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HOW FISHERY DISCARDS AFFECT THE SPATIAL AND TROPHIC ECOLOGY OF TWO GULL SPECIES BREEDING IN SYMPATRY

Dissertação de Mestrado em Ecologia,
orientada pelo Professor Doutor Jaime Albino Ramos e pelo Doutor Vítor Hugo Paiva,
apresentada ao Departamento Ciências da Vida da Universidade de Coimbra.

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Dissertação apresentada à Universidade de Coimbra para cumprimento dos requisitos necessários à obtenção do grau de mestre em Ecologia, realizada sob a orientação científica do Professor Doutor Jaime Albino Ramos (Universidade de Coimbra) e do Doutor Vítor Hugo Paiva (Universidade de Coimbra)

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Abstract

Gulls are opportunistic seabirds, and some populations may be heavily dependent on anthropogenic resources, such as fishery discards and refuse dumps, which have contributed to the increase of many populations. In this study we evaluated the differences in the foraging, feeding and trophic ecology of Audouin's *Larus audouinii* (AG) and yellow-legged *Larus michahellis* (YLG) gulls breeding in sympatry in Barreta Island (South of Portugal). We were specifically interested in evaluating the influence of the fishery activity in the foraging ecology of both gull species. This is the first study about the foraging ecology of AG and YLG in Portugal using several different methods, namely tracking devices, dietary methods and stable isotope analysis.

During the breeding season (May - June 2015) we used tracking devices and conventional dietary methods to examine the foraging and feeding ecology of gulls during workdays (full fishery activity) and weekends (very low fishery activity). AG and YLG exhibited spatio-temporal segregation between them and also among week periods, though they mostly preferred to forage at-sea. The dietary choices assessed using pellets also revealed differences between workdays and weekends, and also among species. On workdays there was a greater variability of prey species in the diet of both gull species, which was more evident in the diet of YLG than on AG. Plus, the YLG consumed terrestrial items, contrary to AG which based their diet only on marine prey. Epipelagic prey (i.e. *Scomberosox saurus* and *Belone belone*), with low commercial value and highly discarded, showed a strong difference in the frequency of occurrence between gull species and week periods. During weekends, both AG and YLG increased the consumption of these prey (AG workdays = 48.3% and weekends = 70.0%; YLG workdays = 2.8% and weekends = 18.2%). In turn, species with commercial value and frequently discard, such as mackerels (*Scomber* spp and *Trachurus* spp) were more important for YLG than AG. Carbon and nitrogen isotopic values of plasma and red blood cells were similar between species, suggesting that they foraged in similar habitats and consumed prey-species with similar isotopic signatures. However, both species showed an enrichment on nitrogen isotopic values, from pre-laying (red blood cells) to incubation (plasma), meaning they increased the consumption of higher trophic level prey. Moreover, the YLG exhibited a larger isotopic niche when compared to AG, suggesting a generalist behaviour.

In our study, AG and YLG species largely exploited the fishery discards, mostly during workdays. During weekends, while AG foraged farthest from shore, YLG showed a more generalist behaviour, also foraging inland, on fishing harbours and refuse dumps. Moreover, the diversity of fish-prey species was always higher in YLGs' diet when compared to AGs, as it was the consumption of demersal species (surely discarded prey). The new European policy for the implementation of a fishery discard ban, is likely to result in a severe food shortage and, consequently, have negative impact on both gull populations. The AG should be the most affected, since it has mainly a marine feeding behaviour, contrary to YLG that showed other predatory skills, and a more plastic foraging behaviour and diverse diet composition. Nonetheless, it is expected that the population of the YLG will decrease. Also, the new discard ban scenario may lead to predation by the aggressive YLG on AG and other seabirds species, which should be closely monitored. In the future, it will be interesting to see if the YLG will return to a more 'natural predation behaviour' of marine prey or if it will increase the consumption of Human-derived resources (e.g. refuse tips), with a likely increase of conflicts with Humans.

Key-words: Yellow-legged gull; Audouin's gull; GPS-loggers; Stable isotope; Diet

Resumo

As gaivotas são aves marinhas oportunistas e algumas populações são fortemente dependentes dos recursos antropogénicos, tais como, as rejeições da pesca e lixeiras que têm vindo contribuir para o aumento das populações. Neste estudo, avaliamos diferenças na procura de alimento, dieta e na ecologia trófica da Gaivota-de-Audouin *Larus audouinii* e da Gaivota-de-patas-amarelas *Larus michahellis*, que se reproduzem em simpatria na Ilha da Barreta (Sul de Portugal). Com objetivo principal avaliar de que forma as atividades da pesca influenciam a estas espécies de gaivota na procura de alimento. Este é o primeiro estudo a investigar a ecologia de procura de alimento pela gaivota de Audouin e patas-amarelas em Portugal, usando diferentes métodos, como dispositivos de GPS, dieta e análise de isótopos estáveis.

Durante a época de reprodução (Maio – Junho 2015), recorremos a dispositivos de GPS e métodos convencionais de identificação da dieta, para avaliar a ecologia de procura de alimento e dieta, comparando com diferentes densidades de atividade piscatória, definidas por dias úteis (atividade piscatória plena) e fins-de-semana (baixa atividade piscatória). A gaivota de Audouin e patas-amarelas exibiram segregação especial e temporal entre elas mas também entre os períodos da semana, embora ambas espécies apresentaram um comportamento preferencialmente marinho. As egagrópilas revelaram diferenças ente os períodos da semana, mas também entre espécies. Durante os dias úteis existiu uma grande variabilidade de espécies na dieta de ambas as gaivotas, contudo foi mais evidente na dieta da gaivota de patas-amarelas do que na gaivota de Audouin. Para além disso, a dieta de gaivota de patas-amarelas apresentou itens provenientes de terra ao contrário da gaivota de Audouin, que se alimentou maioritariamente de presas marinhas. As presas epipelágicas com baixo valor comercial e bastante rejeitadas (*Scomberosox saurus* / *Belone belone*), mostraram uma grande diferença de ocorrência entre as duas espécies de gaivotas e períodos da semana. Durante os fins-de-semana, a gaivota de Audouin e de patas-amarelas aumentaram o consumo dessas presas (Dias úteis = 48.3% / 2.8% e Fins-de-semana = 70.0% / 18.2%, respetivamente). Por sua vez, espécies com valor comercial e frequentemente rejeitadas, como as cavalas e carapaus (*Scomber* spp e *Trachurus* spp), foram mais importantes na dieta da gaivota de patas-amarelas do que na gaivota de Audouin. Os valores de assinatura de isótopos de carbono e azoto para o plasma e eritrócitos foi similar entre as espécies, sugerindo que ambas espécies procuraram alimento em habitats muito similares e consumiram presas com uma assinatura isotópica semelhante. No entanto, ambas mostraram enriquecimento para os valores de azoto, aumentando do período de pré-postura (eritrócitos) para o período de incubação (plasma), indicando que as ambas aumentaram o consumo de presas de níveis tróficos mais elevados. Ainda assim a gaivota de patas-amarelas revelou um nicho isotópico mais amplo que a gaivota de Audouin, mostrando portanto um comportamento mais generalista.

Este estudo mostra que as gaivotas de Audouin e patas-amarelas exploram as rejeições da pesca, principalmente durante os dias úteis. Durante os fins-de-semana, a procura de alimento por parte da gaivota de Audouin foi mais longe da colónia, já a gaivota de patas-amarelas revelou um comportamento mais generalista, procurando alimento em terra, nos portos de pesca e lixeiras. No entanto, a diversidade de presas foi sempre mais elevada na dieta da gaivota de patas amarelas comparativamente à gaivota de Audouin, sendo consumidas presas demersais (provavelmente presas rejeitadas). A implementação da nova política europeia para a proibição das rejeições de pescas no mar, deverá resultar num período de grande escassez de alimento, e consequentemente, deverá trazer impactos negativos para ambas as espécies. A gaivota de Audouin deverá ser a mais afetada, uma vez que apresenta uma dieta maioritariamente marinha, ao contrário da gaivota de patas-amarelas que apresenta outras capacidades predatórias, sendo mais flexível na procura de alimento e na composição da dieta. Ainda assim, é esperada uma diminuição da população da gaivota de patas-amarelas. A nova política de rejeições poderá levar à competição e predação por parte da gaivota de patas-amarelas, espécie mais agressiva, sobre outras aves marinhas, que deverá ser monitorizado de perto. Pesquisas futuras, será interessante avaliar se a gaivota de patas-amarelas irá retomar a uma dieta mais natural, ou, por outro lado, se irá aumentar o consumo de outras presas derivadas da atividade Humana (p.ex. lixeiras), aumentando assim os conflitos com os Humanos.

Palavras-chave: Gaivota de patas-amarelas; Gaivota de Audouin; Dispositivos de GPS; Isótopos estáveis; Diet

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1. Introduction

yellow-legged gull[1]
(*Larus michahellis*)

Audouin's gull[2]
(*Larus audouinii*)

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[1] http://ibc.lynxeds.com/photo/yellow-legged-gull-larus-cachinnans/adult-breeding-plumage

[2] http://www.pbase.com/lorenzde/image/151043176

1.1. Fishery discards as an environmental issue

Human activities induce strong impacts on the structure and functioning of ecosystems (Ellis 2011). The direct impacts include habitat destruction or degradation, such as deforestation for agriculture and urbanization (Vitousek *et al.* 1997; Shapira *et al.* 2008), but also overexploitation of marine resources through overfishing. Marine ecosystems are becoming increasingly vulnerable with strong species declines, and the increment of industrial fisheries lead to the destruction and degradation of marine habitats (Pauly & Maclean 2003; FAO 2014; McCauley *et al.* 2015). On the other hand, anthropogenic activities, like agriculture, hunting, fisheries and refuse dumps can provide superabundant food resources, which benefit a few opportunistic species such as rats, foxes or birds (Oro *et al.* 2004; Haag-Wackernagel 2005; Oro *et al.* 2013). Nowadays, anthropogenic food supplies are influencing the survival and the foraging and reproductive behaviour of many opportunistic species (Oro *et al.* 2004, Navarro *et al.* 2010).

The Worldwide economy and many Human communities depend on marine resources, but paradoxically, Humans are depleting fish stocks through intensive industrial fisheries (Jackson *et al.* 2001; Froese 2004), and deteriorating marine and costal ecosystems, where the majority of the Human population inhabits (Batista *et al.* 2015). Commercial fisheries generate huge quantities of discards in the form of offal, unwanted or over-quota catch, and their industrialization and expansion exerts a global impact on fisheries' sustainability (Kelleher 2005; Bellido *et al.* 2011). Such industrialization of fishery practices destroys benthic marine ecosystems, deplete stocks of pelagic and benthic fish species lead to strong biodiversity losses, with enormous ecological consequences for the functioning of marine ecosystems worldwide (Jennings & Kaiser 1998; Myers & Worm 2003). By providing high amounts of food items for marine predators, fishery discards are altering the dynamics of marine ecosystems (Votier *et al.* 2010). Discards represent a significant quantity of marine catches and are usually considered waste from the Humans' point of view (Kelleher 2005). Between 1992 and 2001 Kelleher (2005) estimated that 8% of all fish caught worldwide was discarded, which represented 7.3 million tonnes of fish wasted per year. The European Union (EU) recognizes that this situation is not economically and environmentally sustainable, and the Common Fisheries Policy (CFP), which was establishes in 1983 in the European Union, proposed new aims for fishery activity and aquaculture practices as an economic and environmental sustainable policy. In the last years the CFP implemented a new policy on fishery discards management which ban the discards at sea (i.e. fishermen are thus obligated to land their discards), and should be implemented gradually between 2014 and 2019 for all commercial fisheries in the European waters (http://ec.europa.eu/fisheries/cfp/fishingrules/discards/indexen .htm).

Many seabird species interact with fishery activities, with negative and positive impacts on their ecology, breeding success or survival (Votier *et al.* 2013; Bodey *et al.* 2014). Fishing activities can cause accidental mortality through by-catch, for instance through the entanglement and drowning of seabirds in longline fisheries (Granadeiro *et al.* 2011; Cama *et al.* 2013). Sometimes fisheries and seabirds target the same pelagic fish species, such competition for food resources and potential local situations of overfishing can inflict deleterious effects on seabirds' ecology (Furness 2003), intimately leading to starvation (Grémillet *et al.* 2016). In contrast, fisheries can also provide new food resources in the form of discards which have an important role in the ecology of scavenging seabirds, representing a superabundant food source (Cama *et al.* 2012; Bicknell *et al.* 2013), predictable in space and time, and therefore very easy to obtain when compared to natural resources (Furne*ss 2*003; Oro *et al.* 2013). Species exploiting these alternative resources minimize energy spending, increase reproductive success and generally their survival (Duhem *et al.* 2003; Votier *et al.* 2013). At the same time, some populations are greatly dependent on discards, feeding on low quality prey and accumulating higher levels of contaminants associated with benthic prey, such as mercury, more than when they are feeding on pelagic prey (Arcos *et al.* 2002; Furness 2003; Grémillet et al. 2008). However, over the last decades seabirds such as gulls and skuas (i.e. typical scavengers) have taken advantage of this situation, learned to exploit this resource and adjusted their foraging behaviour associated with fishing vessels (Votier *et al.* 2010; Ceia *et al.* 2014; García-Tarrasón *et al.* 2015), and their populations have increased exponentially (Furness *et al.* 2007; Bécares *et al.* 2015).

1.2. Gulls and fishery discards

Of all scavenging seabirds, gulls (Laridae) have benefited extremely from the discards and refuse waste, and their populations have increased worldwide especially in Europe (Duhem *et al.* 2008; Ramos *et al.* 2009; Washburn *et al.* 2013). Gulls have an opportunistic behaviour, exploit different types of habitats (e.g marine, coastal and terrestrial) and feed both on natural and anthropogenic food resources (Duhem *et al.* 2003; González-Solís 2003; Ceia *et al.* 2014). The main causes for their exponential growth are the increased food availability at refuse dumps and from fishery discards, generated by the fishery industry (Bosch *et al.* 1994; Mañosa *et al.* 2004; Matias & Catry 2010; Alonso *et al.* 2015). Many gull populations have learned to exploit the discarded fish as an alternative to their natural prey (González-Solís 2003; García-Tarrasón *et al.* 2015), because it provides a locally and daily abundant food (Duhem *et al.* 2003; Pedro *et al.* 2013). However, this type of resource has seasonal variations, may influence their foraging behaviour and fitness, which may have implications on individual specialization over time (Furness 2003; Ceia *et al.* 2014; Alonso *et al.* 2015; Bécares *et al.* 2015).

Overall, the diet of top predators such as seabirds provide important information about ecosystems interactions, such as overlap between species, prey choice or current impact of commercial fisheries on population dynamics (Duffy & Jackson 1986; Iverson *et al.* 2007). A representative example of a seabird which efficiently exploited fishery discards is the Audouin's gull (*Larus audouinii*), endemic to the Mediterranean region. In the 1960's and 1970's it was considered a threatened species with only 1000 pairs (Oro *et al.* 1996; Oro *et al.* 2011). Since 1981, when the first birds established a colony at the Ebro Delta the population increased exponentially (Oro & Ruxton 2001), largely as a result of fishery activities that generated huge amounts of discarded fish. The plastic foraging behaviour of the superabundant yellow-legged gull (*Larus michahellis*, Bosch *et al.* 1994; Duhem *et al.* 2008; Meirinho *et al.* 2014) is also relevant to explain why some populations rely heavily on fishery discards. In some areas, these two species breed in sympatry, and during periods where supposedly there is a reduction of food availability, yellow-legged gull increase predation on other seabird species such as the Audouin's gull (Furness 2003; González-Solís 2003; Martínez-Abraín *et al.* 2003). Moreover, large numbers of seabirds from several scavenging species are attracted to fishing vessels to feed on discards, thus reducing or completely removing discards from the marine environment will lead to a decrease in the risk of accidental by-catch. Though, it will also imply a drastic reduction on a superabundant food resource, with anticipated deleterious effects on the individuals' body condition, breeding success and population dynamics (Bicknell *et al.* 2013). Overall, a significant reduction or complete removal of discards will impact seabird species differently (Bicknell *et al.* 2013, Votier *et al.* 2013).

1.3. Studying the spatial and trophic ecology of seabirds

Conventional dietary methods include invasive and non-invasive techniques to assess the seabirds' feeding and foraging behaviour (Barrett *et al.* 2007), and provide important information about their adaptation to the marine environment and possible overlap in the feeding niche among seabird species (Duffy & Jackson 1986). The collection of regurgitated pellets is a simple method to access diet composition and provide large sample sizes with regular collection (Barrett *et al.* 2007). Prey identifications from pellets are commonly used to study gulls' diet. (González-Solís *et al.* 1997a; Pedrocchi *et al.* 2002; Pedro *et al.* 2013; Ceia *et al.* 2014; Alonso *et al.* 2015). Gulls normally regurgitate one pellet per meal, generally containing the undigested hard remains of their prey, composed by bones, otoliths or scales (Bearhop *et al.* 2001). However, prey items can be difficult to identify if they are significantly or completely digested (Ramos *et al.* 2009). Most diet studies using pellets to reconstruct the seabirds' diet refer only to the breeding season, when samples are relatively easy to collect at the breeding location, where seabirds are accessible (Forero & Hobson 2003; Barrett *et al.* 2007; Inger & Bearhop 2008).

