Fin Whale Presence and Distribution in the Pelagos Sanctuary: Temporal and Spatial Variability Along 2 Fixed-Line Transects Monitored in 2009-2013

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Abstract: Data collected during a 5-year monitoring program carried out midst summer along fixed-line transects in the northern Ligurian sea was used to inspect the variability in the presence and distribution of the Mediterranean fin whale in the Pelagos Sanctuary. The systematic and regular sampling design allowed direct yearly and monthly comparisons. The analysis was conducted at different spatial (regional, sub-regional and local) and temporal (yearly-monthly) scales. Species presence and distribution was then related to changes in ecosystem dynamics, namely the magnitude and spreading of the spring bloom, through near-surface chlorophyll *a* satellite-derived concentrations as a proxy for near-surface phytoplankton biomass. Results indicate strong inter-annual and intra-seasonal variability of species presence at both regional and sub-regional scales, providing new insights into the use of the area by the species. This variability evidences the role of the target species as effective ecosystem sentinels. The local analyses allow the identification of hotspots, some of which are persistent through time and should therefore, be taken into consideration when defining priority areas for conservation actions.

Keywords: Fin whale, Ligurian sea, Distribution, Chlorophyll bloom, Conservation.

INTRODUCTION

One of the main forcing factors for the establishment of the institution of the Pelagos Sanctuary (northern Ligurian sea, northwestern Mediterranean sea) in 2002 [1] was the consistent presence of the only mysticete species regularly sighted in the Mediterranean sea, the fin whale *Balaenoptera physalus* (Linnaeus, 1758). The almost complete separation of the Mediterranean and Atlantic individuals, confirmed by genetic and ecological differences [2, 3], coupled with the risks rising from local human activities, especially marine traffic [4-5], have recently raised concerns about the conservation status of the species within Mediterranean limits. As a result, the Mediterranean sub-population has been listed as “Vulnerable” according to IUCN Red List criteria [7].

Although little is known about fin whale distribution and movements within the Mediterranean sea, they probably reproduce other mysticete species’ migration patterns by moving seasonally from summer feeding grounds to winter breeding areas [3, 8, 9]. Though several concentration areas have been highlighted in the western basin the Pelagos Sanctuary is recognized as the main aggregation spot for the species [3, 9-11]. Therefore, most studies focusing on fin whales’ use of habitat have been carried out here.

While in general fin whales demonstrate a preference for deep offshore waters exceeding 2000m depth [12-14], the use of remote sensing techniques improved our understanding of the species habitat preferences by providing a two-dimensional field with relatively high spatial resolution and low-frequency synoptic time-series over long periods of time with automatic area-averaging [15]. Using such techniques in the western Mediterranean sea revealed that the species’ presence and distribution can be be directly correlated with coupled physical/biological dynamic oceanographic processes (*e.g*. species biomass, primary production, eddy signatures, currents, frontal structures) [13, 16-18]. This occurs at different spatial and temporal scales [18], inclusively for other baleen whale species elsewhere [19-20]. These processes seem to somehow modulate whale patterns for they can create sizeable prey patches, fundamental for baleen whales foraging efforts to be efficient [21-23].

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Mediterranean fin whales feed almost exclusively on euphausiid species (*e.g*. *Meganyctiphanes norvegica, Nyctiphanes couchi*) [15, 24]. While little information is available for the distribution of these prey species, it has been demonstrated that parameters such as near sea surface chlorophyll *a* concentration, sea surface altimetry and/or sea surface temperature can be efficiently used as proxies for food availability [11, 16-18, 25-27].

Because they are top predators directly feeding on lower levels of the marine food web, fin whales are particularly effective in mirroring changes of the ecosystem they inhabit. Specifically in the Pelagos Sanctuary, long-term studies carried out using dedicated and whale watching vessels evidenced strong temporal variability in fin whale presence and distribution in the area, probably directly connected with anomalies of the above mentioned parameters [28-30].

In this work we investigate the variability in the presence and distribution of fin whales in the Pelagos Sanctuary at different spatial and temporal scales, using an innovative dataset, coming from a long term monitoring program carried out along fixed transects crossing the northern Ligurian sea. Changes in species distribution patterns are then described together with the variability in ecosystem dynamics, investigated by means of anomalies in magnitude and width of the spring phytoplankton bloom. Main objectives of this work are to:

- Inspect inter-annual variability in fin whale presence in the Pelagos Sanctuary
- Inspect spatial variability in fin whale presence in the Pelagos Sanctuary
- Put in evidence local hot-spots along monitored transects for species distribution

MATERIALS AND METHODS

Study Area

The study area (SA) is located in the northern portion of the Pelagos sanctuary extending from 42.5° N to 44.5° N and from 7°E to 10° E (Figure **1**). Considering both topographical and oceanographic criteria, the study area has been divided into two sub-regions, the western (W) and eastern (E). The W sub-region includes a narrow continental shelf abruptly followed by a deep (> 2000m depth) and large abyssal plain. Its waters are entirely occupied by the quasi-permanent cyclonic gyre induced by the Liguro-Provençal current, which ensures one of Mediterranean's most productive upwelling areas [31, 32]. Although subjected to both yearly and seasonal variability [33, 34], this gyre favours ecological successions originating large stocks of krill, namely the euphausiid *Meganyctiphanes norvegica*, fin whale's preferred prey in the area [24].

