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Spatial and temporal prediction of fin whale distribution in the northwestern Mediterranean Sea

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Understanding the distribution of the cetaceans is crucial to improving their conservation. Therefore, a prediction model of fin whale's (*Balaenoptera physalus*) summer distribution was developed from data collected between May and August, in the Pelagos Mediterranean Marine Mammals Sanctuary. Explanatory variables were selected by multiple logistic regression, among several physiographic and oceanographic parameters. Depth, chlorophyll (Chl *a*) concentration, and sea surface temperature (SST) were selected for characterizing fin whale presence. Remote sensing imagery (Chl *a* and SST) was used at an 8-d resolution to capture short-term environmental variability. With the selection of a presence/absence threshold by the receiver operating characteristic curve, a correct classification of 70% (49% for presence, 85% for absence) was achieved for the initial dataset. Model reliability was also tested on an independent dataset, collected in the northwestern Basin; a correct classification of 71% (41% for presence prediction, 86% for absence prediction) was obtained. This study contributes to an understanding of where fin whales might concentrate to feed in summer. Weekly predictions of their distribution represent a valuable conservation tool in a marine protected area, for example to prevent collisions with ships.

Keywords: *Balaenoptera physalus*, cetaceans, fin whale, habitat, logistic regression, Mediterranean Sea, oceanography, spatio-temporal prediction.

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Introduction

The fin whale (*Balaenoptera physalus*) is listed as an endangered species worldwide (IUCN, 2003) and is the only common mysticete in the Mediterranean Sea (Duguy *et al.*, 1983). It is the largest marine mammal inhabiting the area and is regularly observed in the western Mediterranean Basin (Forcada *et al.*, 1996; Gannier, 1997). Fin whales in the Mediterranean may constitute a separate resident population with a very limited gene flow with the North Atlantic population (Bérubé *et al.*, 1998). The species is present throughout the year in the northwestern Basin (Duguy and Vallon, 1977; Marini *et al.*, 1996), though abundance decreases in winter (Laran and Drouot-Dulau, 2007). In the area, rather than carrying out global migrations as observed in the Atlantic Ocean, they seem to follow an aggregation–dispersion scheme: they aggregate in specific, relatively small, productive areas in summer, and disperse over wider geographic areas during the rest of the year (Notarbartolo di Sciara *et al.*, 2003). Gannier *et al.* (2004) reported that fin whales were found preferentially in the northwestern Basin (north of the 41°N parallel) and in the northern Tyrrhenian Sea in summer. They related this distribution to the biomass of the surface water layer, because the eastern Basin is characterized by a low chlorophyll (Chl *a*) concentration all year round (Bosc *et al.*, 2004). The occurrence of fin whales in summer has been correlated with concentrations of the euphausiid *Meganyctiphanes norvegica* (Relini *et al.*, 1992), probably their main food resource during the warm season (Orsi Relini and Giordano, 1992; Astruc and Beaubrun, 2001).

Density estimates for fin whales vary between 1.5 and 2.5×10^{-2} individuals km^{-2} (Forcada *et al.*, 1995, 1996; Gannier, 1997; Laran, 2005). However, the true size of the population is still not known with precision, because the only estimate for the Basin is 3583 whales (coefficient of variation 0.27; Forcada *et al.*, 1996), excluding the Tyrrhenian Sea, which is part of the regular summer distribution range (Notarbartolo di Sciara *et al.*, 2003; Gannier *et al.*, 2004).

For several decades, the western Mediterranean Sea has been subject to an increase in human activities, with climate changes and probable impacts on nutrient concentrations (Béthoux and Gentili, 1999; Béthoux *et al.*, 2002). Panigada *et al.* (2006) estimated a fatal collision rate with ships of 0.13% of local fin whale abundance for the Pelagos Sanctuary (see Figure 1) and adjacent waters. To implement appropriate conservation measures, the identification and understanding of main species habitats is crucial.

Geographic information systems and satellite remote sensing are effective tools to understand better the interactions between the environment and cetaceans. Fin whale distributions elsewhere have been related to environmental parameters such as sea surface

