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ESTIMATING ACTUAL SEABIRDS MORTALITY AT SEA AND RELATIONSHIP WITH OIL SPILLS: LESSON FROM THE "PRESTIGE" OIL SPILL IN AQUITAINE (FRANCE)

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Summary.—*Estimating actual seabirds mortality at sea and relationship with oil spills: lesson from the "Prestige" oilspill in Aquitaine (France).*

Aims: Estimations were made of seabirds mortality at sea and drift in relationship with oil arrival during the "Prestige" oilspill.

Location: South Bay of Biscay (Aquitaine), South-West France.

Methods: meteorological data (Météo France), the amount of hydrocarbons collected along the coast line (CEDRE), number of beached seabirds (UMSOM, DIREN) and their distribution and abundance on wintering areas at sea (MNHN-LAPHY), to assess the joint drift of oiled animals and of hydrocarbons in the south Bay of Biscay (Aquitaine) during the "Prestige" oilspill. For the first time at the time of an oil slick, we experimentally dropped into the open sea (off the French basco-landaise coast) ringed corpses of guillemots *Uria aalge* in order to estimate by capture-recaptures approach the rate of reported bodies (1 over 121) at the coast and thus to appreciate the total mortality of the populations of seabirds (UPPA-MNHN).

Results: It is estimated that seabirds mortality was eleven times the amount of beached birds collected on the Aquitaine coasts. That result was in accordance with the decrease in the number of guillemots (the most beached species) observed at sea after the "Prestige" shipwreck.

Conclusions: It is demonstrated that the pooling of databases of different natures and origins was necessary to assess the impact of oil spill pollutions, such as those of "Erika" and "Prestige", on the animal populations and more generally for marine biodiversity conservation.

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Key words: Oil spill, "Prestige", impact, seabirds, mortality estimate, drift experiment, capture-recapture.

RESUMEN.—*Estimación de la mortalidad de aves marinas en altamar y su relación con los vertidos de petróleo: caso de la marea negra del "Prestige" en Aquitania (Francia).*

Objetivos: Estudiamos la mortalidad y la deriva de las aves marinas en mar abierto en relación con la llegada de petróleo durante de la marea negra del "Prestige".

Localidad: Sur del Golfo de Vizcaya (Aquitania), Suroeste de Francia.

Métodos: Hemos relacionado informaciones meteorológicas (Météo France), las cantidades de petróleo colectadas sobre las costas (CEDRE), las cantidades de aves varadas (UMSOM, DIREN) y sus distribuciones o abundancias en los lugares de invernada en altamar (MNHN-LAPHY), para estimar la deriva combinada de las aves y del petróleo en el sur del golfo de Vizcaya durante la marea negra del "Prestige". Por primera vez, durante una marea negra se anillaron cadáveres de arao común *Uria aalge* en altamar para estimar la tasa de cuerpos recobrados por medio del método de captura-recaptura (1 sobre 121) en la costa. Así se pudo estimar la mortalidad total de las poblaciones de aves marinas en Aquitania debidas a la marea negra del "Prestige" (UFR-MNHN).

Resultados: Estimamos que la mortalidad de los aves marinas fue once veces mayor que el número de aves recolectadas en las costas de Aquitania. Este resultado está de acuerdo con la disminución del número de araos comunes (la especie que más se encontró en las playas) observada en el mar después del naufragio del Prestige.

Conclusiones: Demostramos que el cruce de base de datos de distinta naturaleza y origen es necesario para estimar el impacto de una marea negra por petróleo (como la del "Erika" o "Prestige") sobre las poblaciones de aves marinas y de forma más general sobre la conservación de la biodiversidad marina.

Palabras clave: marea negra, "Prestige", impacto, aves marinas, estimación de mortalidad, experimentación de deriva, captura-recaptura.

INTRODUCTION

Every year, in world's oceans and seas, oil spills from ships (either illicitly and deliberately or at the time of shipwrecks) are responsible for the death of a large number of seabirds (Camphuysen, 1998; Camphuysen *et al.,* 2001; Clark; 1992, Heubeck *et al.*, 2003; Wiese *et al.*, 2003). Around the world, most public and research attention has been given to the effects of large catastrophic spills created by accidents such as the "Exxon Valdez" in Alaska, "Torrey Canyon" in British Coast, "Braer" in Shetland Islands, "Sea Empress" in Wales or "Amoco Cadix" in France -where 30 000 to 37 0000 seabirds were killed and collected on the coastline- (Bourne, 1979; Holme, 1969; Ford *et al.*, 1996; Edwards and White, 1999; Piatt *et al.*, 1990).

In France, in the Bay of Biscay, after the "Erika" shipwreck (12 December 1999), which poured 20 000 tons out of its cargo of 30 000 tons of heavy fuel and soiled the French coast, overall 74 000 oiled birds (among them 32 000 and 42 000 seabirds and seaducks, alive and dead respectively; see Cadiou *et al.*, 2003, 2004) were collected on the coast including 80 % oiled Guillemot, the most frequently beached species. More recently, 23180 killed birds (6 120 alive and 17 061 dead) including 90 species were collected in Spain, Portugal and France (including 2 831 killed birds from 29 species only for France) at the time of the oil slick which followed the "Prestige" shipwreck (13 November 2002) near to the Finistere Cape in Galicia (Spain) with 77 000 tons of fuel on board spilling some 63 000 tons at sea (Garcia *et al.*, 2003; CEDRE & Diren Aquitaine, *pers. com.*).

Obviously, any impact of oil surface pollution on seabirds neither depends only on the quality of the fuel nor the total amount poured at the time of the shipwreck (the same is true for illicit discharge in the marine environment) but also varies considerably with the geographic location of the spill, the season during which it occurs, environmental weather conditions as wind and streams (Wiese *et al.*, 2003) and the ecology of the species affected (Reid *et al.*, 2001). Indeed, the drift and dispersal at sea over large distance and thus the subsequent arrival on the coast of floating material such as waste or hydrocarbons, corpses of birds died at sea, depend closely on the direction and the speed of the wind (Wiese *et al.*, 2003; Hope Jones *et al.*, 1968). Moreover, the impact of any oil slick is likely to have an important effect when it occurs during winter (non breeding period) when more species and higher numbers of marine birds are present. It is especially true in the south of the Bay of Biscay given that it is a major wintering zone for many birds species (Hémery, 1985; Castège *et al.*, 2004).

