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Can modelling the drift of bycaught dolphin stranded carcasses help estimate total by-catch and identify involved fisheries? A feasibility study

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1. INTRODUCTION

The catch of non-target or non-commercial species in fishing gear, or bycatch, affects most marine species (Davies et al., 2009; Hall, 1996; Hall et al., 2000; Lewison et al., 2004; Peckham et al., 2008; Read, 2008; Reeves et al., 2013; Soykan et al., 2008; Thompson et al., 2013). The impact of bycatch on marine mega-vertebrates can be direct, such as additional mortality at unsustainable levels for populations, or indirect including depletion of prey, habitat destruction, disturbance of physical and chemical processes (Hall et al., 2000; Kumar and Deepthi, 2006; Read, 2008). Bycatch is a potent threat for long-lived species with slow population growth rates, low fecundity or low survival to adulthood such as seabirds, sharks, sea turtles and marine mammals (hereafter defined as mega-vertebrates) (Cox et al., 2007; Hall et al., 2000; Lewison et al., 2004; Mannocci et al., 2012; Peckham et al., 2008; Read, 2008; Soykan et al., 2008). Uncertainties around the true magnitude of bycatch delays management decision-making and their reduction is therefore a challenge for the effective conservation of mega-vertebrate populations (Lewison et al., 2004; Thompson et al., 2013). Recent studies on the effects of interactions between fisheries and mega-vertebrate demography or population genetics revealed pessimistic conservation scenarios (Mannocci et al., 2012; Mendez et al., 2010). In fact, most fishing gear, such as pelagic or bottom trawl nets, bottom-set gillnets or longlines, contribute to this worldwide threat to large marine vertebrates (Adimey et al., 2014; Davies et al., 2009; Gilman et al., 2005; Lewison et al., 2004; Lewison and Crowder, 2003; Read et al., 2006). Bycatch has been identified as a conservation issue since the 1970s; although it is probably one of the most important man-induced threats to marine mega-vertebrates, it still remains largely unresolved (Breen et al., 2017; Cox et al., 2007; Cruz et al., 2018; Davies et al., 2009; Hall et al., 2000; Hamel et al., 2009; Peckham et al., 2008; Read et al., 2006).

Bycatch issues have long been ignored or under-documented, mostly because the process remains barely visible as it takes place far from ports and fish markets (Hall et al., 2000). Fisheries management has focused for decades on commercial species only. Historically, rising awareness of the detrimental effects of bycatch on species persistence and ecosystems functioning has occurred through charismatic species (marine mammals, sea turtles, etc.). Because bycatch occurs far from the public eye and affects species for which public concerns can quickly become salient, obtaining reliable estimates of its magnitude at a population scale is a difficult endeavour (Read, 2008).

The conventional method to estimate the number of by-caught mega-vertebrates in a fishery is based on the use of on-board observers allowing a fraction of the fishing effort to be sampled (Amandè et al., 2012). This approach has been considered successful in a number of cases (Beerkircher et al., 2002). When vessels are too small to accommodate an additional crew member, this approach can be replaced by port surveys that sometimes produce by-catch estimates or else rapid by-catch assessment (Moore et al., 2010; Poonian et al., 2008). Even when the fleet is composed of vessels that are large enough to accept observers, a variety of processes can prevent the deployment of observers as designed in the sampling scheme precluding any extrapolation to the fleet (Benoît and Allard, 2009). In the case of the common dolphin in eastern North Atlantic, the ICES working group on by-catch in fisheries (WGBYC) recently concluded that despite more than a decade of monitoring in several EU countries it was impossible to conduct a by-catch risk assessment on this species (ICES, 2017a).

Stranding records are an important source of information on marine mega-vertebrates, and can provide critical information to estimate a minimum level of bycatch across fisheries (Adimey et al., 2014; Leeney et al., 2008; Lopez et al., 2003; Silva and Sequeira, 2003). Because of a lack of control over the stranding process, strandings have long been underused as a source of quantitative indicators (Wiese and Elmslie, 2006). However, through the understanding of the small cetacean carcass drifting and stranding processes (eq. 1), the relationships between stranding records and cetacean relative abundance and mortality can be elucidated (Peltier et al., 2014):

$$N_{stranding} = f(\,Abundance, mortality, buoyancy, drift, discovery) \text{ (eq. 1)}$$

where $N_{stranding}$ is the observed number of stranded dead cetaceans; $Abundance$ is the total population size, $mortality$ is the mortality rate (including both natural and anthropogenic sources); $buoyancy$ is the probability of a dead animal to float; $drift$ is the probability of a floating dead animal to drift to a coast and get stranded; and $discovery$ is the probability of a stranded carcass to be discovered and reported.

Recent studies have aimed at improving the representativeness of strandings, by accounting for drift conditions and observation pressure (Authier et al., 2014; Epperly et al., 1996; Hart et al., 2006; Koch et al., 2013; Peltier et al., 2016, 2012), and provided relevant indicators on mega-vertebrate populations. Hence stranding scheme can provide data on cetacean by-catch that are complementary to more conventional approaches, and in some circumstances observer programmes and stranding scheme data sets could ground-truth each other (IWC, 2016).

In the northeast Atlantic, the short-beaked common dolphin (*Delphinus delphis*) is one of the most abundant species (Certain et al., 2011; Hammond et al., 2013, 2002; Kiszka et al., 2007; Laran et al., 2017; McLeod et al., 2003; Murphy et al., 2013), yet also one of the most exposed to being bycaught in fisheries (De Boer et al., 2008; Fernández-Contreras et al., 2010; Kirkwood et al., 1997; Leeney et al., 2008; N. de Boer, 2012; Peltier et al., 2016; Silva and Sequeira, 2003). In the Bay of Biscay and the English Channel, common dolphin bycatch are mostly reported in pelagic fisheries targeting sea-bass (*Dicentrarchus labrax*) or albacore tuna (*Thunnus alalunga*), as shown by compulsory observer programmes conducted under EC 812/2004 (Morizur et al., 1999; Rogan and Mackey, 2007; Spitz et al., 2013). Very high level of bycaught common dolphins have previously been reported. Up to 2000 common dolphins dying in European fisheries per year were estimated by observer programs in the 90s and later again in 2009 (Murphy et al., 2013), whereas 3 650 (IC95% [2 250; 7 000]) common dolphins bycaught per year in the Bay of Biscay and Celtic Sea were estimated using stranding data and reverse drift modelling over the period 1990-2009 (Peltier et al., 2016).

The situation has not changed significantly since decades. Two recent unusual multiple stranding events totalling *c.* 700-800 common dolphins were recorded in February-March 2017 along the French Atlantic coast, and 65% of the necropsied animals were diagnosed as by-caught. They constituted a timely reminder of the importance of the by-catch issue for common dolphin in the eastern North Atlantic. The understanding of ecological relationship between dolphins and fishing activities is the central point for management and decision making process for bycatch reduction. Because of the difficulties in deploying the EU 812/2004 regulation that requires each Member State to design and implement a monitoring scheme for incidental catches of cetaceans (ICES, 2017a; Peltier et al., 2016), the use of additional datasets to improve the knowledge on the cetacean bycatch issue is highly encouraged.