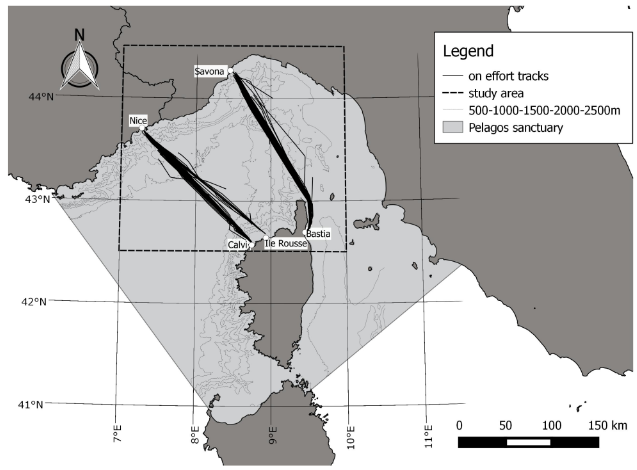

Figure 1: Map of the study area. In the upper right box the Pelagos Sanctuary is presented as the shaded area and the dashed-line box represents the entire study area. In the bigger box, The black lines represent ferry tracks on effort for the whole study period 2009-2013 and the dotted lines represent the W and E sub-regions (Table **1**).

The E sub-region includes a broader continental platform and abrupt topography features. In particular, the Genoa submarine canyon and the nearby seamount are known to be important areas for cetacean populations in the area [14, 35]. Although generally less productive, in some years the eastern expansion of the gyre, caused by a reduction of the input flux of the Tyrrhenian current, allows the enhancement of the local productivity [36]. The geographical boundaries of the study area and the two sub-regions are presented in Table **1**.

Table 1: Geographical Boundaries of the Study Area (SA) and of the Two Sub-Regions, Western (W) and Eastern (E). Latitude Boundaries are the same for the three Considered Regions

Location	Latitude	Longitude
Study area (SA)	42.5-44.5°N	07-10°E
Western region (W)		07-09°E
Eastern region (E)		8.5-10°E

Field Sampling

During the summer periods (June-September) of 2009-2013, cetacean observations were performed in 'passing mode' [37] on board ferries crossing the Ligurian sea along two routes: Nice-Calvi and Savona-Bastia (Figure **1**). Exception occurred from July to September of 2013 when the route Nice-Calvi changed to Nice-Ile Rousse. Given the proximity of the two Corsican ports however, no differences in the sampled area are expected. The two sampled routes crossed regions characterized by different sea bottom topography, sampling from continental shelf to abrupt topography regions and abyssal plain, thus being representative (as a whole) of almost all the different topographic features encompassed by the Pelagos Sanctuary.

Throughout the sampling season, a team of at least three experienced observers embarked weekly on ferries along both routes. For all purposes, a survey in this study refers to two transects (outbound and return) sampled within the same day. During a survey, at least two trained observers were positioned on each side of the command deck scanning 130° sea sectors by eye and using 7X50 binoculars. The ferry route was recorded in continuous using a dedicated GPS. Weather condition (including wind speed and direction, sea state, visibility, cloud cover and precipitation) were recorded at the beginning of a transect and whenever there was any change of weather conditions. Furthermore, whenever a cetacean sighting occurred, a series of recordings would be made related to: species; time; angle and distance relevant to the ferry heading to the sighting (measured using the graticule on the binoculars), number of individuals, and general behaviour. Distance of the sightings from the observer was then converted from graticule values (ranging from 0 to 7) into metres applying the formula by [38]. Surveys were performed only in weather conditions favourable to cetacean research, *i.e*. with a sea state ≤ 4 (Beaufort scale).

Remote Sensing Data

Data from the Moderate Resolution Imaging Spectroradiometer sensor aboard the Aqua satellite (MODIS-Aqua) at 4km resolution were obtained from the GIOVANNI online data system, developed and maintained by NASA GES DISC (http://disc.sci.gsfc.nasa.gov/giovanni). Time-series data of monthly chlorophyll *a* (henceforth referred to as "Chl") concentration (as a proxy for phytoplankton biomass) were extracted for the study area and for the two sub-regions aiming to analyse the magnitude of phytoplankton blooms in the region.

The northern Ligurian sea is mainly oligotrophic during the year while it shows relatively high concentration of chlorophyll *a* during a phytoplankton bloom [31]. These blooms have been widely studied using historical remote sensing datasets (CZCS 1978-1986 - total pigments concentration) and SeaWiFS 1998-2003 – chlorophyll *a* concentration) with all results showing a consistency in the blooming period (*i.e*. March and April), as well as a variability in the size of the blooming area [34, 39, 40].

Based on the initial study area, monthly averages were derived from MODIS daily data for the two blooming months while extending those averages to a broader area (40.5-44.5°N, 6-12°E) in order to capture a wider range of the ecosystem's variability, particularly with regard to inter-annual bloom extension and intensity.

Field Data Processing

Before proceeding to the analyses, some cleaning of the dataset was needed. Different observational heights are known to affect sightings' detectability distance [41]. As a consequence, when two surveys are carried out from different platforms, higher platforms should provide a higher number of sightings. In this study, two different types of ferries were used: smaller ferries, where the observers on the command deck were 15m above sea level and ferry speed was around 15-17 knots, and larger ferries, where the observers were 20-22m above sea level and ferry speed was about 20 knots. The maximum detection distances (corresponding to the last level of the binocular graticule) correspond therefore to 5700m for the 15m ferries and 7500m and 8000m, respectively, for the 20m and 22m ferries. Given such discrepancies and in order to avoid bias due to height differences, all sightings registered above the maximum detectability distance measured from the smaller ferries (≃5000m) [42] were removed. Possible auto-correlation amongst the two transects performed within the same day was then tested with a Spearman rank correlation test on the number of sightings registered during the outbound and the return transects.

Data Analysis

Variability in fin whale presence and distribution was investigated at three different spatial and temporal scales:

a) Inter-Annual Variability in the Pelagos Sanctuary

In order to set the scene about species inter-annual variability and its correlation with the same in ecosystem dynamics the broader regional scale, *i.e*. the entire SA, was considered. Fin whale presence was investigated using Encounter Rates (ER), where:

$$ER = \frac{No.sightings}{km} * 100$$

Encounter rates were computed considering each transect as an independent sampling unit. Yearly averaged ERs were then compared using the non-parametric Kruskal-Wallis test. The Mann-Whitney *post-hoc* test, adjusted with the Bonferroni correction method, was also performed whenever statistical significance ($P<0.05$) was verified.