The impact of oil pollution on seabirds is well documented and in many parts of the world, systematic surveys of beached corpses of birds (Beached Bird Surveys) have been used (Camphuysen and Heubeck, 2001; Seys *et al.*, 2002; Wiese *et al.*, 2003). However, if both absolute and relative abundance of dead and live seabirds species found oiled along coastline (so called "beached birds") are usually considered indicators of oil pollution events over time and space, very little is known about the real impact of such contamination on these species at sea. Obviously, after oil spills, only one fraction of these live and dead oiled individuals can be found on the beach. The remnant is made up of oiled specimens dying and disappearing at sea following sinking, decomposition or predation and also of individuals actually beached at inaccessible sites and thus not found (Tanis and Mozer-Bruyns, 1968; Hope-Jones *et al.*, 1970; Flint *et al.*, 1999). As a major consequence, those birds are not taken into account in "oiled bird census".

This study had three aims. The first was to study the relationship between oiled beached birds abundance and arrivals of hydrocarbons along Aquitaine coast using environmental data, bird abundance distribution data at wintering zones at sea and data on oiled seabirds and total amount of hydrocarbons collected at various beaches. The second, very original in the sense that it was carried out for the first time exactly at the time of the oil slick, was to launch an original release experiment of corpses of guillemots at sea off the coast which received most impact ("basque and landesaise" coast) in order to estimate the fraction of the oiled individuals which died and were not found subsequently on the coast following the "Prestige" oilspill. Guillemot corpses were ringed so that capture-recapture (CMR) estimates provided the rate of discovery of individuals at the coast and thus enable to appreciate the total mortality of seabirds. Eventually those results were compared with the spatio-temporal distribution at sea of species in the absence of pollution.

Material and methods

The study area is located along the Aquitaine coast (Fig. 1) where almost all oiled beached birds were collected and oil arrivals recorded in France. Data for oiled beached birds were collected from the 1 January 2003 (when the first oiled birds were discovered and collected by various rehabilitation centres along the Aquitaine coast) and the 31 March 2003 (when the main wildlife rehabilitation centres closed). Data relative to oil arrivals were collected from 1 January 2003 (when the first oil arrivals on the beaches were noted) and 15 May 2003. Data of the national long-term data base (1980 - 2004) standardized monitoring study of abundance at sea of seabirds and cetaceans were used (Hémery *et al.*, 1985; Castège *et al.*, 2004).

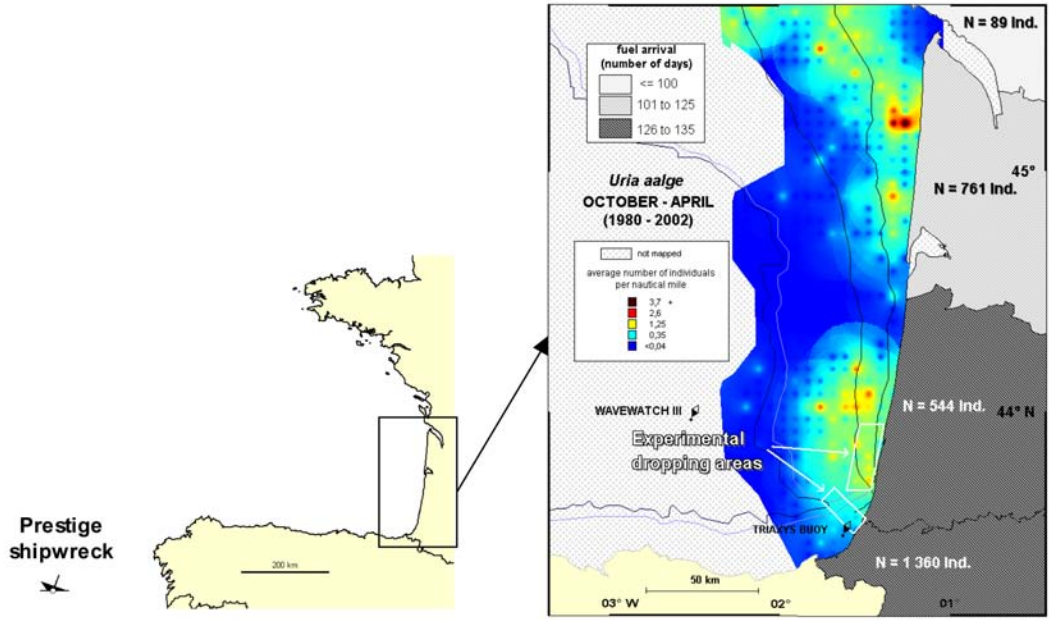

FIG. 1.—Left: location of the “Prestige” shipwreck and the study area. Right: geographical distribution of guillemot abundance at sea in winter (October - April 1980 - 2002, abundance expressed as the average number of individuals per nautical mile); experimental dropping areas ; location of WAVEWATCH III and Triaxys buoy; number of beached birds and days of oil arrivals on the coast represented by administrative regions (Pyrénées-Atlantiques, Landes, Gironde, Charentes-Marîtimes).
[Izquierda: localización del hundimiento del “Prestige” y de las áreas de estudio. Derecha: distribución y abundancia de las araos en alta mar durante el invierno (octubre-– abril 1980 - 2002; abundancia expresada por el número medio de individuos por milla náutica); zonas experimentales donde se depositaron los cadáveres; localización del WAVEWATCH III; número de aves varadas en la plaza y días de la llegada de petróleo a la costa de las distintas regiones administrativas.]

Data collection

Weather data

Use was made of environmental conditions known to affect the number of oiled birds (dead or alive) found on the beach (Wiese *et al.*, 2003) such as wind direction, speed and frequency. Weather information (wind speed and direction) and sea state were obtained from “La Tour des Signaux” station based on the Adour estuary (3 measurements per day at 9 a.m., 11 a.m., 17 p.m.) and the Météo France station located in Biarritz city. Off-shore wind data (i.e. coming from coast and transporting ashore floating waste) and on-shore wind data were respectively coded –1 and +1 and multiplied by the wind speed. Data for swell (height, mean period and direction) were measured in situ by a Triaxis directional wave buoy ashore off Bayonne (location: 43°31’ N, 1°36.8’ W; Abadie *et al.*, 2005; Fig. 1). This TRIAXIS wave buoy (Axys Technology) performs hourly measurements and proceeds to the computation of statistical and spectral wave parameters for the measurement period. These parameters were sent every hour to the coastal station located at the Adour river mouth.

A second data set composed by WAVEWATCH III (Tolman, 1991; 1999) was used to complete the TRIAXIS dataset. WAVEWATCH III is a third generation spectral model used for instance by the U.S. Navy to give simulations of sea states every three hours (*http://www.fnmoc.navy.mil*; location 44°N, 2°30'W).

