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INTERNATIONAL WHALING COMMISSION

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Abstract

Mediterranean fin whales are thought to constitute an isolated sub-population, genetically separated from the eastern North Atlantic. It is listed as 'Vulnerable (VU)' under the IUCN red list of endangered species, with ships strikes representing the main cause of human-induced mortality across the region. Therefore, the identification of critical habitat is essential to channel conservation efforts and mitigate threats. Whilst summering areas of this population are relatively well described, migration routes and wintering grounds remain poorly known. In September 2012, eight fin whales were equipped with location-only satellite transmitters in the Ligurian Sea (north-western Mediterranean), within the Pelagos Sanctuary for Mediterranean Marine Mammals, a well-known summer feeding ground for the species. Subsequently, five more whales were tagged off the Island of Lampedusa in the Strait of Sicily - three in March 2013 and two in 2015 - where small numbers of animals congregate, notably for feeding purposes, during winter. Tag deployment in 2012 occurred late in the summer to maximise the gathering of information outside this season, while in 2013-2015 the aim was to observe migration between known feeding grounds. A Bayesian hierarchical switching state-space analysis was used to identify transiting and area-restricted search (ARS) behaviours. All whales undertook mid- to long-distance migrations, crossing some of the world's busiest maritime routes, and predominantly engaging in ARS behaviour with short-term transiting between feeding areas. One whale migrated from Lampedusa to the Pelagos Sanctuary in five days. The results suggest how a coordinated and dynamic management scheme – as foreseen by Marine Spatial Planning (MSP) - is needed to protect Mediterranean fin whales, emphasising the importance to address conservation issues on the Basin-wide rather than local scale. Furthermore, such information is essential to assess fin whales' critical habitats in the Mediterranean, to define appropriate protected areas within the regional Conventions.

Introduction

Considerable effort has been put into place in recent decades to depict the habitat use and preferences, behaviour, distribution and abundance of fin whales in the north-western Mediterranean (Azzellino et al., 2008; Druon et al., 2012; Forcada et al., 1996; Fossi et al., 2010; Jahoda et al., 2003; Laran and Gannier, 2008; Notarbartolo Di Sciara et al., 2003; Panigada et al., 2011, 2008, 2006, 1999), a well-documented summer feeding ground for the species. However, knowledge on fin whales' distribution and movements during other seasons, as well as the spatial and temporal migratory patterns and routes between the known feeding grounds and the connections to breeding areas remains scarce (Bentaleb et al., 2011; Castellote et al., 2009, 2008; Cotte et al., 2011; Cotté et al., 2009).

Mediterranean fin whales are exposed to several threats, ranging from indirect ones like chemical pollution and climate change (Castellote et al., 2009; Fossi et al., 2010, 2007, 2003), to direct ones such as ship strikes, recognized to be the main cause on human induced mortality for the species in the Region (Panigada et al., 2006). Fatal collisions with vessels represent the main cause of concern for the species conservation across the Mediterranean basin, and, by consequence, are being addressed at the regional and international scale by a joint effort by the Agreement on the Conservation of Cetaceans in the Black Sea Mediterranean Sea and Contigous Atlantic Area (ACCOBAMS), the Pelagos Sanctuary and the International Whaling Commission (IWC), to identify high risk areas where test and apply mitigation measures.

Considering that knowledge of critical areas is essential to channel conservation measures and threat mitigation actions, this paper presents telemetry data from different areas of the sub-population known range within the central and north-western Mediterranean, which proved to be important for helping to develop focussed mitigation measures and providing baseline data to measure their effectiveness.

Material and methods

Fin whales were equipped with location-only satellite transmitters in the Pelagos Sanctuary for Mediterranean Marine Mammals (Notarbartolo-di-Sciara et al., 2008) in September 2012, and off the Island of Lampedusa, in the Strait of Sicily, in March 2013 and 2015 (Fig. 1). While tag deployments in the Pelagos Sanctuary occurred as late in the summer as possible, to maximise the gathering of information outside known summer feeding grounds, in the Strait of Sicily satellite transmitters were deployed in March, when whales are known to concentrate for feeding purposes.

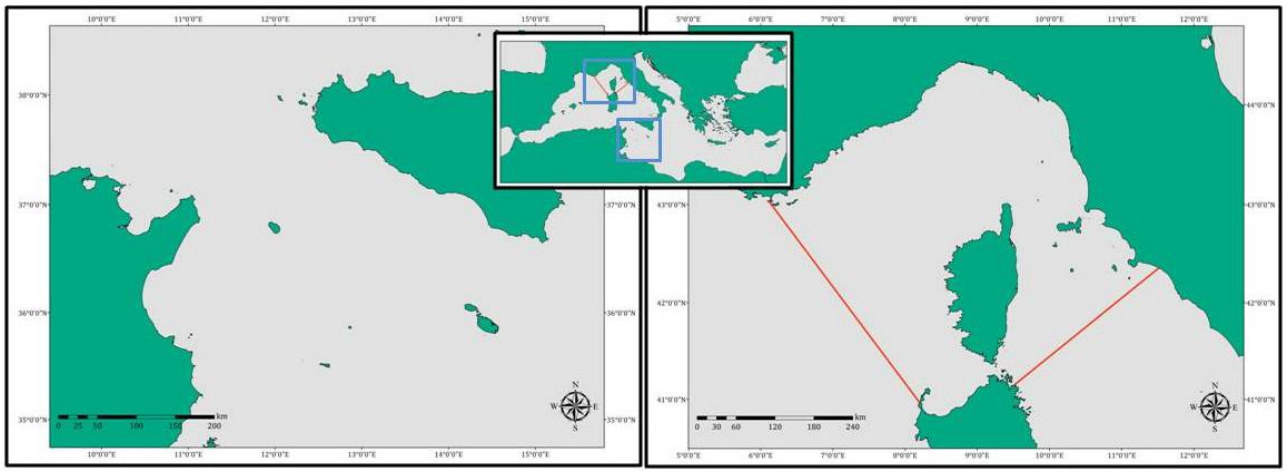


Fig. 1 – The two study area: the Strait of Sicily on the left and the Pelagos Sanctuary on the right.

