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Exploring cetacean stranding pattern in light of variation in at-sea encounter rate and fishing activity: Lessons from time surveys in the south Bay of Biscay (East-Atlantic; France)

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ABSTRACT

To date, the scarcity of year-round and long-term programmes integrating multi-dimensional data has hindered the development of a good understanding of cetacean mortality worldwide. This study uses data from: 1) standardised shipboard surveys (1980–2002), 2) standardised stranding surveys (1980–2002) and 3) landings of fishing fleets (2000–2002) in the Bay of Biscay. It investigates the correlations between stranding, at-sea encounter rate and the fishing index for three common cetaceans: common dolphin (*Delphinus delphis*), bottlenose dolphin (*Tursiops truncatus*) and long-finned pilot whale (*Globicephala melas*). At the monthly scale, a seasonal stranding pattern significantly congruent with the at-sea encounter rate and the fishing index for *D. delphis* is revealed. At the inter-annual scale, stranding and at-sea encounter rates are shown to be correlated ($p = 0.013$ – 0.044 according to species) and significantly increasing in abundance. Temporal variation in the ratio between individuals seen alive at sea and those stranded shows no significant trend suggesting that stranding is better explained by at-sea abundance than by the fishing index. Managers can use these findings to re-evaluate the relative contribution of by-catch fisheries in the context of observed changes of at-sea cetacean abundance and the link to oceano-climatic changes and other anthropogenic causes.

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1. Introduction

Knowledge of the spatial and temporal distributions of specific mortality sources is crucial for the management of species that are vulnerable to human interactions. Estimating mortality is an important component of demographic analyses, having added consequence for long-lived, threatened and endangered vertebrate species. However, calculating such mortality rates and assigning the cause of death are particularly challenging for marine animals. At-sea mortalities are difficult to assess. The analyses of carcass landfall patterns have been performed for different marine animals such as turtles (Epperly et al., 1996; Hart et al., 2006; Murphy and Hopkins-Murphy, 1989), seabirds (Bibby and Lloyd, 1977; Castège et al., 2007; Hyrenbach et al., 2001)

and sea mammals (Evans et al., 2005; Garshelis, 1997; Leeney et al., 2008; McLellan et al., 2002).

Seabirds, sea turtles and sea mammals are among the large marine animals experiencing population declines, an estimated average loss of 84% on historical abundances (Lotze and Worm, 2009). The population dynamic models used for cetaceans (e.g., by the International Whaling Commission) require historical catch records, estimates of intrinsic rates of increase and current abundance. These measures are subject to considerable uncertainty (Baker and Clapham, 2004) as are mortality estimates.

Despite prolific research on cetaceans there are a limited number of long-term programmes that record continuous integrative data on at-sea abundance and distribution, carcass landfall patterns, fisheries by-catches and environmental oceano-climatic patterns. The consequent lack of data has prevented a thorough understanding of historical and ongoing trends in population dynamics, especially in documenting mortality. Strandings are a source of popular and scientific interest

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and are well documented (Dailey and Walker, 1978; Dudok van Heel, 1966). However there is controversy about how useful cetacean stranding patterns are in helping to understand at-sea mortality.

The causes of cetacean stranding remain largely unknown, although many hypotheses have been advanced. Cetaceans can strand alive for putative reasons including: behavioural tendencies of particular species to follow a leader (Odell et al., 1980), disorientation caused by geographical anomalies in the Earth's magnetic field (Kirschvink et al., 1986; Klinowska, 1985), the influence of acoustic “dead zones” (Sundaram et al., 2005), magnetic navigation anomalies (Klinowska, 1985; Vanselow and Ricklefs, 2005), confused navigation arising from bathymetric conditions (Brabyn and McLean, 1992), distraction by activities such as foraging (Wood, 1979) and even regression to ancient instinctive behaviours (Cordes, 1982). Beaching of carcasses occurs following a range of mortality factors. These factors can be natural and/or anthropogenic such as: by-catch through fishing activity (Kirkwood et al., 1997; Siebert et al., 2006), elevated levels of environmental contaminants and infectious diseases (Bennet et al., 2001; Jepson et al., 1999, 2005; Kuiken et al., 1994) and exposure to sonar and the resulting gas-bubble lesions (Jepson et al., 2003). The cumulative importance of these factors is poorly understood (Bearzi et al., 2003) as is the relationship between at-sea individual mortality and observed stranding on shore. It should be noted that even if mass strandings are reported in the literature, their actual importance compared to regular single stranding events could be low. For example, in the study area, no mass stranding of the long-finned pilot whale (one of the species in which mass stranding is often seen) has been observed for at least 25 years (van Canneyt et al., 1999, 2008).