The aim of this work is to test an approach that would be able to identify which fisheries could be involved in the observed unusual stranding events of January-March 2017. This is in line with ToR #3 of the expert group established to develop an independent review of the bycatch estimates derived from strandings in the Bay of Biscay (IWC/SC/67a, 2017). To do this we examined how the likely distributions of mortality of bycaught dolphins inferred from carcass drift modelling coincide with fishing effort statistics in the same area at the same dates for different fleets. The likely mortality areas at sea of common dolphins stranded with bycatch evidences were predicted using the reverse drift modelling methodology (Peltier et al., 2016; Peltier and Ridoux, 2015). The fishing effort data were generated from the Vessel Monitoring System, that automatically collects positional data of fishing vessels, along with other official sources of data to inform fishing gears and target species (Leblond et al., 2008). This study is a contribution of the working group established by the French Ministry in charge of the environment in April 2017, soon after the unusual stranding events had been reported. These two independent data sets were analysed under a General Additive Model framework and the whole exercise constitutes a novel approach to the understanding of cetacean-fishery interactions in the Bay of Biscay.

2. MATERIAL AND METHODS

2.1. The French Working Group on Cetacean bycatch

Following the unusual stranding events of February-March 2017, the French ministry in charge of the environment convened a meeting with the main actors of the cetacean-fisheries interaction network in order to identify and resolve the issue of common dolphin bycatch in the Bay of Biscay. This group gathered representatives from the Directory of marine fisheries and aquaculture (*Direction des Pêches Maritimes et de l'Aquaculture* – DPMA- from the Ministry in charge of fisheries), the Directory of water and biodiversity (*Direction de l'eau et de la Biodiversité* - DEB - Ministry in charge of the environment), the French Institute for marine research and exploitation (*Institut Français de Recherche et* *d'Exploitation de la Mer* - IFREMER,), representatives of the industry from the Committee for marine fisheries and fish farming (*Comité National des Pêches Maritimes et des Elevages Marins* - CNPMEM,), the French agency for biodiversity (*Agence Française pour la Biodiversité* - AFB), a regional grouping of professional fishermen (*Pêcheurs de Bretagne*) and *Observatoire Pélagis* (University of La Rochelle and CNRS). The terms of reference of this working group are (1) to improve knowledge of small cetacean by-catch in the Bay of Biscay, (2) to develop mitigation strategies to prevent by-catch, (3) to raise awareness among fishers on the by-catch issue. Since then, the working group met four times, was informed of the potential of stranding data and carcass drift modelling to help identify areas of mortality at sea, and decided to provide *Observatoire Pélagis* with all the necessary data set on fishing effort per gear type to test whether modelling drift of bycaught dolphin carcasses can help identify the fisheries involved.

2.2. The stranding scheme

The French stranding network (*Reseau National Echouage*, RNE) is coordinated by *Observatoire Pélagis*. Over 300 trained volunteers distributed along the whole French coast collect information on stranded marine mammals according to a standardized protocol (Kuiken and Hartmann, 1993). The observation pressure is supposed to be stable since the late 1980's. Data are now recorded in a MySQL database. Death in fishing gears was diagnosed following Kuiken, 1994. Main evidences were good nutritional conditions, evidence of recent feeding, jaw and rostrum fractures, froth in the airways, oedematous lungs and amputations. Bycatch was diagnosed only on fresh and putrefied carcasses (decomposition codes 1-3) from animals reported mostly from between the Gironde and Loire estuaries (fig 1).

2.3. The origin of observed strandings

The origin of stranded animals recorded during the unusual mortality events of February-March 2017 was determined following the methodology described in Peltier and Ridoux, 2015 and Peltier et al., 2016. The reverse trajectories of stranded examined animals diagnosed as bycaught were calculated from the stranding locations to the likely area of mortality at sea by using the drift prediction model

MOTHY, developed by MétéoFrance to predict the drift of floating object under the influence of tides and wind (Daniel et al., 2002). Carcass immersion was set at 90% in volume, following previous in situ and modelling experiments (see Peltier et al., 2012).

The death-to-stranding time was determined for each individual from visual criteria describing skin erosion (from Peltier et al., 2012). Animals categorized as "fresh" were considered to have < 5 days *post-mortem*, animals classified as "putrefied" had 5-15 days post-mortem. The drift back-calculation provided one location every 3 hours during 30 days. One location per day was retained for each days corresponding to the decomposition code of each individual, and weighted in order to obtain a total weight of 1 per animal drift. Then weighted fixes of dead animal drifts were summed in a 0.4° x 0.4° grid. Four sub-sets of data where defined according to the month of stranding and the decomposition status: February-fresh animals, February-putrefied animals, March-fresh animals, March-putrefied animals.

In order to smooth these grids, a "block averaging" method was used (Petitgas et al., 2014). This method allows averaging the data by block over the 0.4° x 0.4° grid, ranging from 43°N to 47°N, and from 1°W to 4°W. The value in the first block (block 0, origin = x_0) is the sum of the weighted locations encountered within its edges. Then the point origin (x_0) from block 0 was randomized in the lower left corner block 0 for 100 times. At each randomization k, the grid origin x_k varies and the sum of animals dying in each cell is calculated. Each block has then 100 sums associated with it. The mean of all 100 sums was then calculated and located at the centre of the block.

Analyses and cartography were performed using R software, version 3.4 (Ihaka and Gentleman, 1996) and bathymetric maps were plotted with the R library *marmap* (Pante and Simon-Bouhet, 2013).

2.4. Estimating total by-catch mortality at sea

Estimating mortality at sea is based on the general equation:

$N_{stranding} = f(\,Abundance, mortality, buoyancy, drift, discovery)$ (eq. 1)

The number of strandings recorded was thus corrected by different parameters from this equation. The discovery rate was set to 1, considering that the stable observation pressure since decades and the public and authorities awareness during these events allowed detecting and reporting all carcasses. Previous published work corrected spatially the stranding numbers by the probability of stranding in the area (Peltier et al., 2016, 2014; Peltier and Ridoux, 2015). As an approximation in the present work, we considered that storms occurring days and hours before the unusual stranding events would have brought ashore almost all drifting cetacean carcasses. Therefore, the probability of stranding was equally set to 1. Buoyancy rate of dead dolphins (that is the proportion of floating dolphins among all dead dolphins) was previously estimated in the North-East Atlantic at 17.9% [9.3%; 28.8%] (Peltier et al., 2016). Stranding numbers were therefore only corrected by buoyancy rate:

$$N_{dead\ at\ sea} = \frac{N_{stranding}}{Buoyancy}, \text{ where } N_{dead\ at\ sea} \sim Abundance, mortality$$

2.5 Fishing effort data

The fishing effort data were provided by Ifremer and the DPMA, as agreed by the working group on cetacean bycatch.

Since 2000's, all European fishing vessels over 12 meters must be equipped with a Vessel Monitoring System (VMS) transmitter that provides information about each vessel's position and activity. Data are gathered and archived by Ifremer, and is administered by DPMA.

The Fisheries Information System (http://sih.ifremer.fr/) of Ifremer covers all fisheries operating in French waters and aims at building an operational and multidisciplinary monitoring network, allowing a comprehensive view of fishery systems including their biological, technical and economical components. Available information includes VMS data, declarative landing statistics (log-books and sales provided by the ministry in charge of fishery) and Ifremer survey data.