Beached birds data

Daily data of oiled seabirds (alive or dead) were collected by various wildlife rehabilitation centres [Hegalaldia, Biarritz (64) ; Union Française des Centres de Sauvegarde de la faune sauvage (UFCS) - Unité Mobile de Soins pour Oiseaux Mazoutés (UMSOM), Pouydesseaux (40); LPO-Certe (33)] along the Aquitaine coast (Fig. 1) between January and March 2003. This data set was made available to us by the "DIREN Aquitaine" (Bordeaux).

Oil arrivals data

Daily quantities of hydrocarbons were collected at various beaches along the Aquitaine coast by the Centre of Documentation, Research and Experimentation on Accidental Water Pollution (CEDRE) which was responsible for the activity of depolluting sites.

Total mortality estimate for seabirds

Experimental release of corpses

An estimation of the rate of discovered beached individuals is required to assess the total mortality of the populations of birds. Using a CMR approach (Graham Bell, 1974; Seber, 1982), we experimentally released at sea 121 ringed corpses of guillemots, the most collected species in term of number of individuals collected on the coast after the "Erika" and "Prestige" oil spill (Cadiou *et al.*, 2004). The chosen released zones corresponded both to the coast line which received most impact from the "Prestige" pollution and to sectors used by wintering guillemots (Fig. 1). The corpses of freshly dead oiled guillemots collected in different rehabilitation centres were used and marked with combinations of standard metallic MNHN rings and an additional band made of a large (3 x 5cm) orange plastic flag. The experiment was replicated on three dates (February 18, March 18 and April 18, 2003), releasing corpses from coastguard vessels following a line transect methodology. For each experiment, two samples were used: the first on a South-east - North-west transect along the Basque Coast and the second along a South-North transect along the Landesaise Coast (Fig. 1). Each corpse was released every 800 m along the transect, their geographical coordinates being systematically recorded using a Global Positioning System.

Assessment of floating time

An additional *ex situ* experiment (aquariums at the Biarritz "Sea Museum") was carried out to estimate the floating time of the specimens at sea before sinking naturally. This parameter is required in the drift model for corpses (see below). At the same time, a sub-sample (from the sample of dead birds used in the release experiment at sea) made of 8 oiled corpses of guillemots recovered from the rescue centres was plunged in salt water aquariums pumped directly at sea and constantly renewed to mimic natural conditions (air and sea temperature, salinity, microbial communities...).

Corpses drift modelling

Time vectors of the corpses drift were obtained using wind direction and intensity measured 3 times a day (9 am, 11 am, 5 pm) multiplied by a drift coefficient at sea (see Appendix

1 for details). This coefficient is estimated for corpses of guillemot on average to 2.5 % of the wind speed (Hope Jones *et al.*, 1970; Wiese and Jones, 2001). In the study area, the surface current was considered negligible (SHOM, 1973) and thus was not integrated into the drift model. Eventually, modelling drifting guillemot corpses along the Aquitaine coast was performed using Statistical Analysis System (SAS institute).

Total mortality estimation

Estimates for the total mortality of the populations of seabirds (including in particular the oiled individuals which died at sea or were beached but not found on the coast) were derived from the average impacted birds number using mark-recapture method during the release experiment (18 February - April). Asymptotic Standard Error (ASE) was calculated by SAS software (SAS Institute Inc, Cary, NC, USA, release 8.2). Because wind speed and direction strongly influenced the number of beached birds, a wind coefficient (*W*) was calculated for each period using the wind on-shore rate.

W = Σ on-shore wind velocity / Σ wind velocity

The estimated impacted bird number obtained during the release experiment (February - April) was extrapolated to the beginning of the disturbance event (04 January - February) knowing the wind coefficient for the two periods (see § 3.2).

Statistical analysis

Principal Component Analysis (PCA) was used to investigate linear correlations between weather parameters (wind speed an direction), swell (height, mean period and direction), oiled beached birds arrivals and hydrocarbons arrivals (Stabox V. 6.3). The PCA matrix related to 15 explanatory variables [wind (measures per day and added by step of one day time), swell (height, mean period and direction), state of the sea] and 12 variables to explain (additional) [oiled beached birds (alive, dead and total) day per day and shifted by step of one day time, arrivals of hydrocarbons on Aquitaine coast] and on 72 statistical units (January 19 at March 31, 2003). Prior to analysis each variable was normalized. Correlation analysis between hydrocarbons arrivals, beached birds arrivals and weather data was performed using non parametric Kendall test (SAS instituteV.8).

Results

Total mortality estimate of the marine bird populations

The *ex situ* experiment with floating corpses in salted water aquariums indicated that all the individuals were already steadily decomposed when 20 days old and sank between 25 and 30 days, respectively. A maximum floating time of 30 days was logically retained and it was assumed that beyond 30 days at sea, all guillemots corpses have disappeared. Thus, no simulation was carried out beyond 30 days in the drift model.

Using the simple drift model (Appendix 1), theoretical routes were mapped for each of the 121 released birds (Fig. 2). During this simulation period of bird corpses drift, wind conditions were almost offshore (61 % with 44.5 % of south-eastern) carrying away (*i.e.* ashore) all floating material including bird corpses (Fig. 2). It appeared that a majority of dropped birds ($n = 84$) would have disappeared at sea after 30 days. Among the 121 corpses of oiled ringed guillemots released at sea, the model indicated that 37 birds should have been beached along Pays Basque and Landes coast (Fig. 2). However, only one guillemot (FU0991) was recaptured on 19 April, 2003 on the beach of Anglet

