Spatiotemporal analyses of tracking data reveal fine-scale, daily cycles in seabird-fisheries interactions

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ABSTRACT

Human fisheries provide scavengers with abundant and predictable feeding opportunities that may schedule their behavioural patterns. Yet, quantitative assessments on scavenger-fisheries interactions are largely oriented towards assessing their spatial overlap. Using GPS tracking technology, we evaluated how the Audouin's gull, a Mediterranean endemic seabird that makes extensive use of feeding opportunities provided by fisheries, co-occurs (i.e. presumably interacts) with the main fishing gear (i.e., diurnal trawlers and nocturnal purse seiners), both in space and time. Results showed that some individuals were able to adapt their distribution and activity patterns to the scheduled routines of human fisheries. Waveform analyses based on co-occurring positions revealed that most interactions with trawlers occurred during the afternoon (around 16:00 h) when discarding occurs as vessels approach the ports. In contrast, gull-purse seiner interactions largely occurred at night (between 2:00 h and 4:00 h) coinciding with the hauling of nets.

Moreover, we found an individual component in seabird-fishery interactions, showing that there may be differential use of fisheries by individuals within the population. In addition to implications for our understanding of the behavioural ecology of these species, these results may have important management implications as this food subsidy becomes increasingly restricted (e.g., EU Common Fisheries Policy).

Keywords: Discards, gulls, fisheries, interaction, Mediterranean

INTRODUCTION

Among the Earth's biomes, the marine environment is likely one of the most greatly impacted by humans (Halpern *et al.* 2015; Ramirez *et al.* 2017). In addition to human-driven climate impacts, pollution and habitat degradation, marine resource overexploitation can also result in severe changes to marine ecosystems and biodiversity (Cury *et al.*, 2011). For instance, fishing activities have resulted in the complete exploitation of 60% of fish stocks worldwide whereas 33% are overexploited and 7% are depleted (FAO, 2018). Changes in fish abundances caused by fisheries may have further implications within the marine food webs (Pauly, 1998; Essington *et al.*, 2006) with ultimate, often exacerbated, impacts on top predators through bottom-up trophic cascades (Frederiksen *et al.*, 2006; Lynam *et al.*, 2017). Concurrently, human fisheries may also impact these marine predators through direct mortality (i.e., bycatch, Lewison *et al.*, 2014), food depletion (through marine resource overexploitation), or by providing resources that would not be naturally available otherwise (Hudson and Furness, 1988). These new feeding opportunities are largely driven by fisheries' discards, which refers to the part of the catch returned to the sea, often dead (Damalas, 2015).

A large amount of discards are generated daily by industrial and artisanal fisheries and thrown back into the sea. Historically, global estimated discards increased from under 5 million t/year (t = 1,000 kg) in the early 1950s to a peak of 18.8 million t in 1989, and gradually declined thereafter to the levels of the late 1950s of less than 10 million t/year. Globally, this represents between 10% and 20% of the global worldwide catch (Zeller *et al.*, 2018). Discarding occurs at specific times and locations, thus resulting in one of the most important and predictable anthropogenic food subsidies in the marine ecosystems worldwide (Oro *et al.*, 2013). Many species take advantage of this food subsidy, and have adapted their distribution and activity patterns to the scheduled routines of human fisheries (Oro *et al.*, 2013). This is the case for some seabirds, whose foraging behaviour, habitat use, and movement patterns are highly affected by the presence/absence of fishing activity and thus, of discards (Bodey *et al.*, 2014, Tyson *et al.*, 2015, Bartumeus *et al.*, 2010). This can have an influence on species habits with ultimate consequences on life history traits, population dynamics and community structure (Oro *et al.*, 1999; Bearhop *et al.*, 2008). In this scenario, opportunistic species with high adaptability can take advantage of this resource (Oro *et al.*, 2013) since discards can lead to highly competitive feeding interactions (Arcos et al. 2001; Calado *et al.*, 2018). The favoured species are those that make up the communities of scavengers that feed on discards. These communities can vary greatly across different geographic locations in terms of species (Weimerskirch *et al.*, 2000, Tyson *et al.* 2015, Louzao *et al.*, 2011). In the Western Mediterranean, these communities are typically dominated by yellow-legged gulls (*Larus michahellis*), Balearic shearwaters (*Puffinus mauretanicus*), the Audouin's gull (*Ichthyaetus audouinii*) (Louzao *et al.*, 2011) and the Cory's shearwater (*Calonectris diomedea*) (Abelló *et al.*, 2003).

Changes in the dynamics of discard availability may have some direct implications on these scavenger communities. For instance, a decline in the availability of discards can cause food shortages and a subsequent search for locations with better food availability (Calado *et al.*, 2018). The absence of discards has also been tied to greater seabird attendance at longliners and a consequent increase in seabird bycatch (Laneri et al. 2010; Soriano-Redondo et al 2016). Other costs can arise even at the level of biotic interactions. For example, some species may offset food shortages and increased competition for natural resources by shifting their trophic regime from discards to other small seabirds, causing potential negative impacts to their populations (Bicknell *et al.*, 2013).