Magnitude of the spring bloom, being the main event of primary production in the area and one of the strongest over the Mediterranean, has been used in the literature as a proxy for ecosystem dynamics. Therefore, in this study, MODIS-derived near-surface Chl concentration monthly means for March and April, available over the chosen baseline period (2009-2013), were used to build a satellite-derived climatological mean (Chl_{clim}) (or long term mean) for each of these months allowing inferences about spring bloom timing and magnitude in the area. This climatological mean was then used to compute a yearly mean Chl anomaly for that same month and study period. The Chl anomaly (Chl_{an}) for each year (y) was finally computed as:

$$Chl_{an(y)} = Chl_{bl(y)} - Chl_{c\lim}$$

where Chl_{bl} refers to the overall mean value of chlorophyll *a* concentration in the study area for a specific month and Chl_{clim} is the overall average value of chlorophyll *a* concentration in the study area for that same month, computed from 2003 to 2013.

b) Spatial Variability in the Pelagos Sanctuary

Fin whale variability within the SA was investigated applying a sub-regional scale. For this analysis, Nice-Calvi/Ile Rousse transects were considered representative of the W sub-region, whereas Savona-Bastia transects were considered representative of the E sub-region. As a consequence, transects from Nice-Calvi/Ile Rousse and from Savona-Bastia were each grouped on a yearly/monthly basis in order to compute ERs for the western and eastern sub-regions, respectively. To ensure that neither the different amount of effort nor the different number of sightings in different months biased comparisons, the sub-regional ERs were converted to a proportion of the total ER [20]. A Whale Occurrence Index (WOI) for each sub-region (W and E) was therefore computed by dividing the ER relative to each sub-region by the overall ER calculated for the entire study area (ER_{sa}) at the same temporal scale (yearly/monthly). So for example for the western sub-region, the WOI was calculated as follows:

$$WOI_{w(y)} = ER_{w(y)} / ER_{sa(y)}$$

WOI_W and WOI_E were then computed for each year and for each month. Differences between the two sub-regions were statistically tested using the non-parametric Mann-Whitney test. In resemblance to what has been done for the SA, sub-regional group sizes were analysed in order to understand fin whale “real” occupation of both sub-regions. To infer about fin whale sub-regional differences in ecosystem dynamics, Chl anomalies were computed separately for the two sub-regions. To further describe the temporal evolution and spatial distribution of the spring bloom, Chl monthly maps were created separately for March and April from 2009 to 2013.

c) Local Hotspots

Finally, the presence of local hotspots for the species and their persistency over time was investigated. At this end, a 5x5 km grid was overlaid to the study area. Following the methodology presented by [43] an Aggregation Index (AI), given by the number of fin whales sighted, standardized by the mean and by the standard deviation of that sub-region was computed for each cell:

$$AI_{i,t} = \frac{N_{i,t} - SR_t x}{SR_t sd}$$

where N is the number of individual fin whales sighted in cell i at a given temporal scale (t), SRx and SRsd are the mean and standard deviation, respectively, of the number of individual fin whales in the targeted sub-region (depending if the cell was along the Nice-Calvi/Ile Rousse or the Savona-Bastia routes) at a given temporal scale. We used the number of individuals rather than the sightings in order to catch aggregation events of the species that could be indicative of favourable conditions for feeding.

A cell was classified as a "Hotspot" whenever the computed index surpassed its mean value by two standard deviations (AI≥2). Similarly, cells with AI between 0-2 were classified as having a "Normal" occurrence and cells with AI<0 as having an "Occasional" occurrence. This analysis was performed at three temporal scales: five years, monthly and yearly. The first two were used in order to draw a general picture of hotspot occurrence for the species and assess their intra-seasonal stability, respectively, while the yearly scale was used to inspect inter-annual variability of these hotspots.

RESULTS

A total of 41,642km of survey effort were recorded totalizing 305 transects. Sightings of all eight cetacean species regularly occurring in the Mediterranean basin were collected. Among these, the fin whale was the second most sighted (No. sightings=701, No. individuals=842) after the striped dolphin, representing 35% of all records. Due to height range constrains, 70 fin whale sightings, totalling 137 individuals, were excluded from further analyses. Final data used, divided by the two identified sub-regions is summarized in Table **2**. The Spearman's correlation test conducted over outbound and return transect data presented a value of r^2=0.3 confirming the independence of transects performed within the same day.

Inter-Annual Variability

Fin whales were commonly encountered in the study area (mean ER=1.48, SE=0.12, 95% C.I.=0.28), although their ER varied greatly during the study period (Figure **2**). A general increasing ER trend over time was observed, although on a year-by-year basis ERs alternated between higher and lower ERs. In particular lowest/highest ERs were recorded in 2009 (ER=0.44, SE=0.14, 95% C.I.=0.28) and 2012 (ER=2.33, SE=0.35, 95% C.I.=0.7), respectively. The Kruskal-Wallis test confirmed significant inter-annual variability from 2009 to 2013 (H_4=45.45, $P<0.01$). The Mann-Whitney test evidenced similarities between 2009 and 2011 being both significantly lower than the remaining years (Table **3**). Similarly, no statistical differences were evidenced between the years 2010, 2012 and 2013.