The Bay of Biscay supports a diversity and abundance of cetacean species. This is partly due to the submarine Canyon of Capbreton, a unique geographical feature in Europe (Gaudin et al., 2006). Around the Canyon, the convergence and divergence of water masses create areas of enhanced productivity (Neira and Arancibia, 2004; Rubin et al., 1992). A unique long-term dataset is available in this area; it is composed of a combination of standardised shipboard surveys and long-term data from the national French stranding network. This allows for an original approach to investigate the correlation between at-sea encounter rate on different time-scales (within year and between years) and stranding patterns. The five dolphin species occurring regularly along the French Atlantic coast waters are: the common dolphin (*Delphinus delphis*), the harbour porpoise (*Phocoena phocoena*), the striped dolphin (*Stenella coeruleoalba*), the bottlenose dolphin (*Tursiops truncatus*) and the long-finned pilot whale (*Globicephala melas*) (van Canneyt et al., 2008). While common dolphin, bottlenose dolphin and long-finned pilot whale are regularly observed at sea, the harbour porpoise is seldom seen and the striped dolphin is observed only in the far South region of the Bay of Biscay where the three former species only are described by unbiased data (Castège and Hémery, 2009). The Bay of Biscay is a particularly important site for cetacean stranding along the French coasts (van Canneyt and Peltier, 2006). Compared with annual overall stranded cetacean sightings in France, the frequency of occurrence in the Bay of Biscay of the 3 species under study is proportionally high, being 43%, 32% and 67% of the total French number for the common dolphin, bottlenose dolphin and long-finned pilot whale respectively (van Canneyt et al., 2008).

In this paper, we describe and analyse cetacean stranding patterns in relation to monthly at-sea encounter rate of the species and to fisheries activity. By examining the relationship at two different time scales (seasonal and inter-annual), this study provides a starting point for more robust analyses.

2. Materials and methods

2.1. Study area

The study area is located along the Aquitaine coast in the southern half of the Bay of Biscay (from 43° N to 47° N; Western Europe)

(Fig. 1). It corresponds mainly to the ICES (International Council for the Exploration of the Sea) zones 15 E8, 16 E8 and 17 E8. The bathymetry of this zone is characterised by the Canyon of Capbreton, where the shelf break (isobath: 200 m) is only 1.3 nm from the coast and a depth of 1000 m lies no more than 15.6 nm offshore. It has two main features: a deeply entrenched meandering channel and bordering fluvial-like terraces constituting large sediment traps.

2.2. Cetacean survey at sea

We used data from the national long-term database (1980–2002), resulting from a standardised monitoring study of the at-sea abundance of seabirds and cetaceans using line transects (Buckland et al., 1993; Castège et al., 2004, 2007; Hammond et al., 2002; Hémery et al., 1986; Seber, 1982; Skellam, 1958). The dataset has in total 131,000 min of observations (= 2200 h total observation time), made from Coast Guard vessels (Douanes Françaises and the Affaires Maritimes). The monitoring followed a standard protocol since 1976 so those counts can be compared between months and years. The protocol imposed the following main conditions: visibility of at least 1 nm, sea under the state 4 (international sea state code 5), angle of view of 360°, two observers positioned at 6–8 m above the sea level and cruise speed ranging from 15 to 22 knots. The detection of animals was made by naked eye, binoculars being only used for species confirmation and individual characterisation. No *a priori* maximal distance of detection was fixed. In this study, only the relative density of cetaceans here called “encounter rate” and expressed as the number of animals detected under these standardised conditions per unit of time or distance travelled, is considered. Shipboard surveys were conducted from June 1976 to June 2002 and the means of their relative at-sea abundances were calculated for each of the twelve months of the year. All line transects were homogenous and comparable within and between years because they were made from vessels of the Coast Guard, following no pre-determined trip and approximatively giving the same probability for each sea trip to be made at any place in the region (Dawson et al., 2008; Evans and Hammond, 2004). As vessels depart from and return to the same harbour, the cumulated distance (km) travelled and sampled is higher near those harbours (Fig. 1).

Because each species has its own ecological requirements of preferences, each has a species-specific distribution in the survey area, thus requiring for each an assessment of the proportion of suitable units in an area. This is called herein the Specific Occupancy Area (SOA) and is calculated for each species, as the surface area from the sum of the spatial units (grid cells of 3×3 nm) in which each species has been observed (details and maps are provided in Castège and Hémery (2009)) at least once during the study period (1980–2002). The SOA lies within the boundary of the whole study area. This definition of occupancy area enables statistical comparisons between seasons and years and takes into account any possible change in spatio-temporal distribution of each species within the study area. Used in combination with at-sea encounter rates it allows for specific between-month and inter-annual comparisons.

2.3. Stranding survey

A French stranding network was established in 1972 with different team members of several nature conservation agencies and became fully operational from 1980 (Collet and Mison, 1996). This “National Marine Mammal Stranding Network” is coordinated by the CRMM (Centre de Recherche sur les Mammifères Marins; La Rochelle, France). It encompasses the whole French metropolitan coastline (ca 5000 km) and relies on some 150 accredited surveyors operating standardised patrols on beaches so that effort does not vary between months and years (Collet and Mison, 1996). In this