The study of wild animals in their natural environments is a hard task for researchers, even more when the species spend most of their time at-sea (Rutz & Hays 2009). Nowadays, technological advances resulted in high resolution Global Positioning System loggers (GPS-loggers) and other activity logging technologies, making it possible to track the free-ranging movements of animals (Shamoun-Baranes *et al.* 2011a). This technology provides high accuracy within meters of true location, 24 hours coverage

(Burger & Shaffer 2008; Tomkiewicz *et al.* 2010), and provides detail information into their movements, physiology, foraging behaviour or migration (Burger & Shaffer 2008; Shamoun-Baranes *et al.* 2011b). Additionally, marine productivity is not equally distributed across ocean basins, therefore tracking devices enable to collect information about the use of different marine areas by seabird species, which is usually related with differences in marine productivity levels (Camphuysen *et al.* 2012). Patterns of sea surface temperature (SST) and chlorophyll *a* concentration (Chl *a*) are proxies for the marine productivity (Grémillet *et al.* 2004); usually low SST and high Chl *a* concentration values are associated with a high marine productivity (Mann & Lazier 2005). High productivity areas attract zoo-plankton, marine invertebrates and small pelagic fish that in turn will be available for marine predators (seabirds, cetacean or predatory fish) and even fisheries (Weimerskirch *et al.* 2005; Grémillet et al. 2008). Additionally, spatio-temporal changes in marine productivity are responsible for the shifts in the foraging distribution of seabirds at-sea (Hyrenbach *et al.* 2002; Votier et al. 2013). Also, using GPS devices we can quantify the overlap of seabirds with anthropogenic activities (fishery activity) which as we pointed out above, can shape their foraging behaviour.

Scavenging seabirds exploit several different food resources in marine and terrestrial environments. A good example of this are gulls which forage in marine environments for natural prey and prey discarded from fishing vessels; this is the case of the AG and the YLG. Additionally, the YLG can also forage in terrestrial environments (e.g. refuse dumps; Ceia et al. 2014). Therefore, the availability of food resources can change the foraging distribution and diet composition of gulls during their annual cycle (Ramos *et al.* 2011), and will influence their population dynamics. The development of new methods, such as stable isotopic analyses (SIA), became revolutionary tools for the study of dietary and animal movement patterns in terrestrial and marine ecosystems (Kelly 2000). Traditionally, for dietary analysis the carbon ($^{13}C/^{12}C$, $\delta^{13}C$) and nitrogen ($^{15}N/^{14}N$, $\delta^{15}N$) stable isotopes have been used (Inger & Bearhop 2008). Carbon stable isotope (^{13}C) is determined for primary producers which are terrestrial (C_3, C_4, CAM) and marine plants with different photosynthetic metabolism, meaning that each one have different ^{13}C signatures. However, carbon signature of marine plants are much higher than terrestrial plants (Kelly 2000), therefore marine prey has higher values for ^{13}C than terrestrial prey

(Arizaga *et al.* 2013). These differences in the stable isotope values between primary producers are reflected along the food chain in a trophic network (Inger & Bearhop 2008). In the marine environment, carbon isotope values are typically depleted from low to high latitudes, inshore to offshore, and benthic to pelagic regions (Cherel & Hobson 2005). Thus, the ^{13}C signature provide information about the geographic distribution where consumers normally forage, and in the case of gulls it can be useful to distinguish between at-sea and inland foraging locations. In case of the nitrogen stable isotope, tissues of consumers are enriched in ^{15}N relative to the diet from which they were synthesized, and consequently this isotope defines the consumers' trophic position (Forero & Hobson 2003; Cherel *et al.* 2005b; Inger & Bearhop 2008). The variation of nitrogen values firstly depend on the primary producer, marine and terrestrial plants which have different baseline values. Marine plants tend to be enriched by about 4 ‰ relative to terrestrial plants (Kelly 2000), this variation will be influence the ^{15}N values along the food chain. Also differences in nitrogen fixation by plants influence the consumers' values (Kelly 2000). Furthermore, the number of prey taken by a predator and the trophic level at which a specific prey belongs, influences the predators' isotopic signature (Cabana & Rasmussen 1996). In species that feed in a range of ecosystems (terrestrial and marine), assigning a trophic position might be more difficult (Post 2002). In marine consumers, tissues typically enrich between 3-5 ‰ in δ^{15}N at each trophic level (Forero & Hobson 2003; Cherel & Hobson 2005; Bearhop *et al.* 2006). The YLG and AG take advantage of fishery discards, a supplementary and superabundant food resource, by feeding on prey that usually they could not obtain by themselves, such as demersal species (Bartumeus *et al.* 2010; Navarro *et al.* 2010; Arizaga *et al.* 2013). Because demersal species have higher nitrogen isotopic values when compared to pelagic species (Newsome *et al.* 2007), it is possible to discriminate whether seabirds were feeding on demersal fish from fishery discards or 'naturally caught' pelagic prey.

Based on SIA, the use of multiple tissues with different turnover rates from the same individual can provide an understanding of short and long-term isotopic niche consistency (Hobson & Clark 1993; Ramos *et al.* 2011). Stable isotope signatures of tissues usually reflect the diet and habitat use of individual at the time of tissue synthesis (Bearhop *et al.* 2004). Thus different tissues have different periods of synthesis and provide information about trophic position and habitat/resource use, over different time scales from weeks to months or years (Hobson *et al.* 1994; Inger & Bearhop 2008). For example, in a short-term, the avian plasma and red blood cells provide information about diet or habitat use, from a few days to the previous 3 to 4 weeks of the blood sample collection, respectively (Hobson & Clark 1993; Hobson 2005). Overall, traditional dietary methods combined with tracking devices and isotopic analysis, are a powerful approach to study the foraging and feeding ecology of seabirds.

1.4. The ecology of gulls in relation to fisheries

Environmental changes can shape the foraging and feeding ecology of Audouin's (AG) and yellow-legged (YLG) gulls, through the increase or decrease in the availability of food resources. There are important differences between these two species: the AG is a specialist species foraging mainly at-sea and feeding mostly on marine species, whereas the YLG is a generalist species foraging in marine and terrestrial habitats (Arcos *et al.* 2001; González-Solís 2003; Navarro *et al.* 2010). The AG is one of the few gull species with a nocturnal behaviour (Mañosa *et al.* 2004), taking profit from the shoals of clupeoids (mainly *Sardina pilchardus* and *Engraulis encrausicolus*) that are attracted by full moon and lights of fishing vessels to near the surface (Arcos & Oro 2002; Mañosa et al. 2004). Therefore, when the fishing vessels operate at night they provide a good feeding opportunity for the AG (Arcos & Oro 2002). On the other hand, the YLG is a strictly diurnal species commonly feeding on fishery discards (Oro *et al.* 1995) and other anthropogenic food resources (González-Solís *et al.* 1997b).

The foraging and feeding ecology of this two gull species was widely studied in the last years, mostly in the Mediterranean, where these two species breed in sympatry. Several studies (Gonzáles-Solís *et al.* 1997b; Arcos *et al.* 2001; Gonzáles-Solís 2003; Cama *et al.* 2012; Cama *et al.* 2013; García-Tarrasón *et al.* 2015; Bécares *et al.* 2015) reported that the presence or absence of fishery activities, but also periods with high or less fishery intensity (trawlers and purse-seiners or only trawlers, respectively) may change the foraging behaviour of these two gull species. In the presence of high fishery activity (trawlers and purse-seiners), both gull species increased the consumption on epipelagic and demersal prey items (Gonzáles-Solís 2003). On the other hand, with less fishery activity (only trawlers) the YLG decreased the intake of marine prey and increased the intake of human waste from refuse tips, and the AG fed mainly on epipelagic prey and also showed a high consumption of demersal fish derived from trawler discards (Borges *et al.* 2001). According to González-Solís *et al.* (1997b) the gulls niche can be shaped by different ranges of fishery activities: the YLG increased their niche when there are less fishery activity, thereby foraging in other habitats, and the AG did not present differences between periods with more and less fishery activity.

There is also a clear difference on daily patterns between the AG and the YLG. The AG forage during day and night, associated with some fishery activities, such as purse-seiners taking profit from the discards of these fishing practices (Arcos *et al.* 2001), and the YLG present mainly a diurnal behaviour but can also forage before dawn, exploiting the last discards from vessels returning to the harbour (Arcos *et al.* 2001; Gonzáles-Solís 2003). The density of YLG at-sea may be positively correlated with the density of trawler activities, and time of the day at which they operate (Cama *et al.* 2012). In the morning, the trawlers began their activity but with low density of vessels, which means a small amount of discards and therefore a low number of gulls following the fishing vessels. In the afternoon, the density of trawlers increases with high amounts of discards leading to an increase of gull density near the vessels, and suggesting that the YLG optimize their foraging behaviour taking profit from the fishery activity. In areas where a trawling moratorium was established or fishery activity stopped during part of day, the density of the AG decreased significantly, and birds shifted their foraging areas (Cama *et al.* 2013; Bécares *et al.* 2015). Furthermore, several studies reinforced the idea that fisheries discards are very important for the gulls diet: a) Alonso *et al.* (2015) found a positive correlation between prey fish targeted by fisheries and in the diet of YLG, such as European pilchard (*Sardina pilchardus*), Chub mackerel (*Scomber colias*), and horse/blue jack mackerel (*Trachurus spp*.), b) Pedrocchi *et al*. (2002) found a positive relationship between the occurrence of demersal fish in the diet of gulls and the activity of trawler vessels. In Portugal, European pilchard, chub mackerel and horse/blue jack mackerel are important commercial species (Borges *et al.* 2001; Cabral *et al.* 2003; Leitão *et al.* 2014).

A strong evidence that the YLG takes advantage from the fishery activities is the presence of demersal fish on their diet, such as *Merluccius merluccius* (European hake) or *Micromesistius poutassou* (Blue whiting) (Alonso *et al.* 2015). Additionally, these two fish species together with chub mackerel and blue jack mackerel constitute the major part of discards volume from the Portuguese fishing vessels when targeting horse-mackerel and European pilchard (Borges *et al.* 2001; Fernandes *et al.* 2015). This behaviour was also seen in the AG, mainly due to the high abundance of the European pilchard in its diet, which is also one of the most targeted species by fisheries.

During the last decades the increase in the population of both AG and YLG has been related with the high availability of anthropogenic resources, especially fishery discards. Additionally, the European Union is establishing a new fisheries management to ban fisheries discards at-sea gradually from 2014 to 2019 (http://ec.europa.eu/fisheries/cfp/fishing_rules/discards/index_en.htm). Therefore, it is very important to understand the consequences of this discard ban in the feeding ecology of both AG and YLG. When the discard ban is fully implemented it is expected that the YLG will feed more on refuse, potentially increasing the negative interactions with humans, and may also increase the predation pressure on vulnerable seabird species such as the AG and the Little Tern (*Sternula albifrons*). On the other hand, the AG should increase the intake of natural marine prey. This study was carry out on Barreta Island (South of Portugal), where the AG and YLG breed in sympatry and have high availability of predictable food resources from the fishery activities (Monteiro *et al.* 2001; Erzini *et al.* 2002). In order to examine the impact of the discard ban on the (I) foraging distribution (II) diet, and (III) trophic ecology of these two gull species we established two periods of data collection, workdays (full fishery activity) and weekends (very low fishery activity), and combined GPS-tracking devices, conventional dietary methods and stable isotopic analysis (carbon and nitrogen isotopic values). Concerning the foraging distribution and diet, during workdays the AG is expected to forage mostly in marine areas, feeding on pelagic fish and on demersal prey species from the fishery discards. The YLG should also forage in marine areas taking profit of the fishery discards, but could also forage in terrestrial habitats, where they could search for terrestrial invertebrates or waste from refuse tips. During weekends, the AG should keep foraging within the marine environment but increase the consumption of naturally caught prey items. On the other hand, the YLG is expected to decrease the time spend foraging at-sea and increase the percentage of time in terrestrial habitats, thereby increasing the consumption on refuse waste. Regarding the isotopic niche, the AG should exhibit a small isotopic niche, related with a more specialized diet and the YLG should show a larger isotopic niche, given the exploitation of a more diverse array of habitats and prey types. The results of this study will contribute to the future management of both gull species, especially during and after the implementation of recent legislation for the management of waste at refuse dumps (inland) and for the management and prohibition of discards (at-sea).

2. Methods

2.1. Study area

The study was conducted on Barreta or Deserta Island (36^{o} 57’ 40’’ N, 7^{o} 53’ 20’’ W) between May and June 2015. The island is one of five barrier islands within the Ria Formosa National Park, Algarve, Southern Portugal (Ceia *et al.* 2010). During the breeding season, we counted 1203 and 845 breeding pairs of Audouin’s gull (AG) and Yellow-legged gull (YLG) respectively. The Audouin’s gull reproduces mainly on the Mediterranean coast, but began breeding in the Algarve in the early 2000s, presumably as a consequence of dramatic growth of the western Mediterranean population.

Barreta Island spans approximately 7 km, and is situated 5.5 km from the mainland (Ceia *et al.* 2010). The island was artificially stabilized from the other barrier islands to improve the access to the commercial fishing port, located on the island (Olhão) (Monteiro *et al.* 2001). A range of different fishing techniques are used in the waters surrounding the colony, including trawling, purse seining and artisanal fisheries (Borges *et al.* 2001). Such range of fishing techniques leads to the production of differing quantities of fishery discards (Erzini *et al.* 2002).

Ria Formosa is not just important for the fishing industry; but also for salt extraction, aquaculture and tourism (Newton & Mudge 2005; Ceia *et al.* 2010). The region is considered a natural reservoir of biodiversity, especially for avian species, and is also important for bird migration (ICNF 2016). For this reason, the area was declared a Natural reserve in 1978, and is now part of the Natura 2000 network (Ceia *et al.* 2010).

2.2. Study species

The yellow-legged gull (*Larus michahellis*) is a large long-lived seabird (body mass ranging between 750g – 1300g), with a modal clutch size of three eggs (Sanz-Aguilar *et al.* 2009). The breeding season is from mid-March to early May; incubation lasts for 27-31 days, and the young birds fledge after 35-40 days (Sanz-Aguilar *et al.* 2009). YLGs breed mostly in the Atlantic Iberia, French coastline, along the Mediterranean and Black sea coasts, northwest Africa and Macaronesia (Cama *et al.* 2012; Meirinho *et al.* 2014). The YLG exhibit both opportunistic and generalist feeding behaviour, and forages mostly during the day (Arcos *et al.* 2001; González-Solís 2003). Individuals forage at inshore and/or offshore areas taking fish, molluscs, eggs, vegetal matter and songbirds), but also readily uses fishery discards and garbage provided by humans (Pedro *et al.* 2013; Alonso *et al.* 2015). Fishery discards caused a significant shift in their foraging habits over the last decades (Cama *et al.* 2012; Ceia *et al.* 2014), leading to a strong population increase (Oro *et al.* 1995; Duhem et al. 2008), with subsequent ecological and social impacts (Ramos *et al.* 2009). A decrease in foraging distance from the colony due to the close vicinity of nesting sites to fishery discards, had a negative impact on cities, reservoirs and fisheries (Ramos *et al.* 2009; Arizaga *et al.* 2014), but also upon smaller seabird species when the anthropogenic or alternative natural prey species become scarce (Matias & Catry 2010).Therefore, control programmes have been implemented to reduce the number of gulls in several areas especially in the largest gull colonies (Kress 1983; Smith & Carlile 1993; Bosch et al. 2000; Brooks & Lebreton 2001). However, the best control methods of gull populations is the management of food resources from human activities, i.e. fishery discards (Oro & Martínez-Abraín 2007).

The Audouin's gull (*Larus audouinii*) is a medium-sized (body mass ranging between 545g – 690g), monogamous species that typically lays a clutch of three eggs (Oro *et al.* 1999). Nowadays it is one of the few surviving endemic seabird species from the Mediterranean region (Oro *et al.* 1999; Mañosa *et al.* 2004; Cama *et al.* 2013), and was considered the most endangered seabird species, with very low population numbers, during the 1960s and 1970s (Oro & Ruxton 2001; Navarro *et al.* 2010). However, in 1981 a new colony was established in the Ebro Delta, and the population increased considerably until now (Oro *et al.* 1999; García-Tarrasón *et al.* 2015), with more than 50% of the total breeding population at the Ebro Delta (Oro *et al.* 2009; García-Tarrasón *et al.* 2015). It is thought that the combined effect of the breeding site, i.e. a protected area, and new food resources provided by fishery discards (Oro & Ruxton 2001) explain the dramatic growth of the population.

The Audouin's gull is considered an adapted specialist, taking advantage of fishery discards and terrestrial prey species (Navarro *et al.* 2010). The AG exhibits opportunistic behaviour and plasticity in its dietary choices (Christrel *et al.* 2012). Additionally, it is one of the few species in the Laridae family that uses nocturnal vision

(Mañosa *et al.* 2004; Navarro *et al*. 2010). In Mediterranean coasts, the species feeds during the night (Arcos *et al.* 2001) on small pelagic fish; mainly European pilchard and Anchovy (Mañosa *et al.* 2004), and on fishery discards, such as demersal prey (Christrel *et al.* 2012), which constitute more than 75% of its energy intake (García-Tarrasón *et al.* 2015).

In terms of predation, the species often encounters kleptoparasitism, but its main threat are terrestrial predators (Martínez-Abraín *et al.* 2003). The YLG can also compete for resources, which often leads to unsuccessful breeding attempts when the two species coexist (González-Solís *et al.* 1997b; Oro *el al.* 1999; Morales *et al.* 2012). The species is still of conservation concern, mostly due to its dependence on fishery discards and the importance of fisheries management in the surrounding of the colonies for successful breeding (BirdLife international 2015).