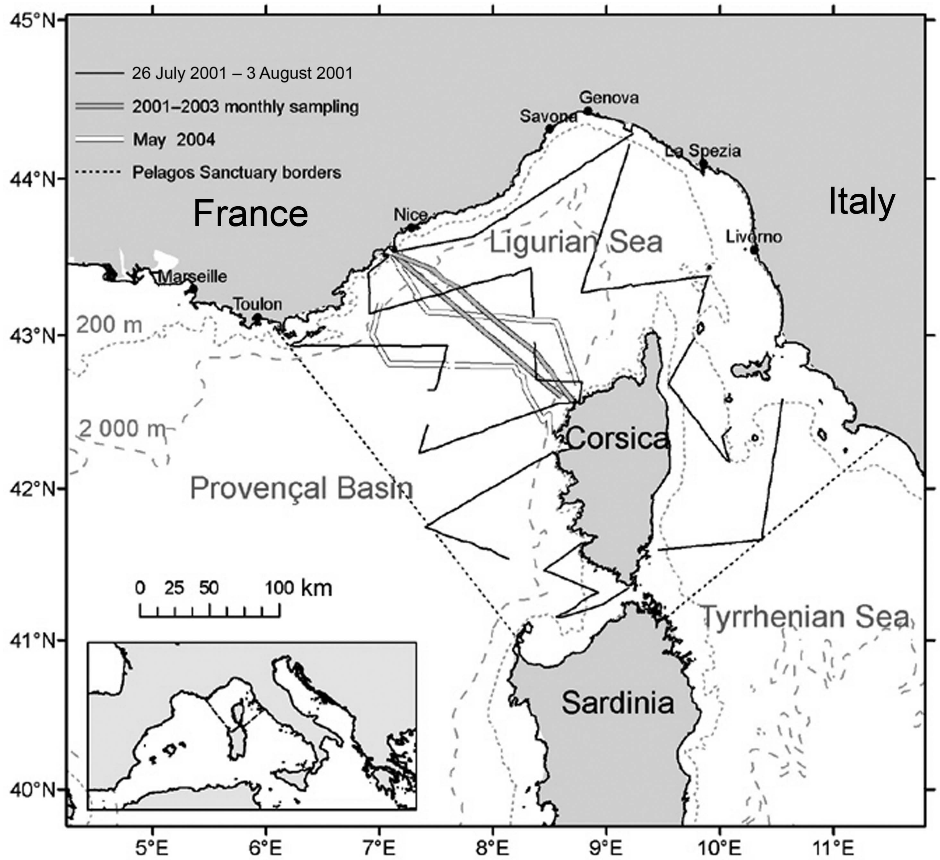

Figure 1. Transects conducted in the Northern Mediterranean Sea with the same motorized vessel between 2001 and 2004.

temperature (SST) (Reilly *et al.*, 1999; Gregr and Trites, 2001; Waring *et al.*, 2001; Hamazaki, 2002), phytoplankton biomass (Azzelino *et al.*, 2001; Littaye *et al.*, 2004), and bathymetry (Gregr and Trites, 2001; Waring *et al.*, 2001; Hamazaki, 2002; Panigada *et al.*, 2005). The objective of this study was to predict the fin whale distribution with physiographic and remote sensed variables (Chl *a* and SST), using sighting data collected in the Ligurian Sea (Figure 1). Moreover, because interannual variations of fin whale distribution have been reported (Gannier, 2002; Laran, 2005) and related to changes in primary production (Littaye *et al.*, 2004), we also consider temporal variability, using environmental parameters computed at periods of 8 d. Main habitats of the species were characterized using generalized linear models (logistic regression).

Methods

Study area

The Mediterranean Sea is semi-enclosed, and primary production varies markedly in some areas, such as the northwestern Basin. In the Ligurian Sea, field hydrological studies and remote sensing have revealed frontal areas parallel to the mainland (Sournia *et al.*, 1990) and to the Corsican coast (Goffart *et al.*, 1995). Phytoplankton bloom in the Ligurian Sea in spring, between March and April (Bosc *et al.*, 2004).

We divided the northwestern Basin into four areas to account for regional peculiarities and to test model predictions in each (Figure 2): (i) the Liguro–Provençal Basin, encompassing the Ligurian Sea and the Provençal Basin; (ii) the Gulf of Lions; (iii) the Central Basin, located south of 42°N; and (iv) the Tyrrhenian Sea, located between the Italian coast and Corsica and Sardinia. The Liguro–Provençal and Central Basins include extensive areas of deep water (>2000 m) and have a narrow continental shelf (Figure 2). Conversely, the northern Tyrrhenian Sea and the Gulf of Lions have a broad continental shelf and a gentle slope.

Cetacean sighting data

Data were collected in the Ligurian Sea from 2001 to 2004. Dedicated surveys were conducted using the same motorized vessel in the Pelagos Sanctuary during summer 2001 and May 2004 and during monthly transects from 2001 to 2003, along two parallel transects between the French mainland and Corsica (Figure 1). All transects selected for analysis were covered under conditions of good visibility (no fog, Beaufort sea state of 3 or lower, etc.), with three experienced observers aboard (Gannier, 2006; Laran and Drouot-Dulau, 2007). During the surveys, the vessel speed varied from 13 to 22 km h^{-1}.

Analysis focused on the main fin whale season locally, from May to August (Laran and Drouot-Dulau, 2007). Transects were divided into 18.5 km (10 nautical mile) segments, corresponding to the distance between consecutive short stops for acoustic sampling (the acoustic data were not used for our purpose here). The remaining segments, corresponding to the end of transects <18.5 km, were considered up to a critical level of 13 km (see below) or if they included sightings of fin whales. For each