Such a shortage in discards may occur in the near future in the EU's Exclusive Economic Zones (EEZ). A discards ban policy (the so-called landing obligation) is being implemented under the current European Union (EU) Common Fisheries Policy (Borges, 2015). EU marine scavenger communities may thus be subjected to some of the impacts discussed above (Bicknell *et al.*, 2013). Within this scenario, reliable assessments on seabird-fishery interactions are key to taking proper management decisions and to providing answers on how communities will respond when discards are no longer available (Oro *et al.*, 2013).

The Audouin's gull is an appropriate model species to study the interactions between fisheries and seabirds. This is particularly true given the forthcoming implementation of the European landing obligation, as the Audouin's gull is known to greatly rely on discards (Oro *et al.*, 1999; Arcos *et al.*, 2001). Many of the previous assessments on the interaction between seabirds and fisheries have considered either the temporal or the spatial dimension, with special attention to the latter (Cama *et al.*, 2011; Cama *et al.*, 2013; Yorio *et al.*, 2010, Bécares *et al.* 2015). Few have addressed this issue by integrating both dimensions simultaneously (but see Votier *et al.*, 2010; Granadeiro *et al.*, 2014). This approach can provide further insights into these interactions and can be key to assessing or predicting possible responses or consequences for seabirds in advance of changes in discard availability. Based on GPS tracking data for gulls and fishing vessels (Vessel Monitoring System, hereafter VMS), we combined temporal and spatially-explicit information to evaluate gull-fishery co-occurrences in both space and time. This allowed us to investigate at a finer scale how the Audouin's gull interacts with the fishing fleet of the NE Iberian Peninsula in a *pre-ban* scenario. Regarding the association between the Audouin's gull and the resources provided by the fisheries, we predicted that the gulls will adjust their feeding strategies to the activity patterns of the co-occurring fishing vessels. In other words, we predicted that the interactions would occur at those times and locations at which the fishing boats generate the best feeding opportunities. On the other hand, and taking into account the existence of individual and distinguishable strategies within the opportunistic/generalist species' populations (e.g., Navarro et al. 2010), we predicted a heterogenic usage of this trophic resource between individuals of this population. The information provided could be useful in making comparisons to *post-ban scenarios*, and to assessing other future changes in the interaction of birds and fisheries, especially when human food subsidies such as discards are involved in the interaction.

MATERIAL AND METHODS

Study area and species

The study area was defined from the movements of the GPS-tracked Audouin's gulls breeding at the Punta de la Banya colony (40°40'N, 0°45'E), a protected sandy peninsula with salt pans in the Ebro Delta Natural Park (NE Spain) (Fig. 1). The area comprised the NE Levantine coast of Spain and extended from the coast over the continental shelf to the upper slope. There are numerous fishing ports scattered along the coast of the study area, which is the most important fishing ground for clupeids and demersal resources in the Mediterranean due to the wide continental shelf and the nutrients contributed by the Ebro River (Maynou *et al.*, 2008). This supports two main fishing activities: trawling (diurnal activity 7:00 h to 17:00 h GMT+1, Fig. 2A and 2B) and purse seining (nocturnal activity, starting at 23:00 h GMT+1 and with no return limit, Fig. 2A and 2C). The fishing activity of both fleets is concentrated on the weekdays (Monday to Friday), with no fishing activity on the weekend. Trawling is a non-selective fishing practice that produces large quantities of discards (Stithou *et al.*, 2019). These discards are thrown back to the sea after every trawl and two to four trawls can be carried out per day. In the Ebro Delta, the trawling fishing vessels begin to produce discards around 11:00 h. However, it is at the end of the fishing day, between 16:00 h and 17:00 h, when all the fishing vessels discard simultaneously as they approach the fishing ports. This results in an abundant and highly predictable food resource for marine scavengers (Martínez-Abraín *et al.*, 2002; Karris *et al.*, 2018). This contrasts with the nocturnal purse-seining activity, which produces few discards but can affect the foraging behaviour of scavengers through a process of resource facilitation, as it concentrates epipelagic fish close to the surface (Arcos and Oro, 2002). The study period coincided with a trawling moratorium established north of the Ebro River (Fig. 1).

The Audouin's gulls breeding at the Ebro Delta typically share their foraging distribution between terrestrial (mainly rice fields) and marine areas close to the colony (Bécares *et al.* 2015; Christel *et al.* 2012), where they often interact with fishing vessels (Oro *et al.*, 1996). This colony has seen some fluctuation in its numbers. Before the 1980s, the Audouin's gull was a scarce species in the Mediterranean, but during the 1980s and the 1990s, the studied colony in the Ebro Delta grew exponentially coinciding with the development of the fishing activity in the study area (Oro and Martinez-Vilalta, 1992).

This exponential growth was likely due to the exploitation of the highly available human subsidies, particularly of discards. In 2011, when the study was carried out there were 11.967 breeding pairs, representing ca. 60% of the global population (Ebro Delta Natural Park, *personal communication*).

