The following supplement accompanies the article

Influence of depredating cetaceans on albatross attraction and attendance patterns at fishing boats

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Effects of interpolation on fine-scale distances of birds from boats

The results presented in the main section show differences in the distance of birds from boats; at two different but very fine spatial scales: first, we show that birds spend more time within 3km of boats when whales are present. Second, when birds are within 3km of boats, our results suggest that birds tend to stay further from boats with an increasing number of whales.

There is a possibility that these results are simply a spurious effect caused by our interpolation of boat locations, or to the movements of boats and birds in the time lag (up to 5min) between their respective recorded locations. In other studies, authors have adopted a much more conservative approach than ours regarding the error in bird-boat relative locations. Torres et al (2011, 2013) accounted for the average speed of boats, and created a circular buffer of incertitude around interpolated boat locations, with a radius increasing as interpolated points are far (in time) from "real", recorded boat locations. Birds falling within this buffer of varying size were considered close enough to boats to have interacted with them. Basically, this assumes that boats could have adopted a circuitous route between two recorded locations; and that boats would have the same probability of presence anywhere within this buffer. This may be required when analyzing trawlers' movements, which can display meandrous movements when fishing. Here we argue that, at least in our case, less conservative approaches are both reliable and potentially offering more insights into seabird behaviour around long-liners.

We begin by showing results from our dataset obtained when relying only on bird locations observed within 5 minutes of recorded (non-interpolated) boat locations. Indeed we have no independent measure to estimate the interpolation error. This analysis confirms results presented in the main section. We then discuss boat behaviour, to argue that the linear interpolation is potentially a more accurate assumption on their movement behaviour than a circuitous-route buffer method; and the implications on analyzing bird behaviour.

Bird distances (and uncertainty) from boats recorded locations

We selected all bird GPS locations that were recorded within 5min and within 30km of at least one fishing boat recorded location (discarding all interpolated boat locations). The time lag between these bird and boat locations was independent of fishing activity and cetacean presence (Fig SI1 left). When within 3km of boats, birds mainly showed speeds < 10km/h (average ± s.d.: 3.5 ± 5.2 km/h), as calculated between successive bird locations, every 15min (Fig. SI1right; (Collet et al. 2015)).