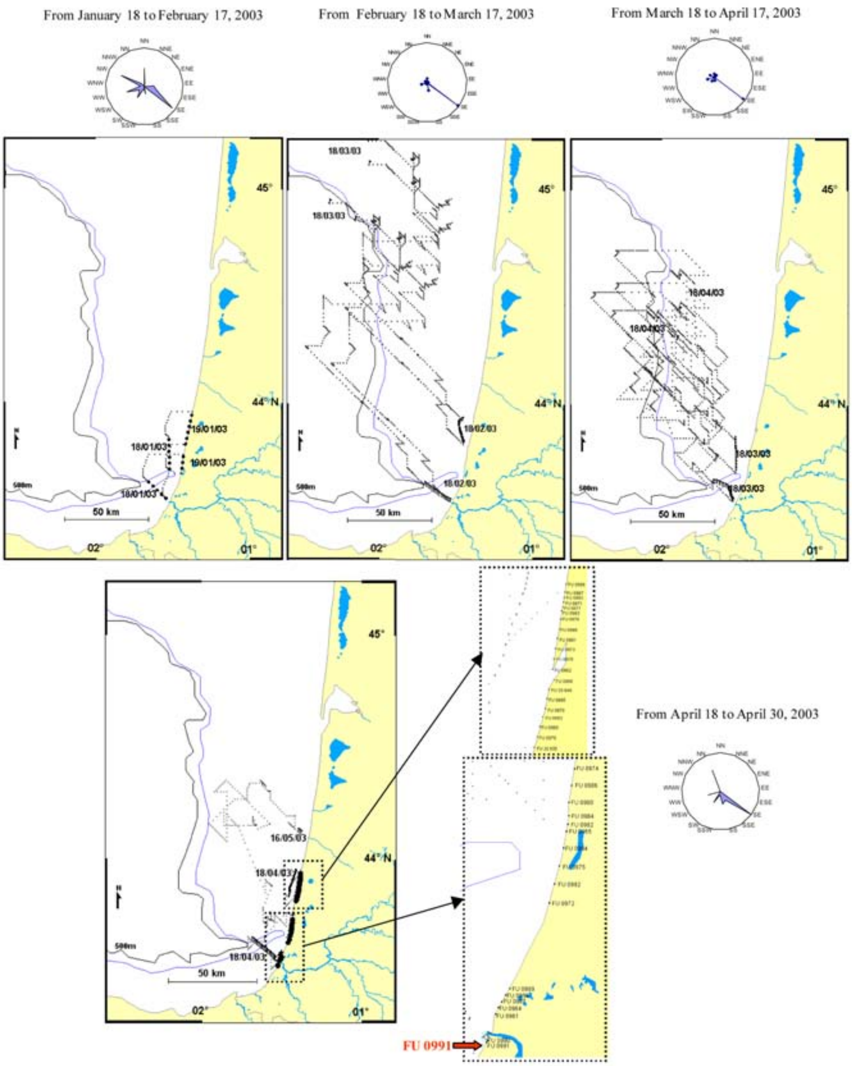

FIG. 2.—Drift model of guillemots corpses at sea : theoretical route for each bird is represented from the dropping point till disappearance or beach arrival; **b)** *n* = 40 corpses, drift from February 18 to March 17; **c)** *n* = 41corpses, drift from March 18 to April 17; **d)** *n* = 40 corpses, drift from April 18 to April 30. The recaptured corpse (FU 0991) the April 19, 2003 is represented. **a)** drift simulation from 18 January to 17 February of a virtual sampling from the same dropping area (*n* = 11 corpses). Wind direction (number of days) is also represented for each drift simulation period.

[Modelo de deriva de los cadáveres de las araos en el mar: ruta teórica de cada aves representada desde el punto desde el cual se arrojo al mar hasta su desaparición o llegada a la playa; ***b)*** n *= 40 cadáveres, derivas desde el 18 de febrero al 17 de marzo;* ***c)*** n *= 41 cadáveres, derivas desde el 18 de marzo al 17 de abril;* ***d)*** n *= 40 cadáveres, derivas desde el 18 al 30 de abril. La recaptura del cadáver (FU 0991) del 19 de abril de 2003 se representa: a) como la simulación de la deriva desde el 18 de enero al 17 de febrero de una muestra virtual de la misma área donde se arrojaron las aves (*n *= 11). La dirección del viento (número de días) se representa también para cada periodo de simulación de derivas.]*

TABLE 1

Compared estimates of birds impacted in the study area during the "Prestige" oil spill: A) mortality estimate from beached bird census (data collected by various rehabilitation centres); B) total mortality estimate from CMR modelling, the recapture probability was estimated during the second period (P2, released corpses at sea experiment). Then, the estimated impacted bird number of the second period was extrapolated to the first one knowing the wind conditions (see text).
[Comparación de las estimas de aves afectadas por el vertido del "Prestige" en el área de estudio: A) mortalidad estimada por censo de las aves varadas en las playas (datos obtenidos por varios centros de rehabilitación); B) mortalidad estimada a partir de los modelos de captura-recaptura (CMR), la probabilidad de recaptura se estimó para el segundo periodo (P2, cadáveres arrojados al mar de forma experimental). Conociendo éstas y las condiciones de viento, se pudo extrapolar el número de aves afectadas en el primer periodo (P1; ver texto).]

Period	**Beached bird number**	**Wind coefficient (*W*)**	**estimated impacted bird number (*n*)**	**Asymptotic Standard Error**		**recapture probability (*P*)**
				n	***p***	
January 04 - February 17 (P1)	2 612	0.6483	18 739	18 807	-	-
February 18 - April 30 (P2)	95	0.3979	11 501	11 543	0.00823	0.00826
TOTAL	2 707	1.04	30 240	22 067	-	-

(Fig. 2). It is important to note that this unique catch was made exactly at the time and at the location where the simulation model indicated it (Fig. 2d).

Capture Marking Recapture modelling provided an estimation of the value for total mortality equal to 30 240 killed birds in Aquitaine area (Table 1). This estimate was eleven times the amount of beached birds collected despite a large Asymptotic Standard Error (ASE).

Correlation between arrivals of oiled beached birds, hydrocarbons and environmental conditions

The two dimensional plan provided by PCA explained 75 % of the total variance (Fig. 3). The active variables, apart from the period and the direction of the swell, were very well represented and correlated positively. The explanatory variables describing wind strongly contributed to the formation of the PC1, the maximum contribution being for 7 days of cumulated wind. The state of the sea, the height and the period of the swell contributed to the formation of the PC1 and PC2 and were strongly correlated. The number of beached birds (alive, dead and total) and oil arrivals were well represented on the correlations circle of the PC1 x PC2 plan and expressed as a gradient along the PC1. The number of beached birds (alive, dead and total) were strongly correlated but not synchronised directly with arrivals of hydrocarbons.