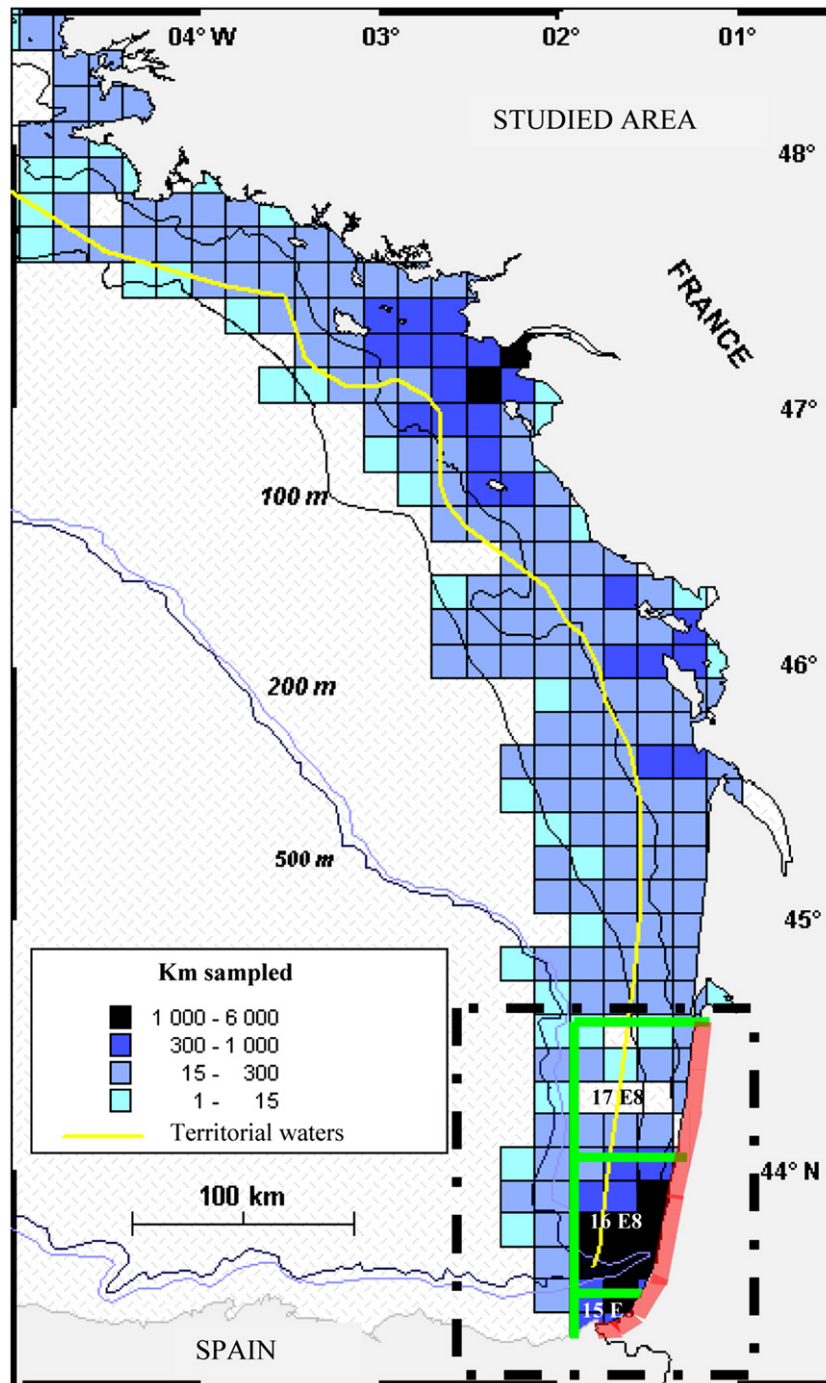


Fig. 1. The study area in the south Bay of Biscay (north-east Atlantic, Europe) is delimited by the black dotted line. Square grid (sample units) in blue indicates kilometres travelled to measure cetacean encounter rate at sea during the whole study (see also Castège et al., 2004). Stranding network used in this study is shown in red. ICES zones (15 E8, 16 E8 and 17 E8) for fishing data are indicated in green.

study, we used the standardised data collected from 1980 to 2002, representing 1501 counts of cetacean strandings.

2.4. Fisheries data and fishing index

Landings of French fishing fleets operating only in the study area are analysed. These data included the composition of landings of a selection of marine species by French fleets operating in the Atlantic, especially by coastal ships operating locally in the southern half of the Bay of Biscay (15 E8, 16 E8 and 17 E8 zones) (Fig. 1). Sources of official data on landings by French fleets and their analysis are

provided in Steinmetz et al. (2008). Only data corresponding to fishing gears known to be harmful to cetacean populations by incidental catches (*i.e.*, fishing net and pelagic trawl fisheries) were used (Andrew and Pepperell, 1992; Hall et al., 2000; Lopez et al., 2002; Majluf et al., 2002; Morizur et al., 1999; Read and Wade, 2000). Fishing index is thus defined as the mean ($\pm$ SE) of monthly values of those official tonnage landings, in a way similar – although simpler – to other classical studies (*cf.* for example Poulard and Léauté, 2002; Ligas et al., 2010). These data were only available from 2000 onwards, therefore only data covering the period 2000–2002 appeared to be suitable for this study.

