

The following supplement accompanies the article

Combining vessel-based surveys and tracking data to identify key marine areas for seabirds

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Supplement 1. Oceanographic context

Within the northwestern Mediterranean Sea, the surface circulation is controlled by 2 permanent hydrographic features: (1) the Northern Current (NC) (or 'Liguro-Provenço-Catalan' Current), a slope current which originates in the east of the Ligurian Sea, and transports rich nutrient waters southwards along the continental slope of the Gulf of Lions and Iberian Peninsula until reaching the south of Cape La Nao (Millot 1999, Arnau et al. 2004); and (2) the Balearic front, a region of strong vertical and horizontal temperature gradients, located over the insular shelf-slope area (Pinot et al. 1995).

In addition, within the continental shelf-slope area, ocean productivity is notoriously high due to different enrichment processes: strong and cold winds from the north and northwest lead to enhanced mixing, the upwelling of nutrients, and land-based runoff including major river outflow, which, in turn, increase plankton production (Estrada 1996, Salat 1996). The Rhone and Ebro rivers are 2 important areas of river run-off, characterized by elevated primary productivity, zooplankton abundance and nekton aggregations, where permanent salinity fronts retain this highly localized productivity near the coast (Estrada 1996, Sabatés 1996). Here, the NC interacts with different physical (e.g. submarine canyons in the Cape Creus) and chemical features (e.g. rivers run-off such as the Ebro) along its path creating diverse meso-scale and coarse-scale oceanographic processes along the shelf-slope region (Millot 1999, Arnau et al. 2004). Thus, the interaction of freshwater inputs and ocean currents, which deliver and advect fertilizing nutrients, results in major suitable spawning habitats for fishes (especially for small pelagic species like anchovy and sardine which might represent an important prey for the species) (Sabatés 1996, Agostini & Bakun 2002, Lloret et al. 2004) and supports one of the most important fishing fleets of the western Mediterranean (Estrada 1996, Salat 1996). For instance, anchovy spawning (June to July) occurs all along the Catalan Coast with apparent peaks near Cape Creus and near the Ebro River outflow and the catches of the species within this area are reported to be the highest in the entire Mediterranean (Lloret et al. 2004 and references therein).

Within the insular shelf-slope area, the Balearic Sea is also characterized by substantial mesoscale variability, with evolving meanders, eddies, and filaments (Pinot et al. 1995). During summer (June to August), this region is relatively protected from northwesterly winds, and thus reaches the warmest surface water temperatures in the western basin (Millot & Taupier-Letage 2005)

Supplement 2. Tracking data

We deployed GPS loggers on 29 Mediterranean Cory's shearwaters breeding at 3 Balearic Island colonies between early August and mid September 2007, but only 19 birds provided tracking data (see Table S1 for detailed information). The programmable GPS recording interval was set at 5 min initially (first 12 deployments) and extended to 10 min thereafter (remaining 17 deployments) to increase battery performance (see Table S1). Average battery life-span was 3.7 d (range 2.0 to 4.4) and 8.3 d (range 6.0 to 10.5) for the 5 and 10 min sampling rates, respectively. At these 2 sampling intervals, we registered an average of 245 and 132 positions per trip.

Table S1. *Calonectris diomedea*. Summary of the GPS tracking effort, including detailed information on the tracking date, number of locations and weight control. * lost GPS, **GPS recovered without information – Prospecting individual or that did not return to the colony

GPS	Band	Date of equipment	Date of retrieval	Days with logger	Days recording	Number of locations	Weight of equipment (g)	Weight of retrieval (g)
Cala Morell 1 (frequency of recording: 5 min)								
G22	6059706	04/08/2007	09/08/2007	*	*	*	615	-
G21	6079597	04/08/2007	10/08/2007	6	3	549	685	655
G23	6059707	04/08/2007	08/08/2007	4	3	659	545	540
G24	6059708	04/08/2007	08/08/2007	4	4	915	-	580
G25	6059709	04/08/2007	09/08/2007	5	4	1061	615	730
G26	6059710	04/08/2007	08/08/2007	4	2	439	510	535
TOTAL Cala Morell 1				23	16	3623		
Illa de l'Aire (frequency of recording: 5 min)								
G27	6128980	05/08/2007	14/08/2007	*	*	*	600	-

GPS	Band	Date of equipment	Date of retrieval	Days with logger	Days recording	Number of locations	Weigh of equipment (g)	Weight of retrieval (g)
G28	6128821	05/08/2007	10/08/2007	5	**	**	615	-
G29	6030995	05/08/2007	11/08/2007	6	5,3	1280	645	625
G30	6151877	05/08/2007	16/08/2007	11	6,2	1646	500	490
G31	6128959	05/08/2007	12/08/2007	7	5	1170	565	585
G32	6151874	05/08/2007	16/08/2007	11	6,2	1646	505	495
TOTAL Illa de l' Aire				40	22,7	5742		
Pantaleu (frequency of recording: 10 min)								
G21	6123012	18/08/2007	26/08/2007	8	8	1061	590	575
G23	6111132	18/08/2007	30/08/2007	12	6,5	805	655	705
G24	6155912	18/08/2007	04/09/2007	17	9,3	1244	595	670
G25	6131520	18/08/2007	-	-	-	-	565	-
G26	6025817	18/08/2007	29/08/2007	11	10,5	1463	595	520
G28	6025591	18/08/2007	26/08/2007	8	**	**	655	565
G29	6131209	18/08/2007	-	-	-	-	620	-
G30	6131534	18/08/2007	28/08/2007	10	10	1390	645	-
G31	6170593	18/08/2007	15/09/2007	*	*	*	675	-
G32	6155909	18/08/2007	24/08/2007	6	6	801	690	735
TOTAL Pantaleu				72	50,3	6764		
Cala Morell 2 (frequency of recording: 10 min)								
G21	6059711	09/09/2007	19/09/2007	10	7	732	650	610
G23	6059712	09/09/2007	18/09/2007	9	9	1207	610	470
G24	6059713	09/09/2007	-	-	-	-	620	-
G26	6059715	09/09/2007	19/09/2007	10	**	**	620	540
G30	6059716	09/09/2007	-	-	-	-	685	-
G28	6059717	09/09/2007	18/09/2007	9	9	1207	700	605
G32	6059718	09/09/2007	19/09/2007	10	1	110	605	490
TOTAL Morell 2				48	26	3256		
TOTAL				183	115	19385		

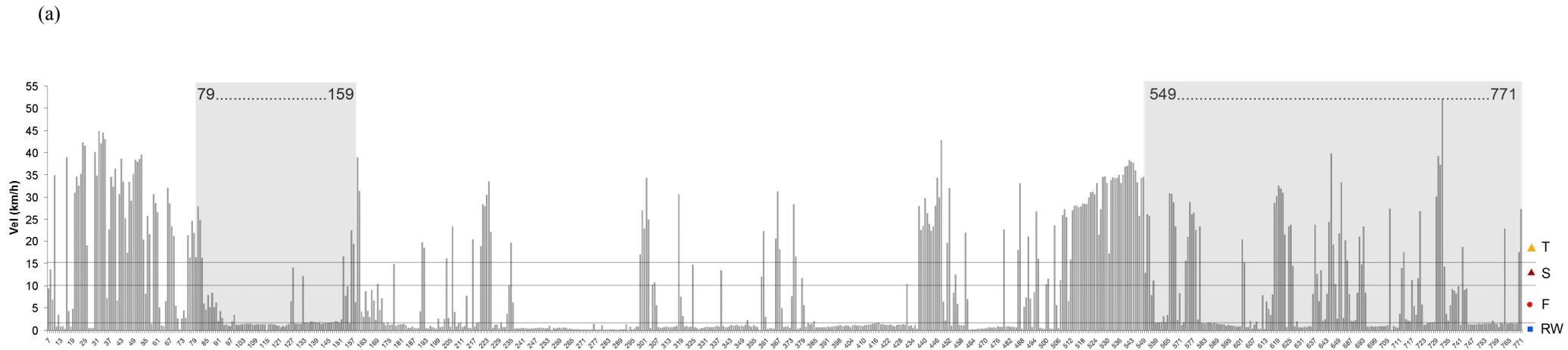
Then, we classified the bird behaviour into 4 categories, on the basis of the movement rates calculated between successive positions (km h^{-1}) of GPS and visual inspection of trips: resting on the water (<2), feeding (2 – 10), searching (10 – 15), and travelling (> 15) (see example in Fig. S1). The first category, resting on the water, was