Beached birds were strongly correlated with the wind measured the very same day ($P < 0.05$, Kendall test; January - February included when all the rehabilitation centres were operational). The oil arrivals were strongly and significantly correlated with birds beached 8 days before ($P < 0.05$; January - February included; Fig. 4). Oil arrivals were strongly correlated with the variables described by 7 days of cumulated wind ($P < 0.05$, Kendall test; January - March included). The state of the sea (strong-

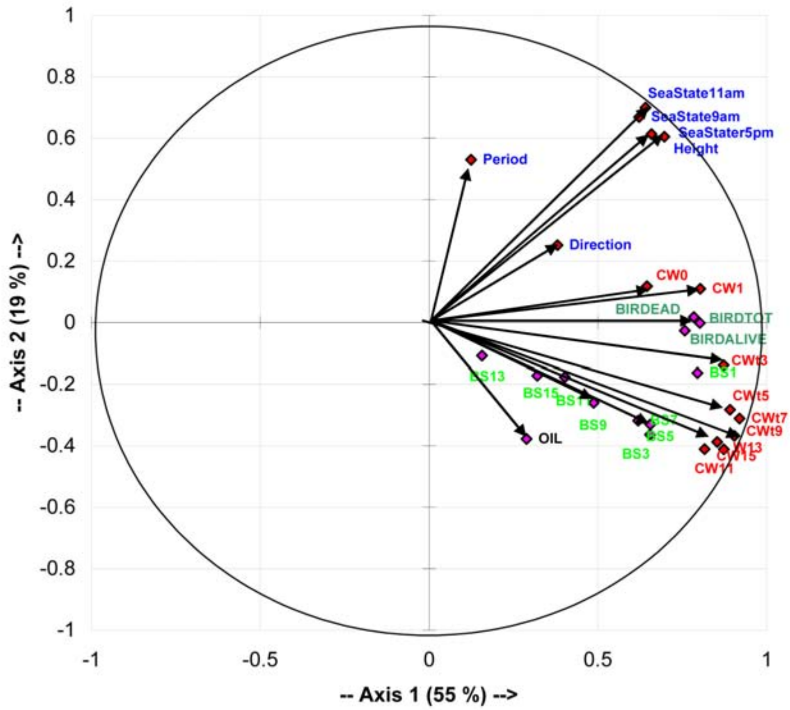

FIG. 3.—Correlation circle within the PC1-PC2 plan of the Principal Component Analysis (PCA). The fraction of the variance captured by the PC's is indicated on the axis. Abbreviations used: **CW** = wind cumulated (added by step of one day time), **Height, Period and Direction** = Swell, **BirdDead, BirdAlive** and **BirdTotal** = Beached birds collected, **BS** = Beached birds shifted by step of one day time, **Sea state** (measured 3 times a day) and **Oil** = arrivals of hydrocarbons .
[Representación circular de las correlaciones de los componentes principales (PC1-PC2) obtenidos del Análisis de Componentes Principales (PCA). La fracción de la varianza capturada por cada PC se indica en el eje.]

ly correlated with wind intensity), height, period and direction of the swell were not strongly correlated with beached birds (alive and/or died) and the oil arrivals.

DISCUSSION

Total mortality estimate of the marine bird populations

As several other authors have done, here too it is pointed out that after other spills offshore winds versus onshore winds can be an explanation of the decreasing number of birds drifting ashore in one period (Stowe, 1982, in Camphuysen *et al.*, 2001). During the "Prestige" crisis, weather conditions have strongly influenced the number of beached birds. This explained the poor rate of simulated beached corpses (only 37 individuals over 121 released at sea could have been found on the beaches according to our drift model), due to frequent offshore winds (61 %) moving ashore corpses which disappeared at sea (Fig.2), a result in accordance with previous studies using wood-

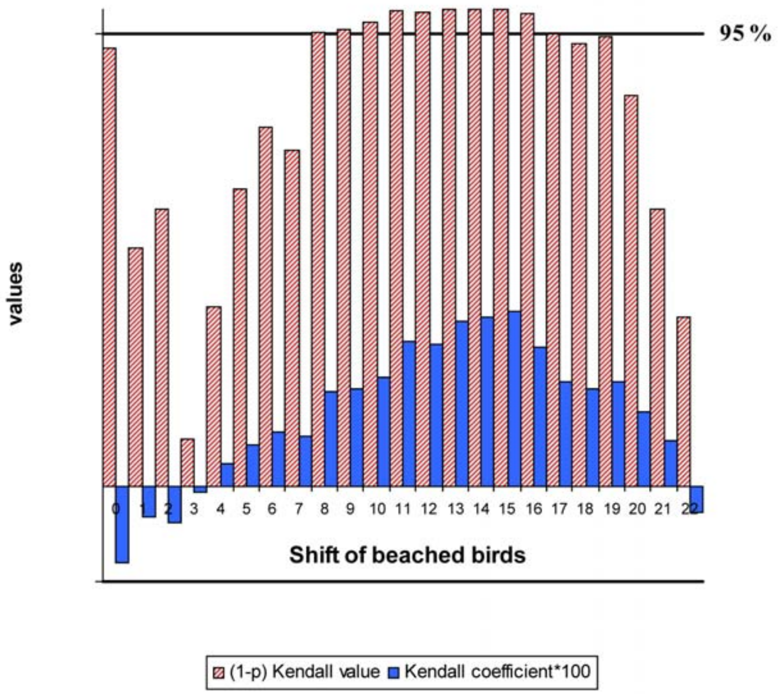

FIG. 4.—Correlation Kendall test between oil arrivals and beached birds shifted by step of one day time (between 0 and 22 days). The black line indicates the significant value [(1 - *P*) > 95]. The Kendall rate is presented.
[Prueba de la correlación de Kendall entre las llegadas de petróleo y de las aves a la playa con un cambio de un día por cada intervalo (entre 0 y 22 días). La línea negra indica el valor de significación [(1 – P*) > 95].]*

en blocks (Flint and Fowler, 1998). Disappearance was attested by the *ex situ* experiment revealing a maximum floating time of 30 days. Given the wind conditions during the crisis, if the maximum floating time provided by Wiese (2003) had been used, the same number of simulated beached birds woiuld have been found (Fig. 2). This time afloat was likely to be less if sea state (accelerating decomposition process) and predation was added. Indeed, Wiese (2003) found that 70% of floating individuals *Uria* spp. sank within 5 days whilst other sank before 20 days. The present modelling approach proved to be of great help in understanding or predicting patterns of corpses drift. The simple drift model designed on other models previously tested (Hope Jones *et al.*, 1968) was quite efficient as the only individual found (FU 0991, "Cavalier" beach (Anglet) the 19 April 2003, Fig.2) was collected exactly at the date and location expected by the drift model.