2.5. Data analysis

2.5.1. Monthly pattern and relationships between cetacean at-sea encounter rate, at beach (stranding) and fishing index: an analysis at the monthly temporal scale

Correlation between monthly at-sea encounter rate, stranding pattern and fishing index is explored through correlation analysis using non-parametric Kendall test. The choice of Kendall's τ (Tau) rank correlation coefficient over Spearman's r is justified by the fact that it can be generalised to a partial correlation coefficient (Legendre and Legendre, 1998). Correlation between at-sea encounter rate and stranding pattern is tested on data from the period 1980–2002. Because fishing index is calculated from 2000 to 2002 only, relationship between this index and encounter rate or stranding pattern is performed for this period (3 years). The effect of interactions between at-sea encounter rate and fishing index (expressed herein as the product between those explanatory variables) on stranding was also tested. At-sea encounter rate and stranding pattern were expressed in relative abundance: mean number of individuals detected under standardised conditions per hour for at-sea encounter rate and mean number of individuals stranded per month for stranding data. Because the common dolphin is highly gregarious (Collet, 1981; Leatherwood and Reeves, 1983), at-sea encounter rate for this species was expressed as the mean number of groups detected under standardised conditions per hour; this is possible because group size didn't vary significantly over time (Kendall test, $p=0.416$). All analyses are made with the Statistical Analysis System (CORR procedure) and MapInfo Software (Fig. 1).

2.5.2. Annual pattern and relationships between cetacean at-sea encounter rate and at beach from stranding: an analysis at the long-term scale

Correlation analysis between annual at-sea encounter rate (mean number of individuals detected under standardised conditions per nautical mile) and strandings (mean number of beached carcasses) is performed using non-parametric Kendall test. Correlation between at-sea encounter rate and number of beached carcasses (hereafter called "stranding") is tested for the period 1980 to 2002 except for the bottlenose dolphin for which the test was performed only from 1990 because bottlenose dolphins were only regularly observed since then.

The ratio between stranded cetaceans and their at-sea encounter rate between 1980 and 2002 was taken as an index of over-mortality or as a lack of stranding compared to the standard. This ratio is called here as the I_M index and simply calculated as: I_M index = strandings / at-sea encounter rate. Identification of years showing anomalous (outliers) data, thus indicating either over-mortality or alternatively under-mortality, was made using Dixon test (Dixon, 1950).

3. Results

3.1. Monthly pattern and relationships between cetacean at-sea encounter rate, at beach (carcasses) and fishing index: an analysis at the monthly temporal scale

There was a strong seasonality in the at-sea encounter rate of the populations of cetaceans studied (Fig. 2). The maximum of at-sea encounter rate estimated for the common dolphin (Fig. 2a) and the long-finned pilot whale (Fig. 2b) corresponded to the end of winter and the beginning of spring with a peak in March. No temporal pattern for the bottlenose dolphin was observed. This species was only regularly observed in the study area since 1999, with a high variability (Fig. 2c). These results indicate a strong seasonality for the long-finned pilot whale and the common dolphin. The latter species is relatively abundant all year long. Seasonality was also observed for stranding patterns (Fig. 2), with the maximum frequency of stranding species occurring at the end of winter and beginning of spring as well. The maximum stranding frequency was