Ifremer is in charge of converting raw VMS location data in fishing effort on the basis of vessel speed (Leblond et al., 2008). Raw data are collected at one-hour interval. In order to calculate the speed of fishing vessels, it is considered that the trajectory of the vessel between two successive points is rectilinear and the speed constant. These segments are then divided following a 3x3 minute grid. Mean speed is estimated from the time difference between each segment extremities. For each segment, the vessel is considered in transit if mean speed > 4.5 knots or if the segment is less than two nautical miles (NM) from a fishing harbour. The vessel is fishing if mean speed < 4.5 knots. The activity is unknown when speed = 0 or when the time interval between two locations exceeds six hours. The sum of fishing effort in hours is provided daily in a 3x3 minute grid, and the information can be split by fishing gear type, flag, vessel length and registration harbour. Finally, fishing effort during mortality events were aggregated in the same 0.4° x 0.4° grid used for aggregating carcass drift locations, and were split per fishing gear types, following the same previously described blocking procedure.

Fishing effort statistics preceding the two mortality events were considered at the same spatial scale, 44.2°N to 47.4°N and -0.8°W to -4°W.

Only trawls, nets and seines fishing gears were examined as longlines, pots or dredges are not suspected to generate small cetacean by-catch in the Bay of Biscay. Twelve fishing gears occurring in the Bay of Biscay were considered (Table 1).

2.6 Generalised Additive Models (GAMs)

Generalised Additive Models (GAMs) were used to explore the spatial consistency of the different fishing gears with the distribution of bycaught common dolphins at sea as obtained by carcass drift back-calculation. Number of bycaught dolphins and fishing effort in hours were $\log(1 + x)$ transformed.

In each cell of the study area, the number of bycaught dead dolphins was explained by the fishing effort of the different fisheries tested. The process of variable selection was not conducted because the aim of this work is rather to identify fisheries co-occurring with dolphin mortality rather than prioritize them.

Gaussian GAMs with an identity link were used to describe relationships between the different fishing gears and the mortality areas at sea of bycaught common dolphins. GAMs were performed using the *mgcv* library, version 1.8-23 (Wood S. N., 2011).

3. RESULTS

3.1. Stranding events

Winter storms Kurt, Leiv and Marcel (February 3rd, 4th and 5th, 2017) and then Zeus (March 6th) generated west winds of up to 150 $km.h^{-1}$. Following these meteorological phenomena, two strong stranding events were recorded along the Atlantic coasts. Between the 1st of February 2017 and the 31st of March, 793 cetaceans were found stranded along the French Atlantic coasts (between Finistere in Brittany and the Spanish border) (fig 1), including 642 common dolphins (81%)(fig 1). Two main events were recorded, from the 3rd to the 10th of February, and then from 28th of February to 14th of March. Among these strandings, 573 small cetaceans were recorded from 44.2°N to 47.4°N (fig 2); 84% of these cetaceans were common dolphins (n=483). Most of them were examined by trained volunteers of the French stranding network (89%, n=431). Two thirds of these examined common dolphins were fresh or putrefied (69% n=297), and among them 95% presented evidences of death in fishing gears (n=281).

3.2. The origin of stranded animals

The section aims at determining where the 281 carcasses showing evidence of by-catch come from. Drift trajectories were predicted during 30 days prior to stranding day for each individual. According to the decomposition status of the carcasses only locations corresponding to the death to stranding time (Table 2) were retained as likely mortality areas.

Prior to the early February event, all trajectories showed a large loop pattern (fig 3). During the last days before stranding, the trajectories were fairly straight with a general WSW to ENE orientation only altered by oscillations related to tidal currents. Before the early March stranding event, a smaller loop is found in late February, followed by a general W to E drift orientation in early March.

For carcasses classified as fresh only the stretch of trajectory from 0-5 days before stranding was considered, and one location per day was retained, weighted so that each individual drift has a total weight of 1and gridded. For carcasses classified as putrefied were processed similarly from day 5 to day15 of their trajectories.

The likely origins of stranded common dolphins were represented separately according to carcass decomposition status (fresh and putrefied) and February or March events (fig 4). During the February event, fresh carcasses mostly originated from coastal areas, between the Gironde and Loire estuaries. In contrast, mortality areas were mostly located along the continental slope of the Bay of Biscay for putrefied animals stranded in February. Common dolphins observed in March originated mostly from continental shelf too, putrefied dolphin mortality areas being more widespread over the continental shelf and slope and with lower densities than for the fresh carcasses.

3.3 Estimation of mortality at sea

The number of dead small cetaceans from the tip of Brittany to the Spanish border in February and March 2017 was estimated at 4 430 small cetaceans (IC95% [2 750; 8 530]), including 3 690 common dolphins (IC95% [2 230; 6 900]). Under the assumption that the proportion of bycaught dolphins determined for fresh and putrefied carcasses would apply to the total number, this would represent *c*. 3 500 bycaught common dolphins from January to March 2017.

3.4 Spatial co-occurrence of dolphin mortality and fishing effort

Generalised Additive Models results suggested that six fishing gears were significantly correlated with the distribution of dolphin by-catch mortality determined by carcass drift back-calculation (see section 3.2.). These fisheries included the French, German and Spanish otter bottom trawlers (OTB_FR, OTB_DEU, OTBESP respectively), the French otter twin trawlers (OTT_FR), the French midwater pair trawlers (PTM_FR) and the French Danish seiners (SDN_FR); all showed p-value < 0.05 (Table 3). Explained deviance reached 52.5%, and $r^2=0.49$.

The relationship between bycaught dolphins mortality map and fishing effort distribution during the four different stranding events was strongly positive for PTM_FR, OTB_ESP and SDN_FR, but negative for

OTB_FR, OTB_DEU and OTT_FR (fig. 5). Limited data were available for OTB_DEU, the relationship with mortality areas of bycaught dolphins must be considered with caution.

4. DISCUSSION

4.1 General

The unusual stranding events reported here correspond to daily figures of stranded common dolphin that are up to 30 times higher than average numbers recorded so far in the same area and season. The total number reported for three months is about twice to nine times greater than the yearly totals recorded during the last two decades (range 85-548; http://www.observatoire-pelagis.cnrs.fr/les-donnees/). However, such unusual stranding events, similar to the present one, albeit of lower intensity, have already been recorded. Since the late 1980's, similar events have been reported in 1989, 1991, 1997, 1999, 2000, 2002, 2008 and 2011. The criterion used to qualify an unusual stranding event was a minimum of 30 common dolphins recovered over 10 consecutive days along a maximum distance of 200 km in the Bay of Biscay (Peltier et al., 2014). It must also be noted here that by-catch mortality is not restricted to these events, as it was estimated that 30-50% of stranded common dolphins reported outside unusual events displayed by-catch marks.

Two areas of origin have been highlighted according to carcass decomposition condition, used here as a proxy of the time elapsed between death and stranding. The coastal area stretches approximately from the coast to off the 100 m isobaths. The offshore area is mostly located from the 100 m isobaths to the continental slope. These limits have to be considered with caution because the resolution of the grid is fairly coarse (0.4°x0.4°).

These events followed up the winter storms Kurt, Leiv, Marcel and Zeus that hit the French Atlantic coasts in early February and early March 2017. If they are not the cause of these stranding events, they probably made this fishery related mortality more visible in the stranding statistics.

During February and March 2017, the death of 4 430 small cetaceans (IC95% [2 750; 8 530]) was estimated. Most of them were common dolphins (81%). This event reached in two months the average annual common dolphin mortality related to fishing activities estimated between 1990 and 2009 (Peltier et al., 2016).

Mortality estimates are corrected by the proportion of buoyant animals, based on an *in situ* experiment (Peltier et al., 2016, 2012), which estimated the probability for a bycaught dolphin to float. This correction factor has a major effect on final estimates and could be further improved by increasing the number of experimentally released carcasses and by refining estimates of discovery rates along the French coasts.

