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From the sky and on the beaches: complementary tools to evaluate common dolphin bycatch in the Bay of Biscay

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ABSTRACT: Since 1989, multiple stranding events of common dolphins have been regularly recorded along the French Atlantic coast. Examination of the carcasses revealed that most animals presented evidence of bycatch. Using stranding data to infer bycatch levels reveals the highest levels of bycatch to have been recorded since 2016 (4000 to 9000 bycaught individuals). This approach is directly influenced by drift conditions, which can greatly contribute to or hinder our ability to estimate bycatch at sea. In the winter of 2021/2022, the French stranding network recorded an unusually high number of strandings until mid-February and few records in March. Investigation of drift conditions revealed low probability of stranding in March due to constant east—west winds. Reverse drift modelling of carcasses stranded in January and February resulted in an estimate of 3670 (95% CI [2750; 5170]) bycaught common dolphins. Dedicated aerial surveys were conducted in the same area during this period, designed to assess abundance and distribution of marine megafauna in French waters. A high number of carcasses of small Delphininae were observed in March 2021, and the number of carcasses floating at sea could be estimated using conventional distance sampling methodology. In March 2021, mortality at sea was thus estimated at 3250 (95% CI [1288;10198]) common dolphins. The complementary use of both methodologies resulted in an estimate of 6920 (95%CI [4038;15 368]) bycaught individuals during winter 2021/2022. This case study highlights that a decrease in strandings does not imply a decrease in mortality at sea. Trends in strandings need to be considered in the light of scientific evidence to avoid delays in decision making.

KEY WORDS: Bycatch · Common dolphins · Bay of Biscay · Strandings · Aerial survey · Conventional distance sampling

1. INTRODUCTION

One of the main keys to success in small cetacean conservation is early decision making (Slooten & Dawson 2021). Unfortunately, history has shown us that effective actions have always been taken too late if at all to save endangered populations of small cetaceans. The Yangtze River dolphin *Lipotes vexillifer* in eastern China was the first documented case of cetacean extinction resulting from unsustainable bycatch levels in the fisheries (Turvey et al. 2007). More recently, the 10 or so remaining vaquitas *Phocoena sinus* in the northern Gulf of California, Mexico, are likely to be the next cetacean species to go extinct (Jaramillo-Legorreta et

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al. 2019). Nearly a dozen species of small cetaceans with restricted ranges are listed as Critically Endangered or Endangered on the IUCN Red List, including all river dolphins and some coastal dolphins such as Hector's dolphin *Cephalorhynchus hectori* and the 2 humpback dolphins *Sousa teuszii* and *S. plumbea*. All these cases involve interactions with human activities, particularly fishing (Brownell et al. 2019), and a lack of adequate conservation persists despite ample scientific evidence of their decline.

While species with wider ranges may be less vulnerable to global extinction, many of them have populations or subspecies that are threatened with extinction. The Baltic Proper, the Black Sea and the Iberian populations of harbour porpoise *P. phocoena* are just 3 examples among many others of local populations of a broadly distributed small cetacean being pushed to the brink of extinction by unsustainable levels of bycatch.

In the waters of the northeast Atlantic, the common dolphin *Delphinus delphis* is the most abundant species. Its range extends from North Africa to Norwegian waters. The species is more common in the Atlantic part of its range than in the eastern part (such as the North Sea and the Baltic Sea) (Murphy et al. 2013, Hammond et al. 2017). Aerial surveys between Gibraltar and Norwegian waters estimated the abundance of the species at 634 286 (95% CI [352 227–1 142 213]) individuals (Hammond et al. 2021). In a zone covering the French waters of the continental shelf (including the Spanish Basque country and as far as English Cornwall) and part of the ocean waters and the French exclusive economic zone, the population was estimated at 181 620 individuals (95% CI [128 600–258 050]) during aerial surveys in the winter of 2021 (Laran et al. 2022). Genetic evidence tends to indicate that common dolphins of the northeast Atlantic form a single panmictic population that could be considered as a single management unit (Evans & Teilmann 2009). However, ecological tracers suggest the existence of separate coastal and oceanic populations on shorter time scales (Lahaye et al. 2005, Caurant et al. 2011).

Along the French Atlantic coasts, the first records of multiple stranding events related to fishing activities date back to 1989. Examination of the carcasses revealed that most of the common dolphins presented evidence of death in fishing gear. Since then, these multiple stranding events have been regularly recorded with varying intensity along the French coasts of the Bay of Biscay. From 2016 to the winter of 2023, common dolphin strandings had reached unprecedented levels (ICES 2023). The reverse drift modelling methodology enables bycatch to be estimated from strandings, by integrating the drift conditions before the stranding, the immersion rate of the carcass, and its probability of being buoyant (Peltier et al. 2016, ICES 2023). The highest bycatch levels were recorded in the Bay of Biscay and Western Channel beginning in 2016, ranging from 3900 (95% CI [2840; 5850]) to 9470 (95% CI [6890; 14 200]; ICES 2023) per year. In comparison, bycatch thresholds (estimated limit at which a species would be significantly impacted by bycatch) for common dolphins within their northeast Atlantic management unit was estimated by the Oslo and Paris Conventions (OSPAR) to be 985 ind. yr^{-1} (Taylor et al. 2022, ICES 2023), and the potential biological removal (PBR) used as a bycatch threshold by the International Council for the Exploration of the Sea (ICES) was calculated to be 4926 ind. yr^{-1}. In all of the above examples, the accumulation of scientific evidence of unsustainable bycatch levels and subsequent population declines has never led to effective actions by governments and managers to reduce bycatch.

One way to strengthen the scientific evidence is to reduce the uncertainty in estimates of bycatch mortality. In the case of common dolphins in the northeast Atlantic, the use of stranding data as a monitoring tool has been developed and refined over time (Peltier et al. 2016, ICES 2023). Two key factors relate bycatch mortality to the number of stranded carcasses in the area: the proportion of buoyant carcasses (estimated by tagging experiments), and the probability that a buoyant carcass would drift towards the coast and get stranded. This factor is a function of the wind and tide that a floating carcass would experience in the weeks following death. This latter factor varies between and within years and contributes greatly to the variability in stranding numbers and, more importantly, to our ability to calculate bycatch mortality in offshore areas. During periods of predominantly westerly winds, most of the continental shelf and slope of the Bay of Biscay has a high stranding probability; conversely, during predominantly easterly wind periods large areas of the Bay of Biscay have a lower probability of stranding, reducing the ability to derive bycatch mortality from stranding data for the whole area of interest and therefore introducing a negative bias in the mortality estimate (Peltier et al. 2013).

From January to March 2021, the second SAMM survey (Suivi Aérien de la Megafaune Marine, Aerial Surveys for Marine Megafauna) was conducted in the Bay of Biscay and the English Channel. The aim of these aerial surveys is to assess the abundance and distribution of cetaceans, seabirds, and other species of marine megafauna under the Marine Strategy Framework Directive (MSFD). The large numbers of dolphin carcasses observed drifting during the aerial survey in March coincided with a period of very low levels of strandings recorded on the coast, while the opposite was true in January and February. It seems that unusual weather conditions during the winter of 2021 led to this stranding pattern and to the persistence of drifting carcasses during the month of March and therefore require particular investigation.