Two types of location-only satellite transmitters were used: the transdermal (Wildlife Computers molds 177 and 193) and the Low Impact Minimally Percutaneous External Electronic (LIMPET) tags (molds 260B and 260C) (Andrews et al., 2008; Zerbini et al., 2006; Kennedy et al., 2013), depending on the weather conditions and the behaviour of the animals. Transdermal and LIMPET tags were deployed with a custom-modified pneumatic system (ARTS, ResTech Norway, Heide-Jorgensen et al., 2001; Gales et al. 2009) or a crossbow (Andrews et al., 2008), respectively.

The locations of the tracked whales were obtained by using a Kalman filtering (KF) algorithm (Douglas et al., 2012) applied to the Argos satellite-derived positions, reported to increase the number of estimated positions and improve their accuracy as well as to enhance the calculation of movement parameters, and therefore, to facilitate further analysis (Silva et al., 2014).

To evaluate the movement patterns and associated behaviour of the tagged fin whales, we applied Bayesian hierarchical switching state-space models (hSSSM) (Jonsen et al., 2013, 2007, 2006, 2005, 2003) to the filtered data to infer transiting (Zollner and Lima, 1999) and area-restricted search (ARS) (Kareiva and Odell, 1987) behaviours within tracks. Animals feeding on patchily distributed resources are expected to engage in ARS behaviour, characterised by increased turning angles and decreased move persistence (i.e. autocorrelation in speed and direction), when encountering sufficiently abundant prey, to increase search effort in the most profitable areas.

The package bsam for R was used for the analysis (Jonsen et al. 2013; R Development Core Team 2013). bsam fits hSSSM using Markov Chain Monte Carlo (MCMC) simulation methods implemented via JAGS. We chose an 8 h time step, which was larger than 80% of the observed time steps. This avoided excessive extrapolation over unobserved portions of a whale's track, while offering a sufficient temporal resolution to characterise switches in behaviour. Poor quality locations of class "Z" were removed prior to modelling to facilitate convergence. Tracks with gaps longer than four days between consecutive locations were split into separate segments. Two MCMC were run in parallel for 120,000 iterations. 100,000 iterations were discarded as burn-in, and 1 every 20 observations was retained for the remaining 20,000 samples, to reduce autocorrelation. Convergence was assessed by inspecting trace, autocorrelation and posterior density plots. Point estimates and uncertainty for model parameters were derived from 2,000 samples from the joint posterior distribution (1,000 samples per chain). The behavioural state of whale k in each time step t (b_{kt}) is a binary variable that can take value of 1 (transiting) or 2 (ARS). Following Jonsen et al. (2007), the behavioural state at each location was classified as ARS if the posterior mean of b_{kt} was greater than 1.75, as transiting if the mean was smaller than 1.25, and as uncertain otherwise.

To assess the occurrence and identify potential feeding habitats, we overlapped an ecological niche model (ENM) and satellite telemetry data. The ENM was built linking knowledge on ecological traits of fin whale (e.g. mobility, feeding strategy) with patterns of selected environmental variables (chlorophyll-a fronts and concentration) to identify favourable feeding habitats. Besides water depth, no physical variable such as temperature and current intensity was found to constrain the fin whale presence. Compared to the habitat modelling described in Druon et al. (2012) where frontal features was shown to play a major aggregation role for that species, the favourable feeding habitat was presently traced by the identification of sea surface chlorophyll-a fronts only and not in combination with the satellite-derived SST fronts. Indeed, infrared data was found to be more unstable from day to day than the optical data (chlorophyll-a data). Overall, the potential feeding habitat derived on a daily basis uses the productive frontal features of chlorophyll-a, a preferred range of surface chlorophyll-a concentration and a minimum water depth.

Results

Overall thirteen individual fin whales were tagged between 2012 and 2015, of which eight in the Ligurian Sea in 2012 and five in the Strait if Sicily in 2013 (3) and 2015 (2), respectively (Fig. 2). Tag performances varied

greatly depending on the type, with transdermal tags lasting between 2 and 142 days and LIMPET tags lasting between 18 and 44 days. Table 1 synthesizes information on the tag type duration and performances.