2.3. Fieldwork

Fieldwork took place over the first weeks of May (6st May – 17st May), with nest walking-traps being used to capture and recapture the breeding adults. Individuals were selected if their nest had a clutch of three eggs (García-Tarrasón *et al.* 2015), and were in the late incubation stage, to reduce the risk of desertion (Christrel *et al.* 2012). The adults were equipped with GPS loggers (Figure 1A; CatTraq GT-120, Perthold Engineering LLC), which weight 17g; always representing < 6 % of the adults' body mass, which was set to be an upper threshold to avoid deleterious effects on seabirds (Phillips *et al.* 2003). The GPS loggers have an accuracy of 4m and store the date, time, longitude, latitude and speed, every 2 minutes with loggers' batteries draining out in about 10 days. Devices were attached to feathers in the mantle region with Tesa® tape. All the process took less than 10 minutes, thus minimizing the overall stress to the animal. GPS-loggers were deployed on 16 birds (AG n=8; YLG n=8) which were removed 7 days. Upon retrieval, 12 birds (AG n=6; YLG n=6) were recaptured and the tracking information successfully downloaded from the devices. We recorded the positions of home range and foraging area of YLG and AG during work days (n=102 and 69 foraging trips, respectively) and weekends (n=35 and

16 foraging trips, respectively). At logger retrieval, a blood sample of about 0.5 ml to 1 ml was collected from the tarsal vein of each tracked individual (Figure 1B; AG n=6; YLG n=5).

At the breeding colony we also collected pellets found around the nests; pellets are the undigested material which includes fish vertebrae and bones, otoliths, scales, feathers (Duffy & Jackson 1986; Barret *et al.* 2007) and in some cases garbage could be found. We collected pellets from early May to late June 2015 on each Friday, to access the gulls' diet composition during workdays; and each Monday, to access the diet composition during the weekend. We previously established a transect along the colonies of both AG and YLG, which was repeated to ensure consistency on the pellets' collection during the two periods (Mondays and Fridays). A total of 211 pellets were collected from AG and YLG during the workdays (n=87 and 71, respectively) and weekends (n=20 and 33, respectively). The samples were placed in plastic bags and stored in the refrigerator until laboratory analysis.

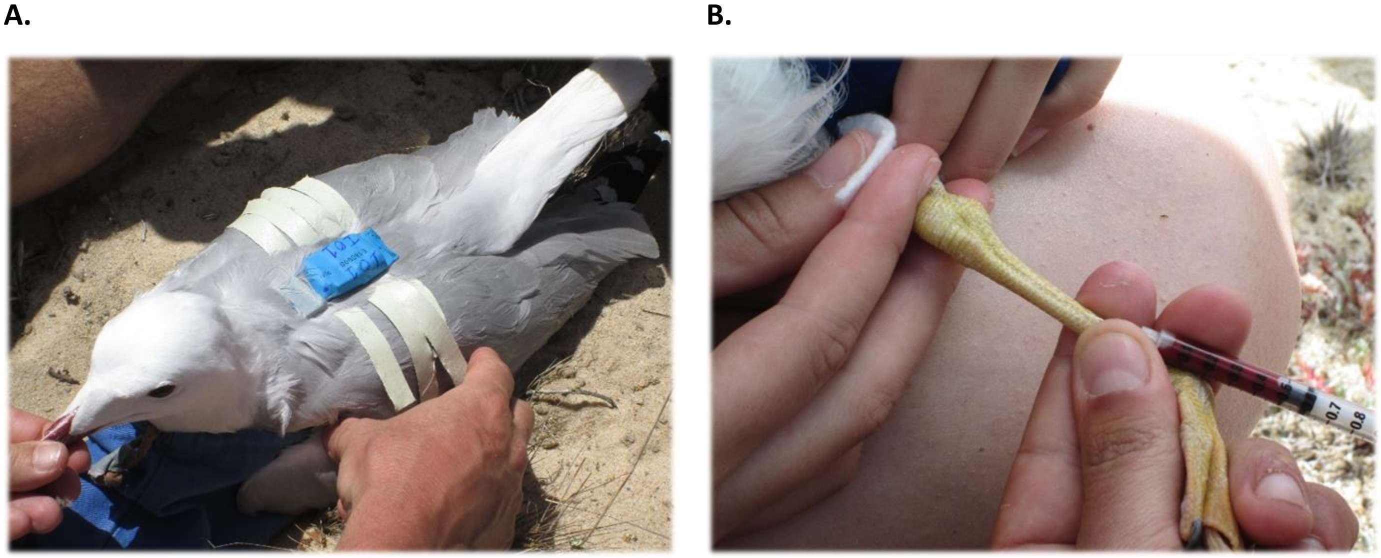

Figure 1. *Fieldwork procedures at the breeding colony* ***(A)*** *Process of logger deployment;* ***(B)*** *Collection of blood samples.*

2.4. Stable Isotope Analysis

In the laboratory, we analysed $\delta^{13}C$ (‰) and $\delta^{15}N$ (‰) stable isotopes on plasma, RBC of each gull species. The $\delta^{15}N$ is mainly used to define the trophic position of the consumer, while $\delta^{13}C$ reflects the foraging habitat of the consumer (Inger & Bearhop 2008). There is a gradient of high to low values of $\delta^{13}C$ from coast to offshore, due to the organic enrichment at the coast that is gradually diluted. Red blood cells (RBC) are regenerated every 12-22 days while plasma has a turnover rate of about 7 days, therefore RBC reflects the trophic ecology the last few weeks, and plasma reflects choices made in the last trips before sampling (i.e. around 7 days; Inger & Bearhop 2008). Blood samples were separated into plasma and RBC by centrifugation at 12000 rpm for 5 min, within 2-4 hours of sampling and stored frozen at –20 °C until preparation for analysis. Before isotopic analysis, plasma samples were treated with successive rinses in a 2:1 chloroform/methanol solution to extract external lipids (Ceia *et al.* 2012). The low lipid content of RBC (or whole blood) does not require lipid extraction (Cherel *et al.* 2007).

The relative abundance of stable isotopes of carbon and nitrogen were determined by a continuous-flow isotope ration mass spectrometer using a CF-IRMS (Isoprime, Micromass, UK). Approximately 0.35 mg of each sample were combusted in a tin cup for determination of nitrogen and carbon isotope ratios. The results are presented in the common delta (δ) notation as parts per thousand or per mil (‰) according to the equation $\delta X = [(R_{sample} / R_{standard}) - 1] \times 1000$, where the X is ^{13}C or ^{15}N, and R_{sample} is the corresponding ratio: $^{13}C/^{12}C$ or $^{15}N/^{14}N$, and $R_{standard}$ is the ratio for the international references Viena - PeeDee Belemnite (PDB) for carbon and atmospheric N_2 (AIR) for nitrogen. The analytical precision for the measurement was 0.2 ‰ for both carbon and nitrogen. All values presented are means ± 1 SD unless otherwise stated.

2.5. Diet sampling analysis

Pellets samples were examined with the aid of a stereomicroscope, and individual prey items were identified to species-level taxonomic discrimination, using vertebrae and otoliths collections from the National Museum of Natural History and Science (Lisbon) and published identification guides (Assis 2004; Tuset *et al.* 2008). We identified mainly fish species, but other marine species were found, such as crab chelae and body, cephalopod beaks, bivalves/gastropods mollusc. Inorganic material from refuse was represented by a range of items, including plastic, glass, paper, bones and organs from unknown species, wood pieces. Some of these items were probably ingested accidentally; nevertheless, they provide information on the foraging areas used by the species, and therefore were not excluded from the dietary analysis. We occasionally found in the pellet samples some vegetable remains and terrestrial prey remains, such as body remains of insects and birds.

2.6. Data analysis

Birds that are circling an area will display a lower calculated speed than the actual GPS speed, and therefore have a higher sinuosity index (Grémillet *et al.* 2004). A histogram of the sinuosity distribution was used to determine the break-off value, thus all positions with a sinuosity index ≥ 2.7 were considered foraging locations. Foraging locations were examined under the *adehabitatHR* R package (Calenge 2006) generating Kernel Utilization Distribution (Kernel UD) estimates within the R environment (R Core Team 2015). The most appropriate smoothing parameter (*h*) was chosen via least squares cross-validation for the unsmoothed GPS data, and then applied as standard for the other datasets and grid size was set at 0.04° (to match the grid of environmental predictors). We considered the 50% and 95% kernel UD contours to represent the core foraging areas (FA) and the home range (HR), respectively. The foraging trips were defined from the time the birds departed from the colony until they return, thereby, GPS points at the colony were excluded from the analysis. Also, to characterize the oceanographic conditions in areas used by the tracked individuals we extracted: (1) Bathymetry (BAT, blended ETOPO1 product, 0.03° spatial resolution, m), (2) Sea Surface Temperature (SST, Aqua MODIS NPP, 0.04°, °C), and (3) sea surface chlorophyll *a* concentration (CHL, Aqua MODIS NPP, 0.04°, mgm^{-3}). BAT was downloaded from http://ngdc.noaa.gov/mgg/global/global.html, while SST and CHL were extracted from http://oceancolor.gsfc.nasa.gov. Weekly averages were used for the dynamic variables (variables 2 – 3), matching the overall tracking period (i.e. 06/05/2016 – 17/05/2016).

The differences in trip characteristics (e.g. trip duration, time spent flying per day-1, % of time spent in foraging areas, maximum distance to the colony, minimum distance to fishing harbours, minimum distance to very high fishing intensity areas), spatial ecology parameters (species interactions and week periods), and the habitat of foraging areas (BAT, SST, CHL) were tested on breeding adults of AG and YLG with Generalized Linear Mixed Models (GLMMs). Were test the effect of week period (workdays vs weekends), species (Audouin's and yellow-legged gulls), and the interaction between week period and species on the foraging trip characteristics, spatial ecology parameters and habitat of foraging areas. For this last category we used time spent foraging on the main habitats surrounding the colony: beach, lagoon, sea, water treatment station, refuse dump and fishing harbour (arcsine transformed percentage data). Once all individual birds made multiple trips, was used the trip identity as a random term to avoid potential pseudo-replication problems in all GLMMs. Gaussian distribution of error terms and a log-link function were used in the modelling. Post-hoc multiple comparisons with Bonferroni correction were used to identify significant differences between categories of each independent variable. Computations were carried out using several functions within different R packages used in the GLMMs were *lme4* (Bates *et al.* 2014) and *lmerTest* (Kuznetsova *et al.* 2016).

To illustrate the AG and YLG daily patterns we established two representative time intervals, which are related with different fishing activities. The night period, between 20h – 08h, related with the departure of purse-seiners at 20h-22h and their arrival at 04h-07h. The diurnal period, between 08h-20h, associated with the activity of trawlers and multi-gillnet. In all cases the gulls and fishing activity was compared between workdays (full fishery activity) and weekends (very low fishery activity).

To evaluate the diet in relation with different fishing activities we separated the pellets in two periods, workdays and weekends, and the following prey categories were used: fish, insects, vegetal remains, refuse, birds species, and others (Include: Brachyura, Cephalopoda, Bivalve/Gastropoda). We divided the fish in two groups, pelagic and demersal fish. The frequency of occurrence (FO%) was calculated as the percentage of pellets with a certain prey type, and the numeric frequency (NF%) as the percentage of the number of individuals of each species in relation to the total number of individuals (Alonso *et al.* 2013). The numeric frequency was calculated in two manners, including all items and including only fish prey. All analyses were separated for workdays and weekends, to evaluate the differences between these two periods. We assessed differences in the occurrence of the main prey (e.g. *Scomberosox saurus* / *Belone belone*, *Scomber spp.*, *Micromesistius poutassou*, *Diplodus spp*.) of the AG and YLG gull diet with Generalized Linear Models (GLM), evaluating the effect of species (AG vs YLG), week period (workdays vs weekends), and the interaction between species and week period. All analyses were performed assuming a significance level of $P \leq 0.05$.

We compared the δ^{13}C and δ^{15}N values of red blood cells and plasma of tracked yellow-legged and Audouin's gulls with MANOVAs (Wilk's lambda), followed by factorial ANOVAs, separately for carbon and nitrogen isotope ratios, with post-hoc Bonferroni pairwise comparisons to identify significant differences among tissues. Moreover, to establish the isotopic niche width of each tracked individual (Jackson *et al.* 2011), based on the isotopic signatures of RBC and plasma, we used metrics available within SIBER (Stable Isotope Bayesian Ellipses in R). The area of the standard ellipse (SEAc), was calculated after small sample size correction, to compare estimated isotopic niches among species and annual phases (pre-laying and incubation), and Bayesian estimate of the standard ellipse and its area (SEA_B) to test differences between tissues (e.g. *p*, the proportion of ellipses of Audouin's gull rbc which were lower than in Audouin's gull plasma, for 10^4 replicates ; (see (Jackson *et al.* 2011) for more details), and to measure the overlap of the isotopic niches among gull species and blood tissues (Jackson *et al.* 2011; Parnell *et al.* 2010). We used the computational code to calculate the metrics from SIBER implemented in the package SIAR (Parnell et al. 2010). All the metrics were calculated using *standard.ellipse* and *convexhull* functions from the *siar* package (Stable

Isotope Analysis in R; (Parnell *et al.* 2010)).

Throughout the results, all values are presented as mean ± SD, unless otherwise stated. All statistical analyses were carried out in R (Version 3.01) (R Core Team 2015). Response variables were tested for normality (Q-Q plots) and homogeneity (Cleveland dotplots) before each statistical test and transformed when needed (Zuur *et al.* 2010). All analyses were performed assuming a significance level of $P \leq 0.05$.

3. Results

Photo: Lucas Krüger

3.1. Foraging patterns and habitat use

Both gull species, the Audouin's (AG) and yellow-legged (YLG), spent most of their time foraging at-sea, over the continental shelf (Figure 2). The YLG foraged from Quarteira harbour to Tavira Island, and the AG foraged from Península do Ancão to Vila Real de Santo António, and there was some spatial segregation between the two species. The YLG also foraged in terrestrial habitats, and visited the refuse dump of Portimão (Figure 2; Figure 3A and B).

In general, AG performed significantly longer trips (in distance and time), foraged farther from the colony (50% kernel UD), closer to very high fishing areas (Figure 2; Figure 3A), and from fishing harbour[3], and spent more time on the foraging areas when compared to YLG (Figure 3A and B; Table 1; Table 2). Comparing the two week periods, both species spent most of their time at-sea, with significantly lower trip durations, and staying closer to fishing harbours[1] during workdays, when compared with weekends (50% kernel UD; Figure 3A and B; Table 1; Table 2). On workdays YLG had a larger home range (95% kernel UD) than on weekends, contrary to AG that increase their home range on weekends (Figure 3A). Analysing the interaction of species*week period, the AG spent more time at-sea, foraged farther from the colony (i.e. in pelagic areas) and therefore closer to areas with a high fishery activity (Figure 2) during weekends when compared with workdays, and the YLG in both week periods (50% kernel UD; Figure 3A; Table 2). During this period YLG foraged closer to the fishing harbours[1] than on workdays and AG in both periods (Figure 3B; Table 2).

AG overlapped significantly more in their foraging area (FA; 50% Kernel UD) when compared to YLG, and this overlap was higher during weekends than during workdays (Table 1; Table 2). The influence of week period on the overlap within each species was also higher for the AG on weekends (91.2%), with a lowest value for YLG on weekends (58.7%). Plus, AG foraged over significantly deeper and more productive (higher Chl *a*) waters when compared with YLG, and this difference occurred mostly during weekends than during workdays (Table 1; Table 2).