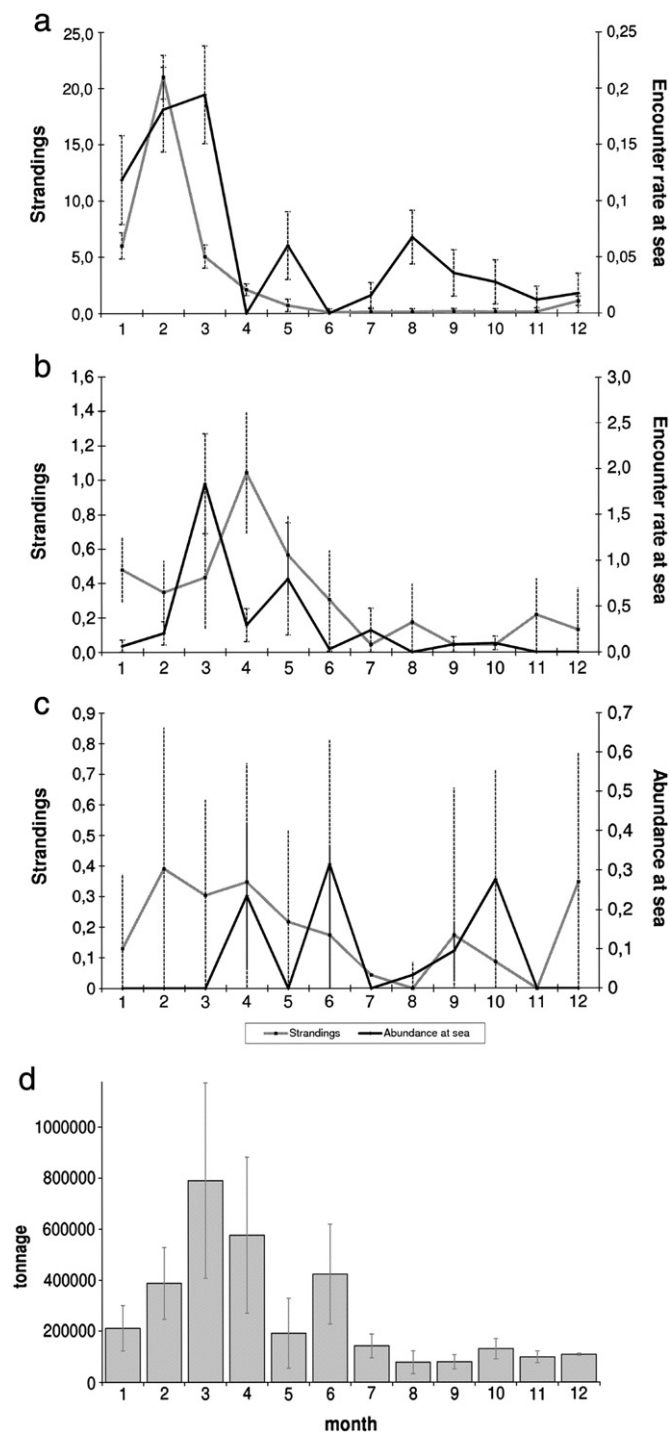


Fig. 2. Monthly mean variation of encounter rate obtained under standardised conditions (1980–2002) for the main species of cetaceans observed in the south of the Bay of Biscay. a: common dolphin (*Delphinus delphis*), b: long finned pilot whale (*Globicephala melas*) and c: bottlenose dolphin (*Tursiops truncatus*). Encounter rate at sea is expressed as the mean number of individuals (group for common dolphin) detected under standardised conditions per hour. Stranding was expressed as the mean number of individuals stranded per month. Vertical bars represent standard errors. d: Monthly average variation of tonnage landings for the fishing net and pelagic trawl fisheries in the south of the Bay of Biscay (ICES zones 15 E8, 16 E8 and 17 E8) from 2000 to 2003. Verticals bars represent standard errors.

observed in February for common dolphin and in April for bottlenose dolphin and long-finned pilot whale. Fishing net and pelagic trawl fisheries that can affect cetacean populations by incidental catches also showed a strong seasonality (Fig. 2d). The fishing index was maximal by the end of winter and the beginning of spring with a

peak in March corresponding roughly to the maximum of abundance of studied cetaceans in the study area.

Overall, a good visual agreement between at-sea encounter rate and stranding is obvious, in particular for the common dolphin and the long-finned pilot whale (Fig. 2). However, differences appear in the timing of the maxima of at-sea encounter rate and stranding. It is also notable that the relatively high at-sea encounter rate observed for the common dolphin during summer does not appear in stranding. Indeed, the three monitored phenomena (at-sea encounter rate, stranding and fishing index) showed the same temporal pattern, peaking from February to April.

Correlation analysis illustrates different relationships among the species (Table 1). A significant correlation ($p=0.0419$) exists between the at-sea encounter rate and stranding of the common dolphin. A strong correlation also exists between the “fishing index” and the two variables “stranding” and “at-sea encounter rate” ($p=0.0443$ and $p=0.0450$ respectively). No correlation was recognised between the interaction of “fishing index/at-sea encounter rate” and stranding patterns ($p=0.6405$).

In the case of the long-finned pilot whale, the different variables are not correlated. Even if the apparent lag of a month between maximum at-sea encounter rate and maximum stranding rate disappears with an artificial shift, there is no significant correlation between at-sea encounter rate and the strandings for this species ($p=0.069$). Despite the relative lack of data on the bottlenose dolphin, a strong correlation appeared between stranding and fishing index (Kendall test, $p=0.0291$). Stranding and interaction “at-sea encounter rate/fishing index” were found to be not significant ($p=0.6130$).

3.2. Annual pattern and relationships between cetacean at-sea encounter rate and at beach from stranding: an analysis at the long-term scale

Despite some inter-annual variation in at-sea encounter rate of the studied species (Fig. 3), on a long-term basis (1980–2002), there was a significant increase of abundance for each of them in the area under survey during the study period (Kendall test – *D. delphis*: $p<0.001$; *G. melas*: $p=0.004$; *T. truncatus*: $p=0.009$). This increasing trend is also seen in the number of stranded animals for the common dolphin and the bottlenose dolphin (Kendall test – *D. delphis*: $p=0.023$; *T. truncatus*: $p=0.029$). By contrast, there is no significant trend in stranding frequency for the long-finned pilot whale in the area under survey during the study period ($p=0.177$).

Table 1

Relations between monthly encounter rate at sea, strandings, fishing index and interaction (expressed herein as the product between fishing index and abundance at sea) in the south of the Bay of Biscay (see text). Correlation analysis is performed using Kendall test. Bold values significance level $p<0.05$.

		Strandings	Encounter	Fishing	Interaction
			at sea	index	
Common dolphin (<i>Delphinus delphis</i>)	Encounter at sea	0.4644			
	Fishing index	$p=0.0419$	– 0.4954		
	Interaction	$p=0.0443$	$p=0.0450$		
		– 0.1325	$p=0.6405$		
Long finned pilot whale (<i>Globicephala melas</i>)	Encounter at sea	0.2857			
	Fishing index	$p=0.2092$	0.2696		
	Interaction	$p=0.2564$	$p=0.3166$		
		– 0.1956	$p=0.5275$		
Bottlenose dolphin (<i>Tursiops truncatus</i>)	Encounter at sea	– 0.0751			
	Fishing index	$p=0.7564$	0.0001		
	Interaction	$p=0.0291$	$p>0.9999$		
		– 0.1491	$p=0.6130$		

Abundance of stranded individuals was strongly correlated to at-sea encounter rate of living animals, for all species (p ranging from 0.013 to 0.044 according to species; Table 2). It was highly correlated in the case of the long-finned pilot whale ($p=0.013$). Temporal variation in the I_M index for the common dolphin and the long-finned pilot whale (Fig. 4) showed no significant trend (Kendall test, $p=0.096$, $p=0.761$ respectively).

