from different regions and seasons. Copepods are shown in the top plot and euphausiids in the bottom plot. Regions are represented by different colours: AZ-Azores (yellow), IB-Iberia (pink), BB-Bay of Biscay (light blue), NAF-North Africa (orange), NAF-UPW-North Africa Upwelling (red), NEA-Northeast Atlantic (dark blue), NWA-Northwest Atlantic (green), MED-Mediterranean (gray). Seasons are represented by different symbols: Winter (diamond), Spring (triangle), Summer (circle), Autumn (square). Smaller symbols represent mean (SD) isotopic values of individual taxa and larger symbols represent the weighted average (SD) by region and season.

**Table S4 –** Percentage mean and SD contribution of different regional sources to the diet of blue, fin and sei whales estimated using Bayesian isotopic mixing models. Regions are: AZ-Azores, IB-Iberia, BB-Bay of Biscay, NAF-North Africa, NAF-UPW-North Africa Upwelling, NEA-Northeast Atlantic, NWA-Northwest Atlantic, MED-Mediterranean.

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  | Blue whale | | Fin whale | | | Sei whale | | | |
|  |  |  |  |  | |  | Spring | | Summer | |
| Region-season | Season | Mean | SD | Mean | SD | | Mean | SD | Mean | SD |
| NAF-UPW-aut | Autumn | **20.0** | 16.7 | 4.5 | 4.5 | | **39.3** | 15.9 | **27.8** | 14.7 |
| NAF-UPW-spr | Spring | 7.5 | 5.6 | 2.7 | 2.1 | | **18.8** | 9.5 | **19.8** | 10.9 |
| NAF-aut | Autumn | **27.9** | 12.8 | 4.1 | 3.6 | | 13.5 | 10.7 | 13.1 | 8.9 |
| NAF-spr | Spring | 10.3 | 8.5 | 3.2 | 2.7 | | 11.7 | 9.1 | 12.6 | 8.8 |
| AZ | Spring | **18.1** | 16.6 | 4.3 | 4.2 | | 7.8 | 5.8 | 14.0 | 11.0 |
| NEA | Summer | 8.3 | 5.8 | 3.1 | 2.3 | | 4.2 | 2.6 | 5.9 | 4.3 |
| NWA | Summer | 8.0 | 5.7 | 3.1 | 2.4 | | 4.8 | 3.1 | 6.8 | 4.9 |
| MED | Winter |  |  | 3.6 | 3.2 | |  |  |  |  |
| IB-spr | Spring |  |  | **63.6** | 11.5 | |  |  |  |  |
| IB-aut | Autumn |  |  | 4.8 | 5.3 | |  |  |  |  |
| BB-aut | Autumn |  |  | 3.0 | 2.3 | |  |  |  |  |