Fieldwork procedure

Between the 8th and the 26th of May 2011, 60 breeding gulls were captured in randomly chosen nests, with either box or tent-labelled traps (Bub, 1991), and equipped with CatTrack GPS loggers (Perthold, 2011). This coincided with the incubation period of the species. These loggers were programmed to record locations (10 m accuracy, Perthold, 2011) every 5 minutes. Devices were sealed using a rubber shrink tube to make them waterproof, and attached to the back of the gulls using a Teflon adjustable harness (Bécares et al., 2010). The total weight of sealed devices (ca. 25 g) roughly represented 3-5% of the bird's body mass, thus below the limit for deleterious effects on individual birds (Wilson *et al.*, 2002; Phillips *et al.*, 2003). Thirty-six tagged birds were recaptured between one and two weeks after the deployment of GPS devices. Recorded data included GPS positions for these 36 individuals between May 8th and 26th. No adverse weather conditions (e.g. rain or strong winds) that could potentially affect gulls' foraging behaviour occurred during the study period.

Data analyses

Habitat use

We compared the differential use of the sea by the gulls on weekdays (Monday to Friday; period with fishing activity) and weekends (Saturday and Sunday; period without fishing activity) using the proportion of the time spent at sea or inland (mainly in rice fields). A foraging trip was defined to include the locations from when a bird left the colony until it returned (BirdLife International, 2005). For each study day, all the foraging trips were taken into account. The proportion of time spent at sea on each foraging trip in terms of the trip total duration was calculated, thus obtaining the daily use of the sea by the gulls. A linear mixed model was fitted, with the logit transformation of the proportion of time spent in each habitat as the dependent variable and the type of day (i.e. weekday, Monday to Friday, and weekend, Saturday and Sunday) as the explanatory variable.

Activity rhythms & Gull-fisheries interaction

We performed a waveform analysis on the daily use of the sea of both the fishing vessels and the gulls, to determine their daily temporal patterns of activity (Fig. 2A). GPS-locations for gulls were grouped into 2-hour intervals, following the temporal resolution for VMS data. Total number of bird or boat positions per time interval were subsequently averaged to obtain a representative 24 h profile (the waveform) of the 17 days of sampling. The phase, defined as the significant increase in sea use by gulls and fisheries, was determined for each waveform by calculating the Midline Estimating Statistic Of Rhythm (MESOR; Aguzzi *et al.*, 2015). The MESOR was computed by re-averaging all waveform values and was plotted as a threshold in the waveform plot. Waveform values above the MESOR indicated a significant use of the sea in a cyclic way, i.e., the phase.

We combined spatio-temporal information on the distribution of gulls and fishing vessels to assess gull-fishery interaction. To do so, we first retained bird positions within a 500 m and 20 min (±10 min) buffer around fishing vessel positions (based on VMS). We selected this spatial threshold after a sensitivity analysis revealed that the number of individuals interacting within a given spatial buffer increased between 0 m and 200 m, but that it stabilised between 300 m and 500 m. Thus, we selected the 500 m buffer for a more conservative approach. Filtered positions were subsequently included in a waveform analysis to test when the interactions occurred, and the interaction magnitude (as revealed by the number of bird positions within our spatiotemporal buffer) in a specific time interval. Finally, we carried out a kernel analysis of density for the interacting positions to assess where the interactions were produced.

The individual component of seabird-fishery interactions

We assessed the repeatability in the individual feeding strategies to consider whether there were different strategies within the population regarding fishing discard use. For every gull trip, we calculated a minimum, dimensionless distance between gulls and fishing boats that accounted for both the temporal and the spatial dimensions and was standardised to the above-defined spatiotemporal buffer (see details in supporting information). This minimum distance can be interpreted as the number of spatiotemporal buffers between a fishing vessel and a gull for a specific trip. We used these distances as an indicator of the degree of gull-fishery interaction to assess the repeatability in feeding strategies. These strategies can range from a complete dependence on fishing discards (high degree of interaction – consistently small distances) to a complete independence (low degree of interaction – consistently large distances), with some intermediate strategies. The repeatability was evaluated by estimating the intraclass correlation coefficient (ICC) using a linear mixed model. ICC values range from 0 to 1, with higher ICC values indicating high intra-individual repeatability in feeding strategies, while lower ICC values denote individuals behaving randomly.

R Statistical Software was used to compute the spatiotemporal buffers, and to carry out the kernel analysis and all statistical analyses (R Development Core Team, 2008).

RESULTS

Based on 36.251 recorded positions outside the colony, Audouin's gulls preferentially used the terrestrial environment (21.084 positions) with less contribution by the marine environment (15.167 positions) to overall habitat use by gulls. However, the relative contributions to habitat use differed between weekdays and weekends, with a three-fold (CI 95%: 1.85 – 4.84; $p < 0.001$) greater proportion of time spent at sea during weekdays.

Regarding the temporal dimension, gulls' daily activity patterns also differed between weekdays and weekends. On weekdays, the temporal patterns of sea use by gulls matched those of trawling boats; i.e., from 7:00 h to 17:00 h, thus both being diurnal (Fig. 2A). In the case of the purse seiners, the phase of the activity pattern was from 22:00 h to 8:00 h (Fig. 2A), and thus coincided less with that of the gulls. However, there was an overlap of 2 hours, from 6:00 h to 8:00 h, when both fleets and the gulls were at sea. On weekends, when there was no fishing activity, the temporal pattern of sea usage by the gulls changed noticeably, with significant sea use from 23:00 h to 6:00 h, and thus being mainly nocturnal (Fig. 3B).