The aim of this work is to explore the potential temporal complementarity of the 2 monitoring strategies during the winter of 2021 to provide realistic and robust bycatch estimates; the objective is not to compare the 2 methods. The hypothesis put forward is that particular weather conditions prevent carcasses from stranding (easterly winds in the Bay of Biscay) and instead will drive them out to sea, where they will be detected in greater numbers during aerial surveys. Therefore, this work does not allow us to explore how to analyse the data from the 2 monitoring methods together but rather to explore how they complement each other during the winter.

The first step will be to examine drift conditions and probability of strandings in order to understand the specific patterns observed. Then bycatch estimates inferred from strandings will be provided, as well as those estimated using distance sampling on drifting carcasses detected during aerial surveys. Finally, the combination of both temporal estimates will be examined.

2. MATERIALS AND METHODS

2.1. Study area

The study area comprises the Bay of Biscay in the northeast Atlantic Ocean (Fig. 1). In the oceanic zone of the Bay of Biscay, the general current is weak and anticyclonic (Puillat et al. 2006). On the continental shelf, tidal currents are weakest south of 45° N (<15 cm s^{-1}), while they reach 30 cm s^{-1} north of the Bay of Biscay (Le Cann 1990). Overall, residual tidal

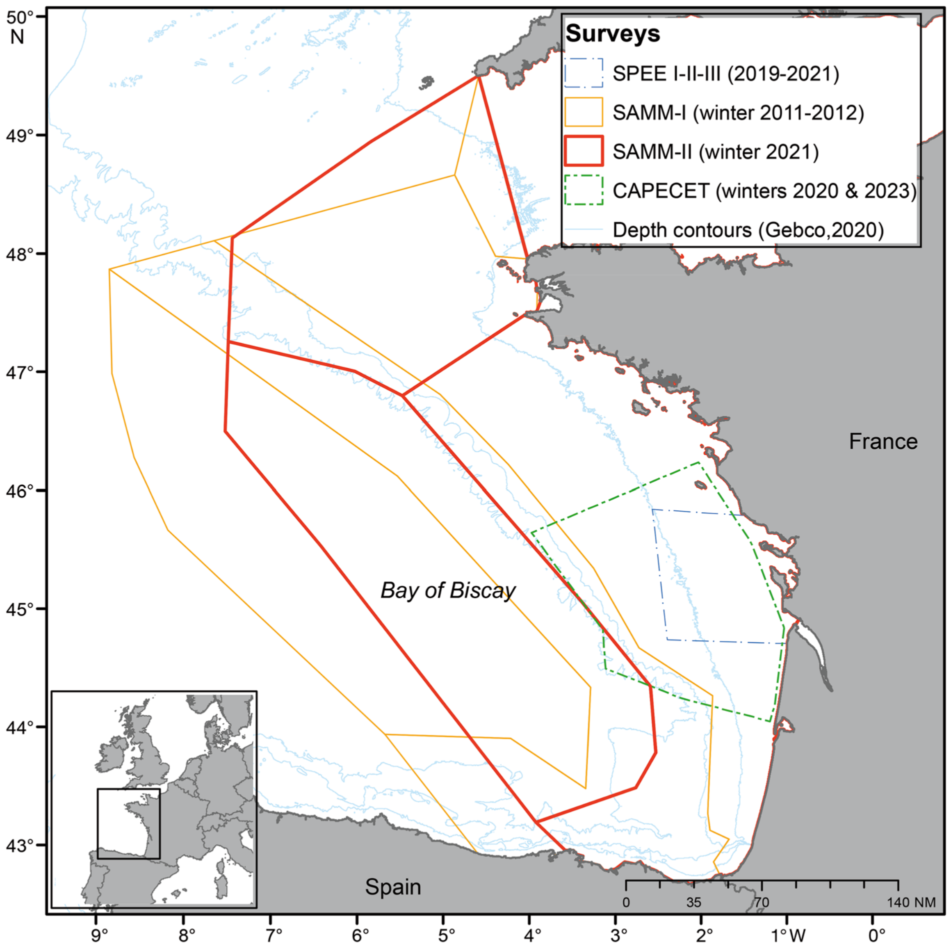

Fig. 1. Study area in the northeast Atlantic. Survey blocs of different aerial surveys investigating marine megafauna during which drifting carcasses of small cetaceans were observed and used to build the detection function. Depth contours: −100, −200, −2000 m; General Bathymetric Chart of the Oceans (GEBCO) 2020, https://www.gebco.net/

currents remain relatively weak on the continental shelf, and water mass circulation is mainly associated with wind-driven surface currents. Although the prevailing winds are predominantly westerly, they are generally north-westerly from late spring to autumn, and south-westerly from autumn to early spring (Le Cann & Pingree 1995).

2.2. Drift prediction model

The simulation of the drift of small cetaceans was carried out using the MOTHY drift model (Modèle Oceanique de Transport d'HYdrocarbures; Daniel et al. 2002). Initially developed to predict the trajectory of oil slicks, then in its 'object version' to predict the drift of containers for safety at sea, it was later adapted to model the drift of small cetaceans (Peltier et al. 2012). In the Bay of Biscay, wind and tidal currents are the main forces involved in the drift of surface objects (Daniel et al. 2003). Wind data were provided by the European Centre for Medium-range Weather Forecasts (ECMWF) at 6 h resolution and bathymetry by the French hydrographic and oceanographic service of the Navy (Service Hydrographique et Océanique de la Marine, SHOM). The model can be used either directly (from the death location to the potential stranding site), or in reverse (from the stranding site to the probable mortality area at sea) (Peltier et al. 2012).

The input parameters are the starting point of the drift (mortality area for direct drift or stranding location for reverse drift), the duration of the drift (estimated here from the decomposition status as described in Peltier et al. 2012, 2020b), the immersion rate (proportion of the carcass submerged) and the diameter of the carcass. The latter is estimated to be 32 cm for common dolphins (Peltier et al. 2012).

2.3. Drift conditions

The stranding probability is defined as the probability of a dead animal floating at sea to reach the coast given the wind and tide conditions encountered at the corresponding dates and locations (Peltier et al. 2013, 2014, Peltier & Ridoux 2015). A theoretical distribution of dead small cetaceans, uniform in time and space, was plotted on a 0.75° × 0.75° grid. The 25 d trajectory of a dead dolphin at the center of each grid cell was simulated forward each day (from the area of death at sea to the potential stranding site) to predict whether or not it would strand as a function of wind and tidal conditions. After this 25 d period, the dolphin is likely to be highly decomposed, and there is a high probability of dislocation. This time threshold is based on research conducted by Peltier et al. in 2012 on the decomposition of small cetaceans. If stranding was predicted, then the cell was assigned a value of 1, and 0 if no theoretical stranding was predicted. These values were averaged weekly in each cell for the months of January to March 2021 and then averaged monthly over the period 2016–2020 for comparison.