The major lesson drawn from this study was that the impact of the "Prestige" would be strongly underestimated if only collected beached birds were considered. The CMR experiment showed that the mortality during the release experiment averaged 11 500 birds corresponding to an extrapolated whole amount of 30 240 birds directly killed in Aquitaine waters by the "Prestige" oilspill; it is approximately eleven times the amount of beached birds collected. The wide ASE associated to this

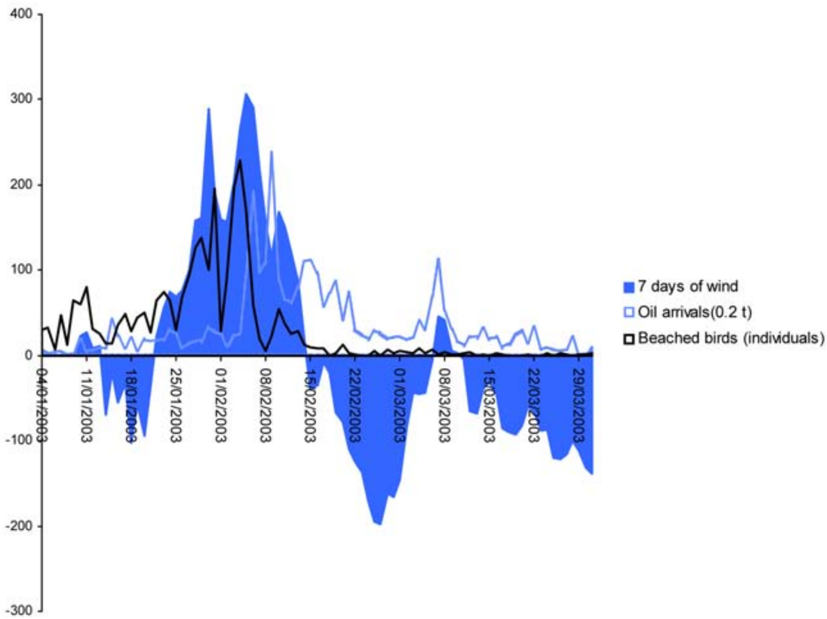

FIG. 5.—Daily variation in beached birds abundance (expressed as individual numbers day^{-1}), oil arrivals (x 0.2 tons day^{-1}) and wind (7 days of additional $data.day^{-1}$) during the study period.
[Variación diaria de la abundancia de aves varadas (expresada como número de individuos x $día^{-1}$), llegada de petróleo (x 0,2 toneladas x $día^{-1}$) y viento (7 días de datos adicionales x $día^{-1}$) durante el periodo de estudio.]

estimate is largely explained by the very low recapture rate. This low recapture rate is not a pitfall as a useful estimate of population size can be obtained even when no individuals have been recaptured (Graham Bell, 1974). One may also consider that the release experiment from the 18 January to the 17 February (P1; Fig. 2) was not carried out because of delayed administrative authorisation whilst the number of beached birds was maximum (Fig. 5); note that at that time, the drift model simulated virtually an important number of beached corpses (Fig. 2). Certainly, if these data could have been incorporated, the final estimation would have been more precise. Nevertheless, because wind conditions and beached birds are strongly correlated, it was decided to extrapolate the estimated impacted bird number of the second period (CMR experiment) to the first period.

During the CMR experiment (18 February - 30 April; P2), if the recapture number would have been more important, the estimated impacted bird number would have been decreasing and stabilizing quickly. The simulation (Fig. 6) indicated that the estimated impacted bird number strongly would have decreased if two extra birds had been recaptured: 11 501 (± 11 543) to 3 832 (± 6 738) respectively for 1 to 3 recaptured birds. Then the estimation decreased slowly from 4 recaptured birds. Because the estimated impacted bird number depend on the recapture number, it would be interesting to standardize the frequency and the travelled distance of beached birds survey in order to maintain a strong and continuous recapture probability.

The experimental release in April was continued because i) there were still wintering

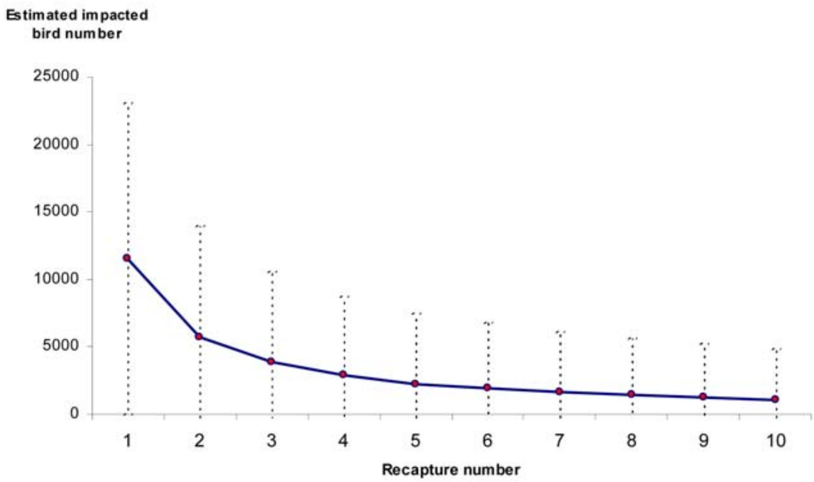

FIG. 6.—Estimated impacted bird number in relation to the number of recapture birds during the CMR experiment. Vertical bars indicate the Asymptotic Standard Error.
[Número estimado de aves afectadas en relación al número de recapturas durante el experimento de captura-recaptura (CMR). Las barras verticales indican el error estándar asintótico.]

seabirds (particularly guillemots; Fig. 7) at sea and also ii) even if most wildlife rehabilitation centres were closed some of them were not. Apart from this apparent weakness in the present study, many results were in agreement to greatly emphasize that the true impact of the "Prestige" on marine birds was far beyond the number of birds collected on the coastline. The important decrease of collected beached birds in February and March did not indicate a decrease of the mortality of seabirds at sea but on the contrary, these two months revealed a maximum abundance of seabird populations and mainly those of the Common Guillemot which was the most impacted species (Fig. 7; Castège *et al.*, 2004). Thus, the impact of the "Prestige" would have been strongly underestimated if only beached birds were accounted for, particularly during this period, because as we highlighted above, birds dead at sea drifted ashore with highly frequent off- shore winds at this time (Ruiz-Villareal *et al*, 2006).