Tab. 1 – Summary of tag type performances

Type	Date	PTT #	Area	# of days
Transdermal	07/09/2012	112707	Pelagos	32
Transdermal	08/09/2012	112697	Pelagos	142
Transdermal	09/09/2012	112716	Pelagos	83
Transdermal	11/09/2012	112709	Pelagos	2
Transdermal	17/09/2012	112708	Pelagos	81
LIMPET	22/09/2012	102223	Pelagos	18
LIMPET	22/09/2012	102221	Pelagos	35
LIMPET	22/09/2012	102224	Pelagos	22
Transdermal	03/03/2013	111868	Strait of Sicily	8
Transdermal	04/03/2013	120938	Strait of Sicily	4
Transdermal	11/03/2013	120942	Strait of Sicily	13
LIMPET	14/03/2015	87776	Strait of Sicily	29
LIMPET	14/03/2015	87780	Strait of Sicily	44

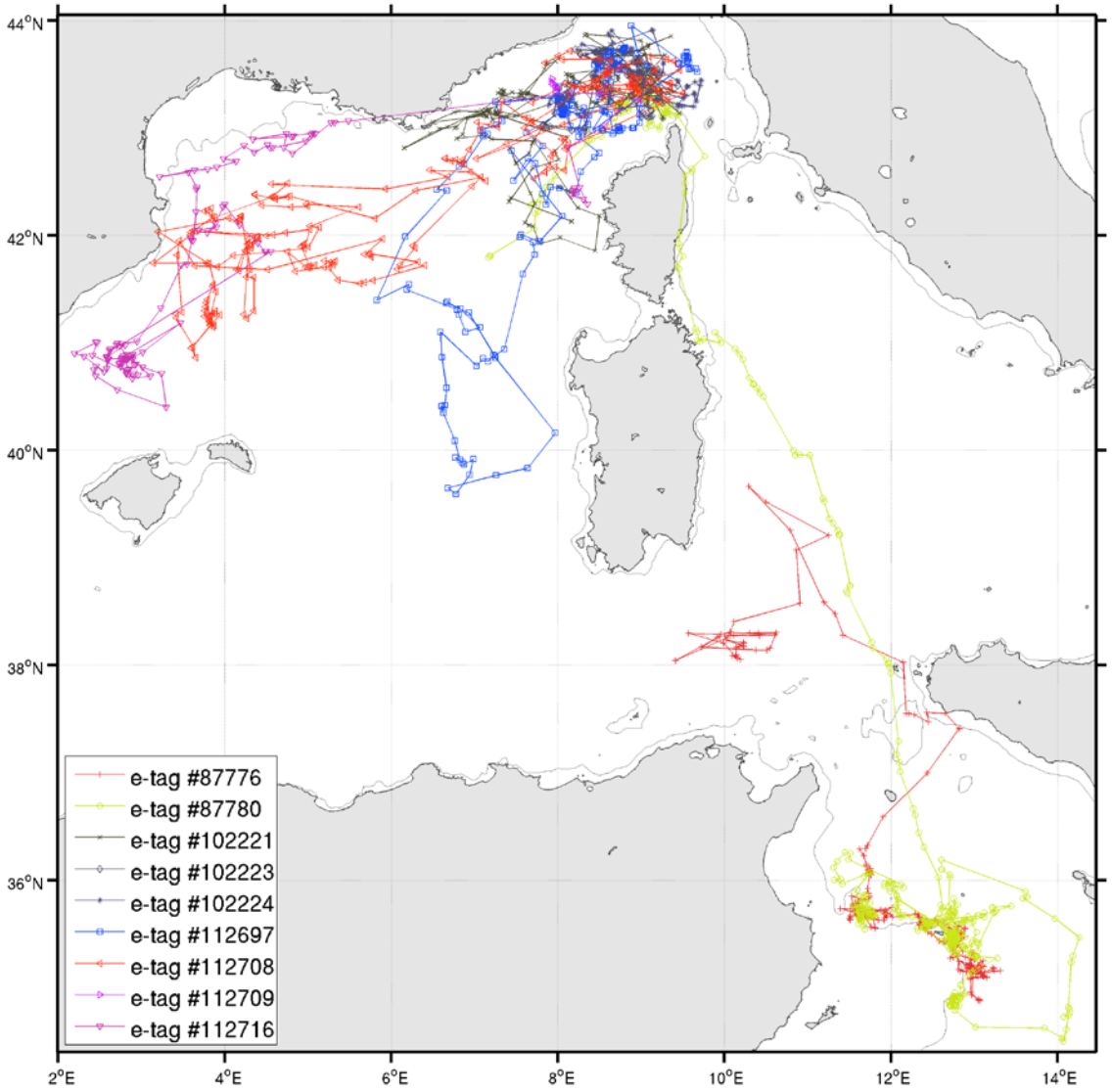


Fig. 2 – The overall tracks of seven fin whales tagged in the Ligurian Sea in September 2012 and two near Lampedusa (2) in March 2015. Different colors correspond to different individual whales and the 90 m-depth contour is shown.

The eight fin whales tagged in the Ligurian Sea in 2012 remained in the Pelagos Sanctuary summer feeding ground longer than expected (Fig. 2), possibly due to particularly mild climate conditions which allowed prolonged feeding activities in the area. Two individuals left the Pelagos Sanctuary area and moved towards the Balearic Islands, remaining in a defined area (100 x 100 km) for approximately 20 days before moving towards the Gulf of Lions and back to the Gulf of Genoa. The state-space model showed how fin whales predominantly engaged in ARS behaviour, with short-term transiting between potential and known foraging areas (Fig. 3). Table 2 summarises the results of the hSSSM analysis applied to the data collected in 2012 in the Pelagos Sanctuary. For some animals, the posterior estimates of bkt indicated a high percentage of locations where the behavioural state was uncertain. This may partly result from the small spatial scale of the animals' displacement compared to the accuracy and frequency of the satellite fixes, causing the model to be unable to discriminate transiting behaviour (Breed et al. 2011).