2.4. Collection of strandings

Only strandings recorded along the French coast were considered. The French stranding network has been operating along French coasts since the early 1980s and is coordinated by the Joint Service Unit Observatoire Pelagis. It consists of around 400 trained volunteers distributed along the French coast who collect data on stranded marine mammals using a standardized observation and dissection protocol (https://www.observatoire-pelagis.cnrs.fr/IMG/pdf/GuideEchouages2015.pdf). Only fresh or slightly decomposed animals with evidence of lethal interaction with fishing gears or those stranded during multiple stranding events were used for this analysis (Peltier et al. 2020b). Death in fishing gear is determined by a combination of several features of the carcass: good health state (good nutritional condition, evidence of recent feeding, in addition to exclusion of any other cause of death), contact with fishing gear (superficial skin lesions, cuts associated with traumatic evidence, jaw and rostrum fractures), hypoxia (persistent froth in the airways, oedematous lungs, emphysema) and/or disentanglement from the net (dorsal fin, pectoral fin or tail fluke amputations; see details in Kuiken 1994, Bernaldo de Quirós et al. 2018). All diagnoses are validated by the Observatoire Pelagis on the basis of collected data, examination reports and detailed photographs. It is assumed that all stranded animals are discovered and reported to the French stranding network.

2.5. Bycatch inferred from strandings

The full methodology is described in Peltier & Ridoux (2015) and Peltier et al. (2016). Using the drift prediction model MOTHY, the origin of stranded animals was estimated according to drift conditions (wind and tides) (Fig. 2). These origins were then corrected by stranding probabilities at weekly intervals to estimate the abundance of drifting bycaught common dolphins. Finally, a correction factor was applied to account for the proportion of animals that sink and float, called 'proportion of buoyant carcasses'. This was derived from information on bycaught dolphins tagged by fishermen since 2004 and is the ratio of tagged individuals that were predicted to strand by MOTHY to those actually recovered (Peltier et al. 2016). These experiments are implemented annually by fishermen on a voluntary basis, and the estimate of the proportion of buoyant carcasses is regularly updated as these new tagging data are validated and incorporated in the analysis. Between 2004 and 2020, 172 bycaught small cetaceans (common dolphins and harbor porpoises) were tagged by fishery observers or by fishermen themselves. Of these, 134 strandings were predicted by MOTHY, and only 28 were recovered. This experiment was carried out in the Bay of Biscay, on a geographical scale comparable to that covered by the present study.

An experiment involving daily monitoring of the buoyancy of a striped dolphin and a harbor porpoise showed that the kinetics of porpoises and small delphinids were comparable (Peltier et al. 2012). Based on these experiments, the most recent estimate of the proportion of buoyant carcasses used in the present study is 24% (95% CI [17–32]) following the methodology described in Peltier et al. 2016) (Peltier et al. 2020a).

2.6. Estimating dolphin carcass abundance by aerial survey

During the winter of 2021, the SAMM-II aerial surveys were conducted from mid-January to late March, following a standard line-transect methodology (Buckland et al. 2001) adapted for a multi-target protocol, recording all marine fauna visible at the surface (Lambert et al. 2019, Laran et al. 2023). Transects were flown at 90 knots (167 km h^{-1}) with a target altitude of 600 ft (183 m). Data were collected using the SAMMOA software (Pelagis LRUniv-CNRS & Code Lutin 2019), which provides an audio recording that can be used for post-survey validation. Seabird (including dead birds), jellyfish, ship and marine debris sightings were collected in strip transects but not considered in this study. For marine mammals (including dead animals), sea turtles or fishes (including elasmobranchs), the perpendicular distance was measured using clinometers. The aircraft stayed on the track line except when circle-back manoeuvres were engaged (stopping effort) to check identification, group size or collect digital photographs of specific marine mammal sightings. Irrespective of taxa, identification was made to the lowest taxonomic level whenever possible. A team of 14 professional observers were trained and involved in the SAMM II survey. Data were controlled and pre-

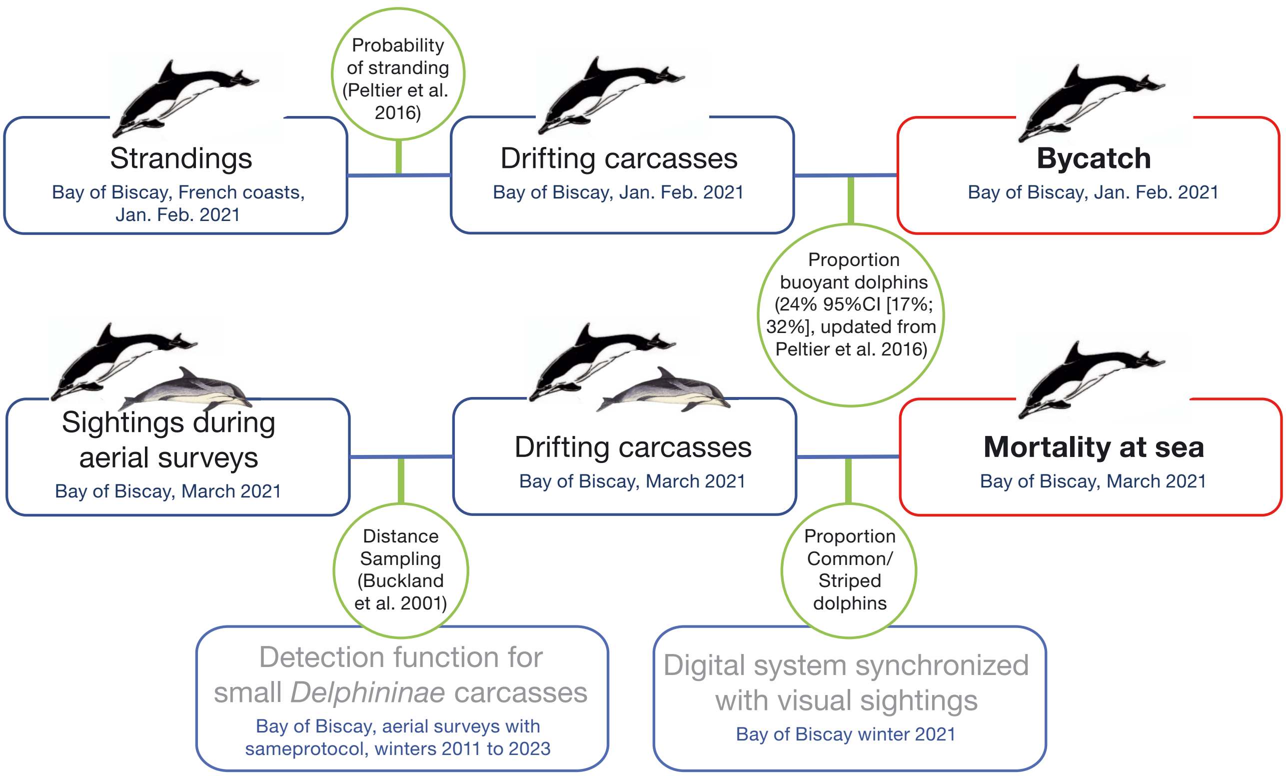

Fig. 2. Theoretical scheme of the bycatch estimate process from strandings and aerial observations

pared using PelaSIG plugin (Nivière et al. 2024) on QGIS 3 (Open-Source Geospatial Foundation Project; http://qgis.org). Within the Bay of Biscay and English Channel waters (322 700 km^2), a total of 19 150 km of effort was retained for analysis among the equal space zigzag track layout designed with Distance 7.3 software (Thomas et al. 2010). The flight sessions were only carried out during good detectability conditions (sea state < 4 Beaufort and subjective condition equal to or better than average), thus limiting the variation in perception bias.