We detected a stepwise increase in the magnitude of gull interaction with trawlers from 9:00 h to 16:00 h, with a maximum at 16:00 h (38.8%). The magnitude of birds' interactions with trawlers sharply decreased after 16:00 h, reaching 8.3% by 18:00 h. Regarding interactions with purse seiners, there was a marked increase in the magnitude of the interactions from 2:00 h to 4:00 h, during which interactions peaked (33.1%). From 4:00 h on, there was a clear decrease in the magnitude of the interaction, reaching 8.3% just before 10:00 h (Fig. 3A). Standard deviations for every analysis are provided in Table 1.

Regarding the geographic location of seabird-fishery interactions, our results showed that the interactions were concentrated within the 30 southernmost kilometres of the colony, near the main fishing port of the Ebro Delta (Fig. 3C).

Using the minimum distances as an indicator of gull-fishery interaction, we estimated that 47.6% of the trips at sea entered the spatiotemporal buffer (500 m, ± 10 min.) of distance around fishing vessels. However, we also detected a large heterogeneity among individuals showing minimum distances that ranged from 0.02 to 19.3 buffers of distance thus indicating a degree of structuring in the foraging strategies within the population (Fig.4). We observed a repeatability of 34% (ICC: 0.34, 95% CI: 0.1963 – 0.4765, $p < 0.001$), a value rated as “fair” on the scale provided in Landis and Koch, 1977.

DISCUSSION

It is well known that fishing activity provides substantial food for opportunistic seabirds (Tasker *et al.,* 2000). However, most studies on this topic have addressed the seabird-fishery interaction either from a temporal or a spatial perspective (Yorio *et al.*, 2010), with few studies integrating the two dimensions simultaneously (Votier *et al.*, 2010; Granadeiro *et al.*, 201; Bécares *et al.*, 2015). Based on our new spatiotemporal approach, we show that Audouin’s gulls scheduled their behaviour to that of fishing vessels, either to benefit from fish concentrations near the surface or to exploit fishing discards. However, this feeding strategy was not homogeneous within the population. As predicted, there was a differential usage of the discards by the different tracked individuals, thus showing the characteristic behaviour of opportunistic species, with a highly plastic trophic strategy (Navarro *et al.* 2010; Ceia *et al.*, 2014). These results provide further insights into the dependence of scavenger communities on human food subsidies, but may also have implications for the management and conservation of these species, particularly within the current context of changes in fishing policies.

Opportunistic scavenger species are capable of shaping their schedules and their use of habitat depending on human activities (Tyson *et al.*, 2015). Accordingly, the Audouin's gulls in our study showed a differential use of the sea depending on whether it was a weekday or a weekend. This result suggests that there is a driver favouring this day-dependent habitat usage. The fishing activity could be a suitable driver to explain this difference, as this activity is only carried out from Monday to Friday in the study area (Bécares *et al.*, 2015).

The daily pattern of sea-use by gulls matched that of the trawlers and purse seiners on weekdays, providing some evidence regarding gull-fishery interactions. A study by Bécares *et al.* (2015) showed a spatial overlap between Audouin's gulls and fishing fleets. However, an interaction cannot be assumed when assessing temporal and spatial overlaps independently. A spatial overlap does not necessarily imply a temporal one nor does a temporal overlap imply that birds and boats are exploiting the same areas. Quantitative assessments on seabird-fishery interactions require a detailed spatiotemporal approach as the one provided in the current study.

The interaction with trawlers can be explained by the great amount of discards provided (Stithou *et al.*, 2019). The magnitude of the interaction increased gradually beginning at the start of the fishing day until 16:00 h, when it reached its maximum. This peak of interaction coincides with the time at which trawlers are returning to port and are thus more concentrated and closer to the coast and the colony (i.e., when discards are most readily available).

Purse seiners operate nocturnally, and produce few discards (Arcos and Oro, 2002). There was a sharp increase in the magnitude of interaction from 4:00 h to 6:00 h (i.e., half of the working day for purse seiners). At that time, the nets are usually pulled out of the water and there is a large concentration of available fish at the surface (Arcos and Oro, 2002). Purse seiners also use a large lamp to attract fish improving visibility for birds making the fish easier to catch (Arcos and Oro, 2002). This can be considered a process of resource facilitation (Daleo *et al.*, 2005), as it allows the gulls to easily pick fish from the surface by dipping (Gaston, 2004). This is somewhat similar to the natural feeding strategy of the Audouin's gull. In natural circumstances (those not associated with fisheries), the Audouin's gull takes advantage of the diel vertical migrations that some small epipelagic fish carry out at night, from the epipelagic zone, to near-surface waters, catching fish at the surface (Blaxter and Hunter, 1982; Arcos and Oro, 2002). This species has also been seen interacting with tuna schools (Oro, 1995), similar to purse seine facilitation, as they pull fish to the surface. However, interacting with purse seiners may be energetically costlier than interacting with trawlers, as it has been shown that discards from trawlers can supply enough energy to get through the breeding season (Oro, 1999), whereas with purse seiners, birds must catch live fish themselves. In regards to the nocturnal activity, this could be explained by individual specialisation or some sort of competitive exclusion (Hardin, 1960), as discarding (produced by the diurnal activity of trawlers) generates highly competitive interactions (Calado *et al.*, 2018).