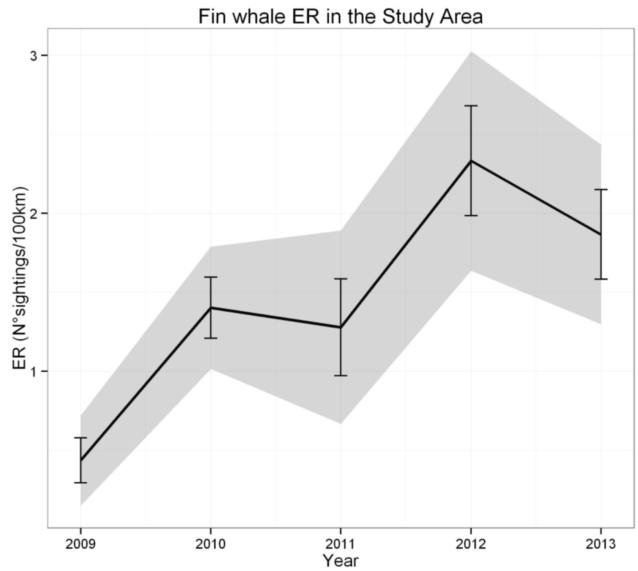

Figure 2: **Yearly mean ER of fin whales in the study area**. The shaded area represents the 95% confidence interval (C.I.) while error bars represent the standard error (S.E.).

During the entire study period fin whales were mainly sighted as a single individual or in pairs (Figure **3**). In 2009 the biggest group sighted

Table 2: Summary of Effort and Fin Whale Sightings Data Collected during the Study Period Along the Two Sampled Routes: Nice-Calvi/Ile Rousse (W) and Savona-Bastia (E). Distance on-Effort Refers to Distance Covered with Observers on Duty and with Good Sea State Condition (Beaufort <=4)

Year	No. of Transects		Distance on-Effort (km)		No. of Sightings		No. of Whales		Mean Group Size (±SD); Range	
	W	E	W	E	W	E	W	E	W	E
2009	25	31	2601.76	4111.86	23	3	33	6	1.43±0.50; 1-2	2.00±0.81; 1-3
2010	32	32	4392.34	4456.29	81	51	106	64	1.31±0.58; 1-4	1.25±0.51; 1-3
2011	30	33	3926.83	4662.75	83	5	92	6	1.11±0.31; 1-2	1.20±0.40; 1-2
2012	30	33	4028.10	4570.87	176	36	238	46	1.34±0.64; 1-4	1.28±0.51; 1-3
2013	27	32	3957.94	4932.82	113	60	163	88	1.46±0.84; 1-6	1.47±0.90; 1-5
Total	305		41641.56		631		842			

Table 3: Statistical Significance of the Mann-Whitney U Test Performed on Yearly ERs in the Study Area. Shaded Cells Represents Statistically Significative Differences

Year	2010	2011	2012	2013
2009	<0.01	0.1264	<0.01	<0.01
2010		0.4288	≃1.00	≃1.00
2011			<0.01	<0.01
2012				≃1.00

accounted for three individuals, while largest fin whale groups (> 4 individuals) were sighted only during 2013. MODIS-derived Chl yearly anomalies (Figure **4-SA**) show an asynchronous pattern between odd and even years with the former revealing weak productivity conditions, *i.e*. below the 10 years-climatological mean and the latter, the opposite situation (*i.e*. positive anomalies). In particular, the strongest positive anomaly (+0.34) was recorded in 2010 while the strongest negative anomaly (-0.26) occurred in 2011.

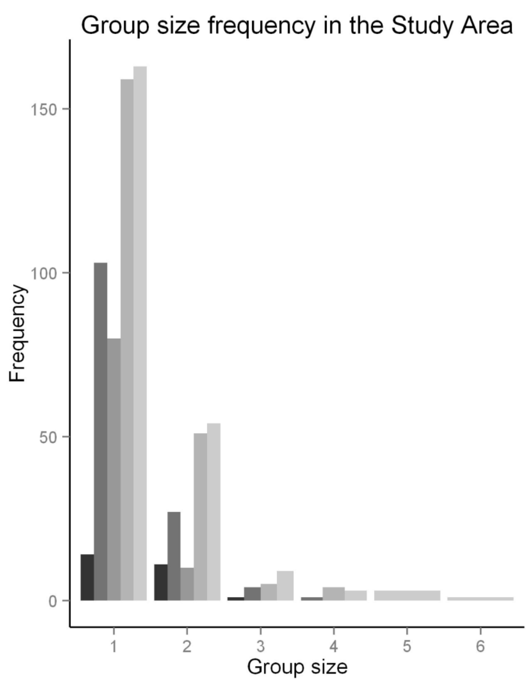

Figure 3: Frequency of group size of fin whale sightings in the study area for the whole study period 2009-2013.

Spatial Variability

Comparing the two sub-regions, the occurrence of fin whales in the western sub-region during the study period was very common (mean WOI=1.97, SE=0.43, 95% C.I.=0.85) while in the eastern sub-region it was more discreet (mean WOI=0.4, SE=0.05, 95%

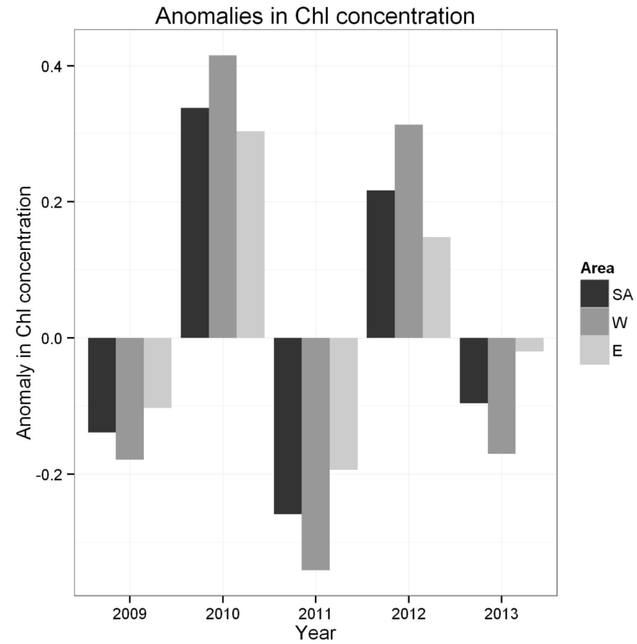

Figure 4: Yearly anomalies of Chl concentration in the study area (SA, black), western sub-region (W, dark grey), and eastern sub-region (E, light grey).