To fit the detection function for small dolphin carcasses in winter in the Bay of Biscay, sightings from similar surveys (same protocol, season and partly same observers) were pooled in order to improve the detection function and associated variance for small dolphin carcasses: SAMM I winter (2011–12), SPEE (Suivi de la mégafaune marine au large des PErtuis charentais, de l'Estuaire de la Gironde et de Rochebonne par observation aérienne, i.e. Monitoring marine megafauna off the Charente Peninsula, Gironde Estuary and Rochebonne by aerial observation) (2019–22) and CAPECET (CAptures de PEtits CETacés dans les engins de pêche, i.e. bycatch of small cetaceans in fishing gears) (2020 and 2023) (Laran et al. 2017, Van Canneyt et al. 2020, Authier et al. 2021) (Fig. 1). A total of 87 detections were retained and a right truncation of larger perpendicular distances was applied at 500 m (reducing the number of detections to 81). The detection function was fitted using a half-normal model with conventional distance sampling (CDS; Buckland et al. 2001), as no covariate (among cloud cover, sea state, turbidity, glare severity, subjective condition or year) significantly affected the detection function. Analyses were performed using the R package *pelaCDS* from the Pelaverse suite of packages (Genu & Authier 2020). Data were spatially stratified in 3 survey blocks (Fig. 1), resulting in a global estimate of the abundance of carcasses floating at surface and its associated confidence interval.

Multiplier in distance sampling (Thomas et al. 2010) provides the opportunity to analyse indirect cues as object of detection rather than animals themselves (such as nest or dungs, and here carcasses). Therefore, to estimate mortality of common dolphins in the area, the estimated abundance of carcasses floating at the surface (from the CDS analysis) was divided by the estimated proportion of carcass which is detectable floating at the surface, taking care to incorporate the variance due to the latter into the former. Here, as no other correction factor was available, we used the proportion of buoyant carcasses and its 95% CI (24% [17%; 32%]) taking into account that carcasses sink rapidly after death (Fig. 2). The associated CI was estimated dividing the minimum interval of abundance by 17% and conversely the maximum interval by 32%.

Finally, to subtract the potential proportion of striped dolphin *Stenella coeruleoalba* in these estimates, we used the proportion of common dolphins (in individuals) identified after analysis of the picture synchronised with visual sightings from the digital system, STORMM. The latter supplemented the visual data collection in 32% of the effort carried out in the Bay of Biscay in the winter of 2021 to disambiguate species identification and verify pod size estimates. The proportion of common dolphins in the Bay of Biscay was estimated to be 92% of the individuals of small Delphininae in the area surveyed in the Bay of Biscay in 2021 (Laran et al. 2022) using this method.

3. RESULTS

3.1. Drift conditions

In winter 2021, the surface of all cells with a stranding probability of 50–100% corresponded to about 35% of the Bay of Biscay in January, 25% in the first half of February, 20% in the second half of February and decreased to only 10% at the end of March (Fig. 3). Thus, the area where dead animals are likely to strand was much smaller from mid-February onwards, as compared to January to mid-February. This means that stranding data can only inform on dolphin mortality occurring in a limited fraction of the Bay of Biscay from mid-February to the end of March.

Compared to the years 2016 to 2020, dolphin strandings came from a smaller part of the Bay of Biscay. They therefore provided information on a smaller fraction of the area usually sampled by the drift. In fact, the areas with the highest probability of strandings (50 to 100%), covered an average of 30% of the surface of the Bay of Biscay during the months of January, February and March over the period 2016–2020 (Fig. 4). As a result, the strandings recorded in winter 2021 are not directly comparable with those recorded in previous years from the end of February onwards, as they only provide information on mortalities in the coastal fringe.

3.2. Strandings

Between 1 January and 31 March 2021, a total of 699 small cetacean strandings were reported to the