Our spatio-temporal approach revealed that gulls interact with fishing vessels (i.e., entered the spatiotemporal buffer) during ca. 50% of their trips to sea. However, these values are very likely underestimated, as the VMS data are collected every two hours, thus limiting the evaluation of interactions to two-hour intervals. Despite this constraint, we were able to detect an individual component in seabird-fishery interactions, thus indicating individual strategies within this population. Individual specialisation refers to the use of available resources resulting in inter-individual niche variation. This inter-individual variation could be consistent over short- and/or long-term periods, and is known to be widespread across a diverse set of taxa (Bolnick *et al.*, 2003). It is especially common amongst generalist predators (Woo *et al.*, 2008), like the Audouin's gull (Christel *et al.*, 2012) . In fact, many generalist populations are composed of ecologically heterogeneous individuals that repeatedly differ in foraging behaviour and use different subsets of the available resources (Bolnick *et al.*, 2003). The specialisation of seabirds on fisheries discards was assessed in Tyson *et al.* (2014), which identified some discards specialists amongst a population of lesser black-backed gulls in the Wadden Sea**.**

Our results on the individual component of the interactions with the two fishing fleets were obtained using the ICC. The ICC result (repeatability of 34%) suggests that there was some consistency in the feeding strategies, with some individuals showing a discard-dependent strategy, and others tending to feed naturally. However, rather than a bimodal distribution of foraging strategies, most individuals showed intermediate foraging strategies within this gradient. The reasons for the individual specialisation in our study case could be related to the stage of the annual cycle of the gulls (i.e., the breeding season). All seabirds are central-place foragers during the breeding season (Rayner *et al.*, 2010), which could lead to partitioning in the use of available resources between individuals, according to the principle of competitive exclusion (Ceia and Ramos, 2015).

The fact that some individuals tend to interact more often with fisheries than others is important in terms of conservation of the Audouin's gull colony in a *post-ban* scenario. These birds could be more affected by a depletion in discards suggesting that the effects of the discard ban will not be homogeneous across the Audouin's gull population. In contrast, the presence of individuals that do not rely on discards would be key to the population overcoming the discard ban, as these individuals would be able to feed more easily in the absence of discards.

The location where the interactions took place was also assessed using a spatiotemporal buffers. The results identified an area located ca. 30 Km south of the colony for both types of fishing gear. However, the fishing activity is carried out all along the Levantine Iberian coast (Fig. 2B, 2C), with some hotspots in particular locations. In addition, a trawling moratorium was implemented north of colony, such that interactions could not occur in that area. On the other hand, the proximity of the interaction hotspot to the colony can again be explained by the breeding stage and central-place foraging, as during the breeding season, the birds are energetically constrained and do not search far from the colony to find their prey (Orians and Pearson, 1979).

Conclusions and perspectives

In this study, we showed the fine-scale spatiotemporal overlap between the Audouin's gull and the fisheries operating near the Ebro Delta. We interpreted this spatiotemporal overlap as an interaction between gulls and fishing vessels. The interactions were not constant throughout the day and showed some variability depending on the fishing fleet and the time of the day, with a larger magnitude of interaction during either discarding or resource facilitation. Furthermore, differences between individuals regarding the feeding strategy were found, indicating a lack of homogeneity within the population. The studied population has seen some fluctuations in the last 40 years (García-Tarrasón, 2014), with a demographic explosion coinciding with an increase in fishing activity in the area. This indicates the importance of the fishing activity, and particularly trawling, for the subsistence of this population. However, since 2009, the population has declined to about

2000 pairs. Fishing activity has not changed significantly in the study area, and discards are still produced. Thus, the decline in the gull population could be attributed to other factors, such as predation episodes. Therefore, human subsidies provided by fishing activity (i.e., discards) could be key to conserving the remaining pairs. However, in the near future, changes to the discarding policies will be implemented in the EU (i.e., Discard ban/Landing Obligation). This could have impacts on this population as well as on other species in the EU and Mediterranean scavenger community. A discard ban could imply a food shortage for this species (Bicknell *et al.* 2013), as an important portion of their energy is obtained from discarded fish, especially in the breeding season (Arcos and Oro, 2002). For this reason, the discard-dependent individuals could contribute to a decline in the population when discards are no longer available, as they may move to other areas in the Mediterranean in search of higher food availability (Bicknell *et al,* 2013).

The NW Mediterranean is known to be a hotspot for clupeiform spawning (sardine, anchovy; natural prey for the Audouin's gull) (Maynou, 2008). If these lipid-rich fish species are equally exploited by the local fisheries after the implementation of the ban, it may be difficult for the fish stocks to recover, and thus making it difficult to meet the demands for both natural-feeding gulls (and other species of the seabird community) and the fishers. For this reason, it is of utmost importance to continue monitoring the seabird populations (as well as the commercial fish stocks) once the ban is implemented, to take appropriate measures that will minimize the impacts. If gulls are not able to overcome the sudden shortage of discard availability, this dependence on discards will have been an ecological trap (Schlaepfer *et al.*, 2002), as gulls will be forced to use sub-optimal habitats with less food availability.