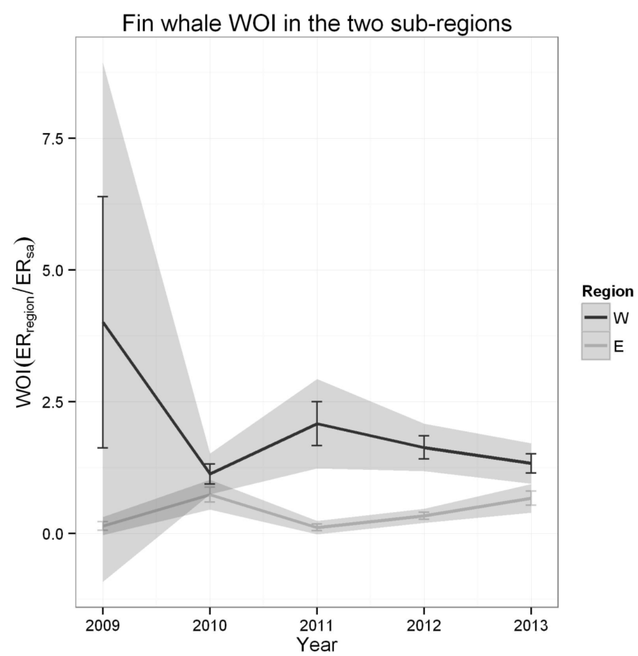

Figure 5: Fin whales yearly WOI in the two sub-regions (western W, dark grey, and eastern E, light grey). The shaded areas represent the 95% confidence interval (C.I.) while the error bars represent the standard error (S.E.).

C.I.=0.1). The Mann-Whitney test performed over the entire dataset highlighted statistical differences between the two sub-regions, with the W sub-region displaying WOI mean values five times higher than the

E. The only exception occurred in 2010 (Figure **5**, Table **4**). Detailed results of the Mann-Whitney test for sub-regional detailed comparisons (*i.e*. each month of each year) are summarized in Table **5**. As verified in the yearly analysis, whenever significant differences were detected, fin whales were mainly distributed in the W sub-region. This disequilibrium in fin whale presence happened frequently during July and September, while little or no differences were encountered in June and August. Exceptions to this last event occurred in June and August 2011 and in June 2013.

Table 4: Statistical Significance of the Mann-Whitney U Test Performed on WOIs to Test Yearly Differences in the Two Sub-Regions. Shaded Cells Represents Statistically Significative Differences

Year	Statistical Significance (P)
2009	<0.01
2010	0.126
2011	<0.01
2012	<0.01
2013	<0.01

Group sizes of the sighted groups do not differ much among the two sub-regions (Table **2**). It is noteworthy however, that in 2013 at least one large group of fin whales has been sighted in both sub-regions (6 and 5 individuals in the W and E sub-regions, respectively).

MODIS-derived Chl yearly anomalies for the two sub-regions show the same general behaviour than the study area (SA) but in all the years it is clear that the sub-region W has the highest amplitude anomalies when compared with the E and even with the study area SA (Figure **4**, **SA**, **W** and **E**). MODIS-derived monthly Chl concentration fields for the study area show that during the study period, spring blooms were always stronger in the western sub-region (Figure **6 A-J**), having an accentuated inter-annual variability in terms of spread and duration of the same. For example, it is evident how in 2009 and 2011 the bloom has lasted less (Figure **6 B** and **F**, respectively) while in 2010 and 2012 the spring bloom was still well developed in April (Figure **6 D** and **H**, respectively). In 2013 the spring bloom was not yet fully developed in March (Figure **6 I**), having had stronger Chl concentrations in April (Figure **6 J**). Although higher concentrations are noticeable in the sub-region W it is important to highlight the strong concentrations also present in the eastern portion of the SA during the entire study period.

Hotspots

The five years analysis (Figure **7**) highlighted the presence of hotspots for the species in both sub-regions. Fin whales in the W sub-region were sighted all along the route, showing a "normal" distribution over the 2000m depth but concentrating essentially in the deepest part of the basin (with most "hotspot" cells found at about 2500m depth). Analysis of the E sub-region determined a "normal" occupation at shallower depths, *i.e*. from 1500m on, than the W sub-region. "Hotspot" cells were however, also found at depths close to 2000m depth, including at seamount surroundings. Some of these hotspots were persistent along the summer season as evidenced by the monthly analysis (Figure **8**). In the W sub-region fin whales were mainly sighted in the deepest portion of the basin (> 2500m depth) during summertime. "Occasional" presence of the animals was recorded in the canyon region off Nice and off Calvi during all months as well. In the E sub-region, the species was widely

Table 5: Statistical Significance of the Mann-Whitney U Test Performed Monthly WOIs to Test Differences in the Two Sub-Regions. Shaded Cells Represents Statistically Significative (Light Grey) and Highly Significative (Dark Grey) Differences

	Month			
Year	June	July	August	September
2009	0.323	<0.05	0.215	0.465
2010	0.148	0.711	0.235	<0.01
2011	<0.05	<0.01	<0.01	≃1.00
2012	0.259	<0.01	0.06	<0.01
2013	<0.01	<0.05	0.105	<0.01