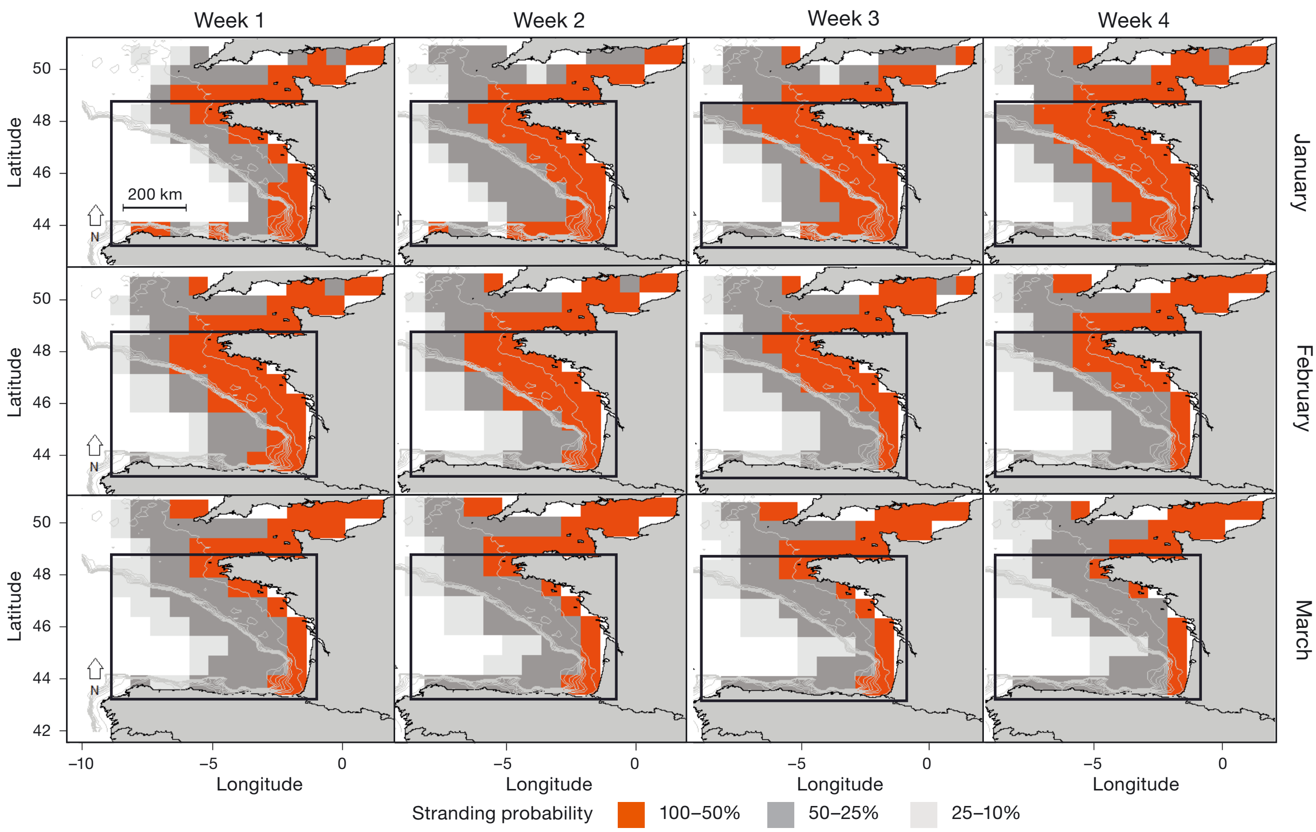

Fig. 3. Weekly stranding probabilities for the months of January through March 2021. Stranding probabilities between 50 and 100% in red, 25 and 50% in dark gray and 10 and 25% in light gray

French stranding network along the French Atlantic and Channel coasts. The vast majority (96%; n = 668) of these strandings were found along the coasts of the Bay of Biscay. Common dolphins were the most common species identified (85% in the Atlantic). Most strandings along the Atlantic coast occurred between 25 January and 5 February 2021 (Fig. 5A). After this date, the number of strandings remained very low. Compared with the average stranding rate for the years 2016 to 2020, the numbers recorded in 2021 were much higher in January and in the first week of February (Fig. 5B). From mid-February to the third week of March, strandings in 2021 were well below the average observed since 2016.

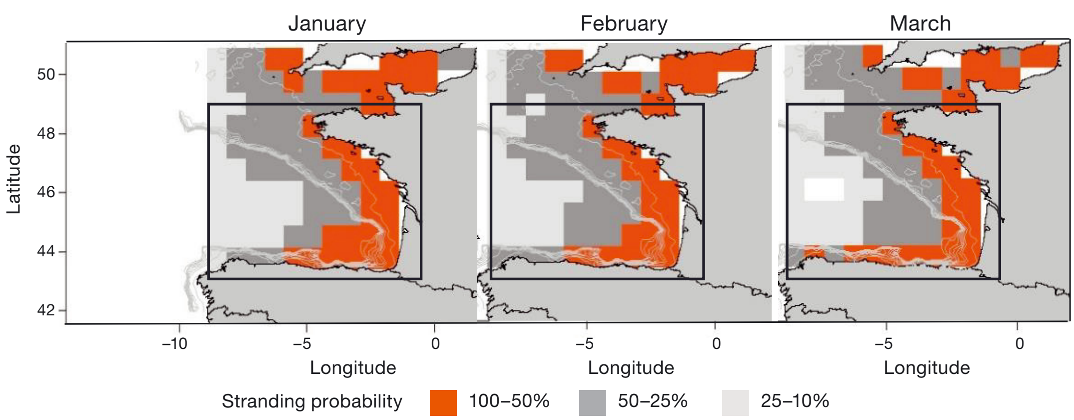

Fig. 4. Average stranding probabilities for January–March averaged over the years 2016–2020. Red cells correspond to stranding probabilities from 50–100%, dark gray cells from 25–50%, light gray cells from 10–25%. Black frame shows the area of interest with regard to the Bay of Biscay

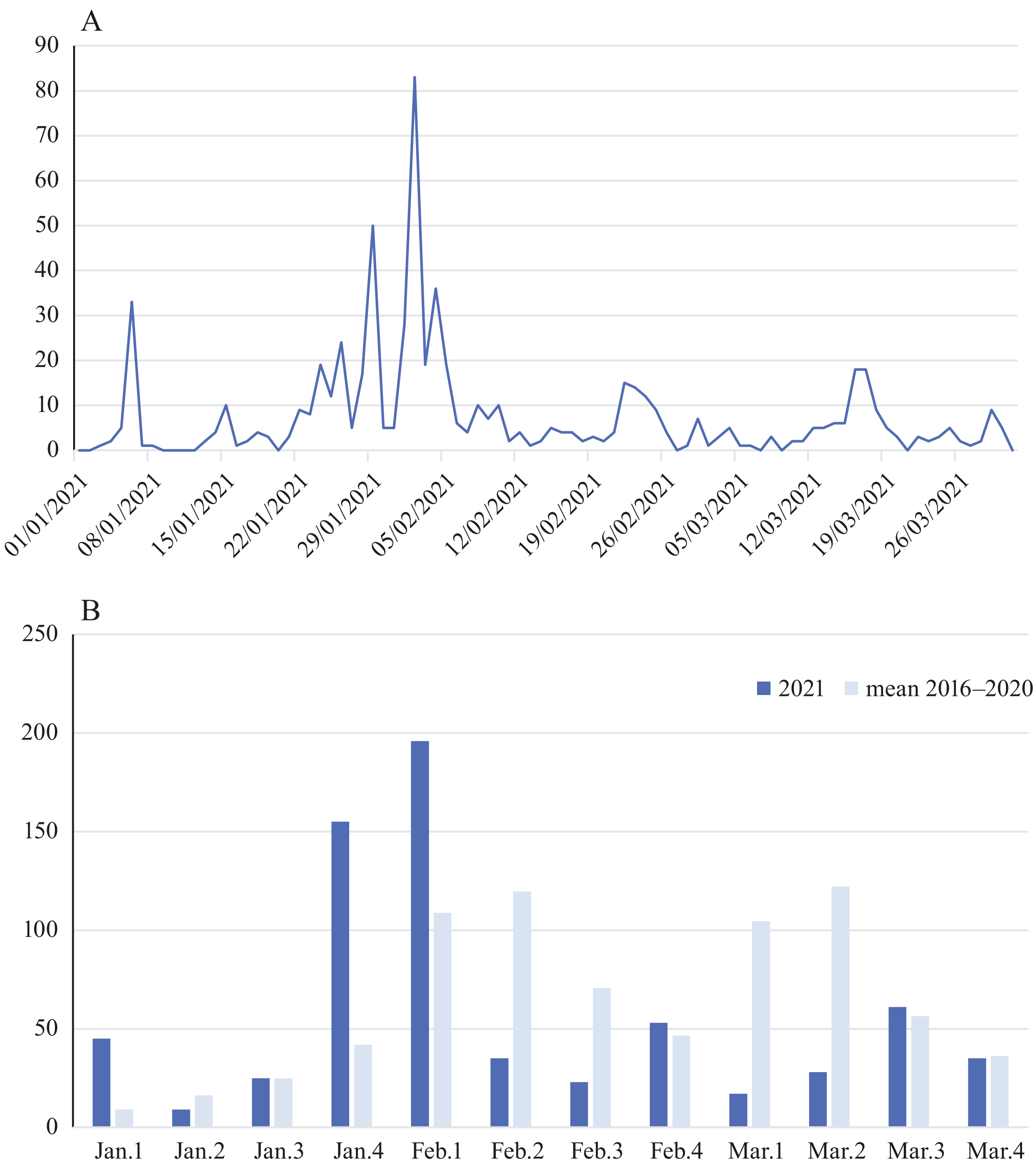

Fig. 5. Temporal distribution of small delphinid strandings in number of stranded dolphins from January–March in the Bay of Biscay (A) per day (dates are d/mo/yr) and (B) per week. Dark blue bars are stranding numbers recorded in 2021; light blue bars are stranding numbers averaged over the period 2016 to 2020. Weeks in (B) are noted following the month, where 1: 1st to 7th; 2: 8th to 14th; 3: 15th to 21st; 4: 22nd to 31st)