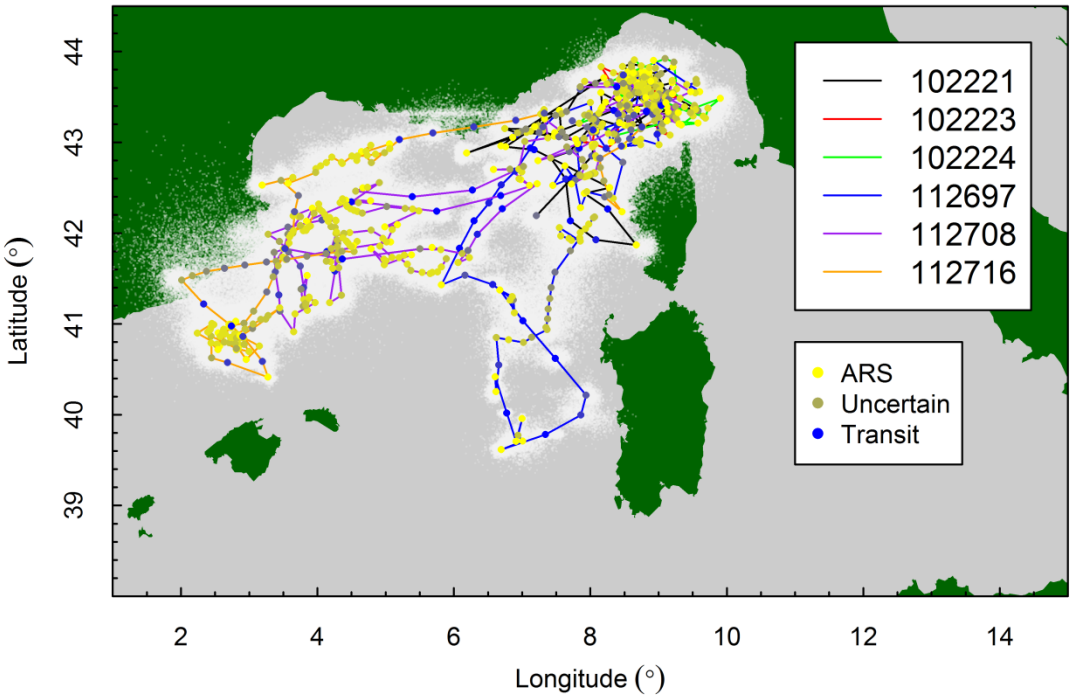


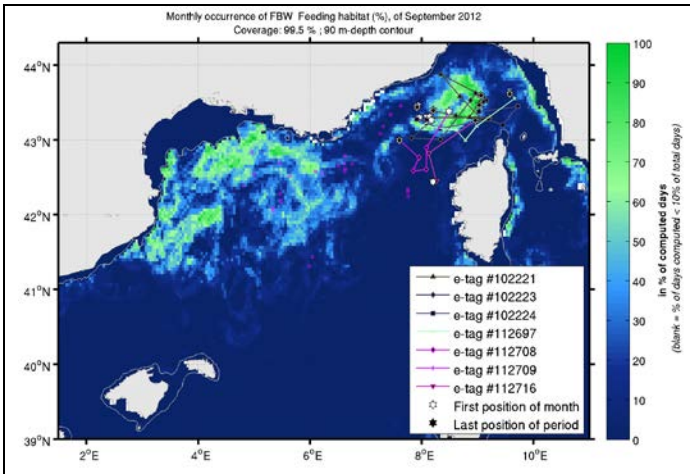
Fig. 3 – Tracks of fin whales tagged in the Ligurian Sea, reconstructed from the posterior estimates of the parameters of the hSSSM, and inferred behavioural states (transiting, Area Restricted Search or ARS, and uncertain). The white points represent model uncertainty around each location, as indicated by the latitude and longitude values at each MCMC iteration.

Tab. 2 – For each fin whale tagged in 2012 in the Ligurian Sea, percentage of locations where the behavioural state was classified as transiting, Area Restricted Search (ARS) or uncertain, based on the posterior mean of the b_{kt} parameter. When the temporal gap between consecutive locations was longer than four days, tracks were split into separate segments for the analysis. These are indicated here with the letter a and b.

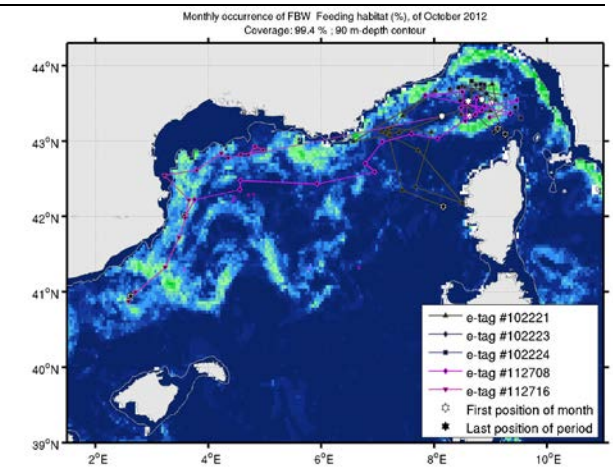
Tag code	Transit (%)	ARS (%)	Uncertain (%)
102221	9	55	36
102223	2	70	28
102224	0	68	32
112697a	10	75	15
112697b	15	58	27
112708a	0	78	22
112708b	9	70	21
112716a	10	10	80
112716b	4	74	21

The potential feeding habitat of fin whales in the western Mediterranean Sea drastically changes from the relatively limited extent during late summer in the Liguro-Provençal basin to most of the area in November 2012. The favourable feeding habitat tends then in December 2012 to be more frequent in the southern part of the area prior to concentrate in the central part of the western Mediterranean Sea in January 2013 and concentrate back in the Liguro-Provençal basin in February 2013. The positions of the seven tagged whales in