Finally, this study provides some information of interest to policy makers. We showed that not all the areas in the study zone were of the same importance (as interactions occurred in specific places around the colony) and that not all times of day were equally important (as the magnitude of the interaction is not constant throughout the day). Our approach allowed us to characterise the interactions between the Audouin's gull and fishing boats. Moreover, this methodology can be useful to assess other aspects of seabird-fishery interactions. Bycatch is a key issue regarding these interactions, as it produces 500.000 seabird deaths worldwide annually (Rodriguez *et al.*, 2019), especially by longliners (Anderson *et al.* 2011). The use of spatiotemporal buffers can help to identify interaction hotspots, and to relate them to bycatch data, allowing for informed policy proposals, well-designed marine protected areas, and other measures to protect seabirds from this mortality focus. This could be of particular interest given the discard ban, as many birds could start feeding near longliners, likely resulting in an increase in mortality due to these interactions (Laneri *et al.* 2010). Moreover, for deeper insights into how the interactions are produced, other complementary methods could be used, such as on-board surveys or the deployment of bird-borne cameras (Votier *et al.*, 2013). These methodologies would allow an evaluation of the interactions from another point of view and would improve our understanding of these interactions. By using these methods, other features about the interactions could be assessed, such as how fish are taken, or the nature of interactions with other scavenging seabird species, therefore providing more ecosystemic and community-based assessments.

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Table 1. Standard deviations for all the averages of the number of positions or individuals in the waveform analysis shown in Figure 3.

Hour Interval	Trawling interaction % positions SD	Purse seining interaction % positions SD	Gulls’ % positions weekend SD
0-2	0	0	13.80
2-4	0	9.83	11.90
4-6	0	36.61	7.30
6-8	14.64	25.73	3.08
8-10	6.55	17.61	6.83
10-12	12.28	7.94	8.57
12-14	10.83	0	6.42
14-16	19.43	0	7.74
16-18	21.78	0	6.72
18-20	10.04	0	6.35
20-22	4.41	0	6.08
22-24	0	2.27	15.30

Figure captions:

Figure 1. Distribution of gulls' GPS positions. The area between A and B was under a trawling moratorium.

Figure 2. Daily cycles of boat activity (A), density of trawler positions (B), density of purse seiner positions (C). Shaded area in A shows the area above MESOR.

Figure 3. Daily cycles of interactions between gulls and boats (A), gulls at sea during the weekend (B). Kernel analysis of the interaction locations (C). Shaded area in A and B show the area above MESOR.

Figure 4. Boxplot showing the minimum distance per individual. Ordered by median value.

Figure1.