Beyond this overall long-term relative stability of I_M index (Fig. 4), outliers in I_M ratio were observed in some years: in 1983 for the long-finned pilot whale and in 1991, 1999 and 2000 for the common dolphin (Dixon test; $p<0.01$). Variation of the I_M index for the bottlenose dolphin was not calculated because this species was observed regularly in the area (both at-sea living individuals and stranded ones) for only a couple of years (Fig. 3).

4. Discussion

In the study area, the temporal patterns in cetacean at-sea encounter rate, number of stranded individuals and fishing activities (at least those impacting sea mammals) are similar and characterised by maximum values occurring in late winter/early spring. Given their superimposition, disentangling the relationship of these three elements may be difficult. For example, the short stranding period of common dolphin (occurring mainly in February during the course of the study) can be explained by an increased presence in seat sea of individuals of this species. Fishing activity is correlated with strandings suggesting a possible impact on this species. However, recurring observations of large numbers of individuals of this species in seat sea during summer time (from July to October) are not translated into strandings. By contrast, this period is the one during which the lowest number of beached individuals is recorded. Interestingly, this summer period corresponds also to the lowest fishing activity generating by-catch. From this information, one could conclude that despite the fact that the maximum number of strandings occurs around February, coinciding with the peak in at-sea encounter rate, part of the stranding phenomena could be inferred to by-catches by pelagic trawl fisheries as indicated in surveys made in the northeast Atlantic (Morizur et al., 1999) and in the Spanish Galician waters (Lopez et al., 2003). In Europe, most of the by-catches by driftnets and trawls affect common dolphin (Couperus, 1997; Goujon et al., 1993; Morizur et al., 1999; Silvani et al., 1999; Tregenza and Collet, 1998). A large proportion of stranded individuals of this species also display scars resulting from fishing nets (Kuiken, 1994). Stomach content analysis reveal that the diet of common dolphin is mainly mackerel, sardine and anchovy, all of which are important commercial target species of pelagic trawl fisheries (Meynier et al., 2008). Furthermore, cetaceans are often seen foraging close to nets, which is a behaviour prone to increase accidental catches (Fertl and Leatherwood, 1997; Lopez et al., 2002; Luque et al., 2006; Morizur et al., 1999). In the study area, the main fish species caught by gillnets fleets are sole, meagre and hake whereas mackerel, seabass, pilchard, anchovy, hake and tuna are most often taken by pelagic trawlers (Fossecave and Bigot, 2005; Léauté and Caill-Milly, 2003). Many of these fishes, especially mackerel, pilchard and anchovy are common preys for common dolphins.

By contrast, the significant correlation between stranding for the bottlenose dolphin and fishing intensity must be viewed with caution, given the small sample size. Bottlenose dolphin were absent from the study area in the past and have only become a regular and common dweller since 1990 (Fig. 4). While more observations are required to confirm the suspected link, this species is considered as frequent victim of by-catch in Galician waters (Lopez et al., 2003) as is the common dolphin.

The maximum value for at-sea encounter rate of long-finned pilot whale corresponds to the maximum of fishing activity in the area but without significant correlation between those two variables. The long-finned pilot whale is a teutophagous species and the peak in