The identification of by-caught stranded dolphins mortality areas allowed us to link spatially an impact indicator with maps of a set of candidate pressures. The analysis of VMS data provided relevant information on the co-occurrence of bycaught common dolphins and fishing effort in the French EEZ. The co-occurrence of bycaught dolphins and fishing effort of different fisheries do not suggest any causal relationship. This only suggest that both events occurred at the same time at the same location. Further investigation should be undertaken to identify the nature of the relationship between common dolphins and the fisheries that have been identified.

Among all considered fisheries, three were positively correlated with bycaught dolphin mortality areas: the French pelagic trawl fishery, the French Danish seine fishery, and the Spanish bottom trawl fishery. Three others were negatively correlated: the French otter twin trawl fishery and the French and German bottom trawl fisheries. The negative relationship can be explained by the spatial distribution of these fisheries in the Bay of Biscay during these events. Indeed, at the same period, these two fisheries were mostly operating in the middle of the continental shelf, while common dolphin mortality was both more inshore and offshore (Annex 1).

VMS data allowed the distribution of fishing effort to be considered in the analysis (Gerritsen and Lordan, 2011; Hintzen et al., 2012; Kroodsma et al., 2018) in order to identify fisheries with highest level of risks for cetaceans. However, the algorithms used to identify fishing effort in hour analysed similarly all fishing gears (trawls, seines, nets, longlines…). The interpretation of net fishing effort have to be carefully considered. Moreover some false-positive results (where vessels were travelling at fishing speeds, but were not actually engaged in fishing) can be detected, even if the probably represents low rate of records (Bertrand et al., 2008; Gerritsen and Lordan, 2011).

The automatic monitoring of fishing vessels was decided by the European Commission (EC) in 1997, and applied to all fishing vessels >24 m overall length in 2000 (Commission Regulation (EC), 1997), to all >18m fishing vessels in 2004 (Commission Regulation (EC), 2003), >15m in 2005 and >12m since 2010 (Commission Regulation (EC), 2009). Therefore, VMS data represent fishing effort by larger vessels, representing only 27% of French fishing fleet in 2016 (Fishery Information System/IFREMER-http://sih.ifremer.fr/). Small scale and artisanal fisheries have long been overlooked, although even recreational and subsistence fisheries can jeopardize marine mammal populations (Cruz et al., 2018; R.L. Lewison et al., 2004b; Mangel et al., 2010; Peckham et al., 2007; Zappes et al., 2013).

4.2 Co-occurrence of European fisheries and bycaught dolphins in the Bay of Biscay

The fishing effort in the Bay of Biscay (ICES areas VIII a,b et d) is one of the most intense in the world (Kroodsma et al., 2018), including a large variety of fishing gears and flags. During the studied periods (February-March 2017) alone, up to 19 fishing gears from 8 different countries were operating in the area. French vessels from the Bay of Biscay land over 200 species (Daurès et al., 2009). The diversity of fisheries operating in this area makes it difficult to interpret cetacean bycatch process as documented in stranding records.

Three groups of fisheries were identified co-occurring positively with bycaught common dolphins during winter 2017 in the Bay of Biscay: French pelagic pair trawlers (PTM_FR), French Danish seiners (SDN_FR), and Spanish otter bottom trawlers (OTB_ESP). PTM_FR and SDN_FR co-occurred with bycaught common dolphin mortality in shallow waters (50 to 100 meter isobaths) from the Gironde to the Loire estuaries. The co-occurrence of bycaught dolphins with OTB_ESP was mainly located along the continental slope of the Bay of Biscay (Annex 2).

The seabass *Dicentrarchus labrax* in the Bay of Biscay are mainly targeted by French vessels with more than 96% of international landings in 2016 (ICES, 2017b). The interaction between common dolphins and PTM_FR in the Bay of Biscay has already been documented. EU funded projects such as PETRACET (Pelagic TRAwl and CETaceans) and NECESSITY estimated annual fishing effort among the main French, Irish, UK, Danish and Dutch pelagic trawl fisheries in the Celtic Sea and Bay of Biscay (NECESSITY Report, 2008; Northridge et al., 2006). In the PETRACET project, most common dolphin bycatches were recorded in the French pelagic pair trawl fishery targeting sea bass (Morizur et al., 1999; Northridge et al., 2006). This fishery operate in winter when spawning fish aggregate (Fritsch et al., 2007; ICES, 2017b), mostly in coastal areas between the Loire and Gironde estuaries (Morizur et al., 1999). The interaction between common dolphins and pelagic trawlers is mainly driven by trophic relationships, as dolphins and sea bass target the same preys during the sea bass spawning season (Spitz et al., 2013). Most bycatches occurred during the night that could probably be related to the nychtemeral activity pattern of small pelagic fishes hunted by the two top predators (Morizur et al., 1999).

The hake *Merlucius merlucius* is the main demersal species supporting trawl fleets in the Bay of Biscay and off the Iberian peninsula. Recently, Spain was estimated to land around 60% of commercial hakes and France 30%. In the mid 90's, high levels of bycatch in French pelagic pair trawl fishery targeting hakes (*Merluccius merluccius*) have been reported (ASCOBANS, 2015; Murphy et al., 2013). Following an important drop of hake stock in NE Atlantic, landings were almost halved between mid 90's and early 2000's (www.fao.org). Since the mid-2010, hake stock recovery led to increased catches (www.fao.org), and allowed a diversification of target species for French pelagic pair trawlers in winter. The hake is now the first species in landings (in weight) recorded along the French Atlantic coasts (19% of total landed weight; Fishery Information System/IFREMER).

The Danish seine was first recorded in 2009 in French fishing fleet operating in the Bay of Biscay (Fishery information system/IFREMER-http://sih.ifremer.fr/, Leblond et al., 2008). Danish seiners are known to fish on demersal and pelagic species as well. Danish seines can be compared to pelagic trawls. Along the French Atlantic coasts, Danish seiners landed 9% of total sea bass weight, whereas pair trawlers landed 26% of seabass weight in 2017 (FranceAgriMer, 2018). In some harbours in 2017, Danish seiner landings were twice higher than trawler landings, suggesting that albeit fairly recently introduced in the area this gear developed rapidly in the Bay of Biscay. The main fishing grounds of Danish purse seiners in the Bay of Biscay is located between the Loire and Gironde estuaries, mostly between the 50- and 100-meter isobaths (Fishery information system/IFREMER-http://sih.ifremer.fr/, Annex 1). Depending on the vessel characteristics and target species, the vertical opening of the seine can reach several meters. The high vertical opening of Danish purse seines and their use to target seabass in winter suggest this new gear might have similar characteristics to pair trawls in terms of common dolphin bycatch.

Spanish fisheries are present in the Bay of Biscay and remain one of the most important European fishing industry. In the 2011/2012 fishing season, Spain landed 20% of the catch selling value in Europe against 11% for France (FranceAgriMer, 2014). The Spanish otter bottom trawl (OTB_ESP) fishery mainly operates along the continental slope of the Bay of Biscay. Bottom trawls are not generally considered to generate massive cetacean by-catch, in particular when fishing in deeper water close to the continental slope. Nevertheless the OTB gear category include several types of trawls, including High Vertical Opening (HVO) tawls towed by single vessels. This fishery increased in recent years in the Bay of Biscay (ICES, 2017b). Because the trawl operates in contact with the seabed, this gear is classified as OTB, but the high opening of the trawl would represent a risk of cetacean bycatch, mostly when targeting hake.