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[3] http://www.worldportsource.com/ports/MAR.php

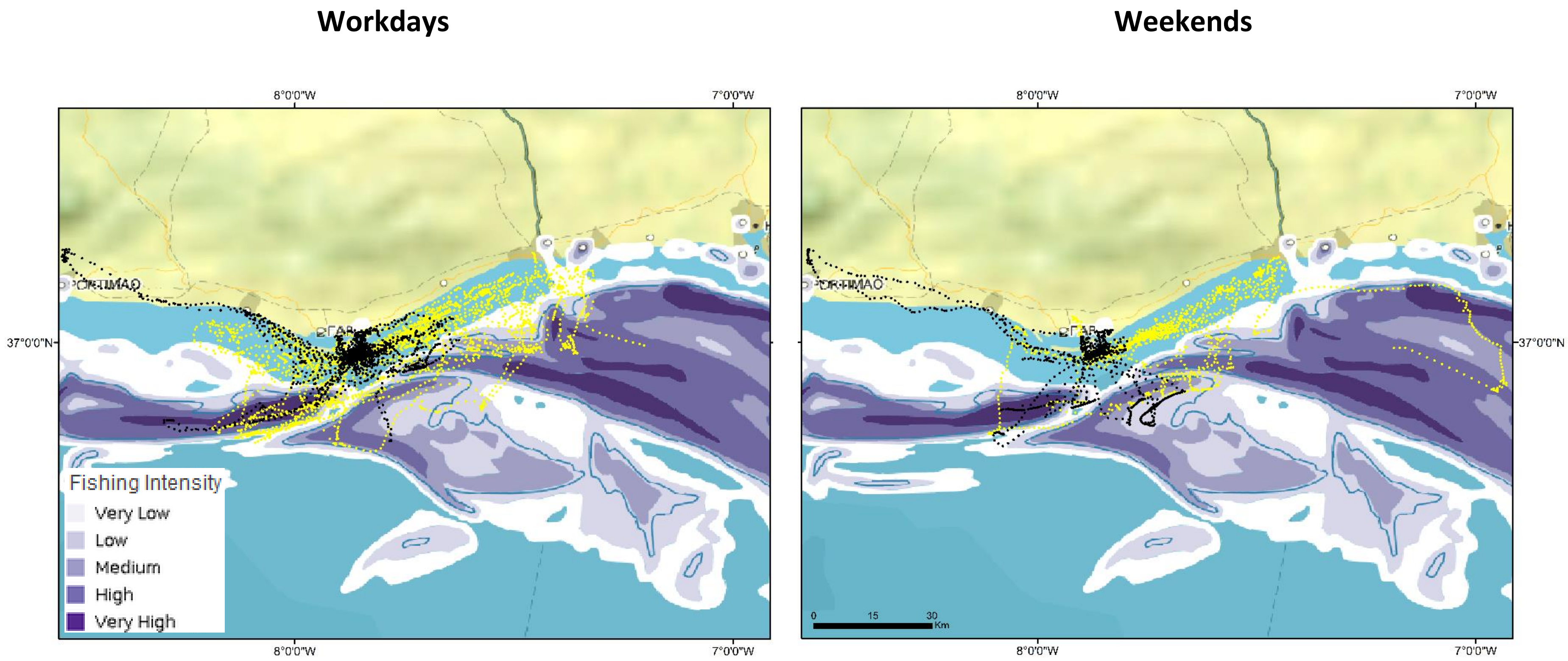


Figure 2*. GPS-locations of yellow-legged (YLG; black colour; n=6 birds) and Audouin's (AG; yellow colour; n=6 birds) gulls foraging movements during workdays (n=102 and 69 foraging trips, respectively) and weekends (n=35 and 16 foraging trips, respectively) of May 2015, overlaid on a map of high fishing intensity areas (https://bluehub.jrc.ec.europa.eu/mspPublic/).*

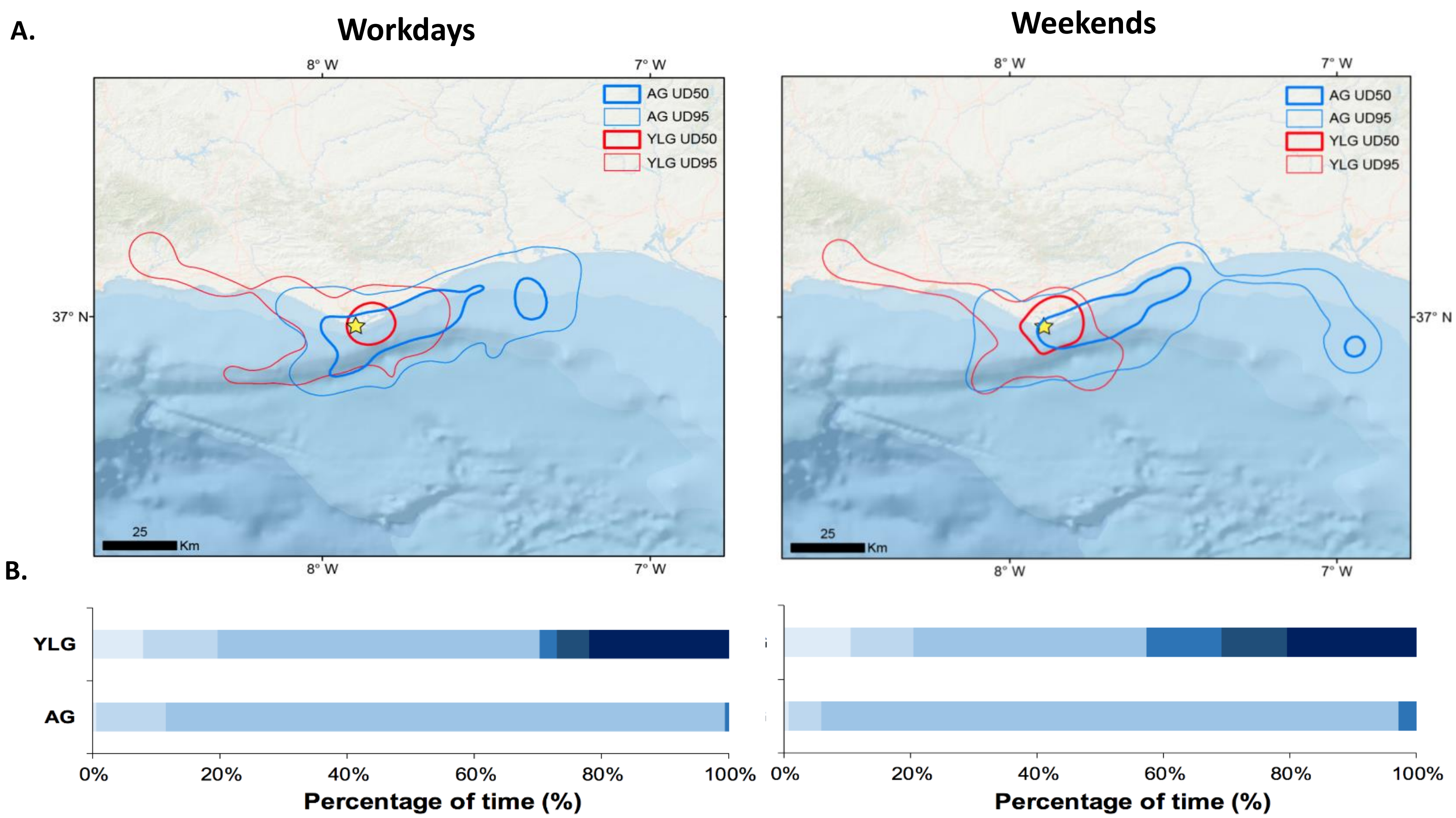


Figure 3. **A-** Home range (thin line; 95% Kernel UD) and foraging area (thick line; 50% Kernel UD) of yellow-legged (YLG; red colour; n=6 birds) and Audouin's (AG; blue colour; n=6 birds) gulls during workdays (n=102 and 69 foraging trips, respectively) and weekends (n=35 and 16 foraging trips, respectively) of May 2015, overlaid on bathymetry. Star indicates the breeding colony at Deserta barrier-island, Faro, Portugal. **B-** Time spend per day (%) by yellow-legged (YLG) and Audouin's (AG) gull on the six main foraging destinations. Treat. Station – Water treatment station

Table 1. *Mean (±SD) foraging trip characteristics of yellow-legged (YLG) and Audouin's (AG) gulls in May (incubation period) of 2015. FA – core Foraging Area; 50% Kernel Utilization Distribution. Environmental predictors for 06/05/2016 – 17/05/2016.*

	Workdays		**Weekend**	
Variables	**YLG**	**AG**	**YLG**	**AG**
Foraging trip characteristics				
N tracks [N birds]	102 [6]	69 [6]	35 [6]	16 [6]
Trip duration (h)	1.8 ± 0.6	3.7 ± 1.2	2.2 ± 1.3	3.9 ± 1.6
Time spent flying per day^{-1}(h)	5.2 ± 2.1	6.8 ± 2.2	3.9 ± 1.7	8.3 ± 2.8
% of time spent in foraging areas	33.1 ± 9.5	43.2 ± 9.8	23.7 ± 8.8	51.7 ± 7.2
Max. distance to colony (km)	25.1 ± 5.6	48.2 ± 11.1	15.2 ± 7.5	54.9 ± 12.4
Min. distance to fishing harbours (km) [#]	25.6 ± 7.6	45.8 ± 6.4	9.4 ± 2.9	50.9 ± 9.8
Min. distance to very high fishing intensity areas (km)*	22.4 ± 4.3	20.2 ± 4.7	28.9 ± 3.7	15.9 ± 2.9
Spatial ecology parameters				
FA overlaps within the same week period and species (%)	75.4 ± 9.3	89.1 ± 9.9	58.7 ± 12.1	91.2 ± 7.2
FA overlaps between week periods and within the same species (%)	69.9 ± 7.5	79.2 ± 8.8	—	—
FA overlaps within the same week period and between species (%)	40.1 ± 9.2		17.2 ± 8.4	
Habitat of foraging areas (within FA)				
Bathymetry (BAT; m)	167.2 ± 14.8	245. ± 24.2	88.2 ± 20.9	322.1 ± 19.3
Chlorophyll *a* concentration (Chl a; mg m^{-3})	1.2 ± 0.8	2.0 ± 0.5	0.9 ± 0.4	2.4 ± 0.9
Sea Surface Temperature (SST; $^{\circ}$C)	20.8 ± 3.5	19.8 ± 3.3	20.1 ± 2.4	19.2 ± 2.3

[#] http://www.worldportsource.com/ports/MAR.php

*See depicting the outputs of the EU Blue Hub project – the first high-resolution map of fishing intensity areas covering all EU waters (https://bluehub.jrc.ec.europa.eu/mspPublic/)

Table 2. *Generalized Linear Mixed Models (GLMMs) testing the effect of the interaction between species (yellow-legged gulls – YLG and Audouin gulls – AG) and week period (workdays and weekends) on foraging trip characteristics and habitat characteristics of foraging areas. FA – core Foraging Area; 50% Kernel Utilization Distribution (50 Kernel UD). Environmental predictors for May 2015. The individual was used as a random effect to avoid pseudo-replication issues. Significant results in* ***bold****. Main effect was evaluated with Post-hoc multiple comparisons Bonferroni corrected tests.*

	Species			**Week period**			**Species *week period**		
Variables	**GLMM**	**P**	**Main effect**	**GLMM**	**P**	**Main effect**	**GLMM**	**P**	**Main effect**
Foraging trip characteristics									
N tracks [N birds]	—	—	—	—	—	—	—	—	—
Trip duration (h)	$F_{3,218}$ = 8.41	**< 0.001**	AG > YLG	$F_{3,218}$ = 2.62	**0.05**	workdays < weekends	$F_{3,218}$ = 2.0	0.09	—
Time spent flying per day^{-1}(h)	$F_{3,218}$ = 3.90	**0.01**	AG > YLG	$F_{3,218}$ = 2.01	0.09	—	$F_{3,218}$ = 1.87	0.14	—
% of time spent in foraging areas	$F_{3,218}$ = 5.42	**< 0.001**	AG > YLG	$F_{3,218}$ = 1.75	0.17	—	$F_{3,218}$ = 3.05	**0.03**	AG weekends > all others
Max. distance to colony (km)	$F_{3,218}$ = 4.11	**0.01**	AG > YLG	$F_{3,218}$ = 1.14	0.34	—	$F_{3,218}$ = 3.91	**0.01**	AG weekends > all others
Min. distance to fishing harbours (km) [#]	$F_{3,218}$ = 3.37	**0.02**	AG > YLG	$F_{3,218}$ = 4.15	**0.01**	workdays < weekends	$F_{3,218}$ = 3.88	**0.01**	YLG weekends < all others
Min. distance to very high fishing intensity areas (km)*	$F_{3,218}$ = 3.91	**0.01**	AG < YLG	$F_{3,218}$ = 1.46	0.22	—	$F_{3,218}$ = 2.89	**0.04**	AG weekends < all others
Spatial ecology parameters									
FA overlaps within the same week period and species (%)	$F_{3,218}$ = 4.98	**0.001**	AG > YLG	$F_{3,218}$ = 1.69	0.18	—	$F_{3,218}$ = 3.37	**0.02**	AG weekends > all others
FA overlaps between week periods and within the same species (%)	—	—	—	—	—	—	—	—	—
FA overlaps within the same week period and between species (%)	—	—	—	—	—	—	—	—	—
Habitat of foraging areas (within FA)									
Bathymetry (BAT; m)	$F_{3,69}$ = 4.09	**0.01**	AG > YLG	$F_{3,69}$ = 1.38	0.26	—	$F_{3,69}$ = 3.57	**0.02**	AG weekends > all others
Chlorophyll *a* concentration (Chl *a;* mg m^{-3})	$F_{3,69}$ = 6.69	**< 0.001**	AG >YLG	$F_{3,69}$ = 1.19	0.33	—	$F_{3,69}$ = 3.18	**0.03**	AG weekends > all others
Sea Surface Temperature (SST ^{o}C)	$F_{3,69}$ = 1.64	0.19	—	$F_{3,69}$ = 2.04	0.12	—	$F_{3,69}$ = 1.21	0.30	—

[#]http://www.worldportsource.com/ports/MAR.php ; *****See depicting the outputs of the EU Blue Hub project – the first high-resolution map of fishing intensity areas covering all EU waters (https://bluehub.jrc.ec.europa.eu/mspPublic

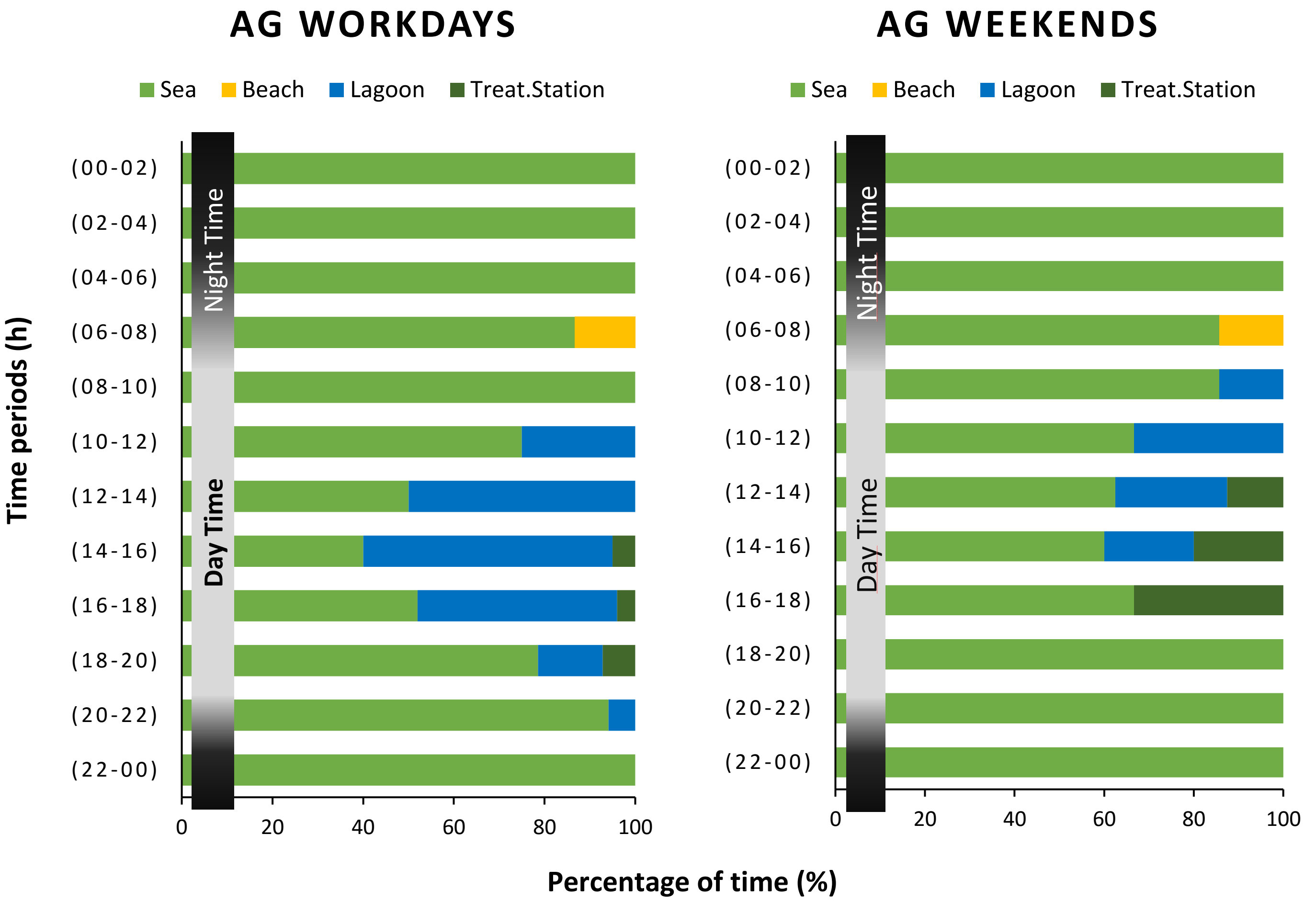


Figure 4. *Percentage of time spent (within 2h slots) in different foraging habitats by Audouin gulls (AG) during workdays and weekends. Treat.station – water treatment station.*

During workdays (Figure 4) the AG concentrated their activity at sea, particularly during the night period; during the morning and day central hours (10h-18h) they decreased their activity at sea, and increased the time on the lagoon. During weekends (Figure 4) their activity was also higher at night, however, during day central hours they spent more time at sea and on resting sites (water treatment station) than on workdays.