the most evident behaviour and it was defined by analysing movement rates estimated in relation to drifting on the water (by currents or wind), considering more than 3 equidistant locations that shaped a lineal trajectory (Fig. S1c,d, in blue). Most of these locations had movement rates $<2 \text{ km h}^{-1}$. In fact, the 92% of the locations with speeds $<2 \text{ km h}^{-1}$ were identified as drifting, while the rest could have represented short periods of resting or feeding ($<20 \text{ min}$) but we were not able to confirm whether birds were resting on the water or feeding.

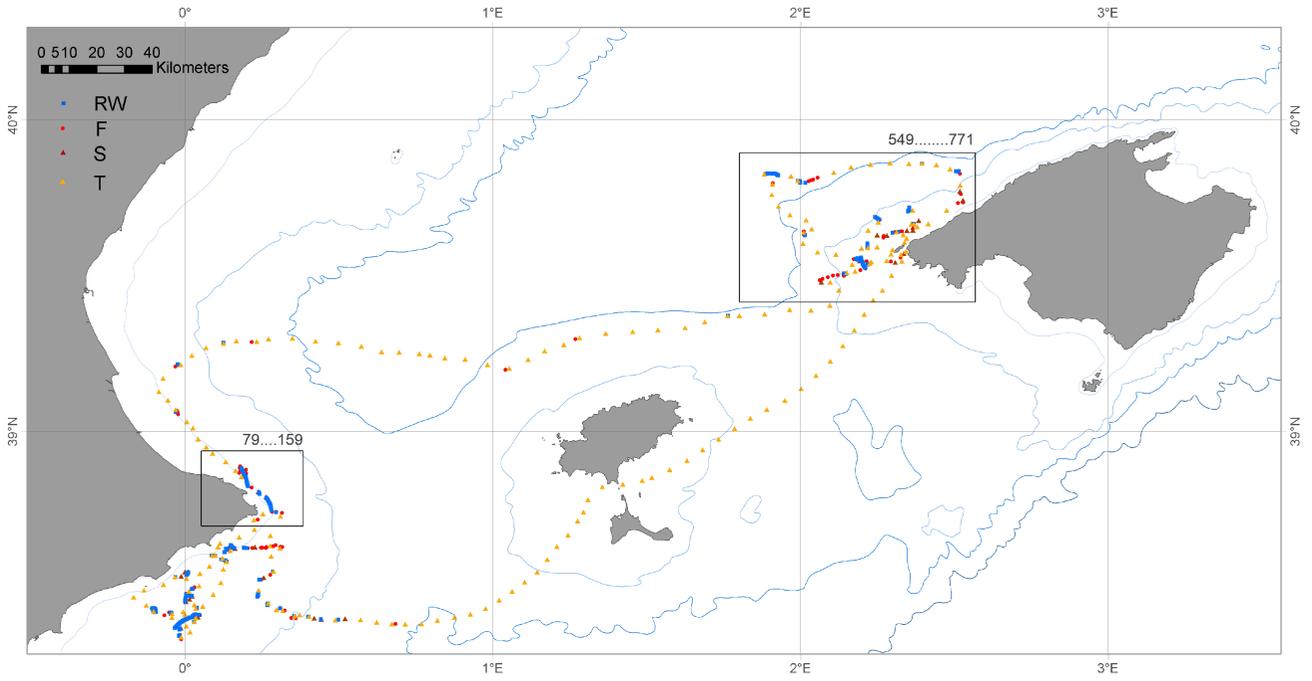
On the other hand, highest movement rates characterised by linear trajectories and equidistant locations between the Balearic Islands and the continental shelf of the Iberian Peninsula were identified as travelling, overall between 20 and 30 km h^{-1} although some individuals reach 40 km h^{-1} (Fig. S1c,d, in orange). It is reasonable to assume that the purpose of most of these speed-up trips is to arrive to specific probably known foraging areas where the real search for food starts (Weimerskirch et al. 2007).

Finally, we observed that most of the movement rates between 2 and 10 km h^{-1} represented no linear trajectories with no equidistant locations, which might be indicative of feeding behaviour. Other breeding Cory's shearwaters tracked in the Salvagens islands by the portuguese BirdLife partner with GPS and activity recorders showed feeding behaviour at those movement rates (V. H. Paiva pers. comm.). Also, a recent study reporting on PTT-tracking of Cory's shearwaters (Navarro & González-Solís 2009) presents a limit of travelling vs. feeding of around 10 km h^{-1} , which supports our criterion for separating feeding movements. Movement rates between 10 and 15 km h^{-1} suggested intermediate behaviour between feeding and travelling that we classified as searching for food.

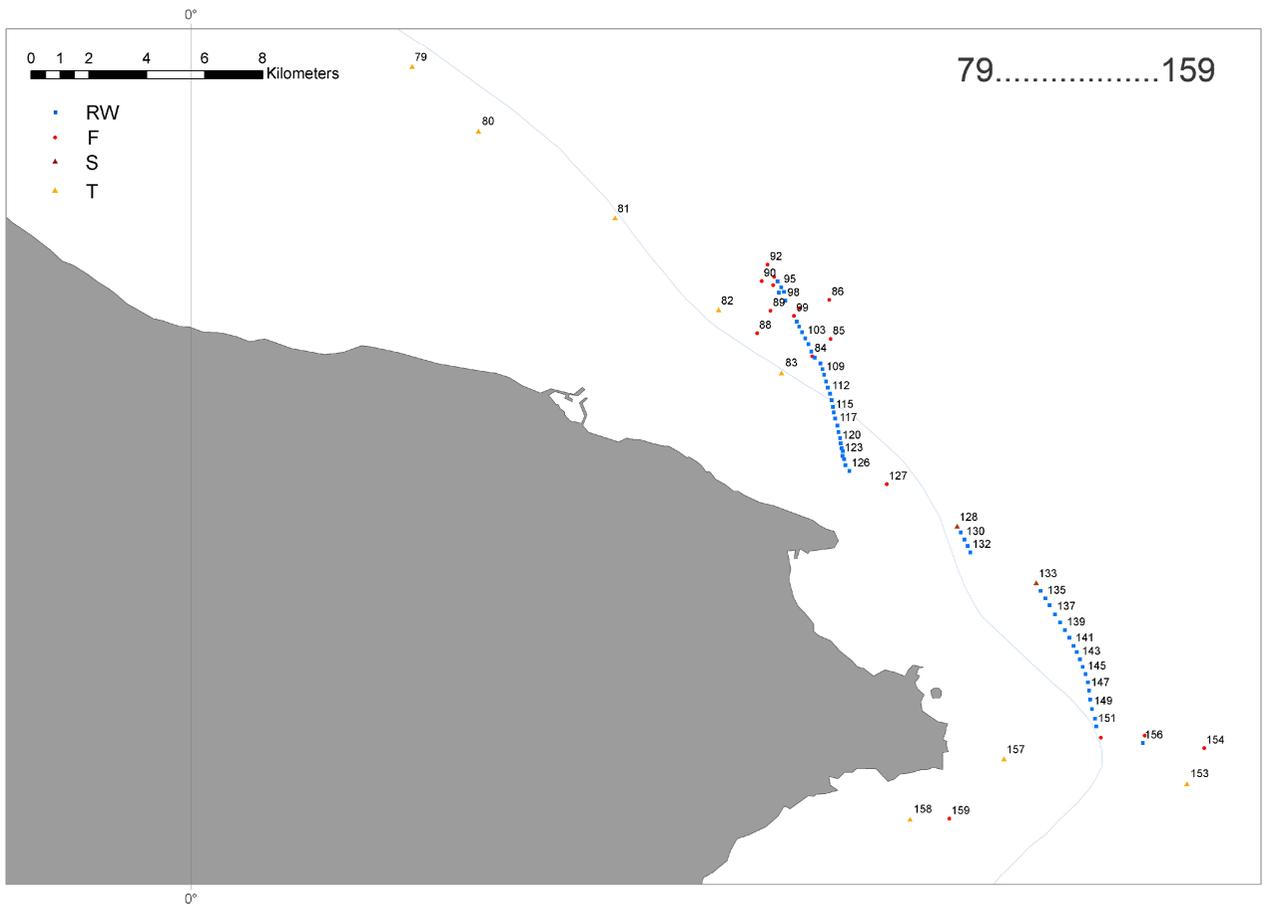
Fig. S1. *Calonectris diomedea*. Example of Mallorca's Cory's shearwater tracking data (Ring 6155909, 19/08/2007 to 24/08/2007). (a) The flying speeds (km h^{-1}) histogram. The grey areas are the locations in 2 small areas: Cap Nao (c) and NW of Mallorca (d). We considered those speeds of 0 to 2 km h^{-1} as resting on the water (RW), 2 to 10 km h^{-1} as feeding (F), 10 to 15 km h^{-1} as searching for food (S) and >15 km h^{-1} as travelling (T). The *x-axis* represents number (sequence) of positions since departure. (b) Total of GPS locations, blue square (RW), red circle (F), brown triangle (S), and yellow triangle (T). (c) Detail of cap Nao area. (d) Detail of NW of Mallorca (Pantaleu colony).