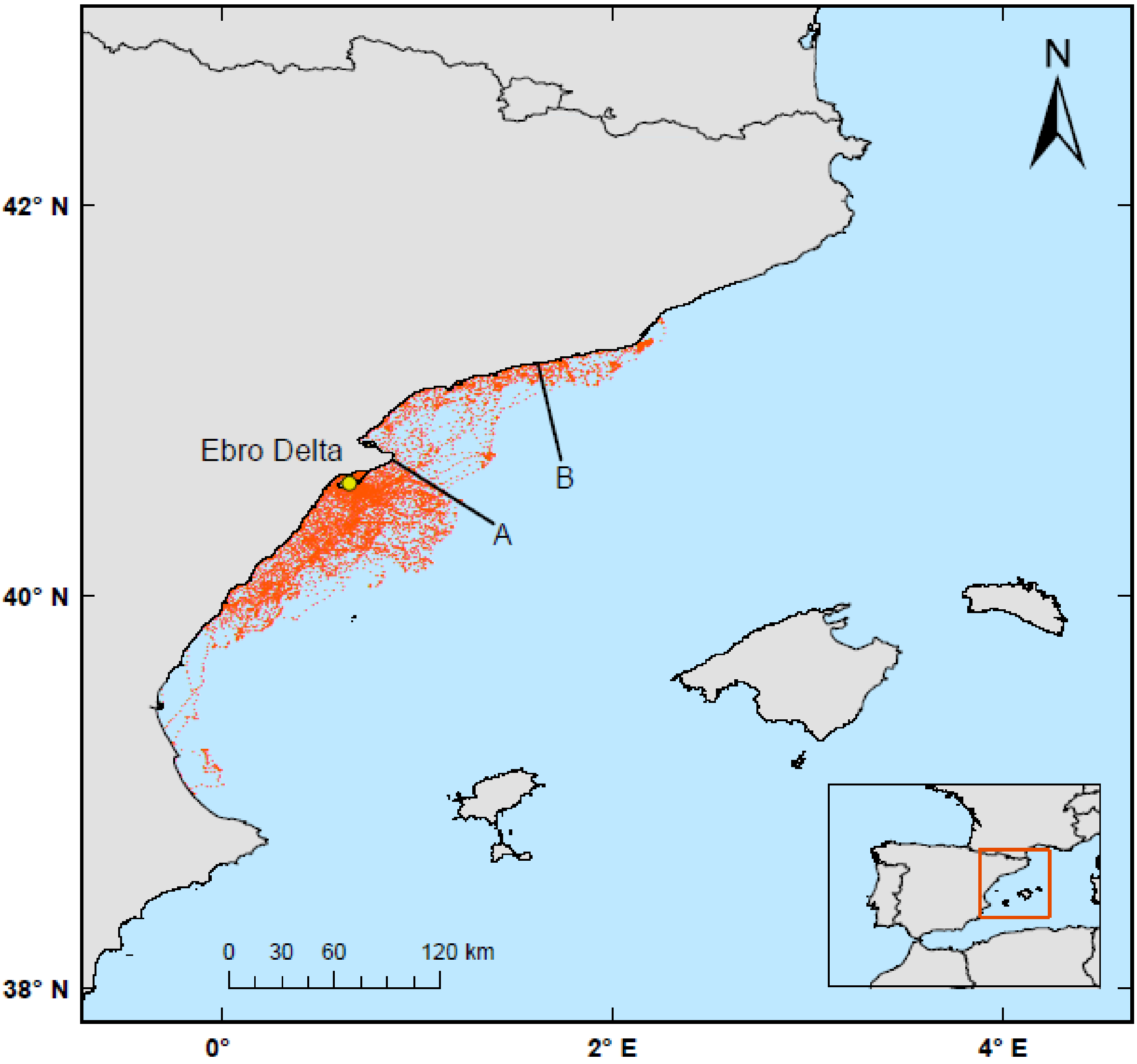

Figure 2.

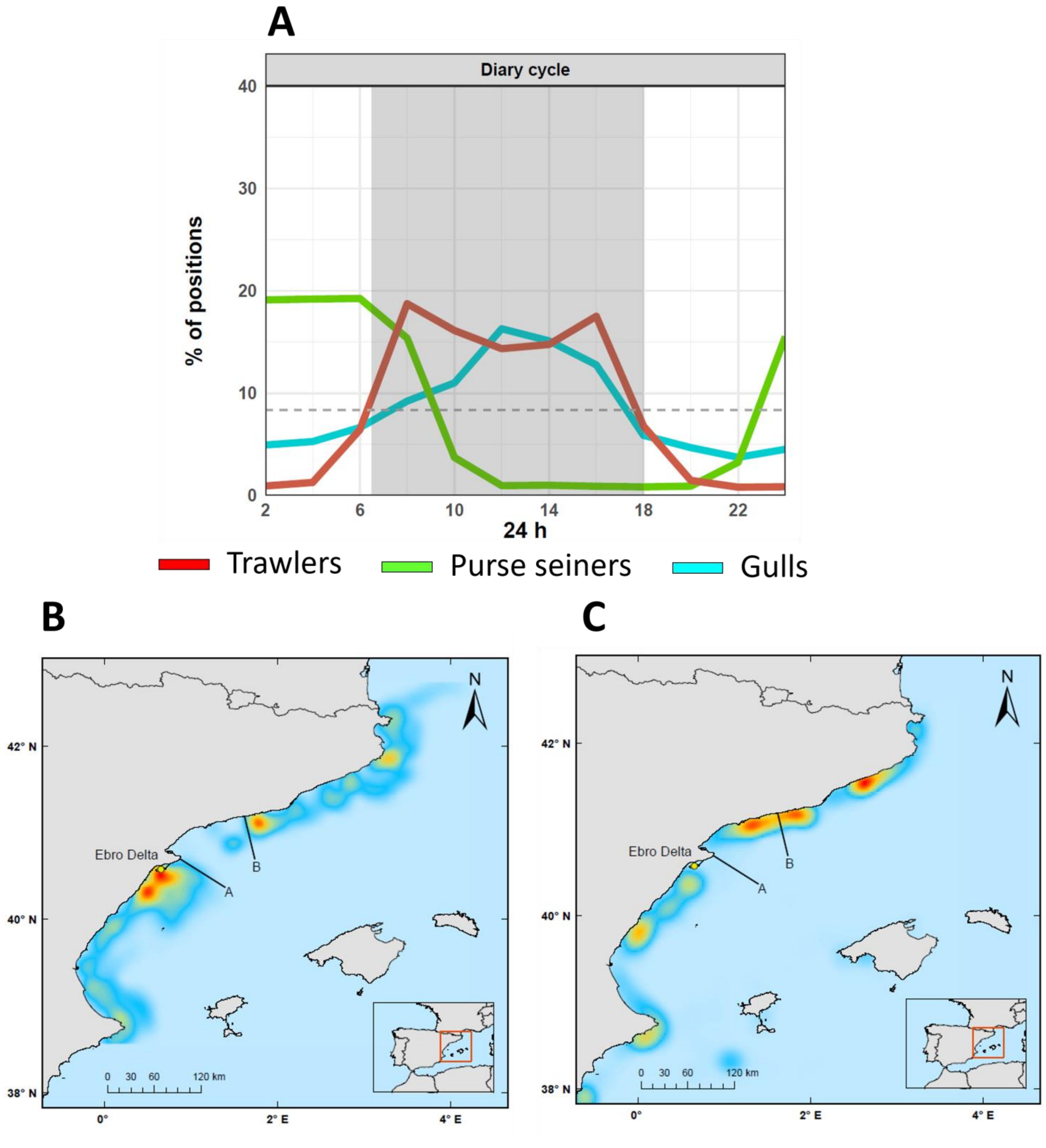
A
Diary cycle
40
30
20
10
0
% of positions
2
6
10
14
18
22
24 h
Trawlers
Purse seiners
Gulls
B
C
N
42° N
40° N
38° N
0°
2° E
4° E
Ebro Delta
A
B
0
30
60
120 km