This is not the first time that this severe underestimation has been pointed out. In Europe, if each oil spill event have been characterized by an estimate of bird mortality relying only on beached bird number, by contrast, few have tried to assess whether this estimate was reliable or not. For example, in their drift experiments, Bibby and Lloyd (1977) showed that between 11 and 59 % of ringed corpses were found on the coast (Table 2). Hope Jones *et al.* (1970) recaptured only 20 %. In 1966, after the shipwreck of the Liberian tanker "South America", the Hydrobiological Delta Institute calculated that the number of birds perished at sea was between 8 to 11 times more important than what could be counted on the coast line (*in* Tanis and Bruyns, 1968). In Alaska, after the shipwreck of the "Exxon Valdez" in 1989, using extrapolation of the number of dead birds recovered on the coastline and observations from aerial and ship-based surveys, Piatt *et al.* (1990) also estimated that the total mortality from oil pollution was 3 to 10 times more important. After the "Prestige" shipwreck, the underestimation of mortality varied from 5 to 13 times according

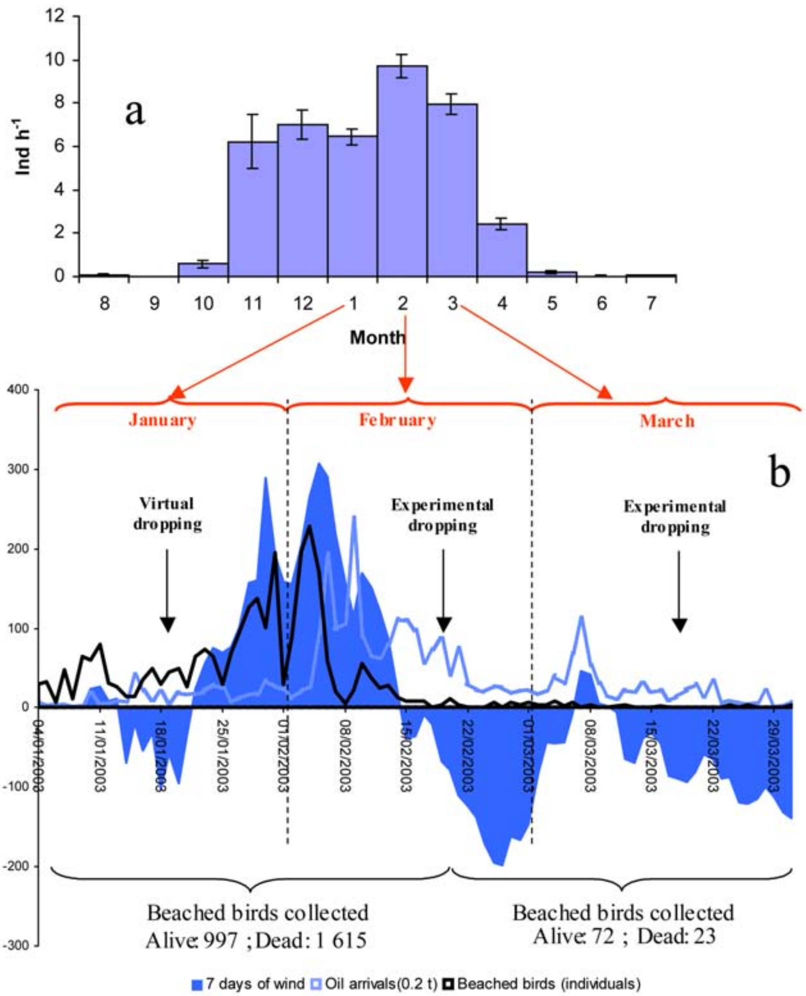

FIG. 7.—a) Seasonal variation in guillemot abundance at sea expressed by the average number of individuals per hour (1980 - 2002); b) evolution of beached birds and oil arrivals during the period of the study. *[a) Variación estacional de la abundancia de araos en el mar expresado por el número medio de individuos por hora (1980 - 2002); b) evolución de las aves varadas y de la llegada de petróleo durante el periodo de estudio.]*

to the studies (Table 2). Arcos *et al.* (2004) estimated this underestimation between 6.5 to 10.8 times more important using drift blocks experiment.

Our CMR-based study is in accordance with those results despite revealing a slightly higher underestimation (x 11) than many other studies above. This could be explained by the fact that our work used standardized methodology combining simultaneously and at the exact time of oilspill *in situ* release and *ex situ* floating corpse's experiments to match perfectly the intrinsic characteristic of the oil spill. However, caution is required before comparing any results with other estimates describing other oil spill events. Indeed, each

TABLE 2

Some total mortality estimate of marine birds (all species) quoted in literature.
[Algunas estimas de mortalidad de aves marinas obtenidas de la literatura.]

Topic	Year	Location	Beached birds collected	Estimate of total mortality death toll	Estimate Methods	Source
Experiment	1966		-	(x 8 to 11)	?	Tanis and Bruyns (1968)
Drift carcasses experiment	1973-1974	Irish Sea	-	11 % to 59 % (x 1.7 to 9)	CMR	Bibby and Lloyd (1977)
Drift carcasses experiment	1969	Irish Sea	-	20 % **(x 5)**	CMR	Hope Jones *et al*. (1970)
Exxon Valdez	1989	Alaska	30 000	100 000-300 000 **(x 3 to 10)**	Aerial and ship-based survey	Piatt *et al.* (1990)
Erika	1999	France (Britain)	74 000	80 000- 150 000 **(x 1.1 to 2)**	Empirical	Cadiou *et al*. (2003)
Prestige	2002	Spain (Galice)	23 181	250 000-300 000 **(x 10.8 to 13)**	Empirical	Dominguez *et al*. (2003)
Prestige	2002	Spain (Galice)	23 181	115 000-230 000 **(x 5 to 10)**	Empirical	Garcia *et al.* 2003
Drift blocks experiment (Prestige)	2002	Spain (Galice)	23 181	150 000-250 000 **(x 6.5 to 10.8)**	CMR	Arcos *et al.* (2004)
Drift carcasses experiment (Prestige)	2003	France (Aquitaine)	2 707	30 240 **(x 11)**	CMR	Our study

oil spill is different and presents its own particular characteristics [(geographic location of the spill, season during which it occurs, ecology of species affected (abundance, breeders, winterers…) and environmental weather conditions such as wind].

