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Isotopic niches of fin whales from the Mediterranean Sea and the Celtic Sea (North Atlantic)

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A B S T R A C T

The fin whale (*Balaenoptera physalus*) is the most abundant and widespread mysticete species in the Mediterranean Sea, found mostly in deep, offshore waters of the western and central portion of the region. In the Mediterranean, this species is known to feed mainly on krill, in contrast to its Atlantic counterpart, which displays a more diversified diet. The International Whaling Commission recognizes several managements units in the Atlantic and the Mediterranean Sea and the connectivity between these populations is still being debated. Questions remain about inter-individual feeding strategies and trophic ecology.

The goal of this study was to compare isotopic niches of fin whales from the Mediterranean Sea and the Celtic Sea (North Atlantic).

$\delta^{13}C$ and $\delta^{15}N$ values were analysed in 136 skin biopsies from free-ranging Mediterranean fin whales sampled in 2010 and 2011 during campaigns at sea.

$\delta^{13}C$ and $\delta^{15}N$ values ranged from −20.4 to −17.1‰ and from 5.9 to 8.9‰, respectively. These values are in good agreement with those estimated previously from baleen plates from Mediterranean and North Atlantic fin whales. The narrow isotopic niche width of the Mediterranean fin whale (Standard Ellipses area SEAc) compared to the North Atlantic fin whale raises many concerns in the context of global changes and long-term consequences.

One could indeed expect that species displaying narrow niches would be more susceptible to ecosystem fragmentation and other anthropogenic impacts.

1. Introduction

The fin whale, *Balaenoptera physalus* (Linnaeus, 1758), is the most abundant and widespread mysticete species in the Mediterranean Sea, found mostly in deep, offshore waters of the western and central portions of the region (Notarbartolo-di-Sciara et al., 2003). While fin whale populations are classified as endangered by the International Union for Conservation of Nature (IUCN) Red List, they are not considered threatened in the North Atlantic (Reilly et al., 2013).

Mediterranean fin whales are currently defined as a distinct subpopulation from those in the North Atlantic (IWC, 2009; Notarbartolo-di-Sciara et al., 2003; Panigada and Di Sciara, 2012). The International Whaling Commission recognizes seven management units in the Atlantic and one in the Mediterranean Sea, comprising three breeding populations (IWC, 2016, 2007). Depending on the subpopulation they belong to, fin whales may face various anthropogenic threats, including ship strikes, entanglement in fishing gear, exposure to noise, chronic exposure to a variety of toxins and pollutants, and possible impacts of global climate change that include potential shifts in prey availability (Aguilar, 2009; Clapham et al., 1999; Davidson et al., 2012; Doney et al., 2012; Pinzone et al., 2015; Pompa et al., 2011). The

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connectivity between these subpopulations is still being debated. Although highly mobile, cetaceans including fin whales can show high levels of population structure in the absence of contemporary geographical barriers as the result of historical processes, social structure and ecological specializations (Bérubé et al., 1998; Roman and Palumbi, 2003). Genetic analyses based on both mitochondrial and nuclear DNA indicated differences between fin whales in the Mediterranean Sea, largely resident in the basin, and fin whales sampled in the Atlantic (Bérubé et al., 1998; Palsbøll et al., 2004). However, acoustic analyses have demonstrated some inter-population movements, prompting debate on the extent to which the two putative populations are geographically isolated (Castellote et al., 2014, 2012; Gimenez et al., 2014). Stable isotope analyses of baleen plates from stranded whales suggest that whales from the Mediterranean and North Atlantic are largely discrete but with occasional exchange (Bentaleb et al., 2011; Giménez et al., 2013; Ryan et al., 2013). The results of $\delta^{18}O$ values analysed in bones of fin whales from northwestern Spain and Iceland suggested intricate structure of fin whale subpopulations exploiting different habitats and with latitudinal migrations that are still far to be completely understood (Vighi et al., 2016).

The small Mediterranean Sea population has been proposed as vulnerable (VU) in IUCN's Red List of threatened species based on (a) the genetic distinction from the North Atlantic population, (b) it containing fewer than 10,000 mature individuals, (c) all mature individuals being in the one population, and (d) an inferred decline in numbers of mature individuals (Panigada and Di Sciara, 2012). The size of the population has been estimated at approximately 3583 individuals (95% CI = 2130–6027) in the western Mediterranean (except for the Tyrrhenian Sea) in 1991 (Forcada et al., 1996) and 901 (95% CI = 591–1374) in the Corsican-Ligurian-Provençal Basin in 1992 (Forcada et al., 1996), which is very low compared to the current estimate of 56,000 whales in the North Atlantic (Roman and Palumbi, 2003). In 2001, the abundance in the Pelagos Sanctuary (Western Mediterranean Sea; Fig. 1a) was estimated at 715 individuals (CV = 31.2%) (Gannier, 2006). Surveys carried out in summer 2009 in the Pelagos Sanctuary estimated abundance of fin whales at 148 (95% CI = 87–254), pointing towards an appreciable decrease in summer abundance and density since the early 1990s (Panigada et al., 2011).