4.3 A co-operative approach to fisheries management and cetacean conservation

The present work is based on a joint analysis of two independently acquired data sets, cetacean stranding data and fishing effort from VMS data. This was only made possible by the collaborative spirit that developed within the newly created working group on cetacean by-catch initiated by the French Ministry in charge of the environment. This allowed us to test how dolphin mortality areas determined by calculating the drift of dolphin carcasses prior to stranding can help identifying candidate fisheries putatively involved in the interaction. To our knowledge, this is the first time that such an approach is attempted. The approach is promising because it provides a new way to study by-catch interactions.

Obviously, more developments and tests are needed before one can delineate fully the role that such an approach can have relative to more conventional methodologies, including on-board observer schemes. Nonetheless, this is a major step forward that allowed several fisheries to be identified for the implementation of more intensive monitoring programmes and precautionary mitigation actions. Beside the scientific aspects, this work stemmed from a by-catch working group constituted of all the main stakeholders involved in the Bay of Biscay by-catch issue at national level. It is a step toward a shared diagnosis of the situation, which is crucial to move toward acceptable mitigation decisions.

5. Conclusion

This work described one of the most intense stranding event ever recorded along the French Atlantic coasts. VMS data have been used to analyse the spatiotemporal correlation of fishing effort and likely mortality areas of stranded animals. Fisheries identified as having spatial and temporal correlation with these events corresponded to several gear types and target species. However, beyond this diversity of gears, two characteristics appeared to be shared: targeting predatory fishes in winter (sea bass and hake) and using high vertical opening gears.

In order to refine the understanding of these interactions with fisheries, and to identify more accurately some segments of the fleets, landed species related to fishing effort should be incorporated into the GAM analyses, in particular for the three fisheries that were shown to be positively correlated with bycaught cetaceans.

One must also keep in mind that the present work designed a proof of concept only dealt with a particular unusual mortality and stranding events observed in the winter 2017 and its conclusions cannot be generalised to other circumstances. In particular, it is expected that by-catches associated to the unusual stranding events that have been recorded in the Bay of Biscay from the late 1980's onwards would greatly differ in their mechanism to the background by-catches that are continuously revealed in the stranding records.

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Tables

Table 1: Abbreviations of fisheries analysed during the four stranding events.

Abbreviation	Fishery
GND_FR	French drift nets
GNS_FR	French set gillnets
GTR_FR	French trammel nets
OTB_FR	French otter trawls bottom
OTB_ESP	Spanish otter trawls bottom
OTB_DEU	German otter trawls bottom
OTT_FR	French otter twin trawls
PTB_FR	French pair trawls bottom
PTM_FR	French pair trawls midwater
SDN_FR	French Danish seines

Table 2: Dates of stranding, drift durations and likely dates of mortality events of common dolphins with bycatch evidences.

Event/Condition	Dates of stranding event	Drift duration (days)	Dates of mortality event	Common dolphin examined, fresh or putrefied with bycatch evidences (n)
February/ Fresh	03/02 to 10/02	[1 ; 5]	30/01 to 10/02	65
February/Putrefied	03/02 to 10/02	[6 ; 15]	20/01 to 05/02	100
March/Fresh	28/02 to 14/03	[1 ; 5]	24/02 to 14/03	53
March/Putrefied	28/02 to 14/03	[6 ; 15]	14/02 to 09/03	63

Table 3: GAM for 12 fishing gears operating in the Bay of Biscay in February and March 2017, as explanatory variables of bycaught common dolphins.

Predictor variables	P-value	Significance level
GND_FR	0.110028	
GNS_FR	0.139957	
GTR_FR	0.446066	
OTB_FR	0.007883	**
OTB_ESP	0.002572	**
OTB_DEU	0.000363	***
OTT_FR	0.042633	*
PTB_FR	0.507864	
PTM_FR	3.13e-06	***
SDN_FR	0.023992	*

Significance level (sig.) is given on the following scale: p-value < 0.001 = ‘***’, 0.001 < p-value < 0.01 = ‘**’, 0.01 < p-value < 0.05 = ‘*’, 0.05 < p-value < 0.1 = ‘.’, 0.1 < p-value < 1 = ‘ ’.

Figures:

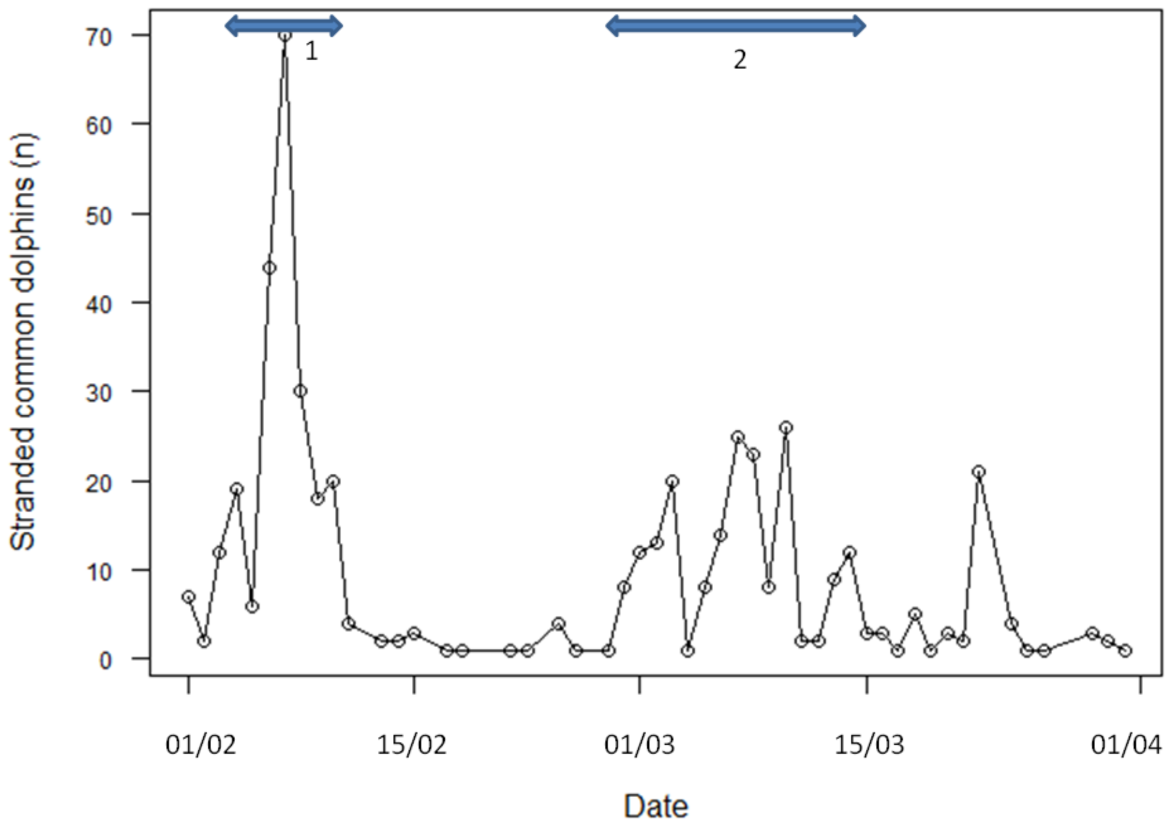


Figure 1: Time series of common dolphins found stranded along French Atlantic coasts, between Gironde and Loire Atlantique departments (n=483). Blue arrows highlighted the two most important stranding events (1=February event; 2=March event).