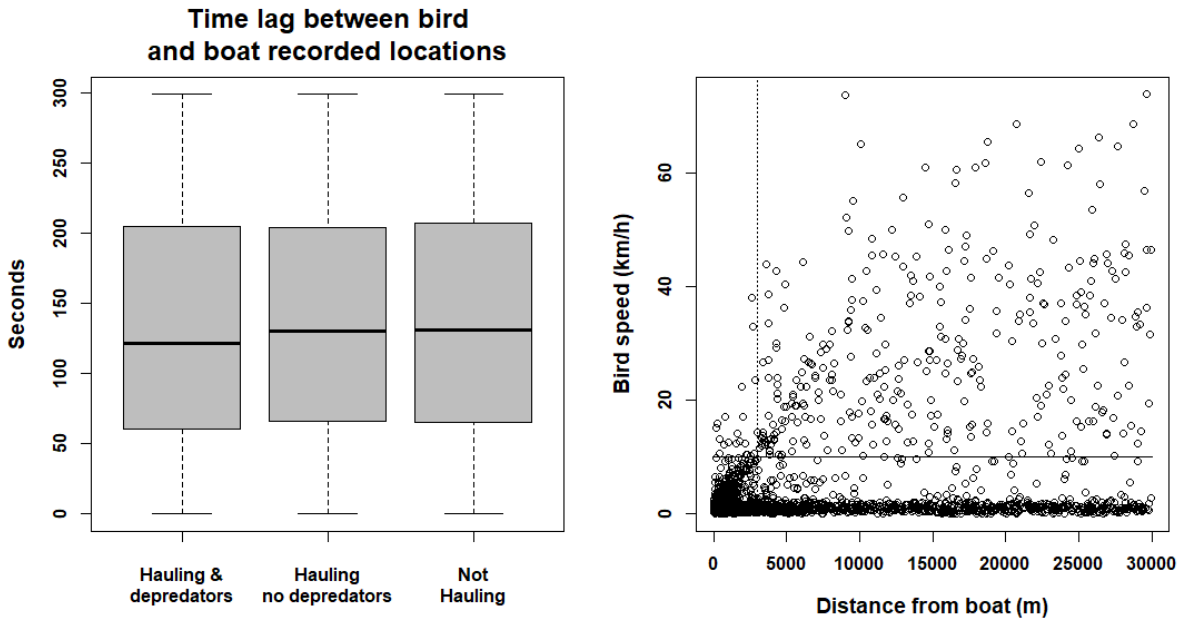

Figure SI1: Data structure for bird GPS locations recorded within 5min and within 30km of a recorded boat location. The time lag between bird and boat recorded locations did not depend on boat activity or presence of cetaceans (left). The category "not hauling" encompasses VMS locations during transit and during setting operations. The 3km threshold used in the main section (dashed vertical line) is a « natural » threshold marking clear changes in patterns of bird speeds (right). Below 3km of a boat bird speed is very low, usually below 10km/h (horizontal solid line).

Given the observed bird speeds and time lags between bird and boat locations, the incertitude in the actual location of birds at the exact time when boats location were recorded is on average of 132 ± 235m (median: 54m, 95% quantile: 522m, max 2450m).

We think this is accurate enough to rely on a 3km threshold to categorize attendance behaviour. Specifically, there is no reason to believe that this could significantly affect our conclusions regarding attraction probabilities or the proportion of time spent within 3km during an encounter, given the duration of encounters containing attendance behaviour (main section). However this uncertainty in bird-vessel distance is quantitatively similar to the observed magnitude of the effect of the number of whales on attendance distance (main section, Fig.3B). This warrants some care in interpreting the absolute distance values within 3km of boats. However, we see no reasons to believe that errors or biases in the bird-boat distance estimates should differ according to the presence/absence of cetaceans. Therefore the relative difference, more than the absolute values, should still be meaningful to interpret.

Bird behaviour when only accounting for non-interpolated boat locations

Next, we examined the distributions of distances from boats, for bird GPS locations falling within 5 min of a "real" recorded boat location (Fig. SI2). These distributions of distances from boats were obtained from 86 different bird tracks in the case of hauling events with depredators (SI2 top), and 88 different bird tracks in the case of hauling events without depredators (SI2 middle). Bird locations within 3km of a recorded boat hauling location occurred in 66 different tracks when depredators were present (n=336 bird locations) and 56 different tracks when no depredators were present (n=317 bird locations). The probability for locations to be within 3km of a boat was higher when whales were present than when whales were absent during hauling (0.58 ± 0.13, $z=4.552$, $p<0.001$, binomial glmm accounting for

foraging trip identity). This is in line with results in the main section showing a higher proportion of "encounters" within 3km of boats; and we interpret this as birds more actively remaining within the 3km "attendance zone" when depredators are present. As a comparison, we also note that birds were less often close to boats where boats were not hauling lines (SI2 bottom).