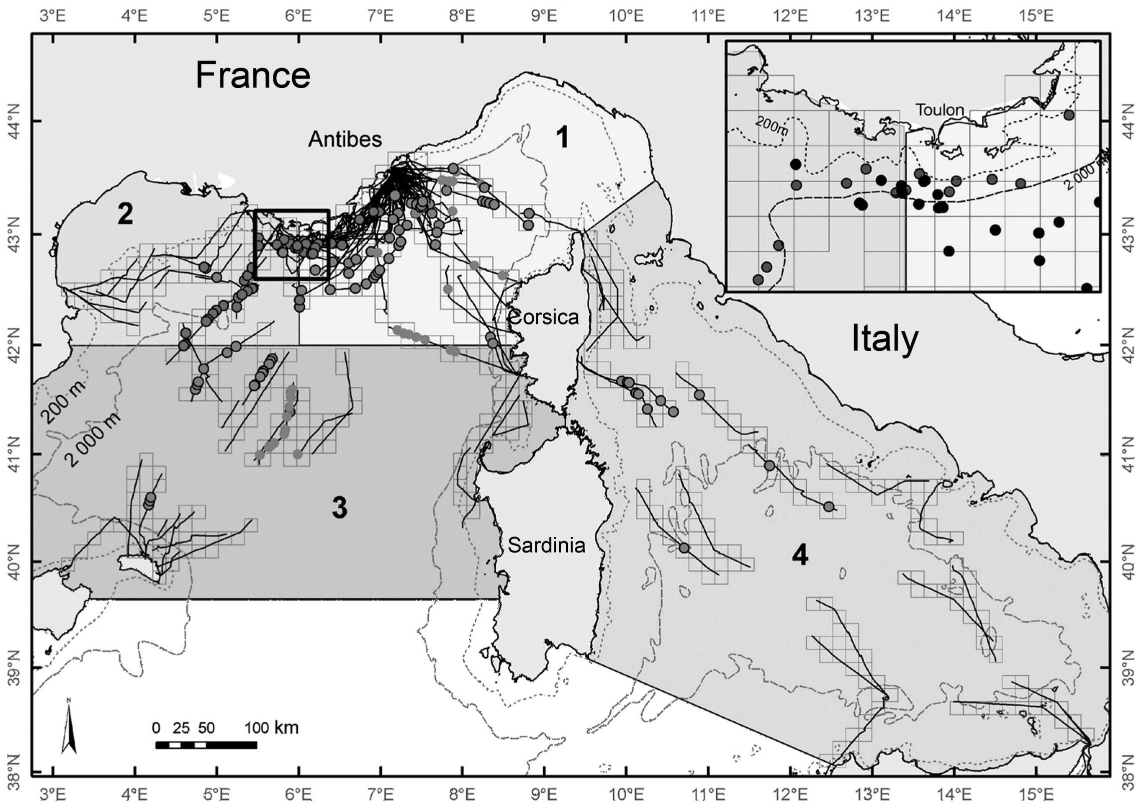

Figure 2. Independent surveys carried out in the northwestern Basin between 1998 and 2005 in good visibility (black line), and fin whale sightings (circles) within four regions: Liguro–Provençal Basin (1), Gulf of Lions (2), central Basin (3), and Tyrrhenian Sea (4).

segment, the presence of fin whales was classified as either 1 (at least one sighting) or 0 (no sighting).

Environmental parameters

Two types of variable were tested: (i) physiographic variables such as depth and distance to the main contours (200, 1000, and 2000 m), varying in space only, and (ii) remotely sensed variables, with SST and Chl *a* varying in both space and time. Most surveying was conducted outside the 200 m isobath (Figure 1). Fin whales are observed mainly in deep offshore waters, and rarely in water shallower than 2000 m (Gannier, 2002; Panigada *et al*., 2005). As our second objective was to test the robustness of model predictions for the northwestern Basin, where the extent of the continental shelf varies (Figure 2), the distance to the 200 m contour was preferred to that to the coast for quantifying the offshore position of cells. For the centre of each segment, shallowest seabed depth was retrieved from the 1 × 1 min digital database GEBCO© (2003), and distances to main contours were computed with ARCView® 9.1. We implemented a negative sign when the point datum was shallower than the contour depth.

Remote sensing provided oceanographic information on large areas and throughout the year. Products used in the present study were Chl *a* from the SeaWIFS sensor (NASA/Goddard Space Flight Center and GeoEye), and SST from the Pathfinder sensor (NOAA/NASA). Both were spatially averaged (Level 3 products) with a resolution of 9 × 9 km at the equator. A temporal resolution of 8 d was preferred, because it seemed to be better adapted to the observation of biological events such as phytoplankton blooms than a monthly time-scale (Bricaud *et al*., 2002). Both parameters were interpolated to the centre of each segment. Chl *a* and SST provided spatial and temporal variability. In addition, spatial averages of both parameters, Chl_{MedOc} and SST_{MedOc}, were estimated for the entire basin, with the aim of capturing temporal variability. The temporal resolution (8 d) was maintained, but pixels with Chl *a* values >2 mg m^{-3} were discarded to avoid biasing the algorithm by including turbid water, as in the plume of the River Rhône (Bricaud *et al*., 2002).

To test whether sampling conditions had an effect on sighting probability, we first ran analyses with sea state (Beaufort scale), visibility index (varying from 4 to 6 for selected transects), and ship's speed.

Model construction

The final habitat prediction model for fin whales was constructed using multiple logistic regression. Segments without sightings were considered as true absence data. The probability of presence was computed as:

$$p = \frac{\exp(y)}{(1 + \exp(y))}, \tag{1}$$

where y is a multiple regression equation including all significant parameters (x_i) and associated coefficients (a_i):

$$y = a_0 + a_1 x_1 + \ldots + a_i x_i. \tag{2}$$

The model was fitted with SYSTAT®11 (SPSS, 2004) using the LOGIT option and forward–backward stepwise selection.

Probabilities for entry or removal of predictors were both fixed to 0.10. Models were compared by computing the difference in their log-likelihoods and estimating the goodness-of-fit χ^2 value. We examined the grid cells for collinearity using R_x^2, the variance in each independent variable x explained by the other independent variables (Gregr and Trites, 2001). A value of R_x^2 of 0.90 and above was considered as highly correlated (Tabachnick, 2000).

