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Changes in abundance and at-sea distribution of seabirds in the Bay of Biscay prior to, and following the "*Erika*" oil spill

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Abstract – We investigated the impact of the "*Erika*" oil spill in the Bay of Biscay (France) on seabird populations. Relative abundance and spatial distribution at sea between 1980−1999 and 2000−2002 periods were compared. This study took place in a standardized monitoring at sea carried out with Coast Guard vessels following the line transect method. This work rests on 107 551 standardized counts of one minute before "*Erika*" and 23 449 after the oil spill. There was not a simple correlation between the number of individuals found oiled and the numerical variation of the populations at sea during the two years following the accident. The guillemot *Uria aalge*, the most frequently collected species in the north of the Bay of Biscay, showed no decrease in at sea abundance during the two years following the pollution. Conversely, some species found in small numbers on the coast (e.g. divers *Gavia* sp., razorbill *Alca torda*, common scoter *Melanitta nigra)* decreased significantly at sea (20 to 80%). Overall, marine bird populations declined significantly in the northern sector of the Bay of Biscay (48°32′ to 46°58′ north) and increased in the southern sector (45°13′ to 43°15′ north), whereas decreases and increases occurred in the central sector (46°57′ to 45°14′ north). Changes in the spatial distribution of the species after the "*Erika*" oil spill occurred through disappearance or retraction (Bay of Vilaine, Houat-Hoedic archipelago), or through displacement and reinforcement (Gouf of Capbreton). Overall, this suggests a redistribution of the populations within the Bay of Biscay, depending on the level of injuries to the ecosystems caused by the pollution.

Key words: Seabirds / Abundance / Line transect / Spatial distribution / Oil pollution

Résumé – Changement de l'abondance et de la répartition en mer d'oiseaux marins, dans le golfe de Gascogne, avant et après la marée noire de l'« *Erika* ». Ce travail s'inscrit dans un suivi standardisé en mer mis en place avec la coopération des vedettes des gardes-côtes selon la méthode du transect linéaire. Ce travail est basé sur 107 551 et 23 449 dénombrements standardisés durant 1 min, respectivement avant et après l'accident de l'« *Erika* ». Il n'existe pas de corrélation simple entre le nombre d'individus retrouvés mazoutés et les variations numériques des populations en mer durant les deux années suivant l'accident. Le guillemot *Uria aalge,* espèce la plus abondante dans les échouages répertoriés, ne présente pas de diminution significative d'abondance en mer pour les deux années suivant la pollution. A l'inverse, certaines espèces peu retrouvées sur les côtes (plongeons *Gavia* sp., pingouin torda *Alca torda*, macreuse noire *Melanitta nigra*) diminuent significativement en mer (plus de 80 %). Globalement, les populations d'oiseaux marins diminuent dans le nord et augmentent dans le sud du golfe de Gascogne. Le centre du golfe présente des augmentations et des diminutions significatives. Cela suggère une redistribution des populations suivant le niveau de pollution atteint dans l'écosystème. Des changements de répartition géographique des espèces se manifestent par la disparition ou la rétraction (baie de la Vilaine, archipel Houat - Hoedic), ou par déplacement et renforcement (gouf de Capbreton).

1 Introduction

Since the beginning of the 20th century catastrophic oil spills have been responsible for the death of large numbers of seabirds (Camphuysen 1998; Camphuysen et al. 2001; Clark 1992; Wiese et al. 2003; Heubeck et al. 2003).

The number of beached – dead or alive –birds and the proportion of the different species found oiled along the coastline are usually considered by the public to reflect the severity of oil pollutions. However, little is known about the long term

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impact of such catastrophes on the dynamic of the abundance and the at-sea geographical distribution of seabirds, in particular in coastal waters.

In the case of a marine pollution, whatever its characteristics, assessing the biological impact on animal populations requires a statistical comparison of their characteristics before and after the incident. Simultaneously, appears the necessity to take into account the context of the natural temporal variability of the physical marine habitat and its long term effects on the dynamic of the populations.

This work presents results of an oil pollution consequences, here that of the *Erika* incident in December 1999 (continuing to June 2000), through the variation of the abundance and the geographical distribution of seabirds in the coastal waters of the Bay of Biscay (Fig. 1) during the winter. The northern sector of the Bay (48°32′ to 46°58′ north) was heavily polluted, the central sector (46°57′ to 45°14′ north) less heavily and the southern sector (45°13′ to 43°15′ north) was not concerned by the oil spill. This quasi-experimental situation ("before" and "after" data, control and treatment) permits, for a large marine area regularly monitored since 1980, a first analysis of the effects of the pollution on seabirds.