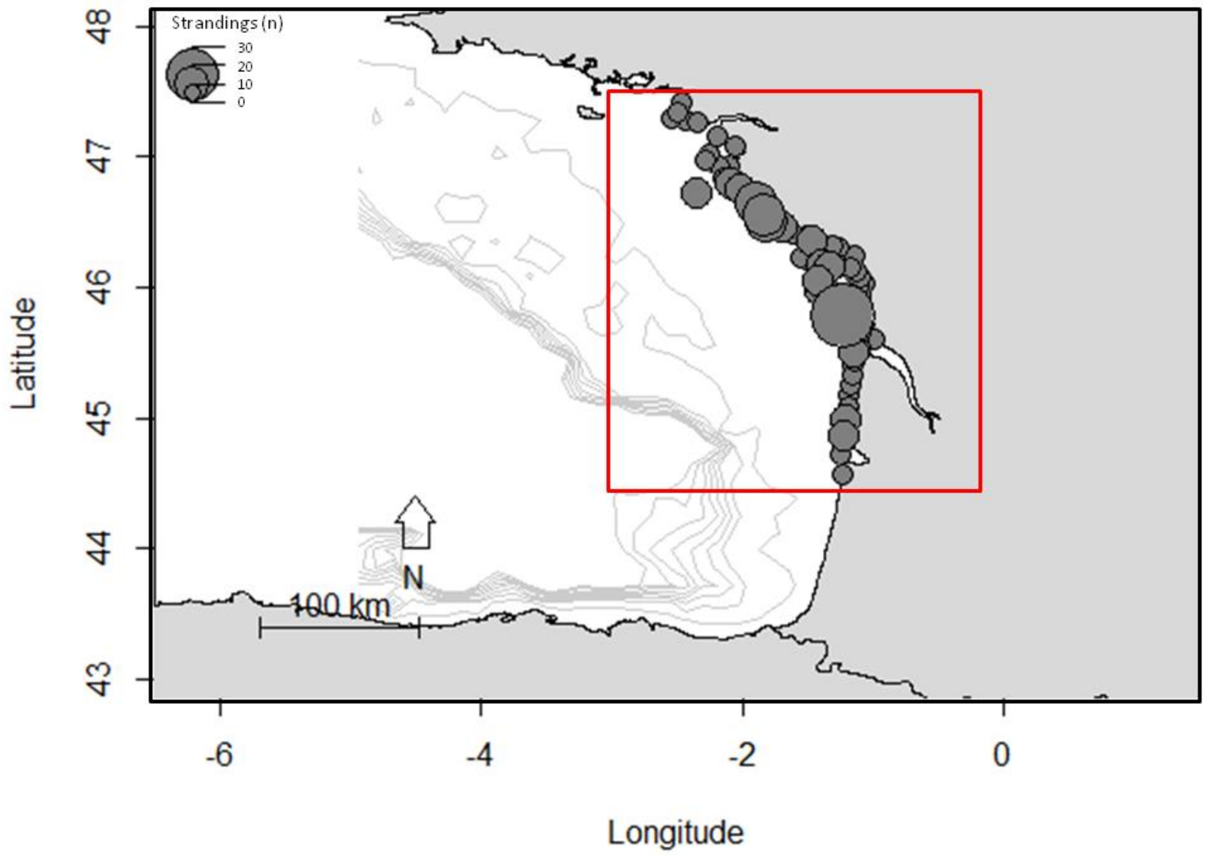


Figure 2: Stranding locations of small cetaceans found stranded between the 1st of February and 31st of March 2017 (n=483). The red box represents the study area.

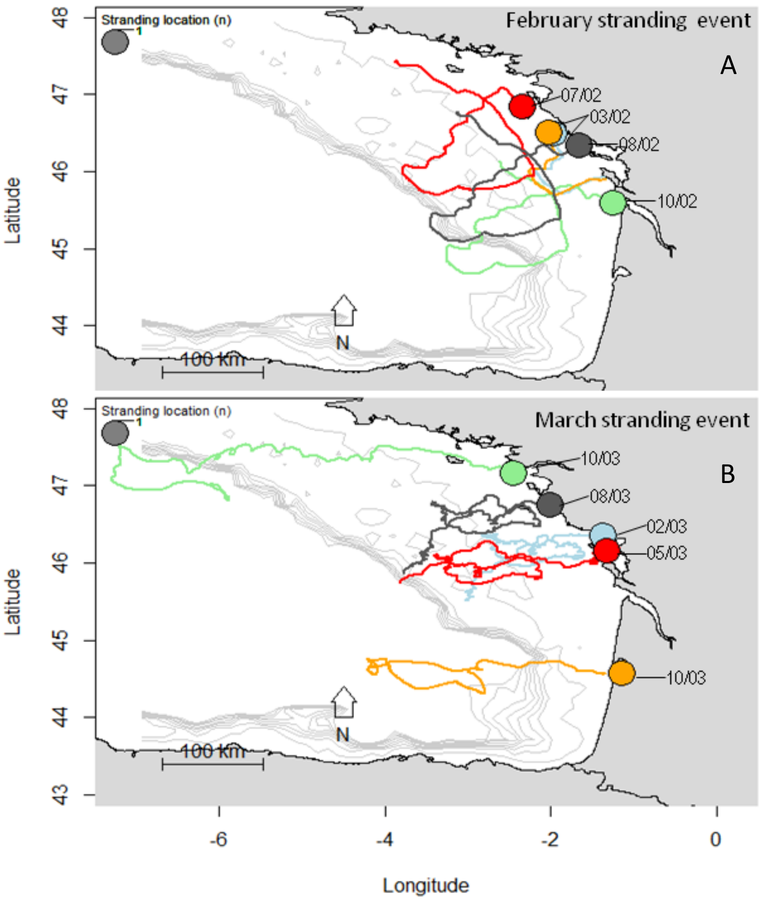


Figure 3: Examples of 30 day drift predictions of different common dolphins found stranded during February (A) and March (B) stranding events (n=10).

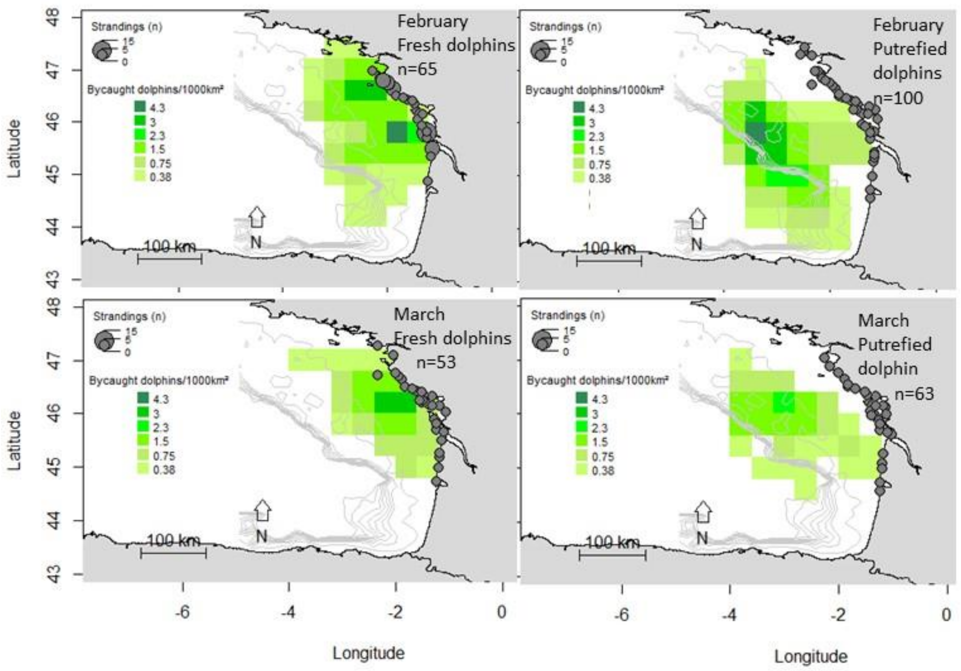


Figure 4: Mortality areas of common dolphins found stranded with bycatch evidences (fresh and putrefied), during February and March events.