3.3. Bycatch estimates inferred from strandings

Reverse drift modeling performed on all stranded carcasses diagnosed as bycaught or collected during the unusual mortality event in late January and early February suggests that the number of common dolphins caught in fishing gear during the winter of 2021 would be 4250 (95% CI [3190; 6000]) individuals for the period 1 January to 31 March (Table 1) and 3670 (95% CI [2750; 5170]) for January and February only.

3.4. Estimating dolphin carcass abundance by aerial survey

Between 17 January and 25 March 2021, 26 cetacean carcasses were counted on effort in the Bay of Biscay, including 23 drifting carcasses of small Delphininae (either striped or common dolphins) (Figs. 6 & 7). The vast majority of these sightings (82%) were collected during March 2021, while the survey effort during this month represents 66% (9237 km) of the

Table 1. Common dolphin mortality in fishing gears in the Bay of Biscay during the winter of 2021, estimated from stranding data only by reverse drift modeling and using a proportion of buoyant carcasses of 24% (95% CI [17–32])

Months	Estimation	95 CI%
January	2930	[2190; 4130]
February	740	[550; 1040]
March	590	[440; 840]
Total winter 2021	4250	[3190; 6000]

effort for the Bay of Biscay survey block (Fig. S1 in the Supplement at www.int-res.com/articles/suppl/n053p509_supp.pdf). The detection function was fitted by pooling previous sightings (Fig. 8) and resulted in an effective strip (half) width (ESW) of 231 m (CV = 16%, Fig. 8). The 18 sightings of carcasses, for March 2021 resulted in an estimated abundance of 848 carcasses (95% CI [448–1885]) floating at the surface in March 2021 within the SAMM-II Bay of Biscay survey block. When correcting for the proportion of buoyant carcasses, a total of 3533 (95% CI [1400; 11 088]) small Delphininae are estimated to have died in the Bay of Biscay in March 2021. Adjusted for the proportion of common dolphins among unidentified Delphininae (digital system), the abundance of dead common dolphins in March 2021 was estimated at 3250 (95% CI [1288–10 198]).

3.5. Total mortality at sea during winter 2021

Given the drift conditions in winter 2021, the estimate of dolphin bycatch in the Bay of Biscay has

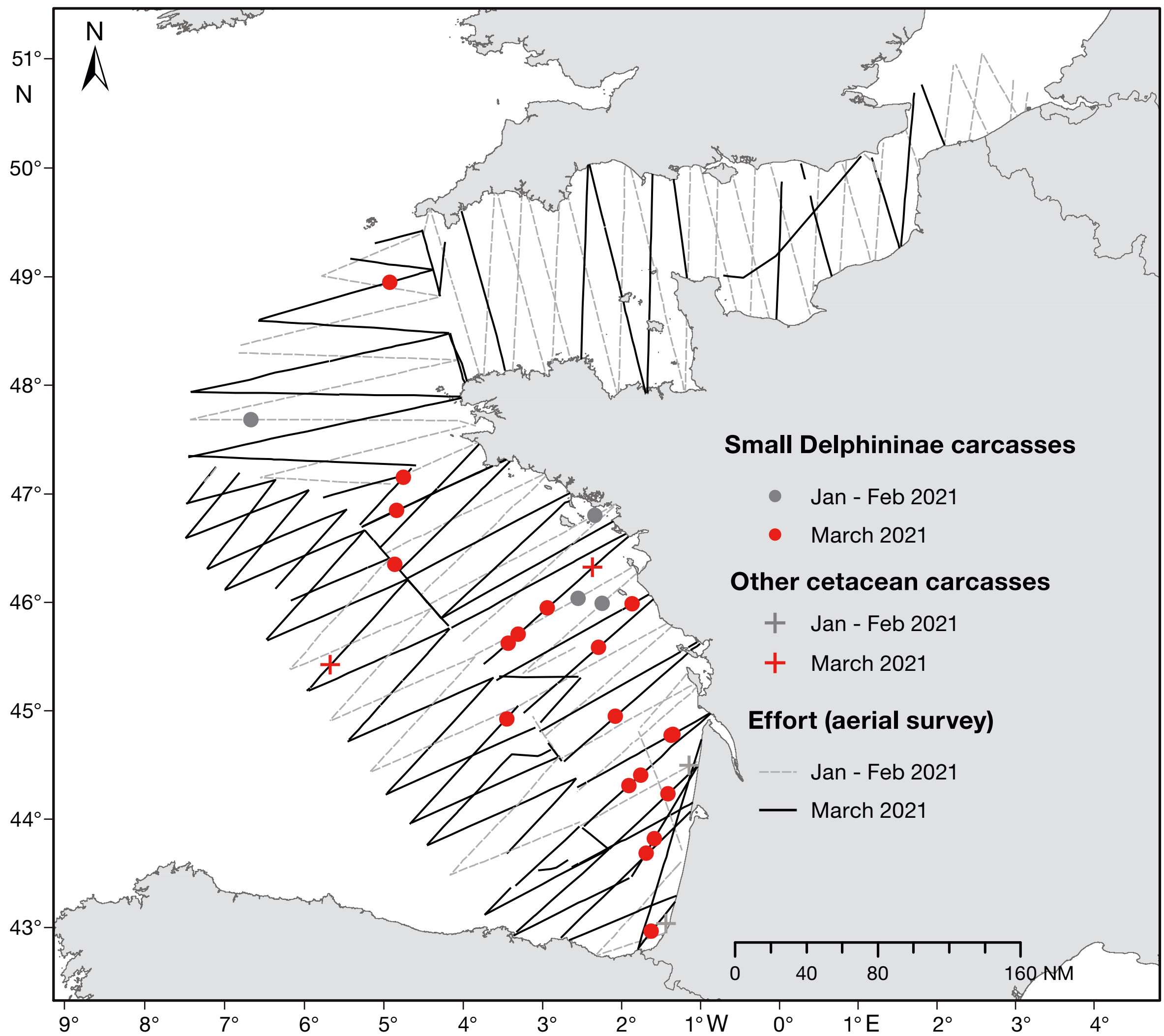

Fig. 6. Locations of small delphinid drifting carcasses recorded during the SAMM-II survey by month of the winter 2021. NM: nautical miles