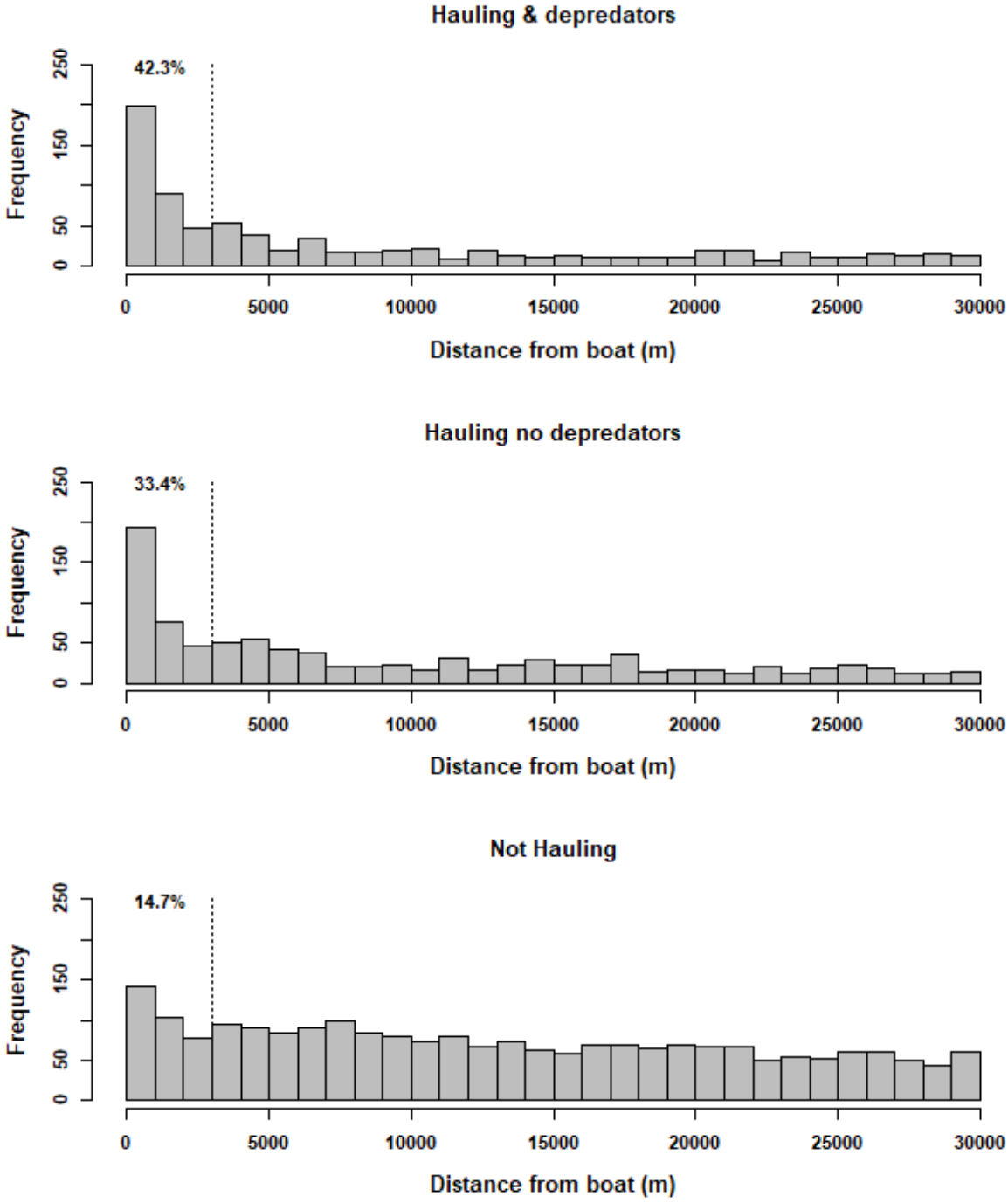

Figure SI2: Distribution of distances between bird GPS locations and vessels' GPS (non-interpolated) locations, when vessels were in hauling operation with killer and/or sperm whales present (top), when vessels were in hauling operation without any depredator present (middle), or when vessels were either transiting or in setting operations (bottom). The percentage of distances <3km is indicated for each situation.

This is consistent with our interpretation that the primary factor attracting birds is hauling activity and not depredator's presence (see also Fig.SI3), but that the presence of depredators makes bird attend longer (or more actively). Note that contrary to analyses presented in the main section, results here do not account for the potential autocorrelation in bird behaviour within the same "encounter event", nor in the timing of bird and depredator's arrival at boats. In the main section, we considered these effects by looking at statistics for each encounter event rather than for each bird locations.