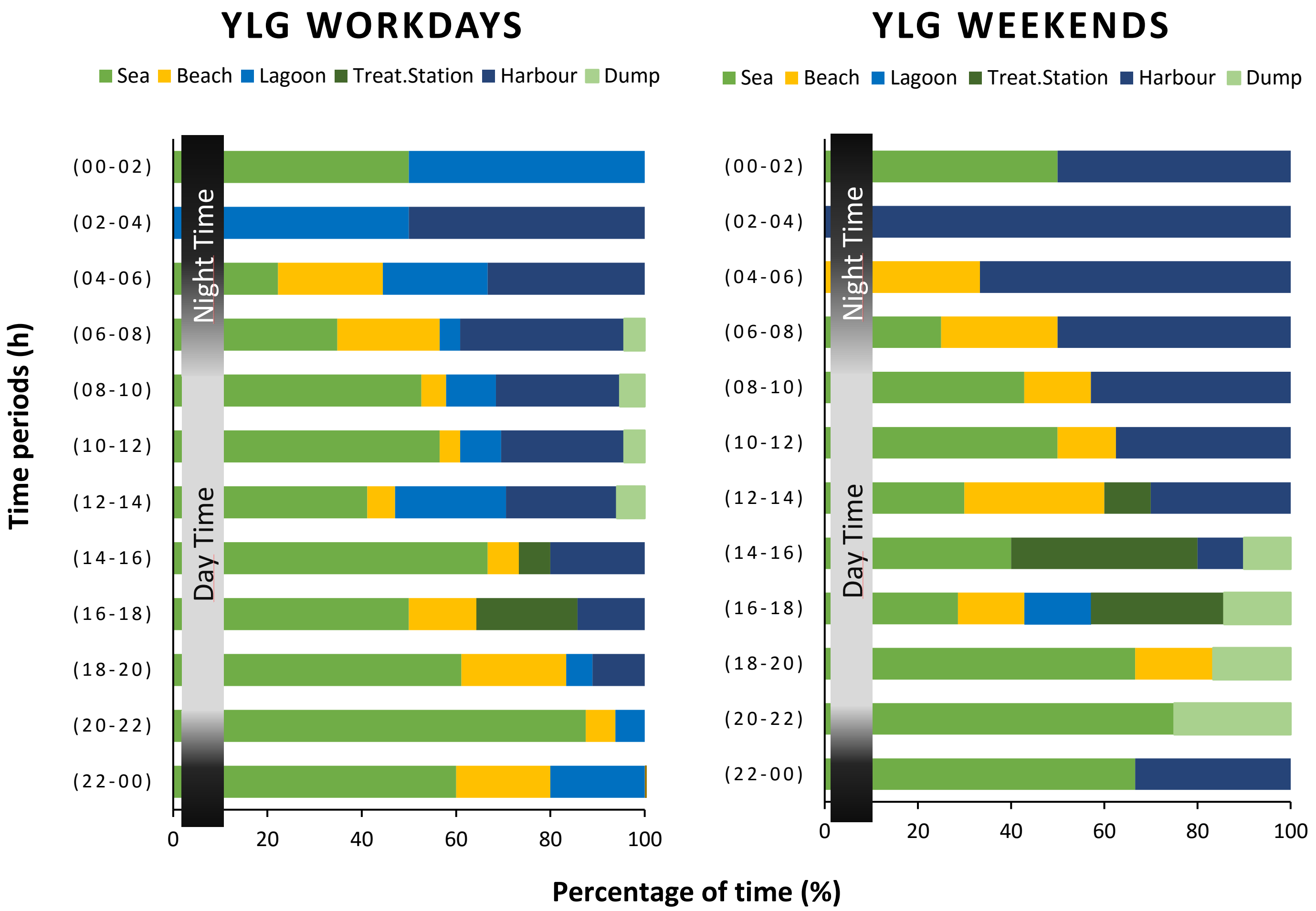


Figure 5. *Percentage of time spent (within 2h slots) in different foraging habitats by yellow-legged gulls (YLG) during workdays and weekends. Treat.station – water treatment station.*

Regarding the YLG, their daily patterns differed from the AG, which exhibited mainly a diurnal pattern. During workdays (Figure 5), the YLG was active at sea from dawn (04h-06h) onwards, and was particularly active on the main fishing harbours from 02 to 04 h, and also throughout the day. Additionally, the YLG concentrated their activity at sea when the purse-seine vessels left the harbour (20h-22h). On workdays birds spent more time on the lagoon than on weekends. During weekends (Figure 5), YLG concentrated their activity at sea from late afternoon until 00h-02h, and from 02-04 h, 100% of their time was spent on the main fishing arbours. During the diurnal period, the YLG spent more time at sea, particularly in late afternoon, and also on refuse dumps and resting sites (treat. station water) than on workdays.

3.2. Comparison of diet between workdays and weekends

During both workdays and weekends fish was the most abundant prey item found in the pellets of both the AG and the YLG (Table 3; Table 4; Figure 6). On workdays there was a greater variability of prey orders in the diet of both gull species, which was more evident in the diet of YLG (Figure 7). During weekends there was a reduction in the variability of prey found in both gull species (Table 3; Table 4; Figure 6). The occurrence of others prey items clearly differed between workdays and weekends. On weekends, the YLG increased the consumption of insects, refused waste, and vegetal remains, while AG increased the consumption of other prey groups, such as Brachyura, Cephalopoda and Bivalve/Gastropoda (Table 3; Table 4; Figure 6).The occurrence of fish differed between species, and also between workdays and weekends (Table 3). AG kept feeding on fish from workdays to weekends (100% F.O. in both periods), while YLG had a more varied diet, and roughly 2/3 of their diet was based on fish and 1/3 on other prey items, such as insects or refuse tips (Table 3). The numerical frequency of fish in the diet of YLG dropped 26% from workdays to weekends (Table 4). In terms of numerical frequency pelagic prey maintained at higher values, in both workdays and weekends, for the AG than for the YLG. In relation to the demersal prey the AG maintained quite similar values between the two week periods. However, the consumption of demersal prey by YLG differed between the two week periods, with an important reduction from workdays to weekends in all analysis (Table 4).

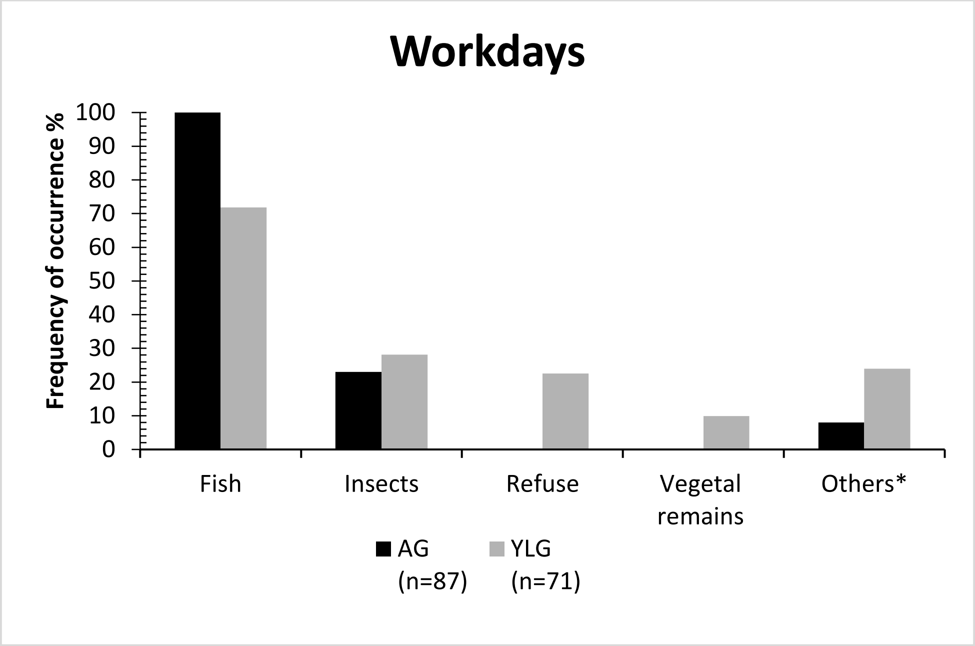
Table 3. *Comparison of the Frequency of occurrence (FO; %) between workdays and weekends of all items present in pellets of the Audouin's (AG) and yellow-legged (YLG) gulls.*

	FO %			
	Workdays		Weekends	
Prey	AG (n=87)	YLG (n=71)	AG (n=20)	YLG (n=33)
Pelagic	88.5	53.5	80.0	60.6
Sardina pilchardus	26.4	14.1	-	27.3
Scomberesox sarus/Belone belone	48.3	2.8	70.0	18.2
Scomber spp.	14.9	19.7	5.0	21.2
Trachurus spp.	9.2	11.3	10.0	9.1
Myctophum punctatum	2.3	-	5.0	9.1
Engraulis encrasicolus	2.3	-	-	3.0
Gadiculos argenteus	9.2	4.2	10.0	3.0
Demersal	47.1	40.9	40.0	42.4
Pagrus sp.	-	2.8	-	-
Micromesisitius poutassou	24.1	26.8	20.0	15.2
Diplodus spp.	19.5	14.1	20.0	27.3
Serranus sp.	12.6	5.6	15.0	3.0
Halobatrachus sp.	-	-	5.0	-
Lithognathus mormyrus	2.3	4.2	-	-
Conger conger	6.9	1.4	-	-
Arnoglossus laterna	-	2.8	-	-
Boops boops	5.8	1.4	10.0	6.1
Chelon labrosus	-	2.8	-	3.0
Citharus linguatula	-	2.8	-	-
Coelorinchus caelorinchus	4.6	2.8	5.0	3.0
Gobius sp.	2.3	1.4	5.0	3.0
Capros aper	2.3	-	-	-
Dicentrarchus spp.	-	1.4	-	-
Phycis spp.	-	2.8	-	3.0
Merluccius merluccius	3.5	7.0	-	3.0
Mullus surmuletos	-	1.4	-	-
Zeus faber	-	2.8	-	-
Marcroramphosus scolopax	-	1.4	-	-
Echiichtys vipera	-	2.8	-	-
Cepola macrophathalma	1.2	-	-	-
Unidentified fish	32.2	29.6	40.0	33.3
Total of fish	100.0	73.2	100.0	81.8
Others				
Insects	23.0	28.2	15.0	51.5
Others*	8.1	18.3	25.0	6.1
Vetegal remains	-	9.9	-	24.2
Refuse		18.3	5.0	42.4
Bird species	-	5.6	-	6.1
Unidentified	2.3	2.8	10.0	3.0

**Include: Brachyura, Cephalopoda, Bivalve/Gastropoda.*

Table 4. *Comparison of numeric frequency (NF; %) between workdays and weekends of all items present in pellets of the Audouin's (AG) and yellow-legged (YLG) gulls (All items), and calculated also considering only the fish prey (Fish). *Include: Brachyura, Cephalopoda, Bivalve/Gastropoda*

	NF %							
	All items				**Fish**			
	Workdays		**Weekends**		**Workdays**		**Weekends**	
Prey	**AG (n=335)**	**YLG (n=229)**	**AG (n=84)**	**YLG (n=177)**	**AG (n=297)**	**YLG (n=146)**	**AG (n=66)**	**YLG (n=72)**
Pelagic	49.3	24.5	50.0	19.8	55.6	38.4	63.6	59.7
Sardina pilchardus	10.4	9.6	-	6.8	11.8	15.1	-	16.7
Scomberesox sarus/Belone belone	28.1	3.1	41.7	4.5	31.6	4.8	53.0	11.1
Scomber spp.	3.9	7.0	1.2	4.0	4.4	11.0	1.5	9.7
Trachurus spp.	2.4	3.5	2.4	1.7	2.7	5.5	3.0	4.2
Myctophum punctatum	0.6	-	1.2	6.2	0.7	-	1.5	15.3
Engraulis encrasicolus	0.6	-	-	0.6	0.7	-	-	1.4
Gadiculos argenteus	3.3	1.3	3.6	0.6	3.7	2.1	4.5	1.4
Demersal	30.7	39.3	28.6	13.0	34.7	61.6	36.4	40.3
Pagrus sp.	-	0.9	-	-	-	1.4	-	-
Micromesisitius poutassou	9.2	17.5	6.0	6.8	12.1	27.4	7.6	16.7
Diplodus spp.	6.6	4.8	6.0	5.1	7.4	7.5	7.6	12.5
Serranus sp.	3.6	2.2	3.6	0.6	4.0	3.4	4.5	1.4
Halobatrachus sp.	-	-	1.2	-	-	-	1.5	-
Lithognathus mormyrus	0.6	1.3	-	-	0.7	2.1	-	-
Conger conger	1.8	0.4	-	-	2.0	0.7	-	-
Arnoglossus laterna	-	1.3	-	-	-	2.1	-	-
Boops boops	1.5	0.4	2.4	1.1	1.7	0.7	3.0	2.8
Chelon labrosus	-	0.9	-	0.6	-	1.4	-	1.4
Citharus linguatula	-	0.9	-	-	-	1.4	-	-
Coelorinchus caelorinchus	3.0	1.3	8.3	0.6	3.4	2.1	10.6	1.4
Gobius sp.	0.9	0.4	1.2	0.6	1.0	0.7	1.5	1.4
Capros aper	0.6	-	-	-	0.7	-	-	-
Dicentrarchus spp.	-	0.4	-	-	-	0.7	-	-
Phycis spp.	-	0.9	-	0.6	-	1.4	-	1.4
Merluccius merluccius	1.2	3.1	-	0.6	1.3	4.8	-	1.4
Mullus surmuletos	-	0.4	-	-	-	0.7	-	-
Zeus faber	-	0.9	-	-	-	1.4	-	-
Marcroramphosus scolopax	-	0.4	-	-	-	0.7	-	-
Echiichtys vipera	-	0.9	-	-	-	1.4	-	-
Cepola macrophathalma	0.3	-	-	-	0.3	-	-	-
Unidentified fish	8.7	9.6	10.7	6.8	-	-	-	-
Total of fish	88.7	73.4	89.3	47.5	-	-	-	-
Others								
Insects	9.6	19.2	6.0	50.9	-	-	-	-
Others*	1.5	5.2	4.8	0.6	-	-	-	-
Vetegal remains	-	-	-	-	-	-	-	-
Refuse	-	-	-	-	-	-	-	-
Bird species	-	2.2	-	1.1	-	-	-	-
Unidentified	-	-	-	-	-	-	-	-



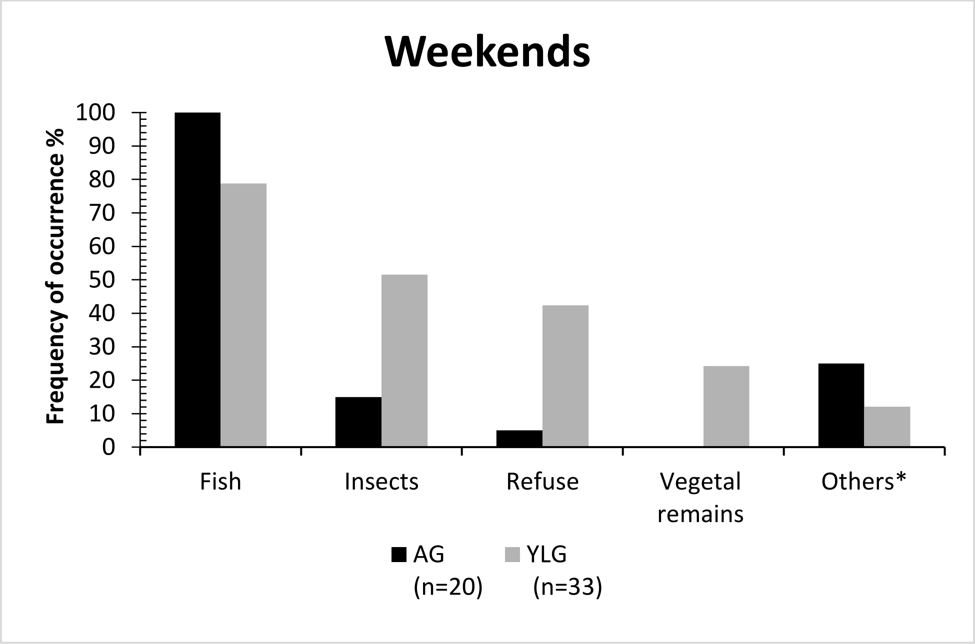


Figure 6. *Frequency of occurrence (FO; %) of the different prey items found in pellets of the Audouin's (AG; black) and YLG (YLG; grey) gulls during workdays and weekends.*

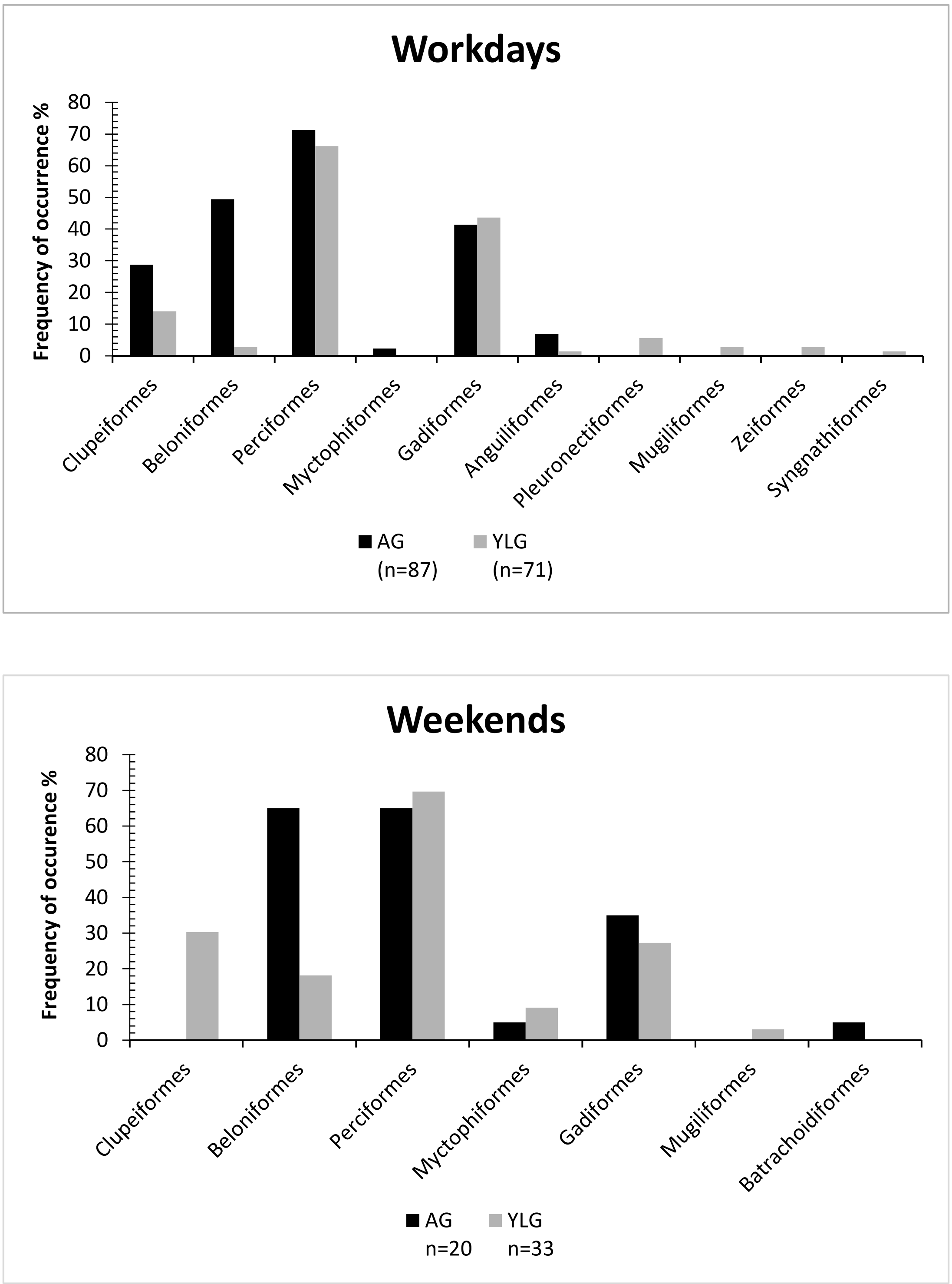


Figure 7. Frequency of occurrence (FO; %) of the fish orders found in pellets of Audouin's (AG; black) and yellow-legged (YLG; grey) gulls, during workdays and weekends.