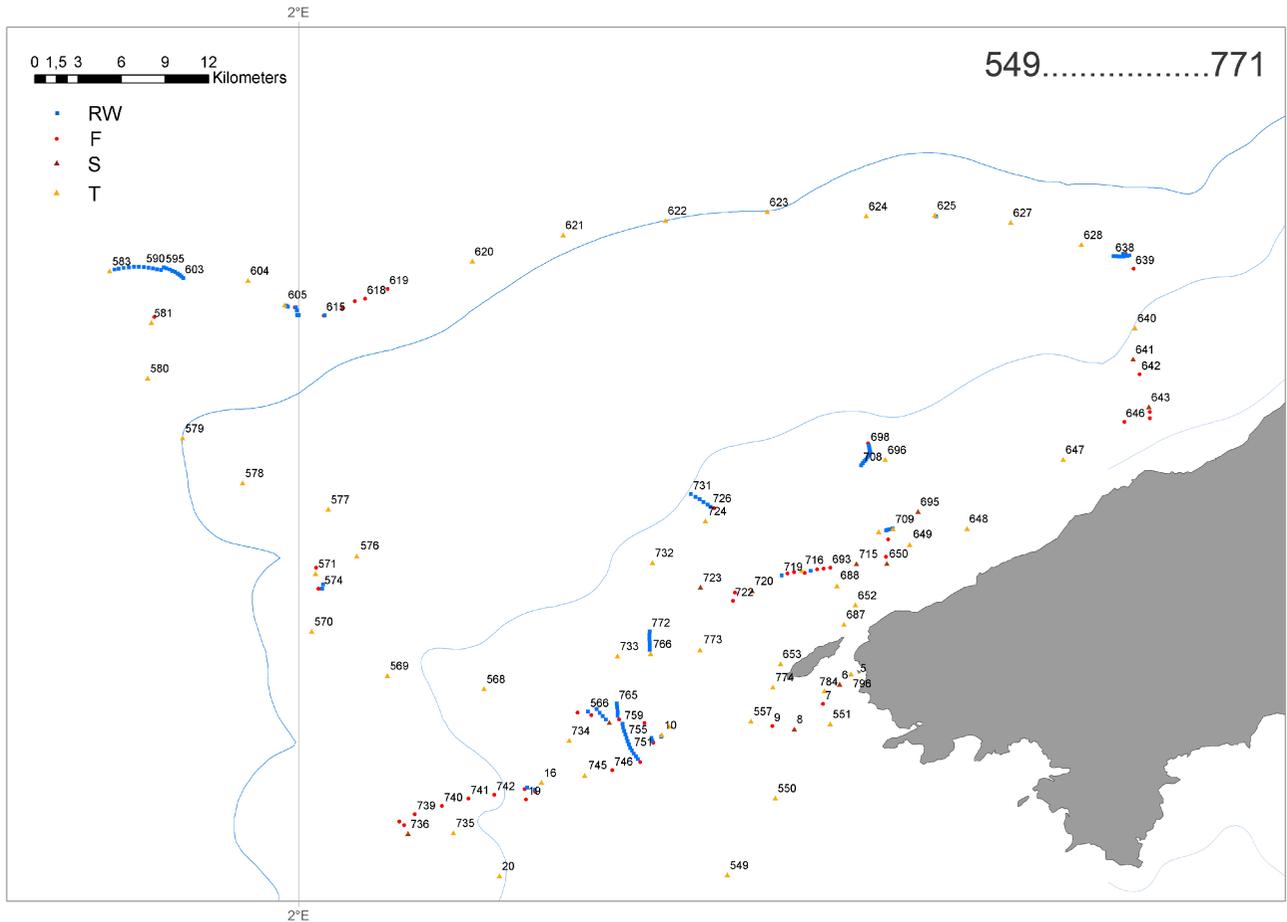
(b)



(c)



(d)



Supplement 3. Time lag analysis

The dynamic nature of marine physical processes (e.g. upwelling) may result in temporal or spatial lags between physical processes and biological responses (Redfern et al. 2006), and it is unlikely that bird distribution responds instantaneously to changes in oceanographic variables (e.g. sea surface temperature, SST, or chlorophyll *a* concentration, CHL). Instead, marine top predator distribution patterns would respond to the effect of oceanographic variables by a lag of undetermined amount of time, since these changes would affect firstly smaller phytoplankton populations and later higher trophic levels, via zooplankton populations. We applied a cross-correlation analysis estimating the Spearman rank correlation coefficient to study the time lag response of tracking and vessel-based observations of Cory's shearwater to annual variability of SST and CHL to the previous year corresponding to each survey (i.e. September 2006