Evaluation of the model's predictive reliability involved comparison of estimated with observed presence/absence, using a confusion matrix, which cross-tabulates the observed presence/absence with the estimated patterns of presence/absence (Fielding and Bell, 1997). The probability threshold α was used to estimate presence, e.g. presence is estimated if $P > \alpha$ using the receiver operating characteristic curve (ROC; Fielding and Bell, 1997). The ROC is created by plotting sensitivity values (true positive fraction) against the (1-specificity) values (false positive fraction) for a range of threshold values α. The ROC curve was obtained with Analyse-it®. The probability threshold for which the difference between sensitivity and specificity was least was then chosen as the threshold between absence and presence. The correct classification rate, expressed as a percentage, represents how successfully a model predicts presence and absence. In addition, the positive predictive power (PPP, rate of positive correct predictions) and the negative predictive power (NPP) were determined.

Large-scale validation

A second dataset was used to validate the model. These independent surveys (conducted by the Groupe de Recherche sur les Cétacés) were carried out from the same sailing vessel from 1998 to 2005 (see Gannier, 2002, for details on the sampling protocol). The entire northwestern Mediterranean Sea was divided into cells of 13 × 13 km corresponding to the transformation of 18.5 km segments (in diagonal) into a square (Figure 2). For each period of 8 d, only cells including fin whale sightings or at least an effort of 13 km (the square's width) and a value for each model parameter was selected for analysis: remote-sensed variables in a given cell can be missing during cloudy periods. Summary information for the transects carried out between mid-June and the end of August is listed in Table 1. Note that spatial coverage differed between years. As trips started and ended in Antibes, this area appears to have been oversampled, but for 8-d periods, this is not apparent. In addition, several opportunistic sightings by French Customs officials were reported on maps for each period, but because no related sampling effort was available, these sightings were used for illustrative purposes only.

Table 1. Summary of survey details for the independent datasets used to test the model.

Year and parameter		18–25 June	4–11 July	12–19 July	20–27 July	28 July—4 August	5–12 August	13–20 August	21–28 August	Total
1998	*L* (km)	440	–	–	444	154	805	447	–	2 291
	N	30	–	–	30	8	33	16	–	117
	N_R	5	–	–	2	3	4	5	–	19
1999	*L* (km)	120	–	–	309	407	130	205	382	1 553
	N	9	–	–	20	27	9	11	17	93
	N_R	6	–	–	3	5	3	5	2	24
2000	*L* (km)	406	–	–	–	278	461	246	–	1 391
	N	27	–	–	–	19	23	16	–	85
	N_R	9	–	–	–	1	1	3	–	14
2001	*L* (km)	–	142	–	252	–	29	–	–	422
	N	–	9	–	18	–	4	–	–	31
	N_R	–	0	–	6	–	4	–	–	10
2002	*L* (km)	–	129	139	148	145	124	166	–	850
	N	–	10	10	13	9	6	12	–	60
	N_R	–	4	6	6	0	0	5	–	21
2003	*L* (km)	230	171	–	–	70	268	–	–	739
	N	16	12	–	–	3	12	–	–	43
	N_R	5	3	–	–	0	3	–	–	11
2004	*L* (km)	–	21	339	308	409	181	–	–	1 259
	N	–	1	24	16	17	12	–	–	70
	N_R	–	0	8	1	6	1	–	–	16
2005	*L* (km)	–	204	245	31	–	–	–	–	481
	N	–	12	16	2	–	–	–	–	30
	N_R	–	3	3	0	–	–	–	–	6
Total	*L* (km)									8 986
	N									529
	N_R									121

L, weekly sampling distance (km); *N*, number of 13 × 13 km cells with sufficient sampling; N_R, number of cells with at least one whale recorded.

Results

In all, 4616 km, divided into 251 segments, were retained for the analysis, and the 111 fin whale sightings (166 individuals) represented 71 segments of presence (28.3%).

"Presence segments" displayed a strong clustering at depths around 2500 m, compared with a more even spread for "absence segments" (Figure 3). Distance to the 200 and the 1000-m isobaths differed for both categories of segment. However, their distributions were similar for SST, and presence cells indicated a slight preference for higher Chl *a*.

Neither ship speed, sighting index nor sea state were selected as explanatory variables for fin whale occurrence. The best model included four parameters: depth, Chl *a*, spatially averaged Chl *a* (Chl_{MedOc}), and SST (Table 2). Collinearity was not considered to be a source of concern, because R_x^2 varied between 0.18 and 0.85. We plotted the ROC curve (Figure 4), resulting in an area under the curve of 0.77 (s.e. = 0.03), significantly different from the area of a random model (*Z*-test 7.99; $p < 0.0001$). The probability threshold between presence and absence was estimated to be 0.44, resulting in an overall correct classification rate of 70% with a PPP of 49%. In other words, when the model predicted presence ($p > 0.44$), it was correct in 49% of the cases. Conversely, our NPP was 85%, so when the model predicted absence, it was correct in 85% of cases (Table 3).

Figure 5 shows how the model fitted some of the sightings in the original data collected between May 2001 and August 2003. Weekly distribution estimates generally correspond to sightings, except for May 2002, and June and August 2003. The model well represented the low sightings in August 2003 compared with 2001 and 2002 (Figure 5). However, several of the May 2004 sightings did not model well, even though whales were located close to areas of expected presence (Figure 5).