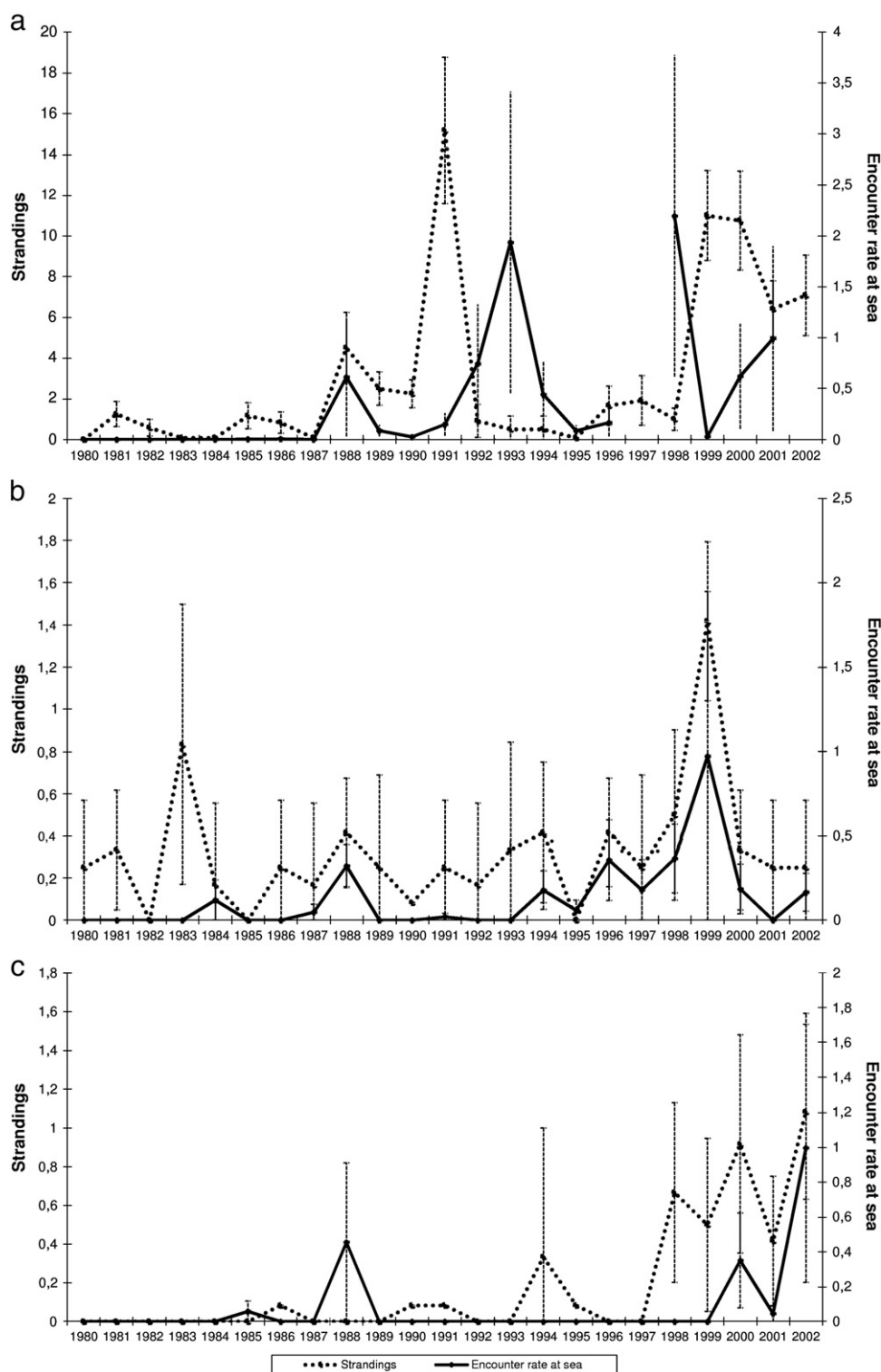


Fig. 3. Mean variation of cetacean encounter rate at sea and stranding in the south of the Bay of Biscay (1980–2002). a: common dolphin (*Delphinus delphis*), b: long finned pilot whale (*Globicephala melas*) and c: bottlenose dolphin (*Tursiops truncatus*). Encounter rate at sea is expressed as the mean number of individuals detected under standardised conditions per nautical mile. Stranding is expressed as the mean number of individuals stranded per month for each year. Vertical bars represent standard errors. NB: data available in 1997 for the bottlenose dolphin are too scarce to allow for accurate calculation of abundance.

its abundance is largely connected to the availability and abundance of its prey, mainly squids and common cuttlefish themselves target species of fisheries. The large abundance of squid during winter in the study area is explained by the local conditions in the deep and narrow canyon of “Gouf de Capbreton”. Stranding in long-finned

pilot whale is not correlated to fishing activity, which is coherent with the absence of by-catches (Couperus, 1997; Morizur et al., 1999). There is less direct evidence, for example scars, of by-catches as opposed to what is observed in the common dolphin (Kirkwood et al., 1997; van Canneyt et al., 1999).

Table 2

Relations between encounter rate at sea and strandings from 1980 to 2002 in the south of the Bay of Biscay. Correlation between bottlenose dolphin encounter rate at sea and stranding is done for the period 1990 to 2002 (see text). Correlation analysis is performed using Kendall test.

		Strandings
Common dolphin (<i>Delphinus delphis</i>)	Encounter at sea	0.32755 $p = 0.0437$
Long finned pilot whale (<i>Globicephala melas</i>)	Encounter at sea	0.41685 $p = 0.0127$
Bottlenose dolphin (<i>Tursiops truncatus</i>)	Encounter at sea	0.60774 $p = 0.0135$

4.1. A long-term perspective: a place for global change

During the course of the study, from 1980 to 2002, in the South Bay of Biscay, cetacean encounter rate has been increasing in all species, with the long-finned pilot whale displaying the smallest increase. The same trend is observed in the stranding phenomenon: the number of stranded cetaceans has increased during the 20-year period.

Global change in oceano-climatic conditions is one of the proposed explanations for the long-term observed change in cetacean community structure and abundance. This has been demonstrated in different parts of the world (MacLeod et al., 2005). The situation in the Bay of Biscay is no exception, as described by Hémerly et al. (2008). Changes in the abundance of many fish species, seabirds and sea-mammals are proven to be strongly related to changes in oceano-climatic conditions as it is depicted by the MOCI index (Multivariate Oceano-Climatic Index; Hémerly et al., 2008). This is particularly true for the common dolphin, a species with strong affinity with warm temperate waters. While their abundance is rising in the south Bay of Biscay, it is decreasing locally in other places such as the Mediterranean (Bearzi et al., 2003). Not surprisingly these changes in community structure

are a consequence of drastic changes in the marine environment. The Bay of Biscay is of particular concern as this zone encompasses biogeographic boundaries of a large number of species of commercial value (Quéro et al., 1989). The statements expressed should be moderated in the sense that they do not necessarily take into account subtle spatial processes that might contribute to determining their long-term variation of occurrence, for example if one considers how animals dwelling in this area during winter and early spring experience other forces in other areas the rest of the year.