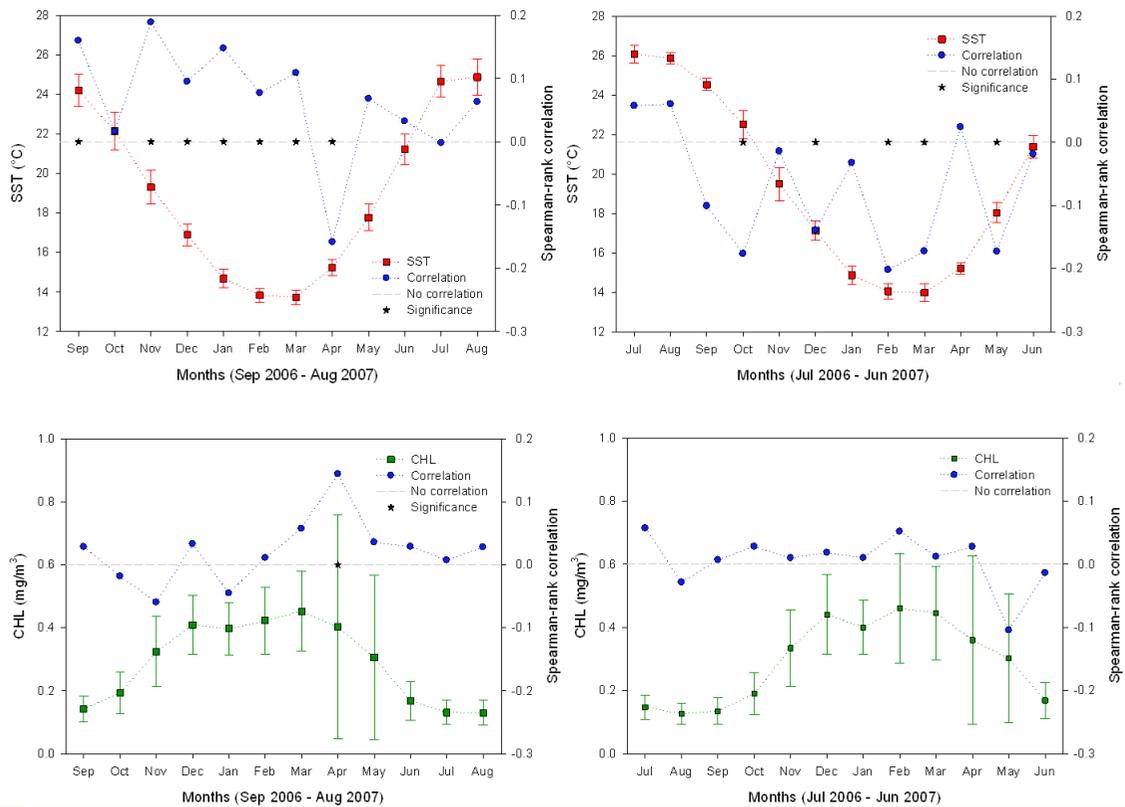
to August 2007 and July 2006 to June 2007 periods for tracking and vessel-based survey data, respectively) (Veit et al. 1996).

For tracking data, April was the only month which showed a statistically significant correlation between tracking data and CHL ($r = 0.14$, $p < 0.001$), whereas for SST 7 mo of the time series showed a statistically significant correlation, being the month of April the only month with a negative correlation value ($r = -0.158$, $p < 0.001$, see Fig. S2). Overall, April was the most statistically different month for the annual comparison for both oceanographic variables for tracking data, which comprised the most spatially extensive dataset of the study area (Fig. 1). Concerning vessel-based data, we did not find any statistically significant relationship between shearwater occurrence and CHL values, but 5 mo were significantly related to occurrence data in the case of SST (Fig. S2). Due to the smaller spatial coverage provided by the latter dataset we relied on the tracking results and hypothesised that the oceanographic characteristics of the month of April might better describe the observed distribution patterns of shearwaters during surveys.

Regarding monthly variation of both oceanographic parameters, CHL values were higher and lower during winter months (Feb and Mar) and summer months (Jul and Aug), respectively, opposite to SST patterns (Spearman-rank correlation coefficient between CHL and SST for both type of data: $r_{\text{tracking}} = -0.436$, $r_{\text{vessel}} = -0.261$, and $p < 0.001$ in both cases). Thus, we assumed that marine productivity was higher between February and March within the study area (see Fig. S2).

With all these results, we decided to use the integrated value of CHL and SST for the period from February to April previous to surveys (June and August 2007) as a reliable and biologically meaningful proxy of oceanographic patterns, rather than using values of the surveyed months. Our results are also supported by Salat et al. (2002) who showed that February was the month of higher CHL values in the surface waters within the Ebro Delta area. Additionally, river outflow is related to nutrient content in the water column (Salat et al. 2002) and small pelagic fish landings (a reliable proxy of abundance), the river outflow being higher in the month of February (Lloret et al. 2004).

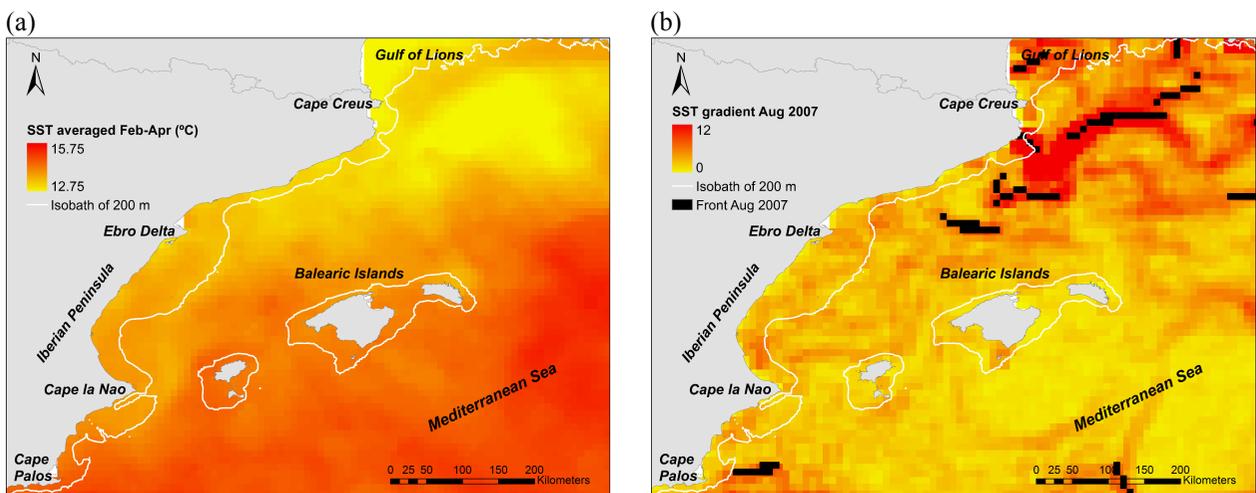
Fig. S2. *Calonectris diomedea*. Time lag response of tracking and vessel-based survey observations of Cory's shearwater to annual variability of SST and CHL. Spearman-rank correlation coefficients between feeding/not feeding and presence/absence and oceanographic variables are shown (for the September 2006 to August 2007 and July 2006 to June 2007 periods for tracking and vessel data, respectively). Statistical significance ($p < 0.05$) is indicated by an asterisk along the 'No correlation' line