Table 2. Estimated parameters for the model, with four covariates.

Parameter	Estimate	s.e.	*p*-value
Constant	9.001	4.651	0.053
Depth	−0.001	0.000	0.005
Chlorophyll concentration	8.404	2.480	0.001
Spatially averaged chlorophyll concentration	−46.222	12.619	0.001
Temperature	−0.248	0.113	0.027

Independent surveys, conducted annually since 1998, were then used to evaluate the predictive power of our model in a wider area. Excluding cells with no values for remotely sensed variables, a total sampling effort of 8986 km, corresponding to 529 cells over successive periods, was available; of these, 121 cells (23%) included sightings of fin whales. The correct classification rate obtained on this independent dataset was 72%, with a PPP of 41% and a NPP of 86%.

To illustrate model performance, weekly predictions were computed for several periods surveyed in successive years (Figure 6). We estimated performance by area (Table 3). In the Liguro–Provençal Basin, for 5558 km of transects and 303 cells, including 72 with whales, the correct classification rate was 71%, with a PPP of 42% and a NPP of 84%. In the Gulf of Lions, with 867 km of transects (56 cells), including 20 cells with whales, the correct classification was 68%, with a PPP of 53% and a NPP of 85%. In the Central Basin, for 1278 km, the correct classification was 74%, with a PPP of 45% and a NPP of 91%. In contrast, for

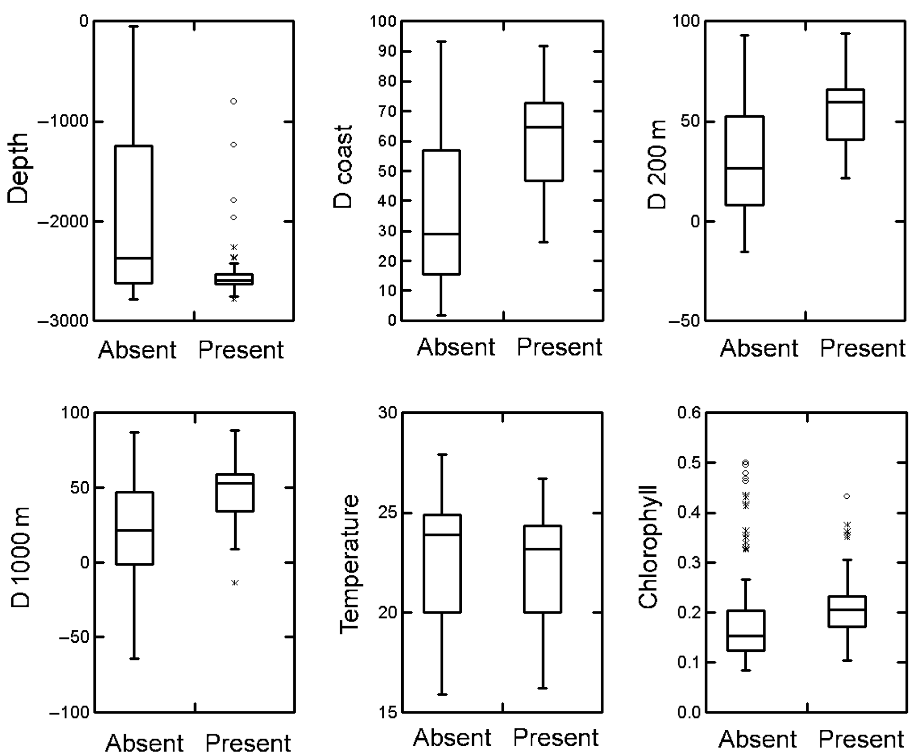

Figure 3. Box plots of fin whale absence and presence segments, as a function of depth (m), distance to the coast (D coast), to the 200 (D200 m) and 1000 m (D1000 m) contours (km), sea surface temperature (°C), and sea surface chlorophyll concentration (mg m^{-2}).

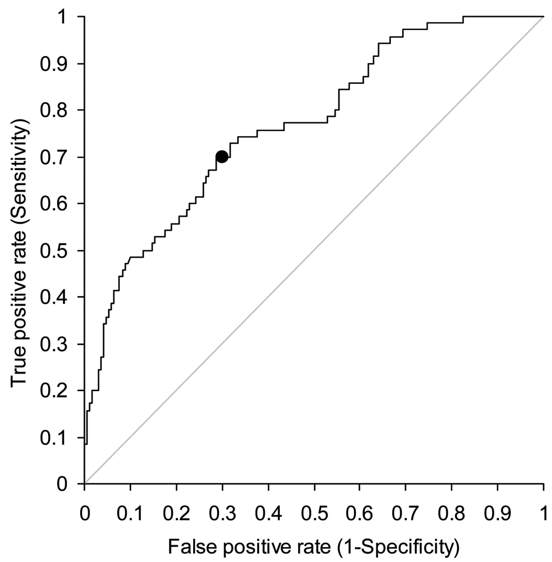

Figure 4. Receiver operating characteristic (ROC) plots for the initial dataset. The maximum sensitivity and specificity are obtained with a probability threshold of 0.44 (black dot) between presence and absence.

Table 3. Distribution of sampling effort (L), number of map cells with sufficient effort (N), the number of cells where at least one whale was seen (N_R), and the results of cross-validation between model predictions and data for the original and independent datasets.