The observed changes have direct implications for the stranding phenomenon. The number of stranded cetaceans is significantly correlated to the at-sea encounter rate of the species. We suggest that an increase in stranding is a result of the increase in the at-sea abundance. The stability of the ratio between stranded animals and living animals seen at sea (the I_M index – Fig. 4) may be seen as a further evidence. However, a more detailed look at the trends for the common dolphin in 1991, 1999 and 2000 suggests “over-mortality” (see definition above), highlighting thus the phenomenon of by-catches. Indeed, the proportion of stranded dolphins showing evidence of by-catch is high for those years; for example, during 1999, it represented 40.7%, 41.7% and 20.8% of the common dolphin, bottlenose dolphin and long-finned pilot whale respectively (Davoust, 2000; van Canneyt et al., 1999).

To summarise, by simply establishing the nature of the connexion between stranding observations and at-sea data, our study is unique in its attempt to depict the fact that the stranding patterns of cetaceans on the study area are a consequence of the abundance of living animals in the coastal waters. Consequently, either deep-sea populations do not contribute very much to the sub-population of stranded animals or they do contribute with the same seasonal and inter-annual patterns as those of individuals living near the coast (this could be the case for the bottlenose dolphin).

5. Conclusion

In this study we investigated the relationship between at-sea encounter rate of cetaceans and stranding events. A simple cross-comparison for 3 cetacean species common in the south Bay of Biscay was used. This original approach, despite its apparent simplicity, shows temporal patterns and indicates strong correlations. It describes the hidden linkage within the population dynamic components for these species. Our study doesn't preclude further investigation of this linkage and works to assess the possible interplay of other processes (e.g. chronic pollution, incidental catches, diseases outbreaks...). Beyond the simplicity of the answer (“the more dolphins in coastal waters, the more observed stranded individuals on beaches”) our results question the importance of the choice of the methodology to be used. We show that seasonal patterns of at-sea encounter rate, patterns of strandings and seasonal timing of fisheries activity (especially those ones that generate incidental by-catches) are extremely similar. By contrast, their inter-annual variations appear to be more subtle to decipher. Interestingly, pelagic pair-trawl fishery has increased notably in the late 80s and early 90s – a period corresponding to the middle of the studied time series – and thus this is a possible confounding factor. We argue however that, in the south Bay of Biscay, the observed increase in stranded numbers over the 22-years long study period is better explained by an increase in at-sea encounter rate of cetacean species rather than an increase in at-sea mortality (which could be the direct consequence of changes in deep layer of the oceans). As emphasised above, it is further indicated by the absence of variation in the Index I_M .

Of course, true comparison between dynamics of living animals and actual mortality is still the most accurate and precise way to measure any over-mortality, in particular the part that could be due to incidental fisheries by-catches.

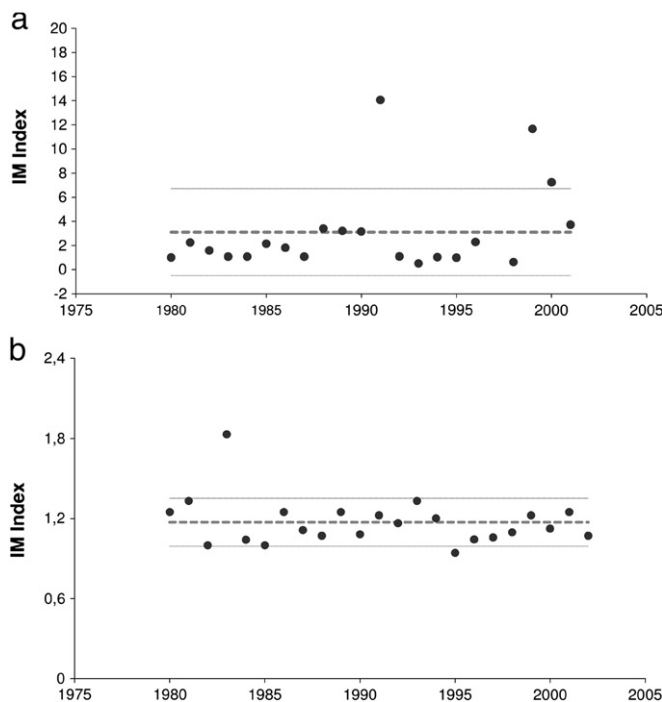


Fig. 4. Temporal variations of the I_M index (i.e. proportion between stranded cetaceans and abundance at sea between 1980 and 2002; see text). Dotted line represents the index mean, horizontal lines stand for standard-errors. a (upper): common dolphin (*Delphinus delphis*) and b (down): long finned pilot whale (*Globicephala melas*).

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