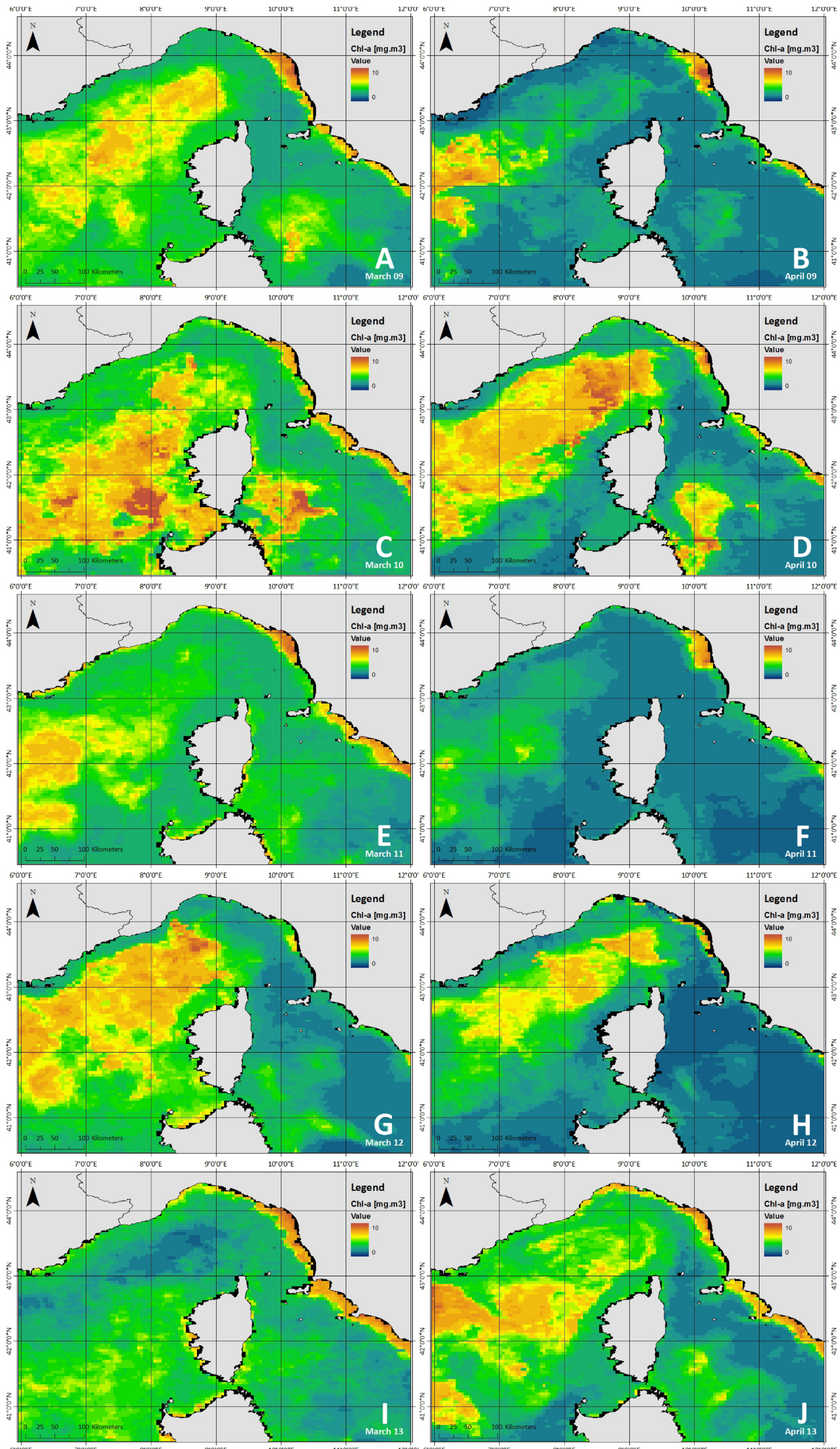

Figure 6: MODIS-derived monthly means of chlorophyll a concentration (in mg m^{-3}) in March (left side) and April (right side) from 2009 to 2013.

encountered in seamount surroundings in early summer (June-July), while a "hotspot" was determined in September in proximity to Genoa canyon area, where species presence was "occasional" during the rest of the season.

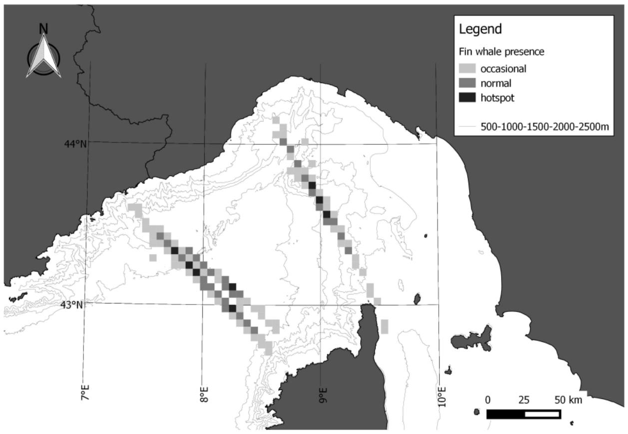

Figure 7: Map of fin whale hotspots for the entire study period (2009-2013). Depth contours of 500-1000-1500-2000 and 2500 m are shown in solid thin lines.

On a yearly basis (Figure **9**) species presence in the W sub-region can be considered regular every year. “Hotspot” cells were found each year, with a minimum of one cell being determined in 2009 and 2012 up to a maximum of three in 2010. Fin whales were scarcely sighted in the E sub-region in 2009 and 2011 but the seamount area still acted as a hotspot during the latter year. In 2010, 2012 and 2013, the species was commonly sighted and “hotspot” cells were mainly determined, once again, around the seamount region.