The GLM analysis showed that Atlantic saury / garfish (*Scomberosox saurus* / *Belone belone*) had a higher importance in the AG diet mostly on weekends, and a much lower importance for YLG during workdays (Table 5). In turn, the mackerels (*Scomber* spp.) were more important for YLG than AG; the week period did not influenced their occurrence, but the interaction between species and week period showed a significantly lower occurrence during the weekends for AG (Table 5). There was an effect of week period and interaction species*week period on the occurrence of blue whiting (*Micromesistius poutassou*) and seabreams (*Diplodus* spp.): a) blue whiting was more consumed on workdays than weekends, and YLG had a lower consumption of this species during weekends (Table 5), and b) seabreams were more consumed on weekends than workdays, and were more consumed by YLG on weekends (Table 5).

Table 5. *General Linear Models (GLM) testing the effect of the interaction between species (yellow-legged gulls – YLG and Audouin gulls – AG) and week period (workdays and weekend) on the occurrence of the main prey items on the Gulls' pellets (see Table 4).*

	Species			**Week period**			**Species * week period**		
Prey	**$F_{3,207}$**	**P**	**Main effect**	**$F_{3,207}$**	**P**	**Main effect**	**$F_{3,207}$**	**P**	**Main effect**
Scomberesox saurus /Belone belone	3.88	**0.01**	AG > YLG	5.56	**0.001**	workdays < weekends	3.35	**0.02**	YLG workdays < all others
Scomber spp.	5.78	**0.001**	AG < YLG	2.01	0.12	—	3.05	**0.03**	AG weekends < all others
Micromesistius poutassou	2.45	0.10	—	3.30	**0.02**	workdays > weekends	3.46	**0.02**	YLG weekends < all others
Diplodus spp.	1.90	0.16	—	5.69	**0.001**		3.76	**0.01**	YLG weekends > all others

3.3. Trophic ecology

The stable isotope signature (Table 6) revealed that breeding adults of the AG and YLG differed between the two blood tissues (plasma vs rbc) (MANOVA, Wilk's lambda, $F_{2,17} = 7.80$, $P = 0.003$). There were no significant differences between species (MANOVA, Wilk's lambda, $F_{2,17} = 0.15$, $P = 0.86$), and no interaction between species and blood tissues (MANOVA, Wilk's lambda, $F_{2,17} = 0.75$, $P = 0.49$). Regarding carbon and nitrogen isotope, a factorial ANOVA revealed a significant effect of tissue on the nitrogen values ($F_{2,18} = 5.53$, $P = 0.03$), but no significant effect of species or interaction between species and tissue on both the carbon and nitrogen signatures (all $F < 1.58$, $P > 0.22$).

Table 6. *Stable isotope $\delta^{15}N$ and $\delta^{13}C$ (mean ± SD; ‰) values and C:N ratio of tissues for Audouin's (AG) and yellow-legged (YLG) gulls from Deserta barrier-Island (Portugal) during May (incubation period) 2015.*

Species and tissue	N	$\delta^{13}C$ ± SD	$\delta^{15}N$ ± SD	C:N
Audouin's gull (AG)				
Red blood cells (rbc)	6	-18.0 ± 0.3	12.5 ± 0.4	3.2
Plasma	6	-18.4 ± 0.5	12.9 ± 0.6	3.1
Yellow-legged gull (YLG)				
Red blood cells (rbc)	5	-18.3 ± 0.6	12.3 ± 0.9	3.4
Plasma	5	-18.1 ± 0.5	13.2 ± 0.5	3.0

The overlap on the isotopic niche was lower for the YLG plasma and AG rbc (4.4%), and higher for the YLG and AG rbc (93.9%), and showed also a much larger isotopic niche during the pre-laying period (rbc) for the YLG than for the AG. The niche width using AG plasma (incubation) was significantly larger than that of AG rbc (pre-laying) (SEA_B: $P = 0.03$; Figure 8). Furthermore, there was an enrichment of nitrogen isotope from the pre-laying to incubation for both species.

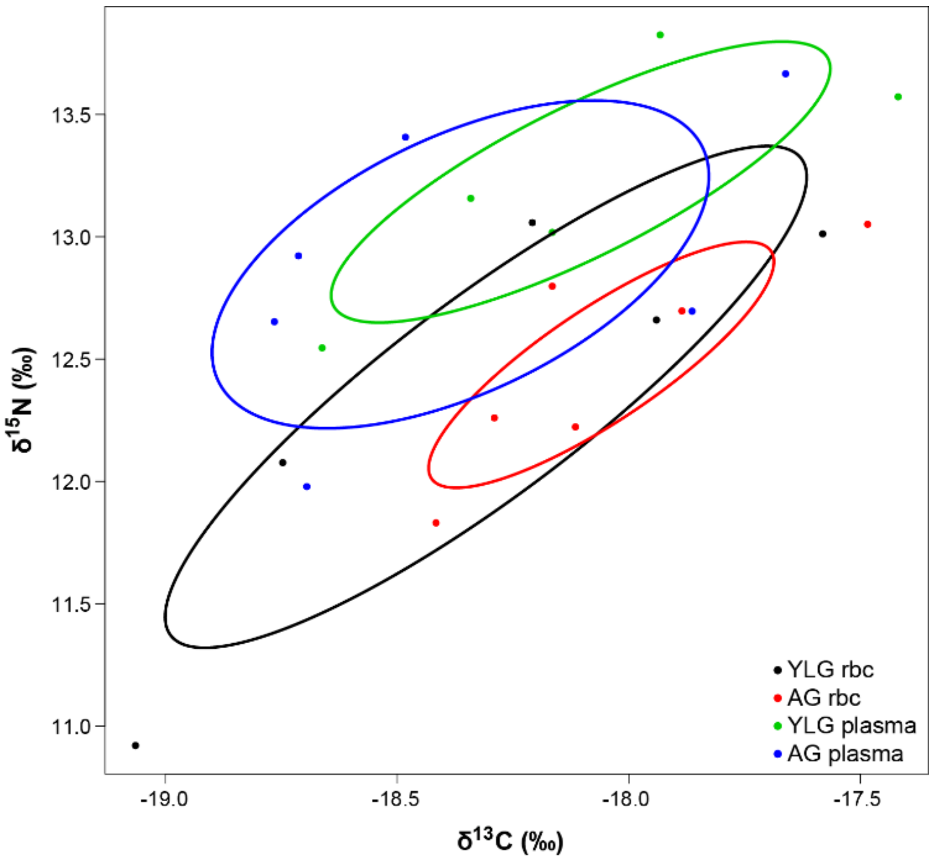


Figure 8. *Isotopic niches of yellow-legged (YLG) and Audouin (AG) gulls, based on Jackson et al. (2011) applied to Stable Isotopic ratios in red blood cells (rbc; pre-laying and incubation periods) and plasma (plasma; incubation period). The area of the standard ellipses (SEAc) is represented.*

4. Discussion

The present work reports on the spatio-temporal differences in the foraging distribution and diet of Audouin’s (AG) and yellow-legged (YLG) gulls during the breeding period. Moreover, we investigated how periods of full fishery activity (i.e. workdays) and very low fishery activity (i.e. weekends) influenced the foraging distribution and diet composition of both species.

This study also confirmed the marine foraging behaviour of AG, even when fishery activity decreased, while YLG had a more generalist foraging behaviour, particularly in the (almost) absence of fishing activity (i.e. during weekends), foraging in both marine and terrestrial environment. However, YLG individuals foraged mainly at-sea, and the prey items consumed were mainly from the marine environment, in contrast with studies in other areas of the Iberian Peninsula (Ramos *et al.* 2009; Ceia *et al.* 2014; Alonso *et al*. 2015).

4.1. Spatial and temporal distribution of gulls in the presence of different fishery densities

In the Algarve, fisheries (mainly purse-seiners/ multi-gillnets) operate from Monday to Saturday morning and stop on Sunday, and trawlers do not operate on weekends (DOCAPESCA 2015, unpublished data). We established two periods with high and low fishery activity, workdays and weekends, respectively. In general Audouin’s and yellow-legged gull showed a foraging plasticity, and their foraging patterns were more similar during workdays, i.e. when food resources were more abundant (Gonzaléz-Solís *et al.* 1997b). During recent decades fishery activity increased exponentially, with fishery discards becoming more predictable in space and time. A large number of species took advantage of such an increase in food resources and shifted their foraging patterns, increasing their foraging activity during events of high fishing activity (Gonzaléz-Solís *et al*. 1997b; Hüppop & Wurm 2000; Arcos & Oro 2002; Votier *et al.* 2010).

The majority of fishing vessels in Portugal (91%) are smaller than 12m and operate only until 6 miles (~9km) from shore (DGRM 2016). Therefore, during workdays (full fishery activity), the AG and YLG were active on at-sea foraging areas that matched mainly with this area. It is clear that both gull species learned to exploit these resources, presumably due to the high availability of discards – a super-abundant and predictable food source – easier to obtain than capturing natural prey. Although the YLG also foraged inland, on fishing harbours and refuse dumps, similarly to the YLG breeding in Berlenga Island (Ceia *et al.* 2014), it concentrated their foraging activity at-sea. The AG exhibited a much larger foraging range at-sea than the YLG (this study) and other gull species from northern Europe (e.g. Lesser black-backed gulls *Larus fuscus*; Kubetzki & Garthe 2003). During weekends (very low fishery activity), supposedly a period with low food availability (at least the super-abundant food supply provided by fishery discards is almost absent), AG kept foraging on marine areas and travelled farther from the colony, foraging over increasingly pelagic habitats. Interestingly, the same species breeding in the delta del Ebro (southern Spain) shifted their foraging distribution to rice fields, preying on American crayfish *Procambarus clarkii* in the absence of fishery activity (Bécares *et al.* 2015; García-Tarrasón *et al.* 2015). On the other hand, during weekends the YLG increased their foraging area and the time spent in other environments, such as fishing harbours, refuse dumps or the resting sites (treat. station water), and decreased the time spend at-sea when compared to workdays. González-Solis *et al.* (1997b), showed that the foraging niche of AG and YLG overlap more during periods with a full fishery activity (purse-seiners and trawlers). Our results suggest the same pattern for workdays, i.e. the niche overlap increased between the two gull species when there was a full fishing activity.

The fishery activity appeared to define the gulls' daily routine. During workdays, our results contrast with previous studies for colonies in the western Mediterranean, which refer a predominant diurnal activity for the AG (Bécares *et al.* 2015). In our study the activity of purse-seiners was not determined exactly, but the AG were particularly active at-sea during the night, increasing their activity from 20h-22h when the vessels left the fishing harbours, suggesting that gulls could follow the fishing vessels and take advantage of fisheries since they start operating at-sea. The same behaviour was suggested by Arcos & Oro (2002). The AG decreased the activity during the middle of the day between 10h-12h and 16-18h, when birds were supposedly resting on the lagoon close to the colony. Nevertheless, they kept exhibiting some activity at-sea, probably feeding on discards from trawlers and multi-gillnets (González-Solís *et al.* 1997b), since purse-seiners usually stop their activity during this period of the day. At night, AG can feed on species that make vertical migrations, such as clupeiforms (Pedrocchi *et al.* 2002), which present one peak at dawn and other peak at dusk. This should contribute to explain why some birds left the colony at dawn or before midnight (Mañosa *et al.* 2004). On the other hand, as we expected, the YLG showed a diurnal activity: some individuals started their activity at dawn (04h-06h), going to the sea or visiting the fishing harbours to take advantage of the last discards from the purse-seiners landing their catches, as reported for YLG breeding in the Mediterranean (González-Solís 2003), or from vessels that began their activity, such as trawlers and multi-gillnets. Finally, the reason why YLG species used beaches in early morning and late afternoon, might be related with discarded fish that comes ashore, as noticed by Alonso *et al.* (2015) for YLG using beaches on the Portuguese west coast.

During weekends, with a decrease of fishery activity, a change in the foraging movements and daily patterns of both species was visible. AG kept their foraging activity during the night, from late afternoon to early morning mostly from 18h-20h until 08h-10h, likely determined by the fishing activity and also the vertical migration of prey species. During the weekend there was a decrease of fishing activities, and contrary to the study of Bécares *et al.* (2015), the AG foraged farther from the colony and spent more time in foraging areas, which led to an increase of time at-sea during day central hours. The YLG maintained their diurnal activity, left the colony in early morning to venture at sea or fishing harbours. However, during weekends, i.e. in the absence or a strong reduction in the number of fishing boats going to sea, the YLG stayed on the harbour until early morning. Moreover, the YLG spent more time on refuse dumps during the weekends, when fishing activities decreased, and this was also reported for the YLG in Mediterranean colonies when fishery activity decreases (González-Solís *et al.* 1997b).

4.2. Dietary differences between week periods

Overall, our results suggest a similar diet to that of most AG colonies in the western Mediterranean, where the main prey type is fish (González-Solís *et al.* 1997a; Pedrocchi *et al.* 2002; Navarro *et al.* 2010). However, the main prey species differed between colonies: in Barreta Island the main fish prey were *Scomberesox saurus* / *Belone belone* (Beloniform fishes), which were also the main prey for the species in 2015 (Calado 2015), while AG in the western Mediterranean feed mostly on European pilchard S*ardina pilchardus* (a Clupeiform fish; González-Solís *et al.* 1997a; Pedrocchi *et al*. 2002). The main prey item for the YLG was fish, but it had an overall generalist diet, as reported for other colonies in mainland Portugal (Alonso *et al.* 2015), Azores archipelago (Pedro *et al.* 2013) and western Mediterranean (Ramos *et al.* 2009), where the species also feeds on terrestrial prey (e.g. land snails) or refuse tips (Pedro *et al.* 2013). Moreover, it is interesting to notice that the main prey of YLG breeding in Berlenga and Galicia is the Henslow's swimming crab *Polybius henslowii* (Munilla 1997; Ceia *et al.* 2014; Alonso *et al.* 2015): in years of decreased availability of such prey, birds increased the consumption of refuse waste and terrestrial invertebrates, investing on a more generalist diet.

Both YLG and AG are species with an opportunistic and plastic foraging behaviour, mostly taking profit from food resources made available through human activities, i.e. from refuse dumps or discarded fish from fisheries (Alonso et al. 2015); González-Solís *et al.* 1997b; González-Solís 2003; Ramos *et al.* 2009). The Audouin's and yellow-legged gull showed differences between workdays and weekends. When analysing the diet composition from pellets, AG kept consuming the same prey fish during workdays and weekends, however, the consumption of *Scomberesox saurus*/*Belone belone* (Beloniformes), increased from workdays to weekends. In fact, these species are heavily discarded by purse-seiners in the Algarve, due to their low commercial value (Borges *et al.* 2001; Erzini *et al.* 2002), and thus should be made available for AG. Purse-seiners operate during the night and AG should take advantage of this, as revealed from their nocturnal foraging activity (Mañosa *et al.* 2004). During weekends, the density of fishing vessels decreased, and the AG might have exploited the few discards that were produced, and presumably also captured *Scomberesox saurus* and *Belone belone*, as these are epipelagic species. Contrary to AG, YLG had a low occurrence of the *Scomberesox saurus* and *Belone belone* on their diet, similarly to what happens with YLG breeding in Berlenga (Alonso *et al.* 2015). Moreover, there was an increase in the category “others prey items” (Brachyura, Cephalopoda, Bivalve/Gastropoda) on weekends, i.e. when the fishery activity decreased.