Dataset and area	L (km)	N	N_R	Correct classification (%)	PPP (%)	NPP (%)
Original dataset	4 450	241	70	70.1	40.0	85.1
Liguro–Provençal Basin	5 558	303	72	71.0	41.5	84.2
Gulf of Lions	867	56	20	67.9	53.3	84.6
Central Basin	1 278	85	19	74.4	45.2	90.9
Tyrrhenian Sea	1 283	85	10	72.9	0.0	86.1
Independent dataset totals	8 989	530	121	71.5	41.1	85.6

PPP, positive predictive power; NPP, negative predictive power.

1283 km of survey in the Tyrrhenian Sea, in none of the 10 cells with whales was any whale presence predicted (i.e. PPP 0%). Our model also had difficulties in correctly predicting whale distributions, for example 18–25 June 1998, 2003, and 13–20 August 2000 (Figure 6). Additionally, our model did not predict several sightings located between the 200 and 2000 m isobaths close to Toulon, for example for 5–12 August (Figure 6).

Comparing correct classification rates between years, a correct classification rate <70% was observed in 2000, 2003, and 2005, with minimum PPPs in 2000 (15%) and 2005 (35%). Prediction rates were best in 1999, 2001, and 2002, and the PPP was >52%.

Discussion

For the first time in the Mediterranean Sea, a model using both physiographic and hydrobiological parameters was fitted on a fine spatial scale. Bathymetry, Chl *a*, and SST were significant characterizers of fin whale habitat. With parameters selected and estimated from data collected in the Ligurian Sea, our model predicted the distribution of fin whales over the entire northwestern Basin relatively well, except for the Tyrrhenian Sea, and sightings outside expected presence areas were often close to the presence/absence boundaries. The higher prediction of absence (NPP) resulted from the small percentage of presence cells in the initial dataset (28%). On the independent dataset, we obtained a better classification rate (71%), consistent with results obtained for the same species with a similar method: Gregr and Trites (2001) achieved 79% of predicted presence in British Columbia and Hamazaki (2002) 63% in North Atlantic Ocean.

Earlier models in the area for the same species either focused on physiography in a more restricted area (Panigada *et al.*, 2005) or included net primary production and temperature with a larger resolution (30 × 30 min cells; Littaye *et al.*, 2004). Another improvement of the proposed model over previous ones for fin whales is the shorter temporal scale. In the northwestern Basin, interannual variability in the distribution pattern of fin whales was documented by Gannier (2002) and Laran (2005), and the same for phytoplankton biomass, especially in the Gulf of Lions and the Ligurian Sea by Bosc *et al.* (2004). Forcada *et al.* (1996) suggested that the relatively small school sizes observed in the northwestern Mediterranean Sea could be explained by a more heterogeneous krill distribution in summer, compared with other feeding grounds of the species worldwide. This assumption is reinforced by sampling information on their main food resource, *M. norvegica*, in the Ligurian Sea in summer (McGehee *et al.*, 2004). Panigada *et al.* (2005) also observed differences in annual mean aggregation size of fin whales in the Ligurian Sea from 1991 to 1999, and proposed that prey availability or distribution might vary, for instance through different patch size, over years. These observations support our approach with simultaneous parameters instead of averages over seasons or decades. In particular, a monthly time-scale would seem to be generally too long for reasonable observation of biological events such as phytoplankton blooms (Bricaud *et al.*, 2002). Previous work on fin whale observations on a temporal scale showed that an 8-d period fitted observations better than a 1-month period (Laran, 2005).

For the northwestern Basin in August, Forcada *et al.* (1996) documented a preferred SST of 22.3–26.3°C (mean 24.2°C). In our model-fitting dataset, cells with whales in August consistently had SSTs in the range 22.4–26.7°C (mean 23.0°C). Temperature effects on fin whale distributions have been mentioned before (Gregr and Trites, 2001), in terms of a preference for frontal areas (Hamazaki, 2002; Doniol-Valcroze *et al.*, 2007). Chl *a* concentration or primary production have also been mentioned as influencing fin whale distribution in the Mediterranean Sea (Azzelino *et al.*, 2001; Littaye *et al.*, 2004).

Habitat characterization, as we consider it here, has two key assumptions: first, whales will generally be seen where food is abundant, and second, the food sources are somehow related to oceanographic conditions (Gregr and Trites, 2001). In summer, fin whale concentrations in the Ligurian Sea have indeed been linked with feeding behaviour (Orsi Relini and Giordano, 1992). In the Atlantic and Pacific Oceans, the distribution of fin whales has also been related to depth (Gregr and Trites, 2001; Hamazaki, 2002), and in the Ligurian Sea, Panigada *et al.* (2005) related fin whale distribution to physiographic variables only,