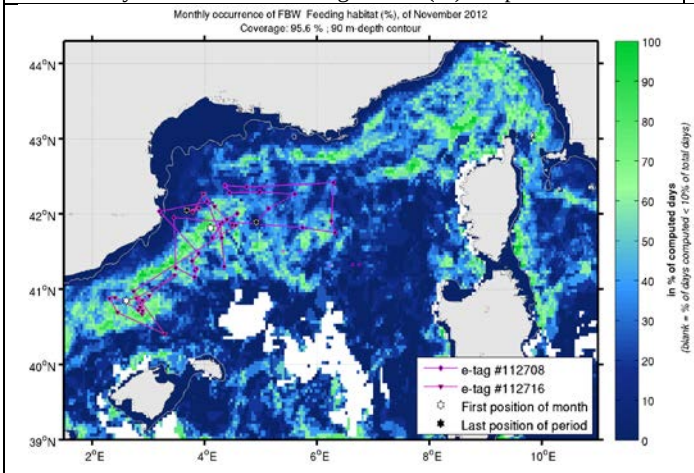
the Ligurian Sea in September 2012 globally follow the habitat relaxation in autumn with clear phases of transit when successive positions are distant and ARS behaviour otherwise (only one position per day is shown) (Fig. 4).



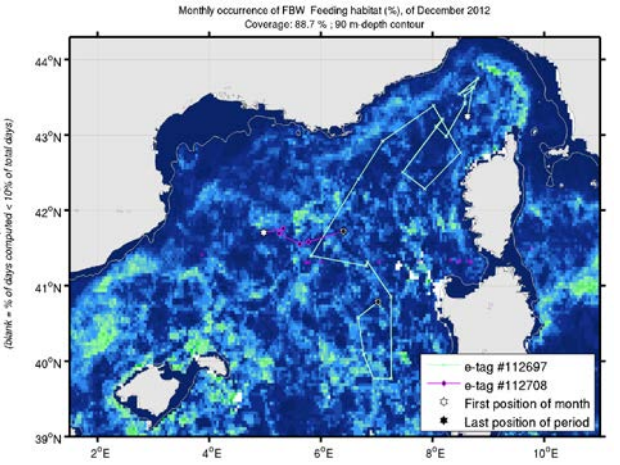
Monthly occurrence of feeding habitat (%) –September 2012



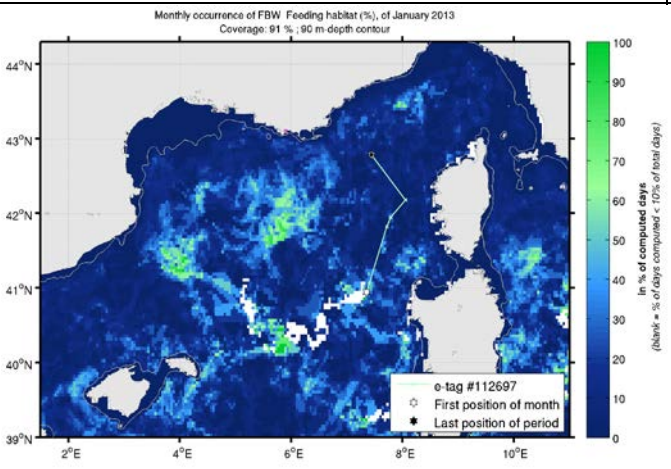
Monthly occurrence of feeding habitat (%) – October 2012



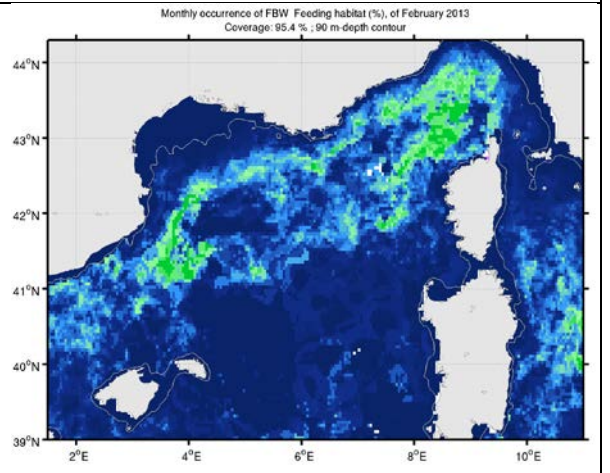
Monthly occurrence of feeding habitat (%) – November 2012



Monthly occurrence of feeding habitat (%) – December 2012



Monthly occurrence of feeding habitat (%) – January 2013



Monthly occurrence of feeding habitat (%) – February 2013

Fig. 4 - Seven Argos satellite derived positions overlapped with favourable feeding habitat (high occurrence of chlorophyll-a fronts). Note that only one position per day is shown.

During the 2013 campaign in the waters surrounding the Island of Lampedusa three individual fin whales were tagged using transdermal tags. Overall, the tags performed worse that those deployed in the Liguria Sea with a duration ranging between 4 and 13 days. The animals remained mainly in the waters surrounding the Island and didn't perform any mid- or long-range migration (Fig. 2). Despite the meagre performance of the tags in terms of deployment duration, the whales' location data were included in the hSSSM analysis, providing useful information on the whales' behaviour and resulting into a predominantly high rate of ARS -behaviour (75-80%), when compared to transiting (Table 3; Fig. 5).

Tab. 3 – For each fin whale tagged in 2013 and 2015 in the Strait of Sicily, percentage of locations where the behavioural state was classified as transiting, Area Restricted Search (ARS) or uncertain, based on the posterior mean of the b_{kt} parameter.