European pilchard *Sardina pilchardus* and Mackerels *Scomber* spp. are the main species targeted and landed by fisheries in the south of Portugal, and are also frequently discarded (Borges *et al.* 2001; Erzini *et al.* 2002). During workdays, pellets of AG contained a high percentage of European pilchard and Mackerels, in contrast with weekends, when both fish species occurred much less, supposedly because of the strong reduction in the number of fishing vessels operating on weekends (DOCAPESCA 2015, unpublished data). The European pilchard and mackerels were also the main fish items in the diet of YLG, both during workdays and weekends. It is unclear how YLG keep the percentage of both prey species in the diet, when there are much less fishing activity, but it might be related with (1) the few fishing vessels operating during weekends, and thus they kept feeding on discards or (2) preying naturally on those species.

Interestingly, lanternfish *Myctophum punctatum* appeared in the diet of both AG and YLG, but this is a species not targeted by fisheries and is rarely discarded (Borges *et al.* 2001; Monteiro *et al.* 2001; Erzini *et al.* 2002). This is an oceanic fish species, usually associated with upwelling regions, that performs vertical migrations at night (http://www.fishbase.org/). As reported by Calado (2015), this prey species was found in the diet of AG during both week periods, which is an evidence of the nocturnal foraging behaviour of AG. Additionally, YLG seem to feed on this prey species only during weekends. Because YLG do not forage at night it was almost impossible for them to capture this prey naturally. However, Ramos *et al.* (1998) proposed that seabirds like yellow-legged gulls, common terns or roseate terns feed on myctophids because some individuals die during the vertical migration and stay afloat, and thus are available for seabirds during the day.

The blue whiting *Micromesistius poutassou* and seabreams *Diplodus* spp, were the most consumed demersal fish species by both gull species during both week periods. Since these are bottom fish species, they can only be available for gulls through discards, and indeed these species are known to be highly discarded by purse-seiners and trawlers in the Algarve (Borges *et al.* 2001; Monteiro *et al.* 2001; Leitão *et al.* 2014). Also, *Dicentrarchus* spp., *Pagrus* sp., and *Zeus faber*, commercial fish species are occasionally discarded (Borger *et al.* 2001), and just occurred in the diet of YLG on workdays. The diversity of demersal species was much higher during workdays than during weekends, presumably because of the strong decrease in the fisheries activity during weekends. In fact, trawlers do not operate during weekends and only purse-seiners and multi-gillnets operate until Saturday (DOCAPESCA 2015, unpublished data), with purse-seiners generating less discards than trawlers (Borges *et al.* 2001). A similar diet pattern for both weekends and workdays occurred when a trawling moratorium was implemented on the Mediterranean Sea (Oro *et al.* 1995; Oro *et al.* 1996). In that study, when trawlers were not operating, the AG and YLG decreased the consumption of demersal fish species and increased the consumption of pelagic prey or terrestrial prey items, in the case of the YLG. Moreover, during workdays the YLG fed on a higher diversity of demersal species when compared to AG, as also reported by González-Solis *et al.* (1997b).

During weekends YLG increased the consumption of waste but not as much as we expected, in relation to other YLG colonies such as Berlenga Island, where birds increased greatly the percentage of refuse when the main prey decreased (Ceia *et al.* 2014; Alonso *et al.* 2015). Because both colonies (Berlenga and Deserta Island in the Algarve) have similar densities of fishery activity, this difference might be explained by the distance to refuse dumps, as shown by Ramos *et al.* (2009) for YLG breeding in Mediterranean islands (e.g Ebro Delta, Medes, Columbretes, and Mazarrón), The tourism may also have an important role in changing the gulls feeding ecology (Neves *et al.* 2006; Pedro *et al.* 2013), but this is likely to be of low importance in our study because Barreta Island is a touristic area without a human settlement.

4.3. Isotopic niche segregation between species

Overall, SIA results revealed no differences between AG and YLG species, which suggests that both species foraged in similar habitats and consumed the same species, thus exhibiting a similar trophic ecology. This was corroborated with the tracking information, with both species mainly exploiting the marine environment, though some YLG individuals foraged over refuse dumps and fishing harbours. Regarding trophic ecology the diet overlap between the two gulls species, might be explained by their feeding on the same prey or the consumption of different prey but with similar isotopic signatures (Bearhop *et al.* 2004). With conventional methods (i.e. identification of prey from pellets) we noticed a high percentage of fish prey in both species' diet, but more pronounced in AG than YLG, besides fish represented more than half of the YLG diet composition.

The AG and the YLG did not showed short-term differences in their foraging areas between the pre-laying and incubation periods, but showed significant differences in feeding ecology between these two periods. During the pre-laying period (i.e. stable isotopic values from red blood cells) the AG and YLG niche largely overlapped, but the YLG showed a larger isotopic niche when compared to AG, supporting the idea of a generalist and specialist ecology, respectively, which was (again) also corroborated by the tracking and dietary information. During incubation there was less overlap between species than during the pre-laying period, and this might be related with some segregation in their feeding ecology. Our results suggest differences in nitrogen isotope values, with an increase from pre-laying to incubation period for both species, which means that both species increased the consumption of high trophic level prey. For both AG and YLG, this might be related with an increase in the consumption of demersal fish from the fisheries discards, which usually shows high values for the nitrogen isotope (Navarro *et al.* 2010). Plus, YLG might also prey on high nitrogen value items from refuse dumps and increase their nitrogen signature from pre-laying to incubation, as previously reported for YLG breeding in Berlenga (Ceia *et al.* 2014). In contrast with our results, Calado (2015) did not found differences between pre-laying and incubation period in both species, suggesting that the inter-annual environmental variability might play a role in shaping the trophic ecology of both gull species (Ramos *et al.* 2015).

The trophic niche of YLG was much larger during the pre-laying than during the incubation period, because during pre-laying the individuals are not constrained by parental duties and thus can display comparatively larger foraging ranges. This behaviour was also reported in other seabird species, such as Cory's shearwaters *Calonectris borealis* (Paiva *et al.* 2010) or Audubon's shearwaters *Puffinus lherminierii* (Ramos *et al.* 2015). Moreover, the fact that AG increased and YLG decreased their trophic niches from pre-laying to incubation, might suggest a decrease in food availability (Mañosa *et al.* 2004), with the resultant increase in spatial segregation between species (González-Solís *et al.* 1997b) in response to the constrain of becoming central-place foragers (Orians *et al.* 1979). This suggests that AG might lose in competition for resources (i.e. fishery discards) in relation to YLG, and thus have to widen its spatial and isotopic niches (Arcos *et al.* 2001; González-Solís 2003).

4.4. Synthesis and applications

In our study we detected consistency between the GPS data and dietary methods, which revealed mostly a marine diet for both gull species, and this was supported by isotopic analysis because we did not find dietary and spatial segregation between AG and YLG. However, the isotopic niche of YLG was much larger than the AG, which was also confirmed by the GPS data. Therefore, we detected a great influence of fishery activities on the distribution, daily activity patterns, and diet of Audouin's and yellow-legged gull. The data presented here for fisheries cannot properly assessed the real position of fishing vessels or foraging relative to scavenging on fishing vessels, but a strong association between gulls and fishery activity was apparent given the main activity periods of the fishing boats operating in the Algarve.

Fisheries activities may provide an easier and predictable food resource for scavenging seabirds in the short-term, but in the long-term, with an overexploitation of fish stocks, the availability of natural prey to seabirds will reduce (Arcos *et al.* 2008). Commercial fisheries have a huge impact on the fish stocks and overall environmental quality of the oceans (Pauly et al. 2002; Kelleher 2005). The new European scenario for the fisheries discards is to reduce the pressure on marine invertebrate and vertebrate populations and rebuild fishery industry with economic and environmental sustainability (Kelleher 2005). Despite the importance of fisheries to sustain the main breeding population of the AG and YLG through discards, this new coming scenario of no fishery discards at-sea does not seem to be a good measure for them.

Both gull species relied heavily on discards, and this new European scenario is likely to have a negative impact on the populations of both species. The AG should be the most affected because this species has mainly a marine feeding behaviour and does not have other predatory skills as the YLG. Several authors refer that the increase of the AG population in the western Mediterranean was due to a high fishery activity (Arcos *et al.* 2008). Regarding the YLG, in contrast to other authors, our birds exhibited a marine foraging behaviour even when fishery activity decreased, therefore, this population should also be strongly affected by a discard ban. The new discard ban scenario could also imply predation by the YLG on eggs and chicks of AG and other vulnerable seabird breeding species in the Algarve such as the Little Tern *Sternula albifrons*. Preying on other seabirds is a well-known behaviour of YLG throughout its range (Martínez-Abraín *et al.* 2003; Catry *et al.* 2004; Sanz-Aguilar *et al.* 2009).

Ideally, this new fishery policy should be implemented gradually and closely monitored in order to facilitate the species adaptation and minimize possible negative effects on the seabird communities. Overall, the population of YLG should decrease to lower levels and the conflicts with humans are also likely to decrease (Wilhelm et al. 2016). It will be interesting to study whether the YLG will return to a more natural diet or whether it will revert to feed on other prey, with a likely increase of conflicts with humans.

References

Alonso, H., Almeida, A., Granadeiro, J. P., & Catry, P. (2015). Temporal and age-related dietary variations in a large population of yellow-legged gulls *Larus michahellis*: implications for management and conservation. *European Journal of Wildlife Research*, *61*(6), 819-829.

Alonso, H., Granadeiro, J. P., Ramos, J. A., & Catry, P. (2013). Use the backbone of your samples: fish vertebrae reduces biases associated with otoliths in seabird diet studies. *Journal of Ornithology*, *154*(3), 883-886.

Arcos, J. M., & Oro, D. (2002). Significance of fisheries discards for a threatened Mediterranean seabird, the Balearic shearwater *Puffinus mauretanicus*. *Marine Ecology Progress Series*, *239*, 209-220.

Arcos, J. M., Louzao, M., & Oro, D. (2008). Fisheries ecosystem impacts and management in the Mediterranean: seabirds point of view. American Fisheries Society, In *American Fisheries Society Symposium*, Vol. 49, No. 2, p. 1471.

Arcos, J. M., Oro, D., & Sol, D. (2001). Competition between the yellow-legged gull *Larus cachinnans* and Audouin's gull *Larus audouinii* associated with commercial fishing vessels: the influence of season and fishing fleet. *Marine Biology*, *139*(5), 807-816.

Arcos, J. M., Ruiz, X., Bearhop, S., & Furness, R. W. (2002). Mercury levels in seabirds and their fish prey at the Ebro Delta (NW Mediterranean): the role of trawler discards as a source of contamination. *Marine Ecology Progress Series*, *232*, 281-290.

Arizaga, J., Aldalur, A., Herrero, A., Cuadrado, J. F., Díez, E., & Crespo, A. (2014). Foraging distances of a resident yellow-legged gull (*Larus michahellis*) population in relation to refuse management on a local scale. *European journal of wildlife research*, *60*(2), 171-175.

Arizaga, J., Herrero, A., Galarza, A., Hidalgo, J., Aldalur, A., Cuadrado, J. F., & Ocio, G. (2010). First-year movements of yellow-legged gull (*Larus michahellis lusitanius*) from the southeastern Bay of Biscay. *Waterbirds*, *33*(4), 444-450.

Arizaga, J., Jover, L., Aldalur, A., Cuadrado, J. F., Herrero, A., & Sanpera, C. (2013). Trophic ecology of a resident yellow-legged gull (*Larus michahellis*) population in the Bay of Biscay. *Marine environmental research*, *87*, 19-25.

Assis, C. A. (2004). Guia para a identificação de algumas famílias de peixes ósseos de Portugal continental, através da morfologia dos seus otólitos sagitta. Câmara Municipal de Cascais.

Barrett, R. T., Camphuysen, K. C., Anker-Nilssen, T., Chardine, J. W., Furness, R. W., Garthe, S., & Veit, R. R. (2007). Diet studies of seabirds: a review and recommendations. *ICES Journal of Marine Science: Journal du Conseil*, *64*(9), 1675-1691.

Bartumeus, F., Giuggioli, L., Louzao, M., Bretagnolle, V., Oro, D., & Levin, S. A. (2010). Fishery discards impact on seabird movement patterns at regional scales. *Current Biology*, *20*(3), 215-222.

Bates, D., Mächler, M., Bolker, B., & Walker, S. (2014). Fitting linear mixed-effects models using lme4. *arXiv preprint arXiv:1406.5823*.

Batista, M. I., e Costa, B. H., Gonçalves, L., Henriques, M., Erzini, K., Caselle, J. E., & Cabral, H. N. (2015). Assessment of catches, landings and fishing effort as useful tools for MPA management. *Fisheries Research*, *172*, 197-208.

Bearhop, S., Adams, C. E., Waldron, S., Fuller, R. A., & MacLeod, H. (2004). Determining trophic niche width: a novel approach using stable isotope analysis. *Journal of Animal Ecology*, *73*(5), 1007-1012.

Bearhop, S., Phillips, R. A., McGill, R., Cherel, Y., Dawson, D. A., & Croxall, J. P. (2006). Stable isotopes indicate sex-specific and long-term individual foraging specialisation in diving seabirds. *Marine Ecology Progress Series*, *311*, 157-164.

Bearhop, S., Thompson, D. R., Phillips, R. A., Waldron, S., Hamer, K. C., Gray, C. M., & Furness, R. W. (2001). Annual variation in great skua diets: the importance of commercial fisheries and predation on seabirds revealed by combining dietary analyses. *The Condor*, *103*(4), 802-809.

Bearhop, S., Waldron, S., Votier, S. C., & Furness, R. W. (2002). Factors that influence assimilation rates and fractionation of nitrogen and carbon stable isotopes in avian blood and feathers. *Physiological and biochemical zoology*, *75*(5), 451-458.

Bécares, J., García-Tarrasón, M., Villero, D., Bateman, S., Jover, L., García-Matarranz, V., & Arcos, J. M. (2015). Modelling Terrestrial and Marine Foraging Habitats in Breeding Audouin's Gulls *Larus audouinii*: Timing Matters. *PloS one*, *10*(4), e0120799.

Bellido, J. M., Santos, M. B., Pennino, M. G., Valeiras, X., & Pierce, G. J. (2011). Fishery discards and bycatch: solutions for an ecosystem approach to fisheries management? *Hydrobiologia*, *670*(1), 317-333.

Bicknell, A. W., Oro, D., Camphuysen, K. C., & Votier, S. C. (2013). Potential consequences of discard reform for seabird communities. *Journal of Applied Ecology* 50(3) 649-658.

BirdLife International (2015). 2015 European red list: *Larus audouinii*. Download from www.birdlife.org (Acceded: 29-01-2016).

Bodey, T. W., Jessopp, M. J., Votier, S. C., Gerritsen, H. D., Cleasby, I. R., Hamer, K. C., & Bearhop, S. (2014). Seabird movement reveals the ecological footprint of fishing vessels. *Current Biology*, *24*(11), R514-R515.

Borges, T. C., Erzini, K., Bentes, L., Costa, M. E., Gonçalves, J. M. S., Lino, P. G., & Ribeiro, J. (2001). By-catch and discarding practices in five Algarve (southern Portugal) métiers. *Journal of Applied Ichthyology*, *17*(3), 104-114.

Bosch, M., Oro, D., Cantos, F. J., & Zabala, M. (2000). Short-term effects of culling on the ecology and population dynamics of the yellow-legged gull. *Journal of Applied Ecology*, *37*(2), 369-385.

Bosch, Marc, Oro, Daniel, & Ruiz, Xavier (1994). Dependence of yellow-legged gulls (*Larus cachinnans*) on food from human activity in two western Mediterranean colonies. *Avocetta*. Nº18, 135-139.

Brooks, E. N., & Lebreton, J. D. (2001). Optimizing removals to control a metapopulation: application to the yellow legged herring gull (*Larus cachinnans*). *Ecological Modelling*, *136*(2), 269-284.

Burger, A. E., & Shaffer, S. A. (2008). Perspectives in Ornithology Application of Tracking and Data-Logging Technology in Research and Conservation of Seabirds. *The Auk*, *125*(2), 253-264.

Cabana, G., & Rasmussen, J. B. (1996). Comparison of aquatic food chains using nitrogen isotopes. *Proceedings of the National Academy of Sciences*, *93*(20), 10844-10847.

Cabral, H., Duque, J., & Costa, M. J. (2003). Discards of the beach seine fishery in the central coast of Portugal. *Fisheries Research*, *63*(1), 63-71.

Calado, J. (2015). Stable isotopes and regurgitations reveal differential consumption of fishery discards by yellow-legged and Audouin's gulls breeding in sympatry. MSc Thesis in Ecology – Faculdade de Ciências e Tecnologia, Universidade de Coimbra. Coimbra, 2015, 98pp.

Calenge, C. (2006). The package "adehabitat" for the R software: a tool for the analysis of space and habitat use by animals. *Ecological modelling*, *197*(3), 516-519.

Cama, A., Abellana, R., Christel, I., Ferrer, X., & Vieites, D. R. (2012). Living on predictability: modelling the density distribution of efficient foraging seabirds. *Ecography*, *35*(10), 912-921.