After determining the effects of the pollution on seabird distribution and population dynamics, we used top chain (trophic levels 3 to 5, Sanger 1987; Hémery 2001) predators such as seabirds to assess the state of the ecosystem and its resilience after the pollution. This publication contributes to quantifying and documenting changes in the marine ecosystem.

2 Material and methods

2.1 Survey method

This work rests on 131 000 counts, each of one minute (representing 2 200 hours of observation), from vessels of the Coast Guard, under standardized conditions (Hémery et al. 1986; Récorbet 1996) of line transects (Seber 1982) conducted from June 1980 to June 2002. Before january 2000, the observations where done during 303 different days (82.1% of the total). Since the *Erika*'s oil spill, 66 days (17.9%) have been sampled on the whole annual cycle (up until december 2002).

The protocol imposed the following main conditions: a visibility at least of 1 nautical mile, a sea condition under the state 4 (international sea state code S), an angle of view of 360°, an observer placed at 6−8 m above the sea level and a cruise speed ranging from 15 to 22 knots. Animal are detected by naked eye, binoculars being used only for the confirmation of the species and the characteristics of the individuals and their behavior (sitting on the sea, flying, diving, etc.). Geographic coordinates are obtained by GPS (Global Positioning System). The distance for detection is unlimited. In the present case, only relative density of seabirds, expressed by the number of animals seen in these standardized conditions by unit of time or distance travelled, are considered. These methodology and information are compatible with the present European Seabirds at Sea Database (ESAS 1996).

Only the standardized observations carried out aboard high-speed (15−22 knots) Coast Guard ships were selected (disposable samplings from other types of ships or from planes and helicopters in the national data bank were eliminated in the present analysis in order to allow for consistency). Observations were integrated in the Statistical Analysis System SAS (SAS Institute 1989) data base. The presence of animals that were obviously related to the presence of ships (e.g. fishing boats) were eliminated when analysing the data in order to avoid representing artificial phenomena of high abundance.

2.2 Species monitored

The seabird species taken into account in this analysis fulfilled one or two of the following criteria: i/ the density of the populations at sea was sufficiently high to hope getting adequate data (up to 300 counts after *Erika* pollution). This allows statistical results in a length of two or three years after the pollution; ii/ the fact that these species were among the most heavily beached birds during this pollution. Overall, 10 seabird species (Table 1) were examined in this work representing 96.3% of the total number of birds found oiled (Anonymous 2000).

2.3 Temporal and geographical distribution at-sea of seabird populations

After pooling the data, the quadrats (grid: 3 × 3 nautical miles) that were insufficiently surveyed (less than two days) and/or that had too high coefficient of variation of species abundance (standard deviation/mean number individuals >10, an empirical value) were eliminated. Thus, only regular phenomena were analysed and represented in this work. So, some very localized or unfrequent phenomenoms could be not mapped. Then, a smoothing of the grid was obtained using two-dimensional IDW (Inverse Distance Weighting) interpolation in the Geographical Information System (GIS) MapInfo. In the figures, the zones indicated "*not mapped*" either were not surveyed or were eliminated according to the above criteria.

Eventually, to define numerically the limits of the abundance classes, we used Ward's algorithm with the criteria of optimal minimal intra-class variance and maximal variance between classes (the distance between two clusters is the ANOVA sum of squares between the two clusters added up over all the variables. At each generation, the within-cluster sum of squares is minimized over all partitions obtainable by merging two clusters from previous generation; cluster procedure (SAS 1989)) to define numerical abundance classes illustrated on the charts.

2.3.1 Variables used to estimate relative population abundance

Relative estimates of population density at sea were obtained in three different ways. First, we considered either the individuals observed per unit of time (hour in Fig. 1, or minute in the Table 1, denoted "Ind min^{-1}") or distance covered (nautical mile, Fig. 1). The second approach was to determine the