DISCUSSION

Being a filter feeding organism foraging at the lowest levels of the trophic network, the fin whale is a particularly effective indicator of ecosystem health and

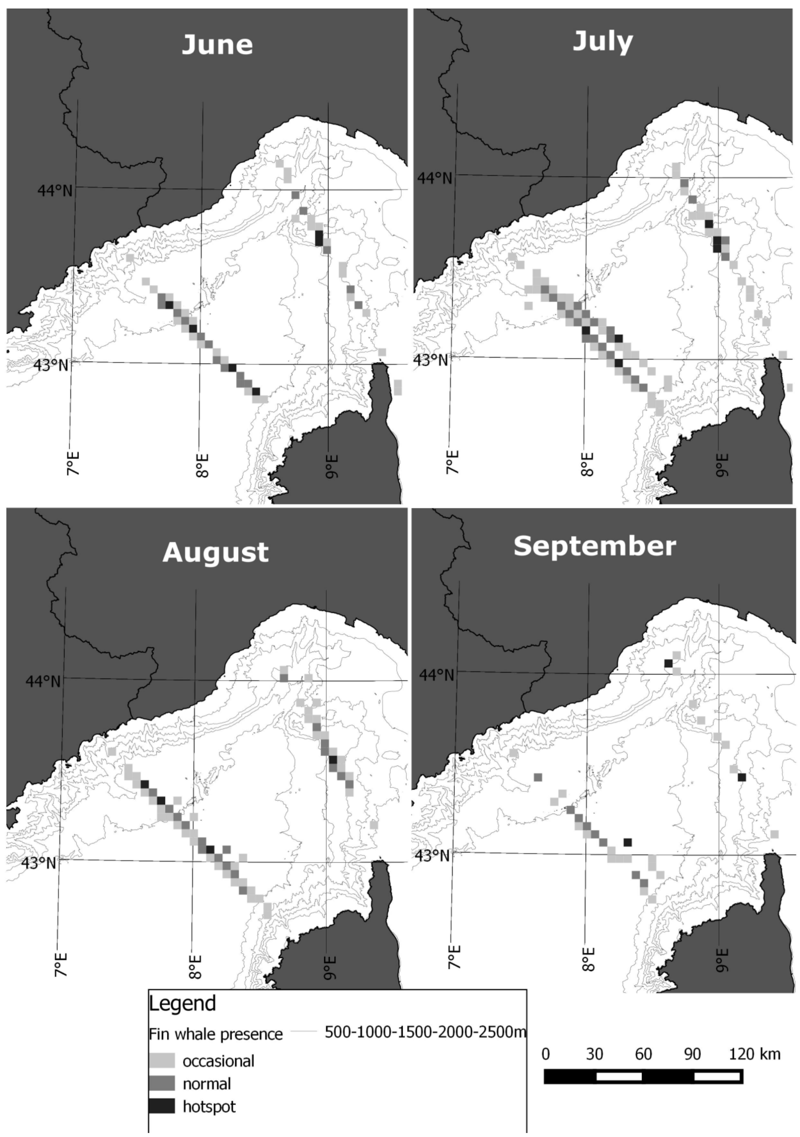

Figure 8: Map of the monthly fin whale hotspots for the entire study period (2009-2013). Solid thin lines represent the depth contours at 500, 1000, 1500, 2000, and 2500 m.

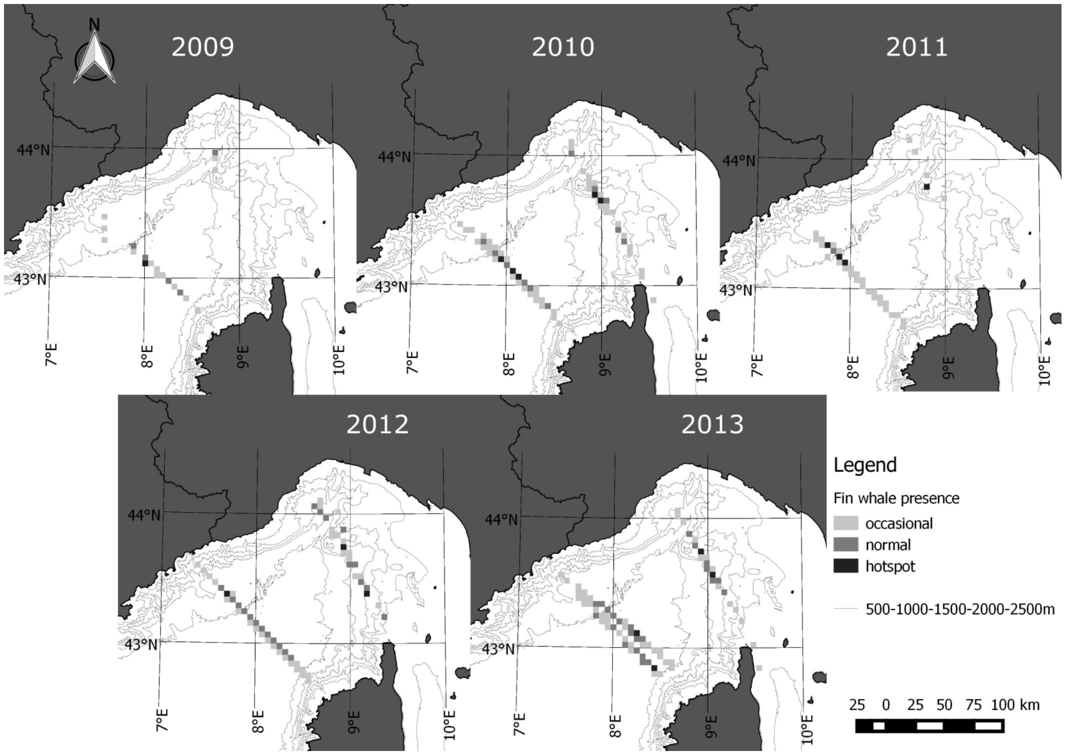

Figure 9: Map of the yearly fin whale hotspots for the entire study period (2009-2013). Solid thin lines represent the depth contours at 500, 1000, 1500, 2000, and 2500 m.

its possible changes [28, 44, 45]. With this work, we suggest the possibility of using ecosystem dynamics indicators as proxies for the forecasting of fin whale presence and distribution in a particular area. The northern Ligurian sea is one of the main areas for Mediterranean fin whales during summer as it represents their major foraging ground in the western basin [3, 46, 47]. With a localized and high aggregation of the species in one place, the area becomes the perfect place to study species' presence, distribution and habitat preferences. Data aiming to estimate fin whale population size in the northern Ligurian sea was first collected at the beginning of the 1990s, determining this area, but particularly the one corresponding to the Pelagos Sanctuary, was particularly rich in fin whale presence [48]. In the following decade however, a diminishing trend has been pointed out raising concerns in terms of species conservation [7, 46, 47, 49]. In [47], a dramatic decrease in fin whale encounter rates from 1995 to 1999 is observed. Our results update the existing information regarding fin whale variability in the area [12, 13, 27, 46, 47] showing not a linear trend, but a more complex pattern with strong fluctuations throughout the five years of research (2009-2013).