Tag code	Transit (%)	ARS (%)	Uncertain (%)
111868	0	70	30
120938	12	62	25
120942	11	70	19
87776	14	63	22
87780	20	64	16

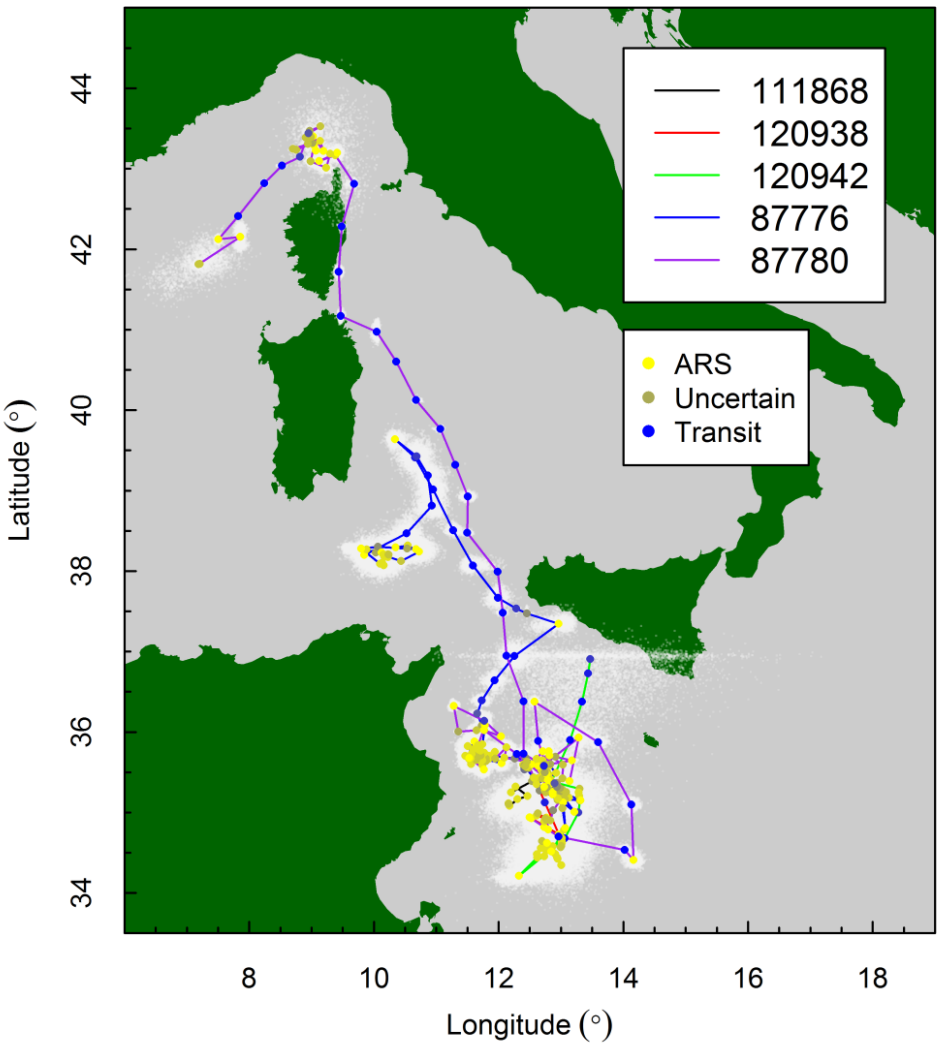


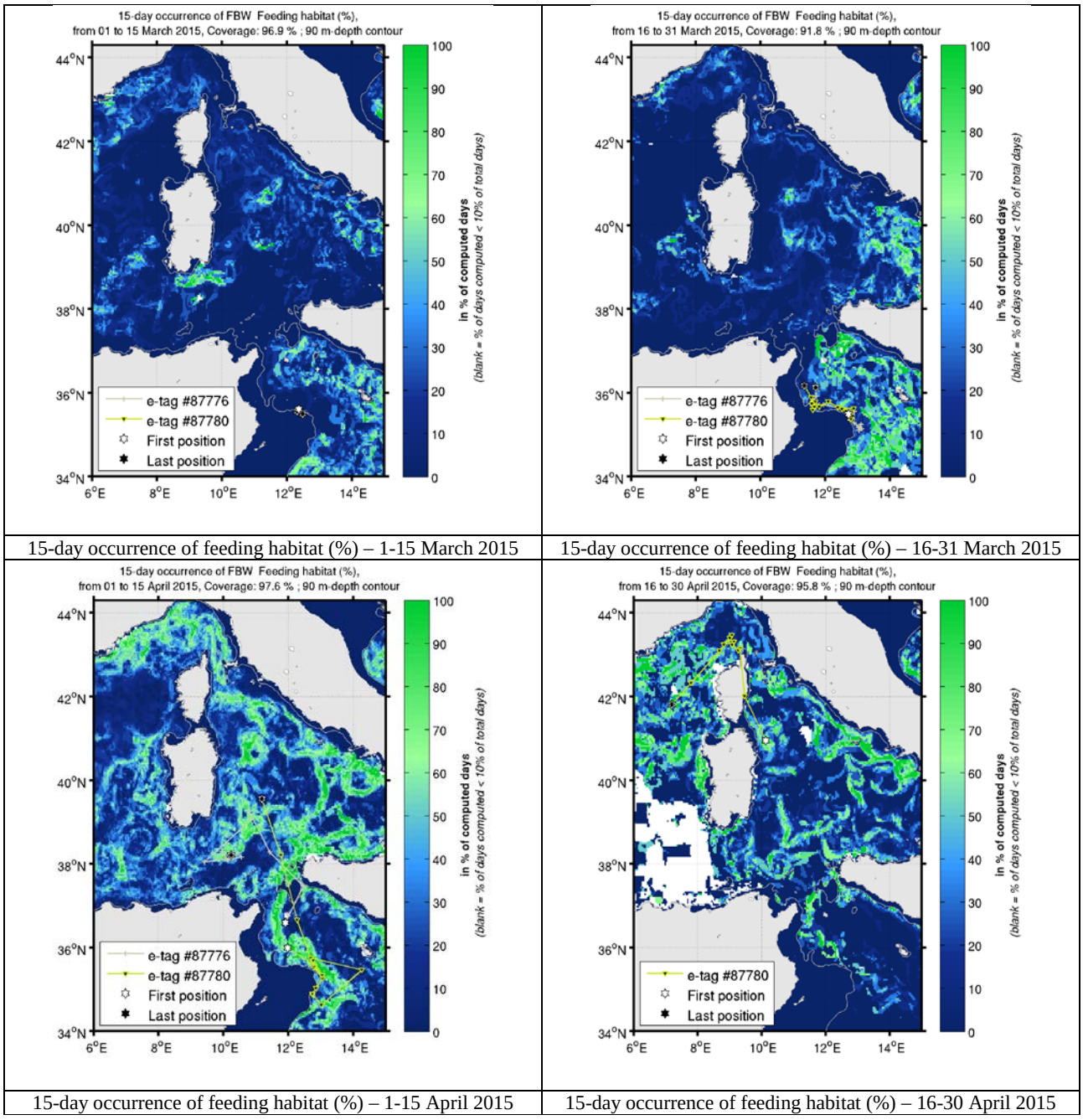
Fig. 5 – Tracks of fin whales tagged in the Strait of Sicily, reconstructed from the posterior estimates of the parameters of the hSSSM, and inferred behavioural states (transiting, Area Restricted Search or ARS, and uncertain). The white points represent model uncertainty around each location, as indicated by the latitude and longitude values at each MCMC iteration.

During the 2015 campaign the best LIMPET tag performances were obtained with tag deployment time being 29 and 44 days. The whales spent consistent time in the waters surrounding the Island of Lampedusa before performing mid-range movements towards the southern coast of Sicily and northern Tunisia.

hSSSM analysis shows the presence of several potential feeding areas in the Strait of Sicily, around the Island of Lampedusa (Fig. 5). Two areas in particular, one south-east of the Island and a second one, closer to the Coast of Tunisia, north-west of Lampedusa seem to play an important role in the feeding activities of fin whales. On the 2nd of April, after spending 19 days in the waters of the Strait of Sicily, one fin whale left the area and moved north towards the Southern Tyrrhenian Sea, engaging in feeding activities off the coast of Sicily and towards the east coast of Sardinia Island. Then it headed back towards the south of Sardina, between Tunisia and the Island and remained in the area for a few days characterized by intense feeding activities.

The movements of second tagged whale highlighted the presence of specific feeding areas within the Strait of Sicily. After remaning in the area for several days, this whale moved straight to the Ligurian Sea, within the Pelagos Sanctuary for Mediterranean Marine Mammals, where it remained for some days, before moving south-westward. The hSSSM analysis highlighted the presence of potential feeding area in the Sicily Channel, as well as the Ligurian Sea within the waters of the Pelagos Sanctuary, corroborating previous knowledge and further supporting the importance of both these areas for the ecology of the species in the Region (Fig. 5).