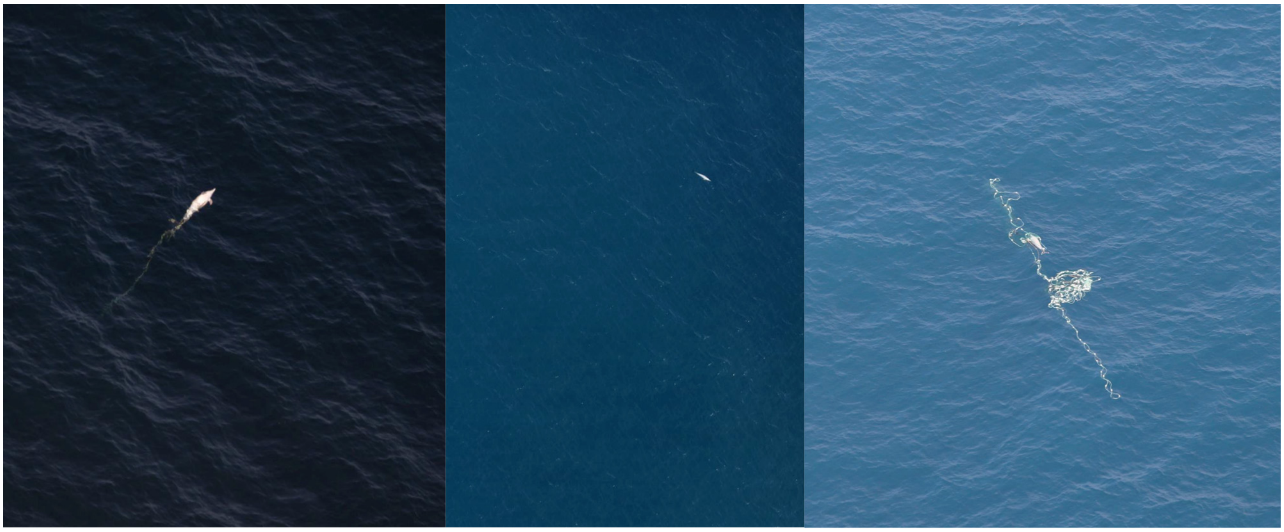

Fig. 7. Examples of dolphin carcasses reported during the SAMM-II aerial survey in March 2021. © Observatoire Pelagis

been calculated by adding the estimates from strandings for January and February, with those from aerial surveys for March. The estimates of bycatch mortality obtained for January and February, 3670 (95% CI [2750; 5170]) common dolphins, can be added to the estimate of common dolphin carcasses drifting in March, 3250 (95%CI [1,288; 10,198]; Fig. 9). Only strandings were used in January and February, while only drifting carcasses were used in March. This temporal complementarity prevents double counting of carcasses: those detected washed ashore in early winter cannot be those seen drifting at sea in March, as they are evacuated and incinerated by the public services following scientific examinations. As a result, the mortality of common dolphins for the entire winter 2021 can be estimated at approximately 6920 (95% CI [4038;15 368]) individuals.

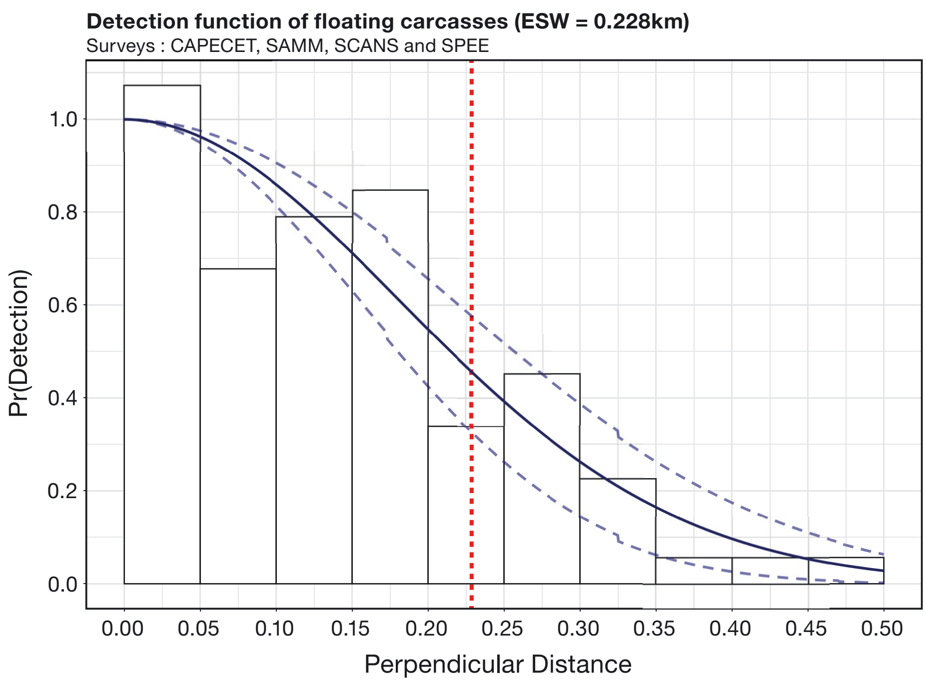

Fig. 8. Detection function for drifting small Delphininae. Width = 500 m, CV = 19.8%, effective strip width (ESW) = 216 m; distribution: half-normal. Pr(Detection): probability of detection