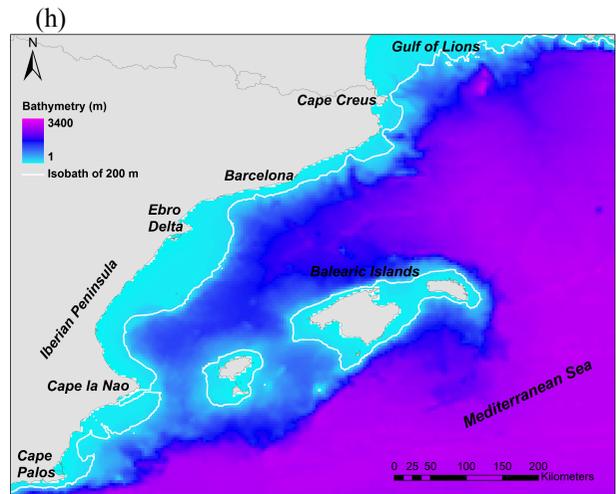
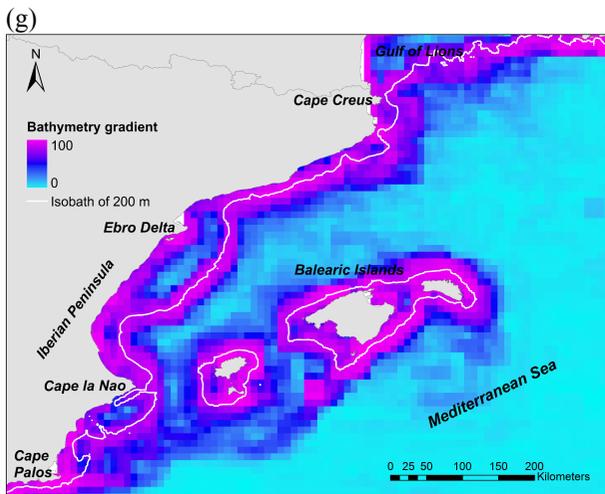
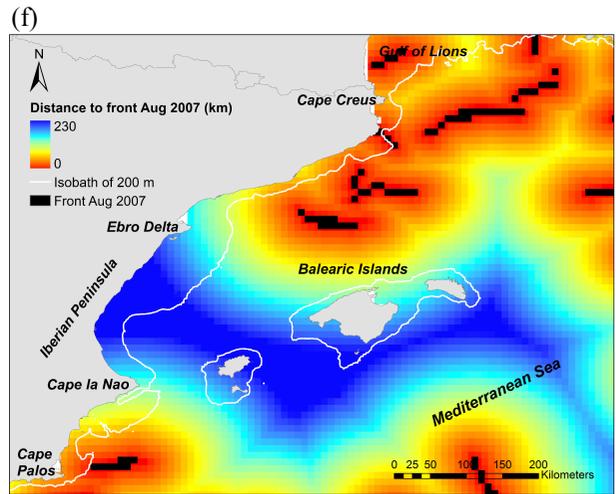
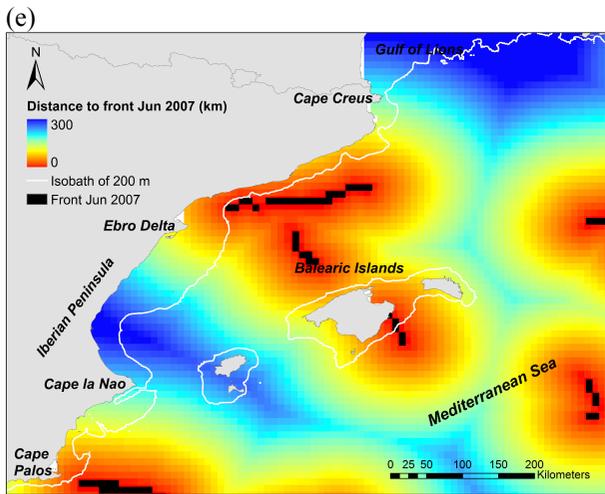
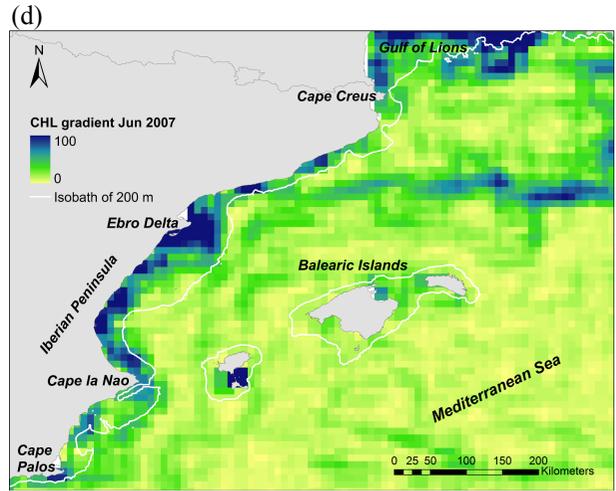
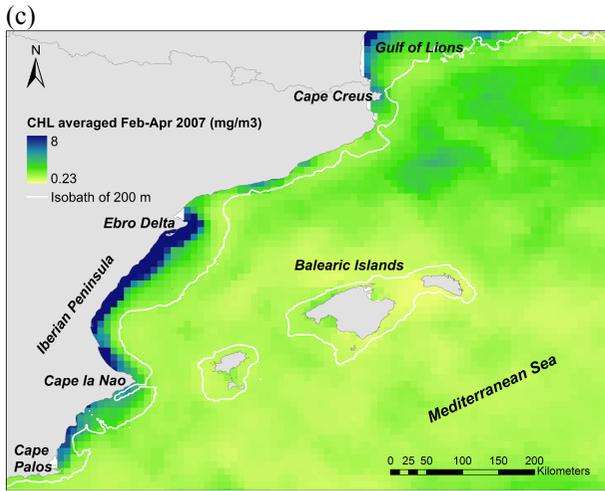


Supplement 4. Oceanographic characterisation of surveys

The seascape occupied by Cory's shearwater is characterised by the oceanographic patterns typical of the western Mediterranean Sea (Fig. S3). The west and the north of the study area (the Ebro Delta and the Gulf of Lions, respectively) were characterised by a higher oceanographic variability at the small scale, reflected in both CHL and SST, and represent the most productive (8 mg m^{-3} , maximum integrated CHL values between February and April) and coldest waters of the study area. Additionally, important mesoscale frontal systems were also identified within the study area, mainly at the north of the Balearic Islands.

Fig. S3. Predictor variables explaining the oceanographic habitat of Cory's shearwater (for both types of habitats: foraging and feeding) such as (a) integrated SST (February to April 2007), (b) fine scale SST gradient in August 2007 and oceanographic fronts (tracking), (c) integrated CHL (February to April 2007), (d) fine scale CHL gradient in June 2007 (vessel-based surveys), distance to the closest front in (e) June and (f) August 2007, (g) bathymetric gradient and (h) bathymetry





Supplement 5. Habitat modelling procedure

Recently, new approaches are advancing for analysing ecological data and making biological inferences such as model selection, instead of the traditional null hypothesis testing (Johnson & Omland 2004). Within this framework, we developed habitat suitability models for identifying key marine areas of the Cory's shearwater in the western Mediterranean.

Development of habitat suitability models

We ranked models based on their Akaike Information Criteria (AIC) value corrected for small sample sizes (AIC_c):

$$AIC_c = AIC + 2p (n / n - p - 1)$$

where p is the number of parameters on model i and n sample size. The model with the lowest AIC_c is considered as the best compromise between model deviance and model complexity (i.e. the number of model parameters; Burnham & Anderson 2002). Comparing AIC_c differences (Δ_i) allow a quick comparison and ranking of candidate models (Anderson et al. 2001, Burnham & Anderson 2004):

$$\Delta_i = AIC_{c_i} - AIC_{c_{\min}}$$

where $AIC_{c_{\min}}$ is the minimum AIC_c value among all models considered.

Also, the probability that model i is the best model for the observed data given the candidate set of models, that is the Akaike weight (w_i), is calculated (Anderson et al. 2001):

$$w_i = \frac{e^{-\frac{\Delta_i}{2}}}{\sum_{i=1}^R e^{-\frac{\Delta_i}{2}}}$$

If the model with lowest AIC_c is not undoubtedly the 'best' (e.g. $w_i > 0.90$), a model averaging procedure might be more appropriate for accounting for parameter uncertainty (Burnham & Anderson 2002). Therefore, we constructed a 95% confidence set of models where the sum of Akaike weights was > 95 , starting with the model with the highest Akaike weight (Burnham & Anderson 2002).

Accordingly, averaged coefficients were estimated from the 95% confidence set of models containing that variable, $\hat{\theta}_a$:

$$\hat{\theta}_a = \sum_{i=1}^R w_i \hat{\theta}_i$$

where $\hat{\theta}_i$ (the parameter estimate of a predictor within a model) is multiplied by the Akaike weights w_i within the 95% confidence set of models containing the parameter of interest.