The following maps (Fig. 6) show the overlapping between the whales satellite derived positions and areas of high concentration of chlorophyll – assumed to be potential foraging habitats - in the Sicily Channel and in portions of the Southern Tyrrhenian Basin, between the Island of Sicily and Sardinia. It is important to notice the synchronism between the start of the northbound migration and the shifting in the occurrence of suitable feeding habitats for the species. In particular, the two whales remain in the area off Lampedusa for the two 15-days periods of the month of March, when probability of feeding habitats is high in the Strait of Sicily and very low in the Tyrrhenian and Ligurian Seas. During the first 15 days of April, as feeding habitats decrease in the Strait of Sicily and increase in the South Tyrrhenian Sea, both whales start moving northbound, towards richer areas; in the second period of April, the feeding habitats are more abundant in the Pelagos Sanctuary, where the second fin whale spent most of the time, before losing the transmitter.



15-day occurrence of feeding habitat (%) – 1-15 March 2015

15-day occurrence of feeding habitat (%) – 16-31 March 2015

15-day occurrence of feeding habitat (%) – 1-15 April 2015

15-day occurrence of feeding habitat (%) – 16-30 April 2015

Fig. 6 - Two Argos satellite derived positions overlapped with favourable feeding habitat (high occurrence of chlorophyll-a fronts). Note that only one position per day is shown.

The two whales tagged off Lampedusa in March 2015 highlight the switch of favourable habitat occurrence in the first half of April from the area south of Sicily to the western Mediterranean Sea. In particular, the whale which emitted until the end of April 2015 went directly from the winter ground to the known summer ground in about five days.