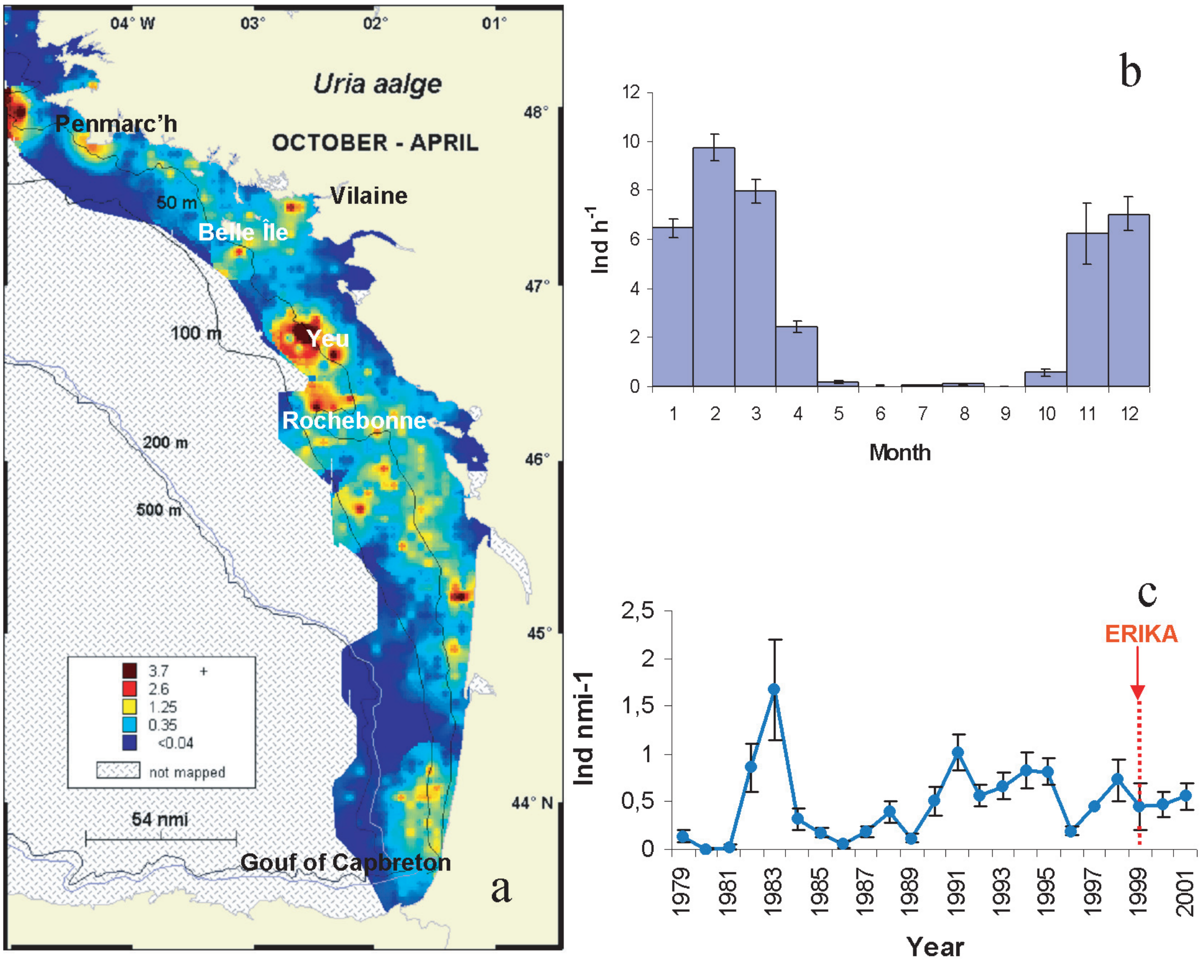

Fig. 1. Guillemot abundance. **a**: geographical distribution in winter (October to April 1980-2002, abundance was expressed by the average number of individuals per nautical mile); **b**: seasonal variation in abundance (expressed by the average number of individuals per hour); **c**: inter-annual variations in the south of the Bay of Biscay (average number of individuals per nautical mile, vertical bars represent standard errors).