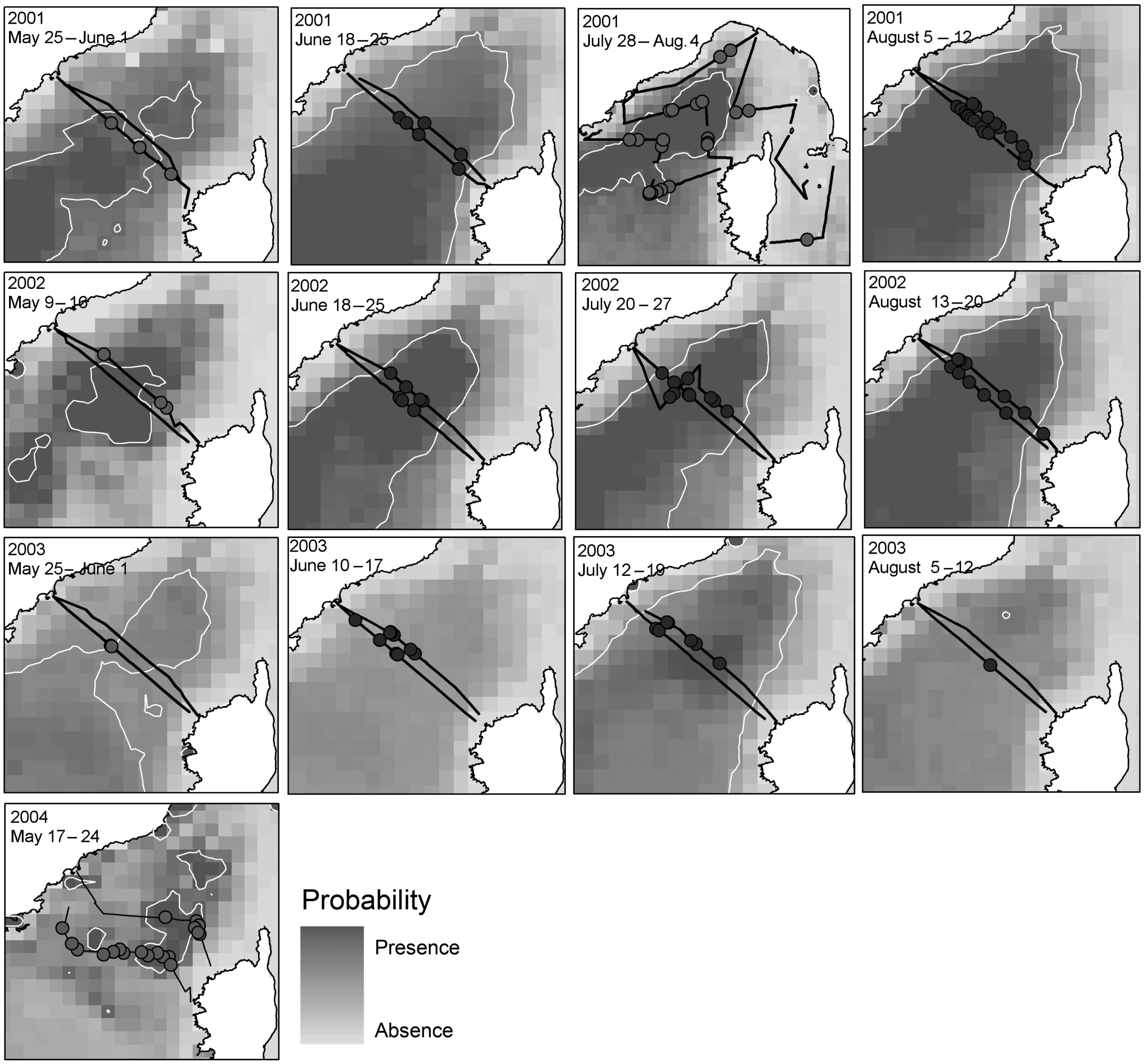

Figure 5. Weekly estimated probability surfaces of fin whale presence. The area predicted to contain fin whales is found within the white contour lines, which show the threshold probability value for predicted presence (0.44). Transects were run between the French mainland and Corsica, and in the Pelagos Sanctuary (black lines); sightings are shown by filled circles.

noting that water depth was the most significant explanatory variable.

Atypical sightings around Toulon, mainly over the continental slope (inset in Figure 2), were not representative of the pelagic distribution known for the species in the Mediterranean Sea. Nevertheless, sightings have been recorded close to the 1000 m contour in the northern Tyrrhenian Sea (Gannier *et al.*, 2004) and also in shallow water (mean 62 m) around Lampedusa Island in winter (Canese *et al.*, 2006). As our model was mainly constructed from observation effort offshore (12 round trips between the French mainland and Corsica), we did not expect to make many observations over the shelf or the continental slope.

Here, we did not use geostatistical procedures to correct spatially heterogeneous observation effort (Monestiez *et al.*, 2006). Our objective was to produce a model that used an easily reproducible method for future applications.

This modelling approach supposes that relationships exist between fin whale food (zooplankton) and simultaneous temperature and Chl *a*. The core of the Ligurian Sea is relatively stable as a consequence of its isolation from peripheral circulation. Between 20–30 km offshore and the coast, the speed of the Ligurian current decreases by half between the surface and 300 m deep (Béthoux *et al.*, 1988). McGehee *et al.* (2004) estimated the residence time of surface water in summer (August) to be one month, and analysis of successive remotely sensed Chl *a* concentrations at single sites demonstrated that phytoplankton biomass decreased without displacement. Aggregations of euphausiids mainly result from vertical migration, the animals remaining below 200 m during daylight (Andersen *et al.*, 2001), sometimes as deep as 1000 m during from May to July (Casanova, 1974; Sardou *et al.*, 1996). Hence, surface Chl *a* concentration may be a good indicator of euphausiid food resource at night.