Figure 3

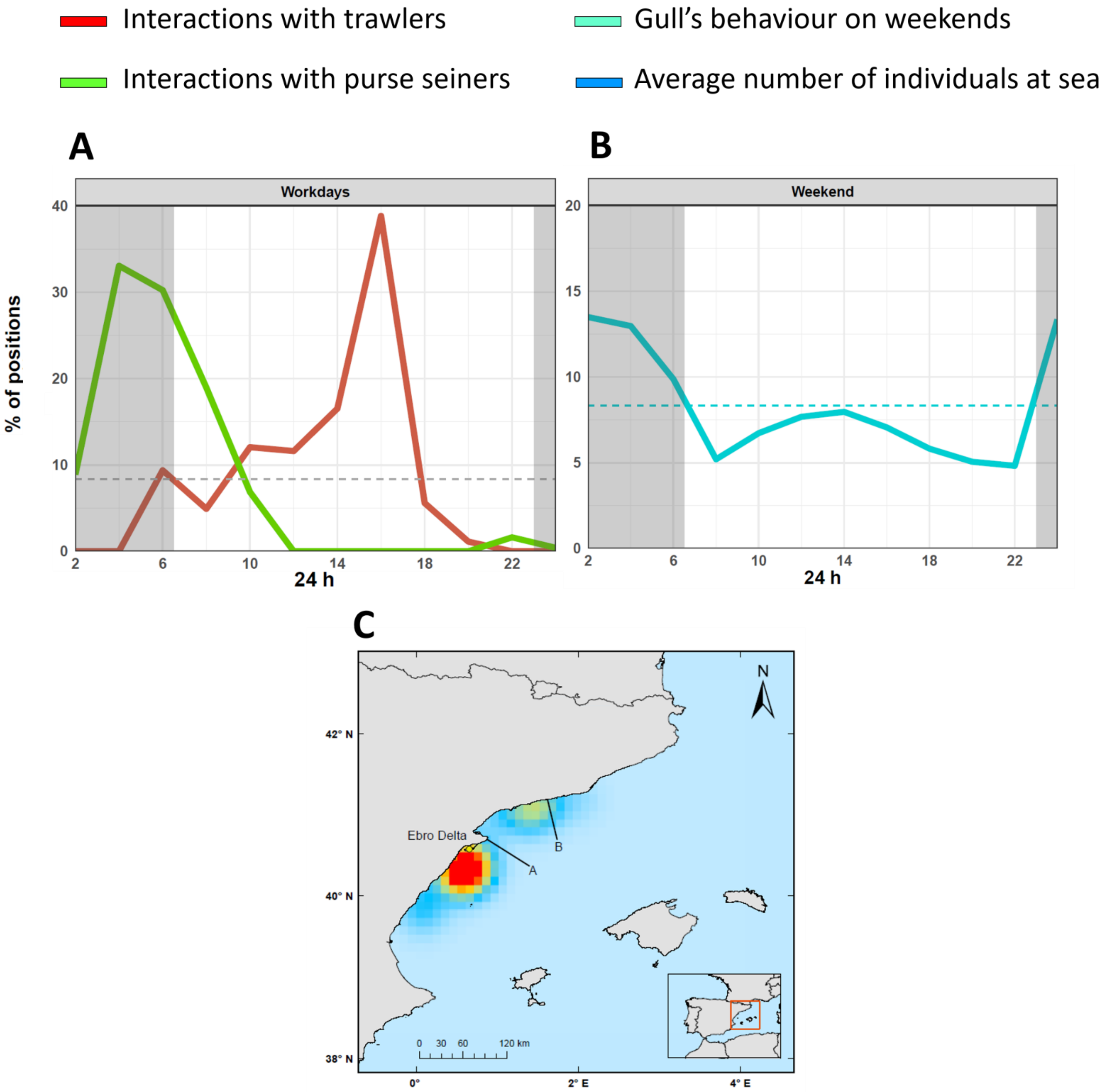
🟥 Interactions with trawlers
🟩 Interactions with purse seiners
Gull's behaviour on weekends
Average number of individuals at sea
A
Workdays
% of positions
0
10
20
30
40
2
6
10
14
18
22
24 h
B
Weekend
0
5
10
15
20
2
6
10
14
18
22
24 h
C
N
42° N
40° N
38° N
0°
2° E
4° E
Ebro Delta
A
B
0 30 60 120 km

Figure 4.