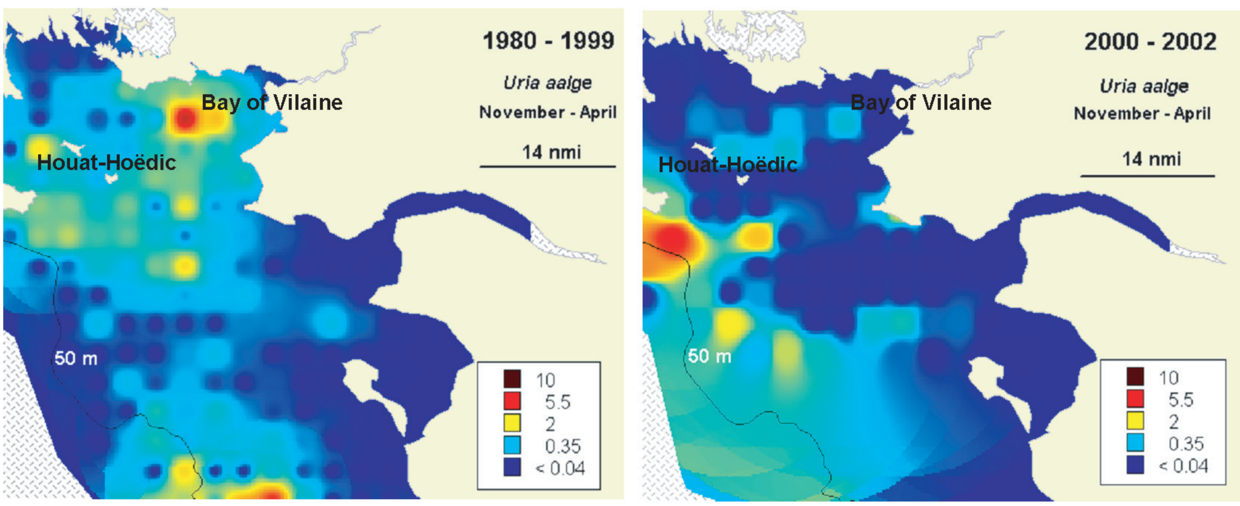

Fig. 2. Temporal variation of the geographical distribution of the guillemot *Uria aalge* in the northern sector of the Bay of Biscay (Morbihan and Loire Atlantique) in winter (November to April). Left: 1980−1999 (before *Erika* incident). Right: 2000-2002 (after *Erika* incident) (abundance expressed by the average number of individuals per nautical mile, $p < 0.01$).

Table 1. Numerical and spatial change (January to April) of the 10 most affected species of seabirds in the 3 sectors north, centre and south of the Bay of Biscay. For the 3 variables tested (Freq, Ind min^{-1} and Grid cell, see text). In each cell, are given (from top to bottom): the variation (red = decreases, or blue = increases in %) between the reference period (1980–1999) and the post-*Erika* period (2000-2002), the number of counts at sea, conducted under standardized conditions in the common SFA ("Specific Frequented Area", see text) and the statistical level of significance *p* for the variables between periods. Slashes indicate absence or very low abundance of the species for the sector. Bottom: plurispecific overall test of Fisher for the variables Freq and Ind min^{-1} (degrees of freedom and probabilities are indicated) in each sector.

	NORTH			CENTRE			SOUTH		
	Freq	Ind min^{-1}	Grid cell	Freq	Ind min^{-1}	Grid cell	Freq	Ind min^{-1}	Grid cell
Divers *Gavia species*	- 67.3% 1827 < 0.0001	- 45.8% 1827 < 0.0001	- 1827 0.999	- 40.0% 1365 0.022	+ 12.5% 1365 0.020	- 1365 0.980	/	/	/
Common Scoter *Melanitta nigra*	- 20.0% 1267 0.042	- 74.0% 1267 0.007	- 1267 0.997	- 71.4% 502 0.442	- 66.8% 502 0.670	* 502 0.656	/	/	/
Razorbill *Alca torda*	- 80.0% 1022 < 0.0001	- 80.7% 1022 < 0.0001	- 1022 0.999	- 72.5% 1612 0.287	- 68.7% 1612 0.272	+ 1612 0.644	- 15.4% 1264 0.535	- 55.8% 1264 0.190	- 1264 0.887
Fulmar *Fulmarus glacialis*	- 100.0% 69 0.037	- 100.0% 69 0.037	- 69 0.999	+ 512.9% 301 0.049	+ 512.9% 301 0.049	+ 301 0.109	/	/	/
Kittiwake *Rissa tridactyla*	+ 46.6% 554 0.892	+ 20.4% 554 0.878	- 554 0.721	- 81.9% 2099 < 0.0001	- 66.6% 2099 < 0.0001	- 2099 0.999	+ 50.0% 2614 0.081	+ 85.4% 2614 0.071	- 2614 0.986
Eider *Somateria mollissima*	+ 20.5% 400 0.608	+ 11.9% 400 0.494	- 400 0.891	/	/	/	/	/	/
Shag *Phalacrocorax aristotelis*	+ 83.7% 482 0.455	+ 100.0% 482 0.594	+ 482 0.500	/	/	/	/	/	/
Guillemot *Uria aalge*	+ 94.9% 1753 0.240	+ 61.0% 1753 0.345	+ 1753 0.276	+ 235.7% 3891 < 0.0001	+ 287.2% 3891 < 0.0001	+ 3891 < 0.0001	+ 37.0% 1867 0.478	+ 8.0% 1867 0.618	+ 1867 0.360
Great Skua *Stercocarius skua*	- 41.7% 96 0.487	- 41.7% 96 0.487	- 96 0.875	+ 184.2% 1308 0.028	+ 150.0% 1308 0.046	+ 1308 0.163	+ 27.0% 4807 0.085	+ 1.7% 4807 0.022	- 4807 0.967
Gannet *Sula bassana*	-4.7% 1272 0.317	- 28.5% 1272 0.189	- 1272 0.946	+ 24.6% 2655 0.227	+ 44.6% 2655 0.203	- 2655 0.127	+ 76.9% 6130 0.002	+ 135.0% 6130 0.181	+ 6130 0.016