Finally, we estimated the variance estimator in order to assess the precision of the estimates (Johnson & Omland 2004, Burnham & Anderson 2002):

$$\text{var}(\hat{\theta}) = \left[\sum_{i=1}^R w_i \sqrt{\text{var}(\hat{\theta}_i | M_i) + (\hat{\theta}_i - \hat{\theta}_a)^2} \right]^2$$

where $\text{var}(\theta_i | M_i)$ is the estimated variance of θ_i the i model.

Detailed results of habitat modeling procedure, based on the Information-Theoretic approach, can be found in Table S2 in order to assess both the foraging and feeding habitats of the Cory's shearwater. Moreover, the correlogram of the residuals of the models with lowest AIC_c for vessel-based survey and tracking data is shown in Fig. S4, where no evidence of significant spatial autocorrelation was found.

Ranking variable importance

Within the Information-Theoretic approach, Burnham & Anderson (2002) suggested summing the Akaike weights for all models containing x_i explanatory variable. However, Murray & Conner (2009) found that this was not sufficiently sensitive to correctly rank variable importance, suggesting alternative methods such as hierarchical partitioning. Burnham & Anderson (2002) acknowledged some limitations of this approach: for example, summing the Akaike weights for all models containing x_i explanatory variables — that is, estimating w_i — cannot yield 0, even if some of the explanatory variables (x_i) have no contextual predictive value at all. They suggest (among others) a randomization method to estimate the baseline value for w_i , denoted as w_0 . Firstly, randomly permute the n values of 1 explanatory variable and leave the other columns unaltered. Then fit all possible combination of models and estimate the corresponding w_i (i.e. sum of the Akaike weights for all models containing x_i

explanatory variables). Thus, we obtain the first value of w_0 of the permuted explanatory variable x_i . Permute 100 times (for example) the n values of x_i and we will obtain the distribution of w_0 . The random permutation renders the dependent and explanatory variables uncorrelated. To obtain baseline values for the w_i , Burnham & Anderson (2002) suggest using the sample median as the single best w_0 . Then, we estimated the corresponding w_i . These authors suggest the potential of measuring variable importance by computing the difference between w_i and w_0 . If the differences is close to zero the predictor might not have any predictive value (see an example on p. 346 in Burnham & Anderson (2002)). Burnham & Anderson (2002) acknowledge that more research of these methods and ideas is needed and worthwhile.

Table S2. *Calonectris diomedea*. Results of the Information-Theoretic-based model selection and multi-model inference for Cory's shearwater feeding habitat inferred from vessel-based surveys and tracking data. The model with lowest AIC_c is the first one in both cases. AIC_c = corrected Akaike Information Criteria; $\Delta_i = (AIC_c)_i - (AIC_c)_{\min}$; w_i = Akaike weights. Grey background shading indicates variables included in the model. INT: intercept, SST: Sea Surface Temperature, SSTG: SST gradient, CHL: Chlorophyll a, CHLG: CHL gradient, BATG: bathymetry gradient, COLONY: distance to colony, COAST: distance to shoreline, FRONT: distance to oceanographic fronts, SHELF: distance to continental shelf.

Vessel-based surveys												
Model	INT	SSTG	SST	CHLG	BATG	COLONY	COAST	FRONT	SHELF	AICc	Δ_i	w_i
1	-1.079 ± 0.038		-0.547 ± 0.164		0.504 ± 0.234		-0.397 ± 0.195			241.581	0	0.133
2	-1.059 ± 0.038		-0.493 ± 0.162		0.688 ± 0.231					241.935	0.355	0.111
3	-1.095 ± 0.038		-0.806 ± 0.249		0.69 ± 0.229	-0.389 ± 0.225				242.933	1.353	0.068
4	-1.112 ± 0.038		-0.832 ± 0.248		0.511 ± 0.234	-0.358 ± 0.222	-0.383 ± 0.197			243.038	1.458	0.064
5	-1.027 ± 0.038		-0.542 ± 0.161				-0.57 ± 0.183			243.229	1.649	0.058
6	-1.129 ± 0.038		-0.896 ± 0.259	0.3 ± 0.173	0.762 ± 0.239	-0.536 ± 0.243				243.967	2.386	0.04
7	-1.142 ± 0.038		-0.871 ± 0.251	0.381 ± 0.183	0.692 ± 0.237	-0.654 ± 0.251		-0.352 ± 0.2		244.769	3.189	0.027
8	-1.051 ± 0.038		-0.789 ± 0.229			-0.329 ± 0.209	-0.565 ± 0.185			244.788	3.208	0.027
9	-1.067 ± 0.038		-0.478 ± 0.162	0.165 ± 0.159	0.717 ± 0.235					244.94	3.359	0.025
10	-1.055 ± 0.038		-0.442 ± 0.167		0.639 ± 0.231			-0.173 ± 0.179		245.056	3.476	0.023
11	-1.096 ± 0.038		-0.769 ± 0.242		0.618 ± 0.229	-0.447 ± 0.226		-0.257 ± 0.192		245.161	3.58	0.022
12	-1.082 ± 0.038	0.101 ± 0.16	-0.541 ± 0.165		0.504 ± 0.233		-0.42 ± 0.199			245.28	3.699	0.021
13	-1.083 ± 0.038		-0.534 ± 0.166	0.1 ± 0.163	0.534 ± 0.24		-0.373 ± 0.198			245.3	3.72	0.021
14	-1.078 ± 0.038		-0.513 ± 0.174		0.485 ± 0.234		-0.379 ± 0.199	-0.103 ± 0.188		245.377	3.797	0.02
15	-1.135 ± 0.038		-0.893 ± 0.256	0.228 ± 0.178	0.594 ± 0.25	-0.471 ± 0.243	-0.32 ± 0.203			245.5	3.919	0.019
16	-1.08 ± 0.038		-0.544 ± 0.165		0.519 ± 0.263		-0.393 ± 0.197		0.023 ± 0.183	245.664	4.083	0.017
17	-1.064 ± 0.038		-0.486 ± 0.162		0.74 ± 0.259				0.085 ± 0.18	245.793	4.212	0.016
18	-1.059 ± 0.038	0.037 ± 0.156	-0.489 ± 0.162		0.691 ± 0.231					245.958	4.378	0.015
19	-1.034 ± 0.038		-0.564 ± 0.163				-0.564 ± 0.185		-0.166 ± 0.159	246.213	4.632	0.013
20	-1.114 ± 0.038		-0.802 ± 0.244		0.477 ± 0.235	-0.402 ± 0.226	-0.348 ± 0.205	-0.186 ± 0.201		246.282	4.701	0.013