Group sizes encountered were in accordance to what has been described for the area [3, 9, 12, 47, 50] with most sightings being of single or paired individuals. This suggests that differences verified in fin whale ERs are probably due to the overall number of whales present in the area and not due to the same found at each time. As species' ecological parameters (*e.g.* presence, group size and distribution) in the Pelagos Sanctuary are expected to vary in response to the environmental features regulating their main food source, summer Chl concentration has been widely used as proxy for phytoplankton biomass and therefore, for habitat modelling [16, 27]. Considerations over the blooming phase have however, rarely been explored. In [26] fin whale summer distribution was successfully correlated with spring primary production after a time lag of only a few weeks. Considering fluctuations in fin whale presence were mostly in accordance with the analyzed Chl concentration anomalies, our work supports the claim that the magnitude, timing and longing of the spring bloom can provide useful insights for the forecasting of the summer presence and distribution of the fin whale in the Pelagos Sanctuary.

Most research efforts for studying the species have been concentrated in the western end of the Ligurian sea following a random sampling design [10, 30, 46]. In this work and for the first time, fin whale data was collected in a systematic manner, using a fixed line transect sampling design and covered both its western and eastern sub-regions. Our results show strong differences between the two with the W sub-region consistently presenting a higher fin whale presence than the E. In this same analysis, it is particularly interesting to note the opposite pattern of the WOI between the two sub-regions: an increase of the WOI in the E sub-region is always reflected by a decrease of the same in the W sub-region. These sub-regional differences can integrate the complex migration pattern of the species in the Mediterranean basin recently evidenced by [51]. Moreover, these differences become more accentuated whenever a weak spring bloom occurs (*e.g*. 2009 and 2011) evidencing how, during these years, the species was almost absent from the E sub-region. On the other hand, during 2010 when the strongest bloom positive anomaly occurred, no differences were determined among the two sub-regions, indicating the species was evenly distributed.

While the study area covered a small part of the total western basin, it cannot be ignored that the variability described in this study partly depends on the ecological conditions in the rest of the northwestern Mediterranean sea. Our MODIS-derived monthly means maps evidenced how the chlorophyll bloom was much stronger within the entire western basin in 2010, extending including southward. If fin whale foraging conditions were more spread out, this probably led fin whales to distribute in the same manner which would explain the relatively low encounter rates registered in the SA when compared to the other "rich" years (2012 and 2013). During the last two sampled years, the spring bloom was considerably less spread and intense, probably forcing fin whales to concentrate in our SA thus explaining the higher ER registered.

In a recent study, the hypothesis of an intermittent [31] secondary foraging ground right outside of the Pelagos Sanctuary boundary line, in the northern Tyrrhenian sea [11], was put forward. The maps produced evidenced the formation of a bloom patch at the northeastern side of Sardinia, particularly during the years of 2009, 2010 and 2013, evidencing its strong inter-annual variability. This elliptic cold patch, previously observed in thermal satellite imagery, is a wind-induced cyclonic gyre with well-defined meanders of comparatively constant wavelength known as the "Tyrrhenian cyclonic gyre" [52]. Accepting the hypothesis of both areas acting as variable foraging grounds for the species, the E sub-region located in-between may act as (1) a transition path between the two (as observed in most years, hence the sub-regional differences) or (2) as a feeding area if the blooms are strong/wide enough to extend into its domains (as observed in 2010, hence the non-existence of sub-regional differences). Such results highlight the importance of not only extending the existing monitoring areas for the species, possibly by adding more fixed transects over the western part of the basin, but also for a joined treatment of data in order to better understand species movement and associated underlying mesoscale dynamics within the summer season.

Sub-regional intra-seasonal differences were also encountered, occurring mostly during July and September. The first is in agreement with the peak of presence reported for the W sub-region [50] while the same in September of 2010, 2012 and 2013 seems to coincide with the years when the Chl bloom was (still) developed in late spring. Considering the cyclonic pattern of the currents in the area, naturally shifting the centre of productivity towards the Gulf of Lions, it does not seem unlikely that favourable foraging conditions may have persisted in the W sub-region until late summer.

At the latest step of our work and by using an aggregation index, we were able to identify hotspots in both sub-regions. Fin whales were mainly found in waters deeper than 2000 m, casting well the known habitat preference of the species [10, 12, 25, 30]. In the W sub-region, several "hotspots" were found especially from June to August while in September fin whales seem to be more scattered, with little aggregation occurring only in waters deeper than 2500m. Considering the general circulation pattern of the area, the presence of such hotpots confirm that fin whales are likely to aggregate in the deepest portion of the basin where the core of the upwelling is located and therefore there are higher concentrations of preys [53]. In the E sub-region, the most relevant areas appear to be the seamount surroundings and Genoa's canyon. Such areas have been previously reported to be important not only for Mediterranean cetaceans in general [25, 35], but for this particular species [14]. If the area is indeed a transition path between two foraging grounds, such structures may act as navigation marks for the whales [22]. However, steep bathymetric features have been known to facilitate mesoscale processes that can influence prey distribution facilitating whales' access to food [20, 21, 54]. Though in general the importance of the cells was variable, the persistency of some hotspots highlighted locals where conservation actions could be more effective in future management plans, namely in the establishment of marine traffic guidelines.

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