		NORTH	CENTRE	SOUTH
Overall Fisher test	↘	24 2.9×10^{-13}	14 2.8×10^{-6}	4 0.334
	↗	16 0.840	18 3.9×10^{-9}	16 5.2×10^{-4}

Significant decrease of abundance

Non significant decrease of abundance

Non significant increase of abundance

Significant increase of abundance

frequency or the proportion of minutes of "positive" observations, that is, during which the species presence was recorded ("frequency index", Seber 1982, called "Freq" in Table 1). This variable has the two-fold advantage of eliminating the eventual disruptive effect due to the contagious behaviour of the animals, as well as the differences in the abilities of observers to estimate the size of large groups of individuals. The third approach used square geographical quadrats grid cells (here 2 × 2 nautical miles, indicated by "*Grid cell*" in Table 1) as sampling units to compare the species presence or absence in different samples of spatial distribution.

2.3.2 Determining variations in species abundance and spatial distribution

We checked for changes in species abundance and spatial distribution after the oil spill, by considering two periods in our observations: "prior to *Erika*" (1980–1999) and "following *Erika*" (2000-2002) (McDonald et al. 2000; Fauchald et al. 2002).

For each species, we defined a "Specific Frequented Area" (SFA), made up by all the geographical grid cells in which the species was observed at least once. Then, only the grid cells common to the two samples (1980–1999 and 2000-2002) were compared. Defining a common SFA makes the samples comparable and allows further tests between the periods, by controlling for possible variations in temporal distribution, abundance or sampling effort (Castège et al. 2003). Nonparametric tests (Conover 1971) were used individually for each species, sector and variable (Table 1). In fine, overall multiple tests of Fisher (Sneyers 1975), here plurispecific and multivariate with Freq and Ind min^{-1} variables, were performed for each sector of the Bay of Biscay (Table 1).

3 Results

3.1 Effects of the *Erika* oil spill on guillemot distribution and abundance

The most frequently beached species, the guillemot (Anonymous 2000), attends the Bay of Biscay essentially during the non breeding period (October to April, Fig. 1); individuals are located primarily between depths ranging from 30 to 90 m. The guillemot distribution shows zones of heavy concentration (primarily the south of Penmarc'h, the south of Belle Île and the Bay of Vilaine, the west of Yeu Island, the Gouf of Capbreton and its northern continental shelf (less than 200 m of depth). During the two winters of 2000 and 2001, guillemots deserted the vicinity of the Bay of Vilaine and shifted to more offshore during the abundance peak from November to April (Fig. 2). Their new distribution in the northern sector of the Bay of Biscay differed significantly from that before the oil spill (χ^2 test, $p < 0.01$).

The number of guillemots recorded at sea in the north of the Bay of Biscay (Table 1) showed no significant change whereas the centre sector presented a higher level after the pollution (2000–2002) than during the reference period (1980–1999). In the south of the Bay of Biscay the annual at-sea guillemot density did not decrease significantly during the two consecutive winters (2000 and 2001) following the pollution (Kendall's rank test $p > 0.05$).

3.2 Effects of the *Erika* oil spill on other seabird distribution and abundance

By contrast, some bird species whose populations were smaller at sea (1980–1999) became significantly less abundant (−20% to −80%, Table 1) (2000-2001), whatever they were found beached in relatively great numbers (common scoter *Melanitta nigra*: 2120 individuals, razorbill *Alca torda*: 1496 individuals) or in small numbers (divers *Gavia* sp.: 301 individuals).