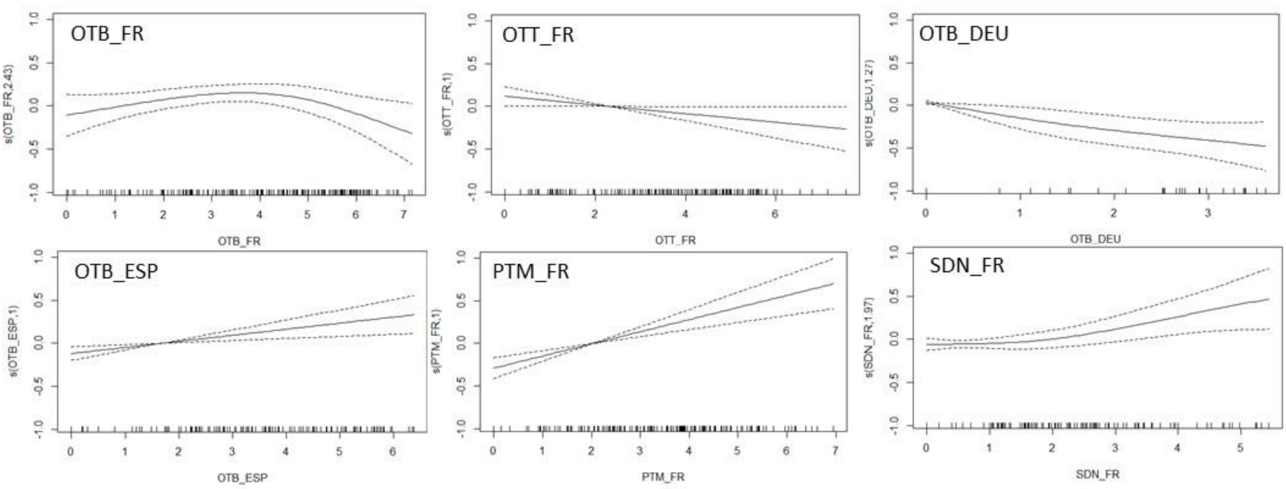
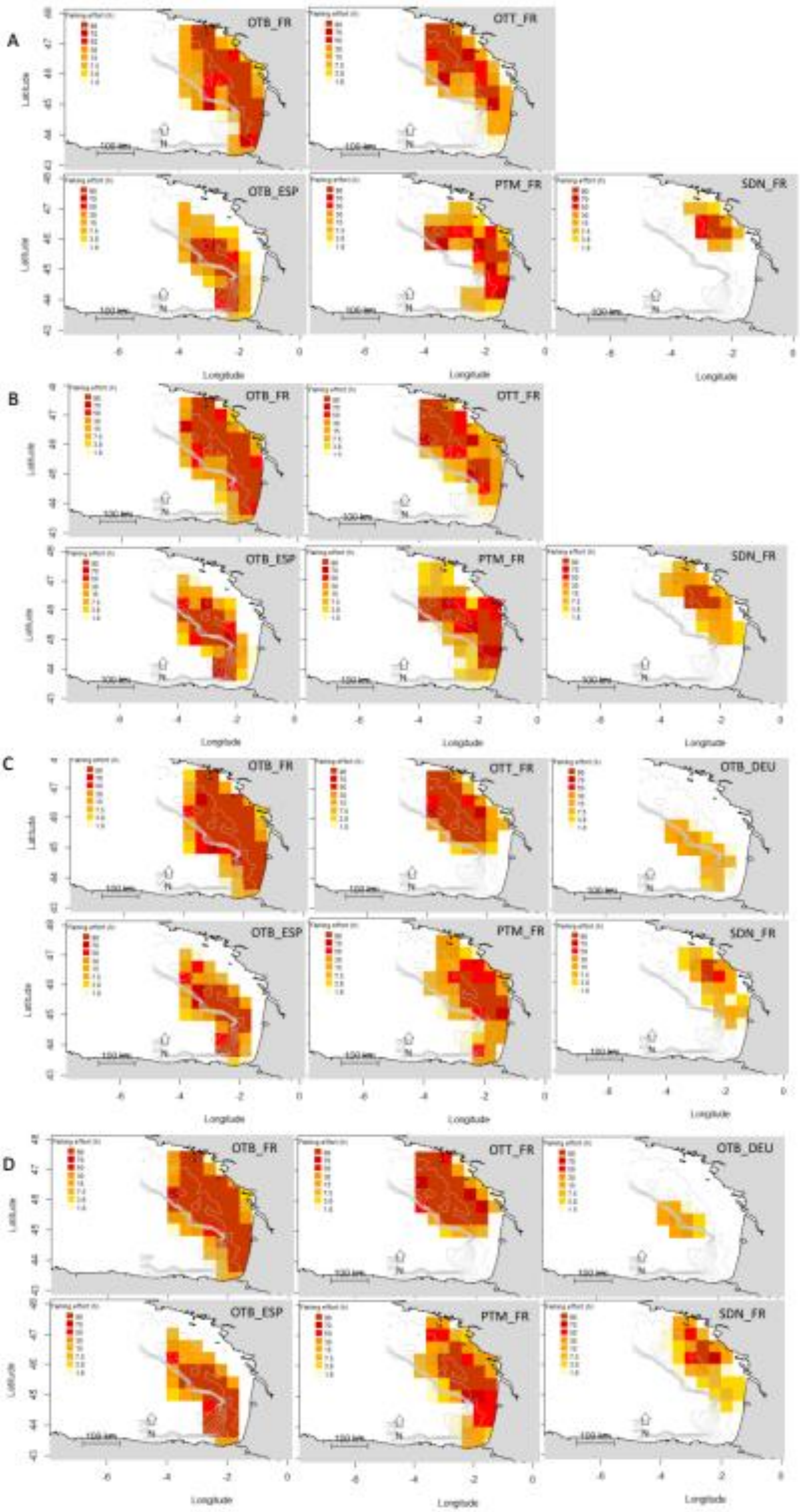


Figure 5: Functional relationships between bycaught common dolphins in the Bay of Biscay during winter 2017 stranding events and the six significantly correlated fisheries.