Discussion

An overall analysis of the movements of the eight whales equipped with satellite transmitters underlines the importance of the waters of the Pelagos Sanctuary, the waters of the French Exclusive Economic Zone in the

Gulf of Lion and the waters adjacent to Spain. These results confirm the results of existing studies that important fin whale habitat extends westward of the Pelagos Sanctuary area, recognising this, it is therefore sensible that mitigation measures for anthropogenic threats such as maritime traffic extend beyond the present boundaries of the Sanctuary which it is already known to have a high level of risk given the high density of vessel traffic in the area.

In addition to being a hotspot for Mediterranean biodiversity, the Strait of Sicily also represents the main deep-water naval traffic channel connecting the Eastern and Western basins of the Mediterranean. The main potential or actual threats in the area include resource depletion, caused by exponential growth of fishing effort, mainly by Italian and Tunisian vessels, as well as direct interaction with fishing activities. The area also has severe vessel traffic levels, being the only passage from the Suez Canal to the Strait of Gibraltar (Fig. 7). This may have a serious potential negative impact on fin whales both with respect to generated noise as well as collisions. The high naval traffic levels occurring in the area suggest the strong need for appropriate conservation and mitigation measures to minimise human-induced mortalities.

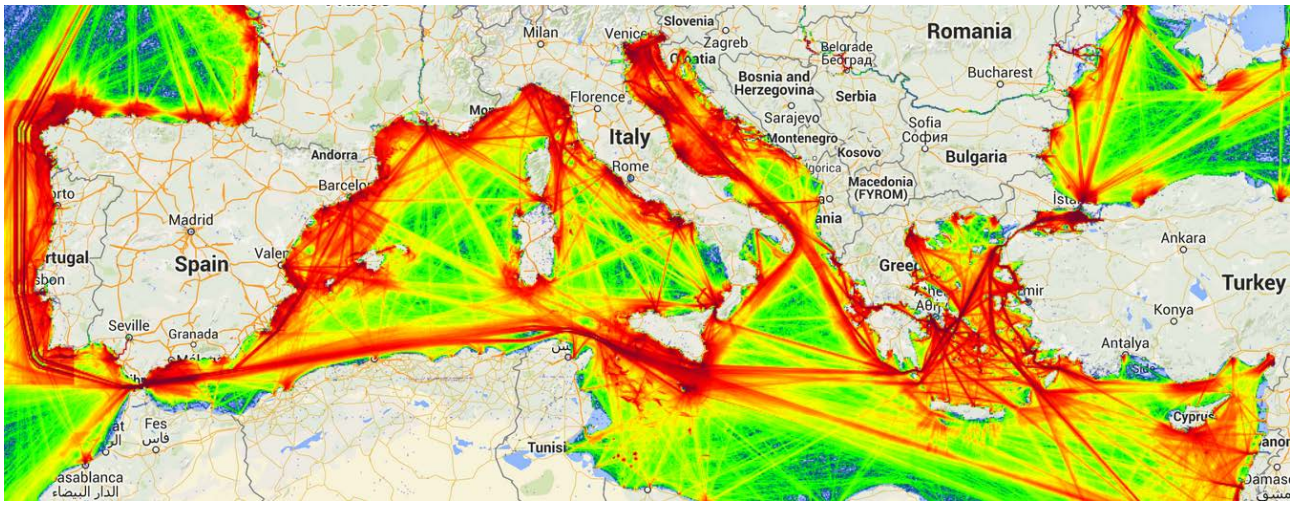


Fig. 7 - Naval traffic obtained through AIS data (14-05-2015).

The present findings provide further evidence for the importance that the Strait of Sicily plays in the central Mediterranean Sea and supports the proposition to establish an effective seasonal/dynamic protection regime in the Strait of Sicily area, in terms of a Marine Protected Area or a SPAMI, with a designated action plan to address actual and potential threats. The residency period of the animals equipped with satellite transmitters for several days after tag deployment, plus the observed feeding activities and the ARS (area-restricted search) behaviour inferred from the Bayesian state-space modelling framework, supports the importance that this area plays specifically for feeding fin whales in the winter months.

The long distance migration of an animal at least 900 kilometres between the Island of Lampedusa, the northernmost tip of Corsica Island and straight in the waters of the Pelagos Sanctuary not only reveals the migratory abilities of this species, but also suggests how the whales appearing in the Sicily Strait in winter could be the same that congregate later in spring and summer in the North-Western Mediterranean for feeding. The connection between whales seen off Lampedusa and those that spend the summer in the waters of the Pelagos Sanctuary demonstrates the large and defined seasonal movements of these marine mammals through the Mediterranean, outside the Pelagos Sanctuary and in association with it. Most importantly, this perhaps unexpected and certainly previously undocumented migration shows how the whales move across areas heavily impacted by human activities, that could expose the animals to increased threats, such as ship strikes,

and where at present no protection or mitigation schemes are in place. This new information thus stresses the need for consideration for a comprehensive mitigation programme at a Mediterranean-wide scale rather than national or small regional scale.

Finally, we suggest that telemetry data are a valuable tool to assess fin whales critical habitats and areas of high habitat use, where concentrated effort to mitigate human induced threats such as ship strikes can be prioritised. These results can feed into coordinated and dynamic management schemes – as foreseen by the Marine Spatial Planning (MSP) - to try to effectively protect fin whales in the Mediterranean. Information on the temporal and geographical distribution and abundance of fin whales (and thus fin whales' critical habitats), are also required for identification of Important Marine Mammal Areas (IMMAs), Specially Protected Areas of Mediterranean Importance (SPAMIs) under the framework of the Barcelona Convention and Ecologically or Biologically Significant Area (EBSAs) within the Convention on Biological Diversity, where focus on cetaceans threats mitigation.

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