Considering the plurispecific approach for the entire Bay of Biscay, each sector showed a particular response. In the northern sector of the Bay of Biscay, among the 10 species under study, four of them (divers, common scoter, razorbill and northern fulmar *Fulmarus glacialis*, Table 1) decreased significantly. No significant variation was observed for the other 6 species. In the centre of the Bay of Biscay, among the 8 species studied, 2 significantly decreased (divers, kittiwake *Rissa tridactyla*) whereas 3 significantly increased in number (northern fulmar, guillemot, great skua *Stercorarius skua*). In the south of the Bay of Biscay, among the 5 species tested, a significant increase was observed for the great skua and the gannet, whereas distribution and abundance of the other three species studied in this sector (razorbill, kittiwake and guillemot) did not show significant change after the oil spill (Table 1).

To summarize, according to the overall multiple test of Fisher (Table 1), significant observed changes were: decreases only in the northern sector of the Bay of Biscay, decreases and increases in the central sector, and increases only in the southern sector.

4 Discussion

Among the bird species with high abundance at sea, the guillemot and the gannet showed no significant decline in the Bay of Biscay during the two winters following this pollution, although they were the most affected species, in terms of oiled individuals.

When assessing the impact of catastrophic events, it is also desirable to determine which individuals suffered the heaviest mortality. Concerning the guillemot, most of the individuals present in the Bay of Biscay to winter are young (<2 years old) birds. As they become older and especially after they have started breeding (at 3–5 years old), guillemots do not attend the Bay of Biscay any more in winter, but remain in the vicinity of their breeding colonies around the british isles or further up north (Cramp and Simmons 1983). Thus, the surviving individuals from the cohorts affected by the *Erika* will not be observed in the Bay of Biscay during the subsequent years. However, a low production of youngs, resulting in fewer individuals being observed in the Bay of Biscay in winter, might occur three to five years after the oil spill, when these birds recruit into the breeding population. Because seabirds have a deferred sexual maturity (Schreiber and Burger 2002), it is desirable to also check to which extent the other species that suffered from the *Erika* oil spill should bear the delayed impact of the pollution, even though the individuals that spend the winter in the Bay of Biscay form several age classes, including adults. Indeed, these categories of individuals may originate from different localities. The complexity of the phenomenon highlights the necessity of a monitoring during at least five years after the oil spill (Gerrodette 1987; Hatch 2003; Clarke et al. 2003).

The changes occurring in the spatial distribution of marine birds after the oil spill followed three processes: disappearance or retraction (Bay of Vilaine, Houat-Hoedic archipelago), displacement (Plateau de Rochebonne) and reinforcement (north of the Gouf of Capbreton) of the different zones. These movements likely represented a response to the change in the availability of the trophic resources (pelagic, demersal or benthic fishes and invertebrates), constituting the diets of these highly mobile top predators (e.g. Whittow and Rahn 1984; Croxall 1987) On the whole, marine bird populations declined in the north (more polluted) and increased in the south (not polluted) of the Bay of Biscay. These changes were simultaneous, suggesting a redistribution of birds within the Bay of Biscay according to the level of ecosystems exposure to the *Erika* pollution.

Because of the demographic inertia (Croxall and Rothery 1991; Hémery 2001) of the populations structured in age groups, with a long generation time and an age-specific migratory behaviour, two additional years of monitoring at sea are needed to assess correctly the impact of the pollution on the trophic networks and, ultimately, on the entire ecosystem. The oceano-climatic variability of the marine environment will further have to be taken into account in order to distinguish the effects of anthropic and natural factors (Hémery et al. 2002).

5 Conclusion

There is not a simple correlation between the number of individuals found oiled and the numerical variation of the at-sea populations during the two years following the *Erika* accident. The impact of the *Erika* oil spill on seabirds varied among species. Among the most affected (in terms of number of individuals found on beaches) species, some declined (razorbill, common scoter) whereas others stayed stable like the guillemot and the gannet, the two most affected species (Anonymous 2000). By contrast, among the least often found species, some decreased very strongly in the north of the Bay of Biscay. It is the case for *Gavia* sp. and *Fulmarus glacialis*; these species shared small population size at sea before the pollution (pers. obs.).

In addition, the simultaneous desertion of zones with high population densities and reinforcement of other areas suggest a spatial redistribution of the species in the Bay of Biscay. The population trends, as well as links with colonies, are not fully understood and deserve more studies, e.g. in the form of predictive spatial modelling and Population Viability Analysis (PVAs) (e.g. Ferrière et al. 1996; Vitalis and Couvet 2001).

The changes mentioned above, apprehended by the marine birds which are highly mobile top predators, could represent significant modifications of the ecosystems in coastal waters after pollution.

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