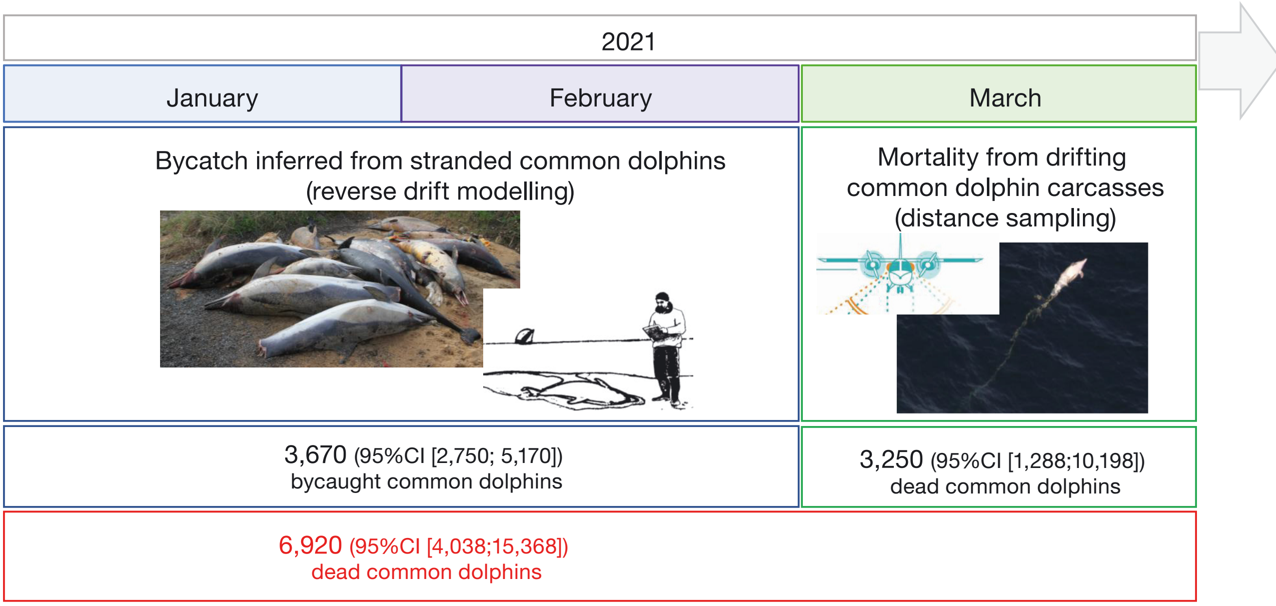

Fig. 9. Summary of mortality estimates inferred from strandings and from aerial surveys during winter 2021

4. DISCUSSION

4.1. Bycatch inferred from strandings

The use of strandings to estimate bycatch at sea now contributes to management advice and strategies in northeast Atlantic waters, as it does at the International Whaling Commission (IWC) and ICES (IWC 2022, ICES 2023). The reverse drift modeling strategy captures the magnitude of the bycatch phenomenon, regardless of vessel length, flag, target species and fishing practices. Successful implementation requires several key elements, including an efficient stranding network, fresh or moderately decomposed carcasses, an available drift prediction model, and favorable drift conditions. In the case of carcasses found in an advanced state of decomposition, it is impossible to establish the cause of death, leading likely to an underestimation of bycatch. It is assumed that all stranded cetaceans are reported to the stranding network. Although there may be disparities in observation pressure, the high level of frequentation of French coasts, even in winter, the high level of strandings reported several times, and the absence of areas with significantly lower levels of strandings suggest that undetected animals are likely to remain rare (Peltier et al. 2012).

The specific case of winter 2021 highlights that the use of strandings alone is insufficient to estimate bycatch in the Bay of Biscay as a whole when drifting conditions are unfavorable for strandings, for instance, during a persistent easterly wind regime. The decision to retain only the estimates based on strandings in January and February was based on such drift conditions. Even in this case, retaining data from the second half of February, when drift conditions were less favorable, likely resulted in an underestimation of bycatch. The modeling process relies heavily on the proportion of buoyant animals as a crucial parameter. This was obtained from 172 tagged carcasses and applied uniformly across all seasons and areas of the Bay of Biscay. Annual, spatial or seasonal variations in this proportion could lead to either over- or underestimation of bycatch. It is also assumed that this process is binary: The dolphins either float for an extended period, drifting and potentially get stranded depending on the drift conditions, or they sink and are lost to the stranding process. A more detailed understanding of the process could be gained through a telemetric approach that includes depth recorders.

Although there are limitations on the use of stranding data to estimate bycatch at sea, it has the advantage of being entirely independent of the capacity to deploy observers on board fishing vessels. Therefore, deployment bias (non-random assignment of observers to vessels and ports), the observer effect (possible changes in fishing practices when an observer is on board) or the low detection of carcasses that may come off the net before being hauled up on deck do not impact the estimates of bycatch inferred from strandings (Benoît & Allard 2009, ICES 2016, Murphy et al. 2019). Although it can be challenging to implement fishery observation programs, these programs have the advantage of enabling the identification of fisheries with high bycatch rates and are highly complementary to estimates based on strandings.

4.2. Mortality from aerial surveys

To the best of our knowledge, this study is the first attempt to estimate small cetacean mortality using distance sampling methodology from aerial surveys, although the method has been previously used for terrestrial carcasses (Bellan et al. 2013, Tomas et al. 2021) and recently for seabirds (Giralt Paradell et al. 2023). Large whale strandings have been counted by aerial surveys (Willoughby et al. 2022) or very high-resolution satellite imagery (Fretwell et al. 2019). However, so far, sighting density of marine mammals has never been extrapolated to the survey block using distance sampling methodology, possibly due to the limited numbers of sightings.

Considering the presumed binary buoyancy behavior of small cetacean carcasses (i.e. float or sink but never refloat after sinking; Moore et al. 2020), the overall proportion of sinking and floating dolphins was estimated at 24% (95% CI [17%; 32%]) (updated from Peltier et al. 2016). This was applied to both methods of mortality estimation. Because drifting carcasses were always observed as individuals, there was no bias when estimating group sizes. It was not possible to determine the cause of death of animals sighted during the aerial survey. Nevertheless, common dolphins showing external marks of bycatch constitute the vast majority of small cetaceans found stranded and examined during the winter (up to 90%). This cause of death may be assumed to be common amongst all drifting common dolphins on the continental shelf in winter.

4.3. Specific case of winter 2021

The drifting conditions during winter 2021 differed significantly from those which have been observed in the Bay of Biscay since 2016. Although westerly winds typically prevail (Le Cann 1990), an easterly pattern was persistent from mid-February onwards in 2021.

This unusual occurrence indicates that a decrease in strandings should not be assumed to correspond to a similar decrease in mortality at sea. Given the stranding probabilities, strandings are representative of mortality in the Bay of Biscay in January and February only, whereas in March they only provide information on a narrow coastal area. The concomitant large-scale aerial survey SAMM-II offered a perspective on common dolphin mortality at sea during winter 2021. Although the 2 surveys were conducted over the same period (January–March), the data used for these analyses were not collected simultaneously: only strandings were used to estimate mortalities during January and February, while only carcasses seen from aerial surveys were used to estimate mortalities during March. There was no overlap between the 2 approaches, as the carcasses stranded in January and February could not be observed drifting in the Bay of Biscay in March. In the winter of 2021, bycatch estimates fell within the same range observed as in previous years since 2016 (between 4000 and 10 000 common dolphin bycatch; ICES 2023). Therefore, it cannot be concluded that the mortality of common dolphins decreased in the winter of 2021.

5. CONCLUSIONS

The relative decrease in strandings observed during the winter of 2021 compared to 2019 and 2020 should not be interpreted as a reduction in bycatch at sea. In fact, the successive analysis of strandings at the beginning of the winter (January and February) and of carcasses observed at sea in March shows that the mortality at sea did not decrease during the winter of 2021. In all cases, stranding time series must be interpreted in the light of environmental conditions and the observation effort of stranding networks, which can lead to variations in trends that are not linked to changes in cetacean populations. In the sensitive context of the EU Commission's infringement procedure towards France, the dynamics of strandings and bycatch are scrutinized by the political sphere, fishing industry, NGOs, media, and society. They therefore must be considered with caution and scientific interpretation and support in order to avoid misinterpretation and a delay in decision-making which has proved fatal to other small cetacean species.

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