Aside from the main trends described above, this study also revealed subtle patterns. For example, even if the estimate of the total mortality of marine birds presented an important ASE (due to a poor rate of recaptured corpses), this was in accordance with the decrease in numbers of guillemots (the most affected species) observed at sea (Fig. 8). During the three years following the "Erika" oil spill, no significant decrease in the abundance

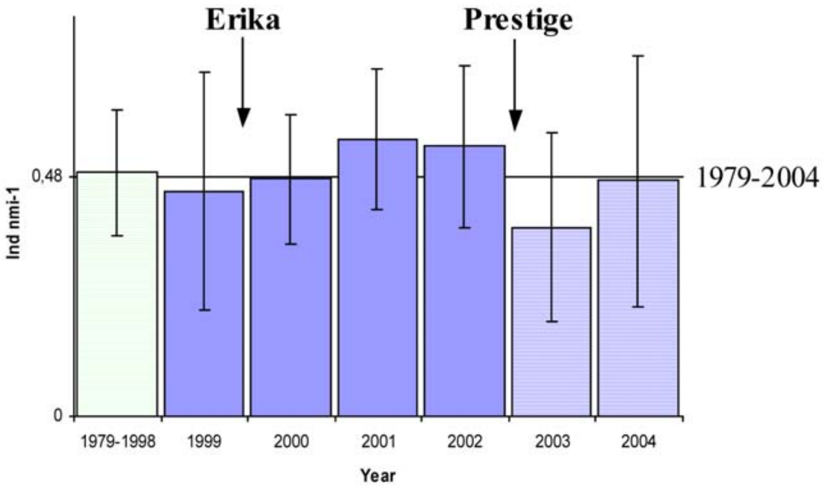

FIG. 8.—Variation of guillemots abundance (mean number of individuals per nautical mile) in the south of the Bay of Biscay (1979-2004). Verticals bars represent standard errors obtained under standardized conditions (Castège *et al.*, 2004).
[Variación en la abundancia (número medio de individuos por milla náutica) de araos en el sur del Golfo de Vizcaya (1979 - 2004). Las barras verticales representan un error estándar (Castège et al. *(2004).]*

of guillemots at sea was observed while a decrease was noted despite not significant ($P > 0.05$) after the "Prestige". This decrease could be explained by the combined effect of both oil spills. Indeed, most of the individuals present in the Bay of Biscay were young birds (< 2 years old). As they grow older and especially as they initiate breeding (at 3 - 5 years old), guillemots do not winter any more the Bay of Biscay but stay in northern areas (Cramp and Simmons, 1983). Thus, those surviving individuals from the cohorts affected by the "Erika" were likely to be not observed in the Bay of Biscay during the subsequent years. However, a low rate of juveniles production, resulting in fewer individuals being observed in the Bay of Biscay in winter, occurred three to five years after the catastrophe when these birds recruited into the breeding population. Eventually, it appeared that both the long term impacts of "Erika" and the underestimated gross mortality caused by the "Prestige" were likely to explain the decrease in the number of guillemots observed in the south of the Bay of Biscay.

The applied issue is that, because seabirds have a late sexual maturity (Schreiber and Burger, 2002), it is crucial to monitor the seabird's abundance affected by oil spills at least five years after the accident.

Correlation between arrivals of oiled beached birds and hydrocarbons

It has been demonstrated here that beached birds patterns were strongly correlated with wind measured the same day ($P < 0.05$). This suggests that birds beached on the Aquitaine coast came from a population that wintered in coastal waters where their abundance is maximum (Fig.1), and in particular Aquitaine and near Spanish areas. It is unlikely that beached birds may have come from remote areas such as Galicia because of limited floating time and rapidity of the response.

Moreover oil arrivals were strongly correlated with the variables described by 7 days of cumulated wind ($P < 0.05$). This result is not surprising as the shipwreck occurred in a remote place and the oil drifted slowly and with complex patterns before reaching French coastal waters and soiled the Aquitaine coast (CEDRE, 2005). Oil arrivals were strongly and significantly correlated ($P < 0.05$) with birds beached 8 days before (Fig.4). This suggests that once oiled, birds reach the nearest coast mainly because of impermeability loss (Hémery *et al.*, 2005). This phenomenon can explain the early arrival of birds on the coast before the oil as this is often observed during pollution by hydrocarbons (Camphuysen and Heubeck, 2001).

The applied issue is clearly that the beached birds precede (about 8 - days advance in the case of "Prestige") the arrivals of hydrocarbons on the beaches.

Conclusion

This study showed that in the case of "Prestige", oil arrivals on Aquitaine coast were strongly and significantly correlated with birds beached 8 days before. As quoted in literature for others oil spill, this further confirm that beached birds can be used as indicators of oil pollution.

The originality and novelty in this approach was to assess real total mortality through *in situ* and *ex situ* experiments carried out exactly at the time of oil spills. The derived parameters (i.e. floating time, expected proportion and location of beached corpses, mortality estimate and confidence interval) matched perfectly the intrinsic characteristics of the oil spill, thus giving the best 'warranty' in term of estimate reliability. Furthermore, the combination of a simple drift model to a CMR experiment proved to be a powerful strategy. However, because each oil spill is different in nature and presents its particular characteristics (geographic location of the spill, season during which it occurs, ecology of species affected, environmental weather conditions…) any estimate of mortality calculated after an oil spill may not be extrapolated to others.

Broadly speaking, the main question in assessing the real impacts of any oil spill on seabirds population is to know if the number of birds recovered on beaches after the spill is true or represents only a fraction of the real mortality. In this study, it is demonstrated how the impact of the "Prestige" oil spill was strongly underestimated by the sole consideration of beached bird collection. In particular, it was obvious that off-shore wind masked the real mortality whilst bird abundance at sea was maximum (February - Mars). This leads to advocating the use of drift models, even as simple as the one proposed in this paper, either to simulate expected location of beached corpses either to assess true mortality using CMR method for example. Using such an approach, the total mortality of marine birds was demonstrated to be about eleven times the amount of beached birds collected on the Aquitaine coast.

This result is in accordance with those provided by the ongoing standardised monitoring of seabirds abundance at sea. This further explains why guillemots declined recently in the south of the Bay of Biscay; indeed, it is hypothesised that the differed impact of the "Erika" shipwreck, expected between 3 or 4 years after the catastrophe, added to the mortality caused by the "Prestige".

Because of their complexity, in particular effects delayed in time, true assessment of oil spill impact needs further monitoring of marine ecosystems on a long term basis, at least five years after the accident. More generally, the pooling of databases of different nature and origins proves to be necessary to apprehend the impact of pollutions, such as those of "Erika" and "Prestige", on the animal populations and more generally for the conservation of the marine biodiversity.

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APPENDIX 1 *[APÉNDICE 1]*

Simple model for corpses drift (see § 2.3.3)

$$\begin{bmatrix} D_d \\ D_i \end{bmatrix}_{t,t+1} = \delta \times \begin{bmatrix} W_d \\ W_i \end{bmatrix}_{t,t+1}$$

where:
D_d and D_i represent drift direction an drift intensity for corpses;
W_d and W_i represent wind direction (degree) and wind intensity (km per hour);
δ is the drift coefficient (in this study we assume that $\delta = 2.5$ % for Guillemot corpses - Hope Jones *et al.*, 1970; Bibby and Loyd, 1977).