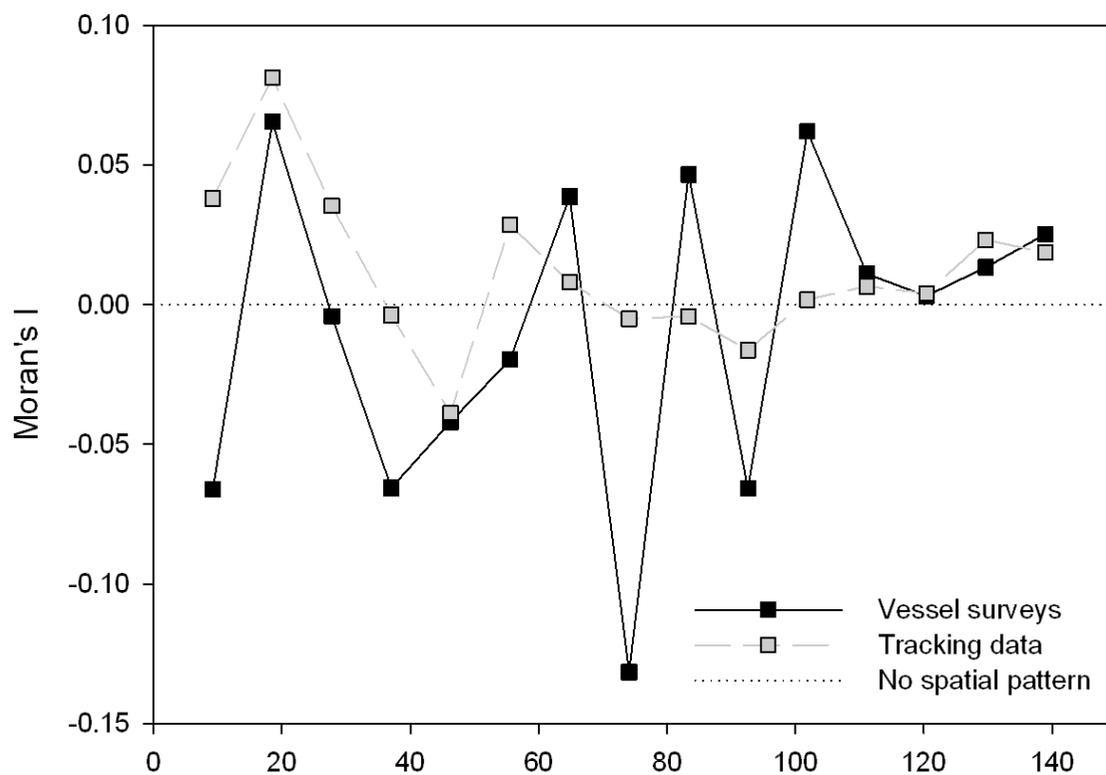
Model	INT	SSTG	SST	CHLG	BATG	COLONY	COAST	FRONT	SHELF	AIC_c	Δ_i	w_i
21	-1.033 ± 0.038		-0.49 ± 0.168				-0.537 ± 0.189	-0.169 ± 0.187		246.474	4.894	0.012
22	-1.114 ± 0.038	0.094 ± 0.16	-0.825 ± 0.248		0.512 ± 0.234	-0.355 ± 0.223	-0.404 ± 0.201			246.81	5.23	0.01
23	-1.099 ± 0.038		-0.798 ± 0.25		0.731 ± 0.259	-0.384 ± 0.225			0.065 ± 0.182	246.905	5.325	0.009
24	-1.03 ± 0.038	0.1 ± 0.16	-0.535 ± 0.161				-0.593 ± 0.188			246.91	5.33	0.009
25	-1.095 ± 0.038	0.037 ± 0.157	-0.803 ± 0.249		0.694 ± 0.23	-0.389 ± 0.225				246.977	5.396	0.009
26	-1.066 ± 0.038		-0.755 ± 0.226			-0.394 ± 0.214	-0.512 ± 0.193	-0.261 ± 0.201		247.135	5.554	0.008
27	-1.112 ± 0.038		-0.832 ± 0.249		0.511 ± 0.266	-0.358 ± 0.223	-0.383 ± 0.2		0.001 ± 0.185	247.158	5.577	0.008
28	-1.027 ± 0.038		-0.54 ± 0.163	0.015 ± 0.157			-0.568 ± 0.185			247.299	5.719	0.008
29	-1.064 ± 0.038		-0.835 ± 0.236			-0.355 ± 0.212	-0.557 ± 0.186		-0.191 ± 0.16	247.454	5.874	0.007
30	-1.012 ± 0.038				0.673 ± 0.227					247.478	5.897	0.007
31	-1.148 ± 0.038		-0.871 ± 0.251	0.313 ± 0.191	0.579 ± 0.251	-0.584 ± 0.256	-0.24 ± 0.217	-0.29 ± 0.21		247.672	6.092	0.006
32	-1.065 ± 0.038		-0.418 ± 0.167	0.192 ± 0.163	0.668 ± 0.233			-0.201 ± 0.179		247.754	6.173	0.006
33	-1.13 ± 0.038	0.058 ± 0.158	-0.894 ± 0.259	0.305 ± 0.174	0.77 ± 0.241	-0.54 ± 0.244				247.953	6.373	0.005
34	-1.131 ± 0.038		-0.892 ± 0.26	0.297 ± 0.174	0.788 ± 0.267	-0.532 ± 0.244			0.042 ± 0.184	248.033	6.452	0.005
35	-1.023 ± 0.038				0.597 ± 0.223			-0.3 ± 0.173		248.337	6.756	0.005
36	-1.053 ± 0.038		-0.803 ± 0.231	0.102 ± 0.166		-0.371 ± 0.22	-0.548 ± 0.187			248.507	6.927	0.004
37	-1.053 ± 0.038	0.092 ± 0.159	-0.782 ± 0.23			-0.326 ± 0.209	-0.586 ± 0.189			248.548	6.968	0.004
38	-1.142 ± 0.038	0.043 ± 0.16	-0.87 ± 0.252	0.385 ± 0.184	0.698 ± 0.239	-0.656 ± 0.252		-0.348 ± 0.199		248.837	7.256	0.004
39	-1.071 ± 0.038		-0.473 ± 0.162	0.161 ± 0.16	0.762 ± 0.261				0.075 ± 0.181	248.867	7.286	0.003
40	-1.142 ± 0.038		-0.87 ± 0.252	0.38 ± 0.183	0.702 ± 0.264	-0.652 ± 0.252		-0.351 ± 0.2	0.015 ± 0.186	248.904	7.323	0.003
41	-1.067 ± 0.038	0.048 ± 0.157	-0.473 ± 0.163	0.168 ± 0.16	0.722 ± 0.235					248.945	7.365	0.003
42	-1.082 ± 0.038		-0.49 ± 0.176	0.123 ± 0.167	0.518 ± 0.24		-0.344 ± 0.205	-0.129 ± 0.19		248.95	7.37	0.003
43	-1.06 ± 0.038		-0.436 ± 0.168		0.687 ± 0.259			-0.17 ± 0.179	0.078 ± 0.18	248.968	7.388	0.003
44	-1.085 ± 0.038	0.106 ± 0.161	-0.528 ± 0.166	0.105 ± 0.163	0.535 ± 0.24		-0.396 ± 0.202			248.985	7.405	0.003
45	-1.016 ± 0.038				0.521 ± 0.235		-0.288 ± 0.185			249.011	7.431	0.003
46	-1.055 ± 0.038	0.027 ± 0.157	-0.44 ± 0.167		0.642 ± 0.232			-0.171 ± 0.179		249.126	7.545	0.003
47	-1.08 ± 0.038	0.091 ± 0.162	-0.513 ± 0.174		0.487 ± 0.234		-0.402 ± 0.204	-0.088 ± 0.189		249.182	7.601	0.003
48	-1.098 ± 0.038		-0.763 ± 0.243		0.649 ± 0.259	-0.442 ± 0.227		-0.253 ± 0.193	0.048 ± 0.183	249.211	7.63	0.003
49	-1.137 ± 0.038	0.103 ± 0.161	-0.887 ± 0.257	0.233 ± 0.179	0.597 ± 0.25	-0.472 ± 0.244	-0.342 ± 0.207			249.229	7.648	0.003
50	-1.096 ± 0.038	0.022 ± 0.159	-0.767 ± 0.242		0.62 ± 0.23	-0.447 ± 0.226		-0.255 ± 0.193		249.261	7.681	0.003
51	-1.082 ± 0.038	0.101 ± 0.163	-0.541 ± 0.166		0.506 ± 0.263		-0.42 ± 0.203		0.003 ± 0.186	249.399	7.818	0.003
52	-1.084 ± 0.038		-0.532 ± 0.167	0.1 ± 0.163	0.548 ± 0.269		-0.369 ± 0.201		0.02 ± 0.183	249.407	7.827	0.003
53	-1.079 ± 0.038		-0.511 ± 0.175		0.5 ± 0.264		-0.375 ± 0.202	-0.103 ± 0.188	0.022 ± 0.183	249.482	7.901	0.003
54	-1.039 ± 0.038		-0.515 ± 0.171				-0.533 ± 0.191	-0.156 ± 0.188	-0.156 ± 0.16	249.615	8.034	0.002