ANNEX

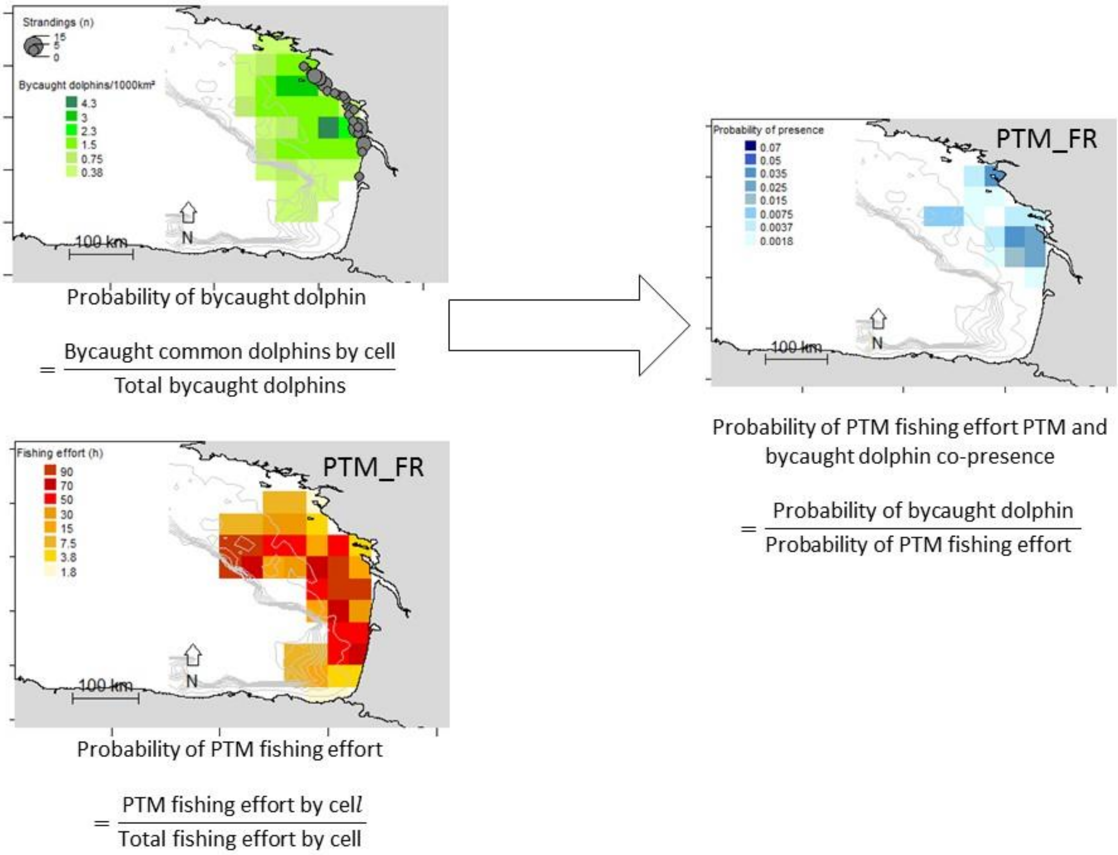
Annex 1: Fishing effort of the six significantly correlated fisheries during February mortality event of dolphins recovered fresh (A) and putrefied (B), and March mortality event of dolphins recovered fresh (C) and putrefied (D).

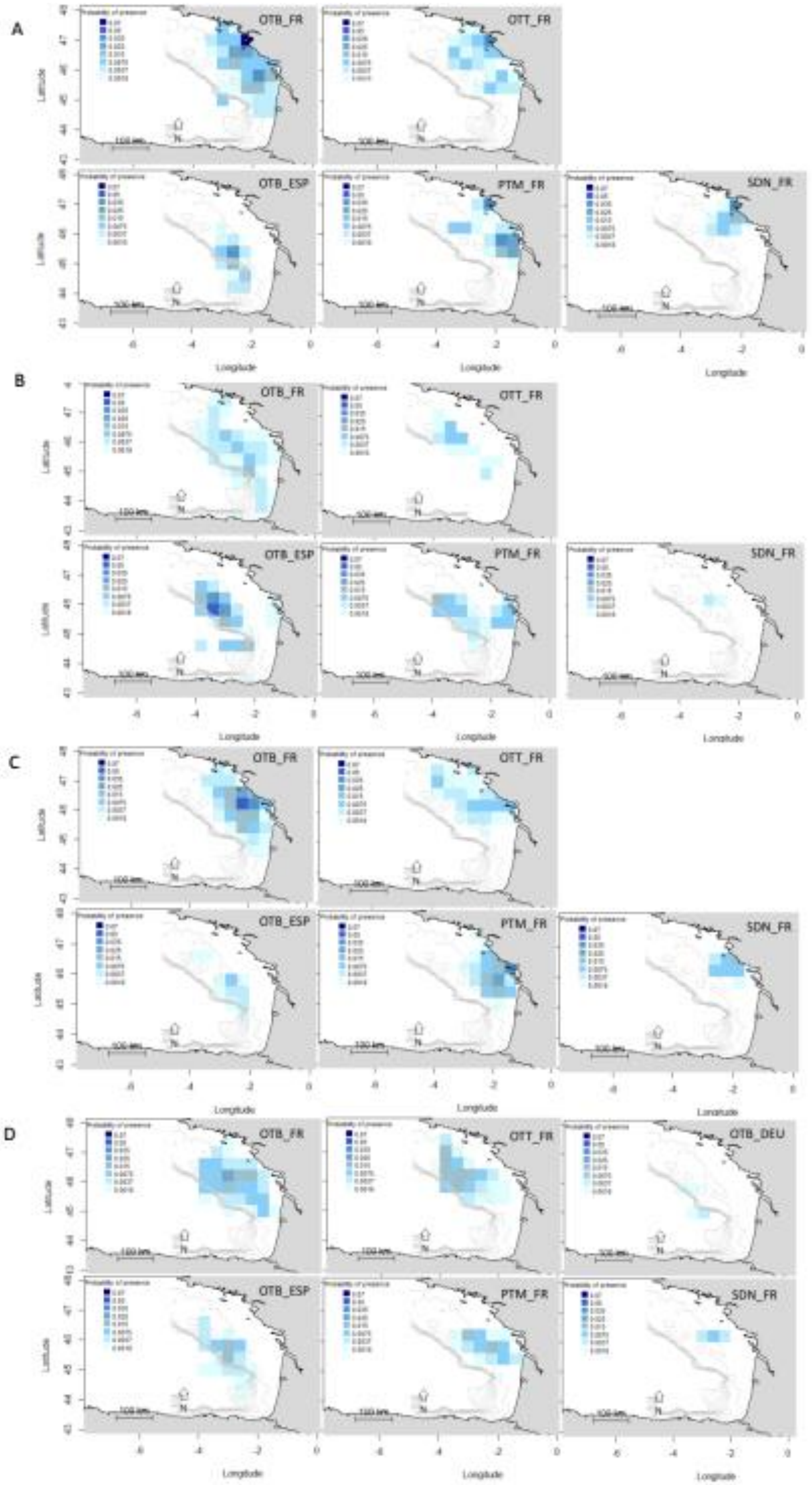


A
OTB_FR
OTT_FR
OTB_ESP
PTM_FR
SDN_FR
B
OTB_FR
OTT_FR
OTB_ESP
PTM_FR
SDN_FR
C
OTB_FR
OTT_FR
OTB_DEU
OTB_ESP
PTM_FR
SDN_FR
D
OTB_FR
OTT_FR
OTB_DEU
OTB_ESP
PTM_FR
SDN_FR
Latitude
Longitude

Annex 2: Co-occurrence between the mortality areas of bycaught common dolphins and fishing effort of the six significantly correlated fisheries during February mortality event of dolphins recovered fresh (A) and putrefied (B), and March mortality event of dolphins recovered fresh (C) and putrefied (D).

Construction of these maps:





A
B
C
D
OTB_FR
OTT_FR
OTB_ESP
PTM_FR
SDN_FR
OTB_DEU
Latitude
Longitude
Probability of presence