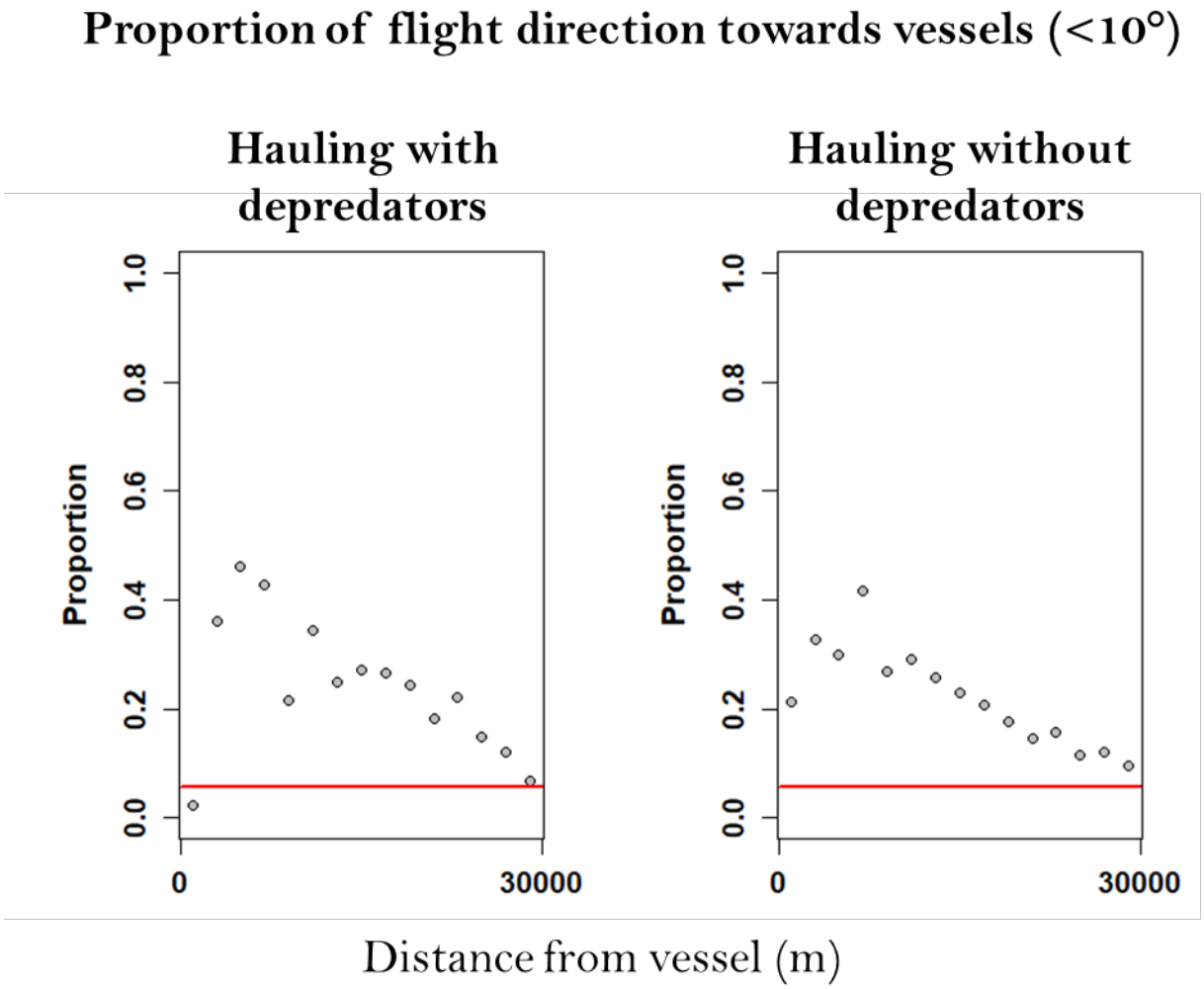

Figure SI3: Probability of bird flight direction towards boats (<10°), function of distance from boat (m, by bins of 2km), and presence (left) or absence (right) of depredators. Red line materializes random expectations on flight direction (10/180). For sample size reasons, vessels 'interpolated locations were included to make these figures. These graphical results further suggest that depredators did not affect larger-scale detection distances.

Discussion on interpolation accuracy

We do not have external data to estimate the error in interpolated boat locations. However we believe the simple analyses presented above confirm the reliability of our conclusions.

The circular buffer method employed in (Torres et al. 2011, 2013) results in pooling bird locations and behaviour from various distances from boats, from 0-10km. Yet we clearly

show here, and in other studies, that birds do not behave equally with boats when they are within 3km than within 10km, 30km, or further. Therefore, while the method proposed by Torres et al allows a conservative estimation of bird fine-scale overlap with boats, and may be needed to account for the higher location uncertainty of trawlers, we believe our method is more accurate to discuss changes in bird behaviour in reaction to the fleet studied here.

More generally longliners may mostly follow straight lines between recorded locations. Deviating from a straight line increases fuel consumption and wastes time (Janc et al. 2018). During hauling operations, it is also unlikely that longliners make circuitous routes. How straight movements of seabirds attending longliners (or trawlers: Torres et al., 2011) is probably dependent on both the seabird species and the scale at which straightness is calculated. Regarding the longline fleet studied here, we have previously shown that wandering albatrosses spend an important proportion of time between 3 and 30km from boats, where they probably drift at the sea surface, before taking off to catch up with boats moving faster; or possibly forage independently (Collet et al. 2017). This may result in more sinuous path when close to boats (M. Fontenille, J. Collet, H. Weimerskirch, *unpublished data*). Conversely, black-browed albatrosses interacting with boats followed them more tightly and spent much less time away within the 3-30km area (Collet et al. 2017). In their case path straightness may not be affected (M. Fontenille, J. Collet, H. Weimerskirch, *unpublished data*).

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