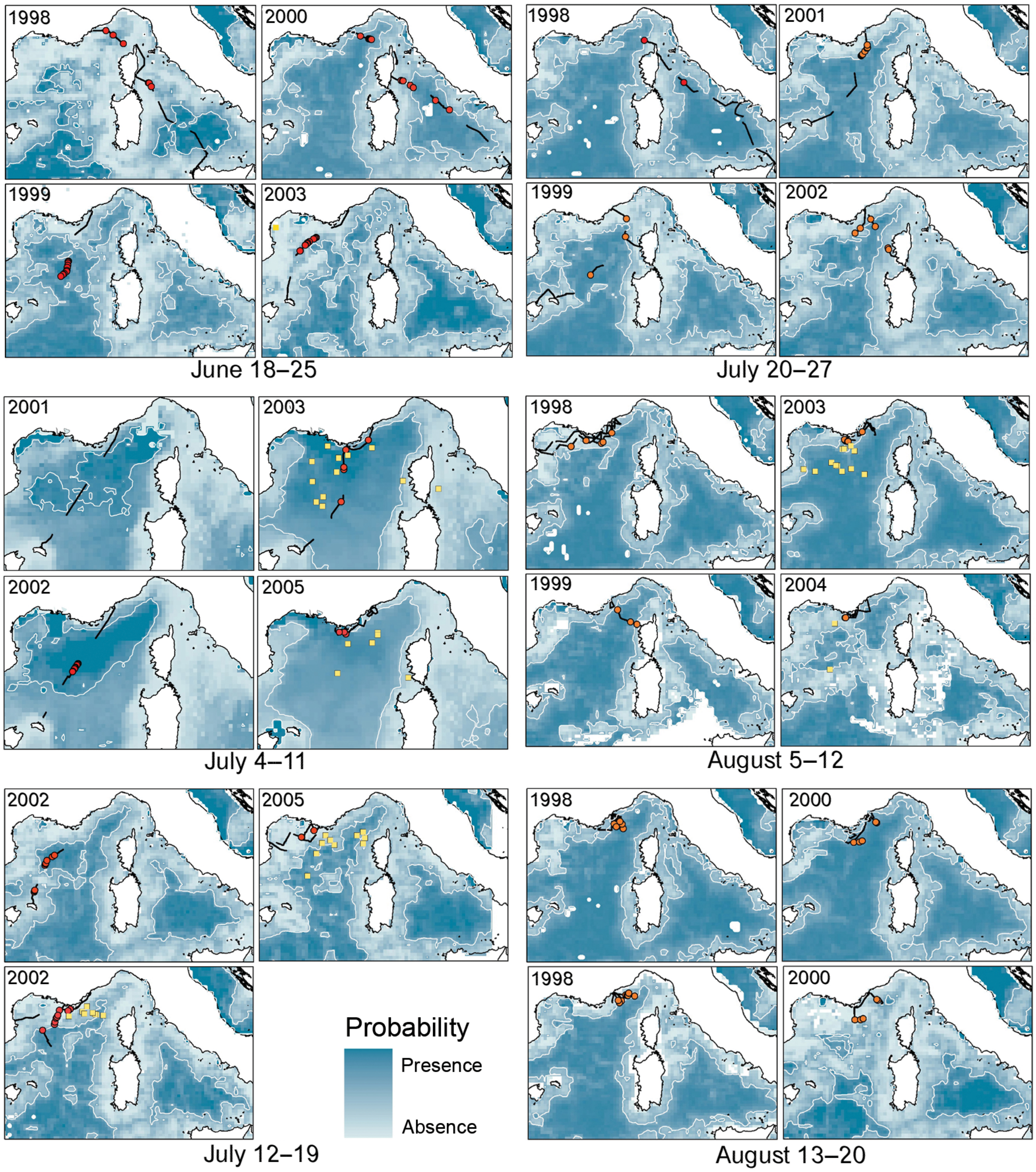

Figure 6. Predicted probability surfaces of fin whale presence for several weeks from the independent transects run from 1998 to 2005. Transects are shown as black lines, and sightings as circles. Additional opportunistic sightings from the French Customs are shown as squares.

Future research will consider temporal lags between sightings and environmental parameters, to account for zooplankton development after egg production. This phase would be in early spring for *Meganyctiphanes norvegica* (Cuzin-Roudy and Buchholz, 1999). An advantage of such temporal models would be to allow prediction in real time, considering the delay in accessing satellite remotely sensed data. In future, this project could serve as a tool to aid management in the Pelagos marine protected area.

Cetaceans are exposed to a number of threats, including direct human disturbance, anthropogenic noise, pollution, and collisions with ships. With the increasing number of fast ferries crossing the Pelagos Sanctuary, collisions are a cause for concern, given the evidence from both stranded and free-ranging fin whales (Panigada *et al.*, 2006). Therefore, as suggested by Panigada *et al.* (2006), regular adjustments to main shipping routes would be a preferred management tool to permanently defined critical habitats. Concomitantly, of course, ship speed should be reduced and/or the number of lookout observers increased when entering an area of model-predicted whale presence.

In addition, the effect of global warming on the summer distribution of whales might be estimated. Changes in the timing of the spring phytoplankton bloom have already been observed from remotely sensed data (our own unpublished data), and climate changes have had detectable impacts upon the nutrient concentrations in the basin (Béthoux and Gentili, 1999). Therefore, another aim of future work could be to produce prediction maps of fin whales in relation to future climate change, to forecast possible changes in the distribution of the species.

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