Model	INT	SSTG	SST	CHLG	BATG	COLONY	COAST	FRONT	SHELF	AIC_c	Δ_i	w_i
55	-1.135 ± 0.038		-0.894 ± 0.257	0.228 ± 0.178	0.588 ± 0.28	-0.472 ± 0.243	-0.322 ± 0.206		-0.009 ± 0.187	249.638	8.058	0.002
56	-1.039 ± 0.038	0.128 ± 0.162	-0.558 ± 0.163				-0.593 ± 0.19		-0.186 ± 0.161	249.685	8.104	0.002
57	-1.064 ± 0.038	0.028 ± 0.157	-0.484 ± 0.163		0.74 ± 0.258				0.081 ± 0.181	249.859	8.278	0.002
58	-1.022 ± 0.038			0.204 ± 0.158	0.696 ± 0.229					249.862	8.282	0.002
59	-1.077 ± 0.038		-0.8 ± 0.232			-0.415 ± 0.217	-0.506 ± 0.195	-0.25 ± 0.203	-0.18 ± 0.16	249.995	8.414	0.002
60	-1.072 ± 0.038		-0.776 ± 0.227	0.19 ± 0.179		-0.491 ± 0.235	-0.468 ± 0.198	-0.326 ± 0.21		250.109	8.528	0.002
61	-0.96 ± 0.038		-0.464 ± 0.155							250.123	8.543	0.002
62	-1.037 ± 0.038			0.241 ± 0.162	0.624 ± 0.224			-0.325 ± 0.173		250.188	8.607	0.002
63	-1.115 ± 0.038	0.074 ± 0.162	-0.799 ± 0.245		0.48 ± 0.235	-0.397 ± 0.227	-0.366 ± 0.209	-0.172 ± 0.203		250.213	8.632	0.002
64	-1.034 ± 0.038		-0.558 ± 0.165	0.035 ± 0.158			-0.558 ± 0.187		-0.171 ± 0.16	250.263	8.682	0.002
65	-1.034 ± 0.038	0.084 ± 0.161	-0.489 ± 0.168				-0.557 ± 0.194	-0.157 ± 0.188		250.302	8.722	0.002
66	-1.018 ± 0.038				0.689 ± 0.228	0.16 ± 0.15				250.413	8.833	0.002
Averaged model	-1.079 ± 0.177	0.074 ± 0.019	-0.644 ± 0.015	0.233 ± 0.02	0.612 ± 0.021	-0.431 ± 0.024	-0.438 ± 0.024	-0.225 ± 0.019	-0.013 ± 0.019			

Tracking data

Model	INT	BAT	SSTG	CHL	FRONT	AIC_c	Δ_i	w_i
1	-0.247 ± 0.135	-0.749 ± 0.088			-0.292 ± 0.112	903.938	0	0.445
2	-0.292 ± 0.123	-0.732 ± 0.088	-0.16 ± 0.096		-0.321 ± 0.113	905.286	1.348	0.227
3	-0.321 ± 0.11	-0.712 ± 0.085				906.137	2.2	0.148
4	-0.233 ± 0.14	-0.732 ± 0.094		0.051 ± 0.094	-0.285 ± 0.117	907.683	3.745	0.068
5	-0.273 ± 0.129	-0.704 ± 0.095	-0.173 ± 0.098	0.078 ± 0.097	-0.316 ± 0.117	908.672	4.734	0.042
6	-0.336 ± 0.108	-0.699 ± 0.086	-0.086 ± 0.09			909.238	5.301	0.031
Averaged model	-0.272 ± 0.048	-0.735 ± 0.03	-0.154 ± 0.06	0.061 ± 0.052	-0.301 ± 0.052			

Fig. S4. *Calonectris diomedea*. Correlogram of the residuals of the model with lowest AIC_c for vessel-based survey and tracking data within 15 distance lags. No evidence of significant spatial autocorrelation was found for the residuals of both models with lowest AIC_c .



LITERATURE CITED

- Agostini VN, Bakun A (2002) 'Ocean triads' in the Mediterranean Sea: physical mechanisms potentially structuring reproductive habitat suitability (with example application to European anchovy, *Engraulis encrasicolus*). *Fish Oceanogr* 11:129–142
- Anderson DR, Burnham KP, Gould WR, Cherry S (2001) Concerns about finding effects that are actually spurious. *Wildl Soc Bull* 29:311–316
- Arnau P, Liqueste C, Canals M (2004) River mouth plume events and their dispersal in the Northwestern Mediterranean Sea. *Oceanography (Wash DC)* 17:23–31
- Burnham KP, Anderson DR (2002) Model selection and multimodel inference. A practical Information-Theoretic approach. Springer-Verlag, New York
- Burnham KP, Anderson DR (2004) Multimodel inference: understanding AIC and BIC in model selection. *Sociol Methods Res* 33:261–304
- Estrada M (1996) Primary production in the northwestern Mediterranean. *Sci Mar* 60:55–64
- Johnson JB, Omland KS (2004) Model selection in ecology and evolution. *Trends Ecol Evol* 19:101–108
- Lloret J, Palomera I, Salat J, Sole I (2004) Impact of freshwater input and wind on landings of anchovy (*Engraulis encrasicolus*) and sardine (*Sardina pilchardus*) in shelf waters surrounding the Ebre (Ebro) River delta (north-western Mediterranean). *Fish Oceanogr* 13:102–110
- Millot C (1999) Circulation in the Western Mediterranean Sea. *J Mar Syst* 20:423–442
- Millot C, Taupier-Letage I (2005) Circulation in the Mediterranean Sea. In: Salor A (ed) *The Mediterranean Sea: the handbook of environmental chemistry*. Springer-Verlag, New York
- Murray K, Conner MM (2009) Methods to quantify variable importance: implications for the analysis of noisy ecological data. *Ecology* 90:348–355
- Navarro J, González-Solís J (2009) Environmental determinants of foraging strategies in Cory's shearwaters *Calonectris diomedea*. *Mar Ecol Prog Ser* 378:259–267

- Pinot JM, Tintoré J, Gomis D (1995) Multivariate analysis of the surface circulation in the Balearic Sea. *Prog Oceanogr* 36:343–376
- Redfern JV, Ferguson MC, Becker EA, Hyrenbach KD and others (2006) Techniques for cetacean-habitat modelling. *Mar Ecol Prog Ser* 310:271–295
- Sabatés A (1996) Distribution pattern of larval fish populations in the Northwestern Mediterranean. *Mar Ecol Prog Ser* 59:75–82
- Salat J (1996) Review of hydrographic environmental factors that may influence anchovy habitats in the northwestern Mediterranean. *Sci Mar* 60:21–32
- Salat J, Garcia MA, Cruzado A, Palanques A and others (2002) Seasonal changes of water mass structure and shelf slope exchanges at the Ebro Shelf (NW Mediterranean). *Cont Shelf Res* 22:327–348
- Veit RR, Pyle P, McGowan JA (1996) Ocean warming and long-term change in pelagic bird abundance within the California current system. *Mar Ecol Prog Ser* 139:11–18
- Weimerskirch H, Pinaud D, Pawlowski F, Bost CA (2007) Does prey capture induce area-restricted search? A fine-scale study using GPS in a marine top predator, the wandering albatross. *Am Nat* 170:734–743