Studies on Mediterranean fin whales feeding habits inferred from surface feeding visual observations from stomach content and faeces analyses suggested that the euphausiid *Meganyctiphanes norvegica* is the main food item in the western Mediterranean Sea (Canese et al., 2006; Notarbartolo-di-Sciara et al., 2003; Orsi Relini and Giordano, 1992). Off northwest Spain, stomach contents of captured whales during past whaling industry contained exclusively krill *M. norvegica* (Aguilar, 2009, 1985; Mizroch et al., 1984). In some areas from the North Atlantic, fin whales supplement their diet with small schooling fishes such as capelin, anchovies, sprat and herring (Mizroch et al., 1984; Ryan et al., 2014). Indeed, in the Celtic Sea sprat and herring account for half of the estimated diet composition which may account for the higher apparent trophic level compared with fin whales in the Bay of Biscay, the Mediterranean Sea and Icelandic waters (Ryan et al., 2014, 2013; Víkingsson, 1997). How these differences in diet influence species susceptibility, adaptability and conservation remains an open question and it is crucial to understand how fin whales respond to changes in prey availability, as well as how prey is affected by changing environmental conditions (Víkingsson et al., 2015). The potential effects of global environmental changes on Mediterranean fin whales may influence the entire population, with virtually no space to move to northern latitudes (Evans et al., 2010).

$\delta^{13}C$ and $\delta^{15}N$ values were previously investigated in baleen plates from fin whales sampled off Ireland (n = 7) (Ryan et al., 2013) and from the Mediterranean Sea (n = 9) (Bentaleb et al., 2011). Analysis of different tissues comes with certain caveats. Skin biopsies ensure known provenance, however the tissue turnover rate is estimated to be 8–10 weeks (Hicks et al., 1985; St. Aubin et al., 1990), during which time a highly mobile animal may move considerable distances. Baleen can only be sampled from dead (usually stranded) whales that are subject to wind and currents over potentially large distances, which usually precludes knowledge of fine-scale provenance. Skin is metabolically active and therefore provides a relatively temporally discreet insight into isotopic niche. Baleen however, due to it being an inert tissue, provides time-integrated data over which spatio-temporal reference points are difficult to discern given that growth rates and provenance are usually unknown (Ryan et al., 2013). Therefore, skin biopsies are preferable for the purposes of the present study where the key aim is to describe the isotopic niche of contemporary fin whales in the Mediterranean.

Stable isotope ratios of carbon ($^{13}C/^{12}C$ reported as $\delta^{13}C$) and nitrogen ($^{15}N/^{14}N$ reported as $\delta^{15}N$) values have become widespread and powerful trophic markers, as the stable isotope composition of consumer tissues are mostly derived from those of their food (DeNiro and Epstein, 1981, 1978). Contribution of each assimilated prey source are proportionally reflected in the tissues of a predator, after accounting for isotopic fractionation in the digestion and assimilation process (DeNiro and Epstein, 1981, 1978). This trophic fractionation typically results in enrichment in the heavier isotope (i.e. increase in $\delta^{13}C$ and $\delta^{15}N$) whose magnitude depends on the considered element. Trophic enrichment in ^{13}C is usually low (i.e. less than 1‰; Mccutchan et al., 2003). The $\delta^{13}C$ value of a consumer is therefore close to that of the diet and is typically used to indicate relative contributions to the diet of different potential primary producers in a trophic network, indicating for example the aquatic *vs.* terrestrial, inshore *vs.* offshore or pelagic *vs.* benthic contribution to food intake (Louis et al., 2014; Smith et al., 1996). ^{15}N trophic enrichment is more variable, but typically more marked than for ^{13}C, leading to a greater stepwise enrichment in ^{15}N with increasing trophic level (DeNiro and Epstein, 1981; Minagawa and Wada, 1984). Nitrogen stable isotopes are therefore mostly used to estimate an animal's trophic level (Post, 2002). The above-mentioned enrichment factors have been measured for several marine mammal species (Caut et al., 2011; Giménez et al., 2016; Hobson et al., 1996) including fin whales (Borrell et al., 2012). Bentaleb et al. evaluated $\delta^{13}C$ and $\delta^{15}N$ values in muscle and skin of 65 fin whales from the Mediterranean Sea and calculated the difference with data published previously for krill (Bentaleb et al., 2011).

Since the first conceptualization of the ecological niche as an *n*-dimensional hypervolume of which each dimension represent an environmental and/or resource requirement (Hutchinson, 1957), use of this concept has expanded in the ecological literature. It was proposed that $\delta^{13}C$ and $\delta^{15}N$ values can be used as a proxy to characterize the ecological niche of animals, given the effects of habitat and resource use on these isotopic patterns (*e.g.* (Bearhop et al., 2004; Flaherty and Ben-David, 2010; Newsome et al., 2007). Examining variance in intra- and inter-individual isotope values can be an effective way to investigate resource specialization. This approach allows one to estimate a proxy ecological niche known as the 'isotopic niche' (Newsome et al., 2007).

Here, we provide (1) an analysis of $\delta^{13}C$ and $\delta^{15}N$ values in skin biopsies of 136 fin whales sampled in the North-western Mediterranean Sea and (2) a comparison of isotopic niches of