Cama, A., Bort, J., Christel, I., Vieites, D. R., & Ferrer, X. (2013). Fishery management has a strong effect on the distribution of Audouin's gull. *Marine Ecology Progress Series*, *484*, 279-286.

Camphuysen, K. C., Shamoun-Baranes, J., Bouten, W., & Garthe, S. (2012). Identifying ecologically important marine areas for seabirds using behavioural information in combination with distribution patterns. *Biological Conservation*, *156*, 22-29.

Catry, T., Ramos, J. A., Paiva, V. H., Martins, J., Almeida, A., Palma, J., & Luís, A. (2006). Intercolony and annual differences in the diet and feeding ecology of little tern adults and chicks in Portugal. *The Condor*, *108*(2), 366-376.

Catry, T., Ramos, J.A., Catry, I., Allen-revez, M. and Grade, N. (2004). Are salinas a suitable alternative breeding habitat for Little Terns? *Ibis* 146, 247-257.

Ceia, F. R., Paiva, V. H., Fidalgo, V., Morais, L., Beata, A., Crisóstomo, P., & Ramos, J. A. (2014). Annual and seasonal consistency in the feeding ecology of an opportunistic species, the yellow-legged gull (*Larus michahellis*). *Marine Ecology Progress Series*. *497*, 273-284.

Ceia, F. R., Patrício, J., Marques, J. C., & Dias, J. A. (2010). Coastal vulnerability in barrier islands: The high risk areas of the Ria Formosa (Portugal) system. *Ocean & Coastal Management*, *53*(8), 478-486.

Ceia, F. R., Phillips, R. A., Ramos, J. A., Cherel, Y., Vieira, R. P., Richard, P., & Xavier, J. C. (2012). Short-and long-term consistency in the foraging niche of wandering albatrosses. *Marine biology*, *159*(7), 1581-1591.

Cherel, Y., & Hobson, K. A. (2005). Stable isotopes, beaks and predators: a new tool to study the trophic ecology of cephalopods, including giant and colossal squids. *Proceedings of the Royal Society of London B: Biological Sciences*, *272*(1572), 1601-1607.

Cherel, Y., Hobson, K. A., & Hassani, S. (2005b). Isotopic discrimination between food and blood and feathers of captive penguins: implications for dietary studies in the wild. *Physiological and Biochemical Zoology*, *78*(1), 106-115.

Cherel, Y., Hobson, K. A., Bailleul, F., & Groscolas, R. (2005a). Nutrition, physiology, and stable isotopes: new information from fasting and molting penguins. *Ecology*, *86*(11), 2881-2888.

Cherel, Y., Hobson, K. A., Guinet, C., & Vanpe, C. (2007). Stable isotopes document seasonal changes in trophic niches and winter foraging individual specialization in diving predators from the Southern Ocean. *Journal of Animal Ecology*, *76*(4), 826-836.

Christel, I., Navarro, J., Del Castillo, M., Cama, A., & Ferrer, X. (2012). Foraging movements of Audouin's gull (*Larus audouinii*) in the Ebro Delta, NW Mediterranean: A preliminary satellite-tracking study. *Estuarine, Coastal and Shelf Science*, *96*, 257-261.

DGRM, 2016 http://www.dgrm.minagricultura.pt/xportal/xmain?xpid=dgrm&xpgid=genericPageV2&conteudoDetalhe_v2=174422 (acceded in 20-05-2016)

Duffy, D. C., & Jackson, S. (1986). Diet studies of seabirds: a review of methods. *Colonial Waterbirds*, 1-17.

Duhem, C., Roche, P., Vidal, E., & Tatoni, T. (2007). Distribution of breeding sites and food constrains size and density of yellow-legged gull colonies. *Ecoscience*, *14*(4), 535-543.

Duhem, C., Roche, P., Vidal, E., & Tatoni, T. (2008). Effects of anthropogenic food resources on yellow-legged gull colony size on Mediterranean islands. *Population ecology*, *50*(1), 91-100.

Duhem, C., Vidal, E., Legrand, J., & Tatoni, T. (2003). Opportunistic feeding responses of the Yellow-legged Gull *Larus michahellis* to accessibility of refuse dumps: The gulls adjust their diet composition and diversity according to refuse dump accessibility. *Bird Study*, *50*(1), 61-67.

Ellis, E. C. (2011). Anthropogenic transformation of the terrestrial biosphere. *Philosophical Transactions of the Royal Society of London A: Mathematical, Physical and Engineering Sciences*, *369*(1938), 1010-1035.

Erzini, K., Costa, M. E., Bentes, L., & Borges, T. C. (2002). A comparative study of the species composition of discards from five fisheries from the Algarve (southern Portugal). *Fisheries Management and Ecology*, *9*(1), 31-40.

FAO (2014). The State of World Fisheries and Aquaculture, *FAO Fisheries Department*, Rome. ISSN 1020-5489.

Fernandes, A. C., Pérez, N., Prista, N., Santos, J., & Azevedo, M. (2015). Discards composition from Iberian trawl fleets. *Marine Policy*, *53*, 33-44.

Forero, M. G., & Hobson, K. A. (2003). Using stable isotopes of nitrogen and carbon to study seabird ecology: applications in the Mediterranean seabird community. *Scientia Marina*, *67*(S2), 23-32.

Froese, R. (2004). Keep it simple: three indicators to deal with overfishing. *Fish and fisheries*, *5*(1), 86-91.

Furness, R. W. (2003). Impacts of fisheries on seabird communities. *Scientia Marina*, *67*(S2), 33-45.

Furness, R. W., Edwards, A. E., & Oro, D. (2007). Influence of management practices and of scavenging seabirds on availability of fisheries discards to benthic scavengers. *Marine Ecology Progress Series,* 350, 235-244.

García-Tarrasón, M., Bécares, J., Bateman, S., Arcos, J. M., Jover, L., & Sanpera, C. (2015). Sex-specific foraging behavior in response to fishing activities in a threatened seabird. *Ecology and Evolution*. *5*(12), 2348-2358.

González-Solís, J. (2003). Impact of fisheries on activity, diet and predatory interactions between yellow-legged and Audouin's gulls breeding at the Chafarinas Islands. *Scientia Marina*, *67*(2), 83-88.

González-Solís, J., Oro, D., Jover, L., Ruiz, X., & Pedrocchi, V. (1997b). Trophic niche width and overlap of two sympatric gulls in the southwestern Mediterranean. *Oecologia*, *112*(1), 75-80.

González-Solís, J., Oro, D., Pedrocchi, V., Jover, L., & Ruiz, X. (1997a). Bias associated with diet samples in Audouin's Gulls. *Condor*, 773-779.

Granadeiro, J. P., Phillips, R. A., Brickle, P., & Catry, P. (2011). Albatrosses following fishing vessels: how badly hooked are they on an easy meal? *Plos One*, *6*(3), e17467.

Grémillet, D., Dell'Omo, G., Ryan, P. G., Peters, G., Ropert-Coudert, Y., & Weeks, S. J. (2004). Offshore diplomacy, or how seabirds mitigate intra-specific competition: a case study based on GPS tracking of Cape gannets from neighbouring colonies. *Marine Ecology Progress Series*, *268*, 265-279.

Grémillet, D., Lewis, S., Drapeau, L., van Der Lingen, C. D., Huggett, J. A., Coetzee, J. C., & Ryan, P. G. (2008). Spatial match–mismatch in the Benguela upwelling zone: should we expect chlorophyll and sea-surface temperature to predict marine predator distributions? *Journal of Applied Ecology*, *45*(2), 610-621.

Grémillet, D., Péron, C., Kato, A., Amélineau, F., Ropert-Coudert, Y., Ryan, P. G., & Pichegru, L. (2016). Starving seabirds: unprofitable foraging and its fitness consequences in Cape gannets competing with fisheries in the Benguela upwelling ecosystem. *Marine Biology*, *163*(2), 1-11.

Haag-Wackernagel, D. (2005). Parasites from feral pigeons as a health hazard for humans. *Annals of applied biology*, *147*(2), 203-210.

Hobson, K. A. (2005). Using stable isotopes to trace long-distance dispersal in birds and other taxa. *Diversity and Distributions*, *11*(2), 157-164.

Hobson, K. A., & Clark, R. G. (1993). Turnover of 13 C in cellular and plasma fractions of blood: implications for nondestructive sampling in avian dietary studies. *The Auk*, *110*(3), 638-641.

Hobson, K. A., Piatt, J. F., & Pitocchelli, J. (1994). Using stable isotopes to determine seabird trophic relationships. *Journal of animal ecology*, 786-798.

Hüppop, O., & Wurm, S. (2000). Effects of winter fishery activities on resting numbers, food and body condition of large gulls *Larus argentatus* and *L. marinus* in the south-eastern North Sea. *Marine Ecology. Progress Series*, *194*, 241-247.

Hyrenbach, K. D., Fernández, P., & Anderson, D. J. (2002). Oceanographic habitats of two sympatric North Pacific albatrosses during the breeding season. *Marine Ecology Progress Series*, *233*, 283-301.

ICNF – Instituto de Conservação da Natureza e da Floresta (2016). Parque Natural da Ria Formosa. Download from: http://www.icnf.pt/portal/ap/p-nat/pnrf (Accessed: 27-01-2016).

Inger, R., & Bearhop, S. (2008). Applications of stable isotope analyses to avian ecology. *Ibis*, *150*(3), 447-461.

Iverson, S. J., Springer, A. M., & Kitaysky, A. S. (2007). Seabirds as indicators of food web structure and ecosystem variability: qualitative and quantitative diet analyses using fatty acids. *Marine Ecology Progress Series*, 352-235.

Jackson, A. L., Inger, R., Parnell, A. C., & Bearhop, S. (2011). Comparing isotopic niche widths among and within communities: SIBER–Stable Isotope Bayesian Ellipses in R. *Journal of Animal Ecology*, *80*(3), 595-602.

Jackson, J. B., Kirby, M. X., Berger, W. H., Bjorndal, K. A., Botsford, L. W., Bourque, B. J., & Hughes, T. P. (2001). Historical overfishing and the recent collapse of coastal ecosystems. *Science*, *293*(5530), 629-637.

Jennings, S., & Kaiser, M. J. (1998). The effects of fishing on marine ecosystems. *Advances in marine biology*, *34*, 201-352.

Kelleher, K. (2005). Discards in the world's marine fisheries: an update. *FAO Fisheries Technical Paper*. Nº 470. Rome, pp. 131

Kelly, J. F. (2000). Stable isotopes of carbon and nitrogen in the study of avian and mammalian trophic ecology. *Canadian Journal of Zoology*, *78*(1), 1-27.

Kress, S. W. (1983). The use of decoys, sound recordings, and gull control for re-establishing a tern colony in Maine. *Colonial Waterbirds*, 185-196.

Kubetzki, U., & Garthe, S. (2003). Distribution, diet and habitat selection by four sympatrically breeding gull species in the south-eastern North Sea. *Marine Biology*, *143*(1), 199-207.

Kuznetsova, A., Brockhoff, P. B., & Christensen, R. H. (2016). lmerTest: Tests in Linear Mixed Effects Models. Rpackage version 2.0-30. (https://CRAN.R-project.org/package=lmerTest)

Leitão, F., Baptista, V., Zeller, D., & Erzini, K. (2014). Reconstructed catches and trends for mainland Portugal fisheries between 1938 and 2009: implications for sustainability, domestic fish supply and imports. *Fisheries Research*, *155*, 33-50.

Mann, K.H., Lazier, R.N. (2005) Dynamics of Marine Ecosystems: Biological-Physical Interactions in the Oceans. *Wiley*. 512 pp.

Mañosa, S., Oro, D., & Ruiz, X. (2004). Activity patterns and foraging behaviour of Audouin's gulls in the Ebro Delta, NW Mediterranean. *Scientia Marina*, *68*(4), 605-614.

Martínez-Abraín, A., González-Solis, J., Pedrocchi, V., Genovart, M., Abella, J. C., Ruiz, X., & Oro, D. (2003). Kleptoparasitism, disturbance and predation of yellow-legged gulls on Audouin's gulls in three colonies of the western Mediterranean. *Scientia Marina,* 67 (Suppl. 2), 89-94

Matias, R., & Catry, P. (2010). The diet of Atlantic yellow-legged gulls (*Larus michahellis atlantis*) at an oceanic seabird colony: estimating predatory impact upon breeding petrels. *European journal of wildlife research*, *56*(6), 861-869.

McCauley, D. J., Pinsky, M. L., Palumbi, S. R., Estes, J. A., Joyce, F. H., & Warner, R. R. (2015). Marine defaunation: Animal loss in the global ocean. *Science*, *347*(6219), 1255641.

Meirinho A, Barros N, Oliveira N, Catry P, Lecoq M, Paiva V, Geraldes P, Granadeiro JP, Ramírez I & Andrade J (2014). *Atlas das Aves Marinhas de Portugal*. Sociedade Portuguesa para o Estudo das Aves. Lisboa. (www.atlasavesmarinhas.pt)

Monteiro, P., Araújo, A., Erzini, K., & Castro, M. (2001). Discards of the Algarve (southern Portugal) crustacean trawl fishery. *Springer Netherlands*. *In Advances in Decapod Crustacean Research,* 449, 267-277.

Morales, L., Martrat, M. G., Olmos, J., Parera, J., Vicente, J., Bertolero, A., & Abad, E. (2012). Persistent Organic Pollutants in gull eggs of two species (*Larus michahellis* and *Larus audouinii*) from the Ebro delta Natural Park. *Chemosphere*, *88*(11), 1306-1316.

Moreno, R., Jover, L., Munilla, I., Velando, A., & Sanpera, C. (2010). A three-isotope approach to disentangling the diet of a generalist consumer: the yellow-legged gull in northwest Spain. *Marine Biology*, *157*(3), 545-553.

Munilla, I. (1997). Henslow's swimming crab (*Polybius henslowii*) as an important food for yellow-legged gulls (*Larus cachinnans*) in NW Spain. – *ICES Journal of Marine Science*, 54: 631–634.

Myers, R. A., & Worm, B. (2003). Rapid worldwide depletion of predatory fish communities. *Nature*, *423*(6937), 280-283.

Navarro, J., Oro, D., Bertolero, A., Genovart, M., Delgado, A., & Forero, M. G. (2010). Age and sexual differences in the exploitation of two anthropogenic food resources for an opportunistic seabird. *Marine Biology*, *157*(11), 2453-2459.

Neves, V. C., Murdoch, N., & Furness, R. W. (2006). Population status and diet of the yellow-legged gull in the Azores. *Arquipélago. Ciências Biológicas e Marinhas*. ISSN 0873-4704. Nº 23ª, 59-73.

Newsome, S. D., Martinez del Rio, C., Bearhop, S., & Phillips, D. L. (2007). A niche for isotopic ecology. *Frontiers in Ecology and the Environment*, *5*(8), 429-436.

Newton, A., & Icely, J. (2002). Impact of coastal engineering on the water quality of the Ria Formosa Lagoon, Portugal. *In International Conference LITTORAL*, 1-5.

Newton, A., & Mudge, S. M. (2005). Lagoon-sea exchanges, nutrient dynamics and water quality management of the Ria Formosa (Portugal). *Estuarine, Coastal and Shelf Science*, *62*(3), 405-414.

Orians, G.H., Pearson, N.E. (1979). On the theory of central place foraging. In: Horn, D.J., Mitchell, R.D., Stairs, G.R. (Eds.), *Analysis of Ecological Systems*. The Ohio State University Press, Columbus, 154–177.

Oro, D., & Martínez-Abraín, A. (2007). Deconstructing myths on large gulls and their impact on threatened sympatric waterbirds. *Animal conservation*, *10*(1), 117-126.

Oro, D., & Ruxton, G. D. (2001). The formation and growth of seabird colonies: Audouin's gull as a case study. *Journal of Animal Ecology*, *70*(3), 527-535.

Oro, D., Bosch, M., & Ruiz, X. (1995). Effects of a trawling moratorium on the breeding success of the yellow-legged gull *Larus cachinnans*. *Ibis*, *137*(4), 547-549.

Oro, D., Cam, E., Pradel, R., & Martínez-Abraín, A. (2004). Influence of food availability on demography and local population dynamics in a long-lived seabird. *Proceedings of the Royal Society of London B: Biological Sciences*, *271*(1537), 387-396.

Oro, D., Genovart, M., Tavecchia, G., Fowler, M. S., & Martínez-Abraín, A. (2013). Ecological and evolutionary implications of food subsidies from humans. *Ecology letters*, *16*(12), 1501-1514.

Oro, D., Genovart, X., Ruiz, X., Jiménez, J., & García-Gans, J. (1996). Differences in diet, population size and reproductive performance between two colonies of Audouin's Gull *Larus audouinii* affected by a trawling moratorium. *Journal of avian biology*, 245-251.

Oro, D., Martínez-Abraín, A., Villuendas, E., Sarzo, B., Mínguez, E., Carda, J., & Genovart, M. (2011). Lessons from a failed translocation program with a seabird species: Determinants of success and conservation value. *Biological conservation*, *144*(2), 851-858.

Oro, D., Pérez-Rodríguez, A., Martínez-Vilalta, A., Bertolero, A., Vidal, F., & Genovart, M. (2009). Interference competition in a threatened seabird community: a paradox for a successful conservation. *Biological Conservation*, *142*(8), 1830-1835.

Oro, D., Pradel, R., & Lebreton, J. D. (1999). Food availability and nest predation influence life history traits in Audouin's gull, *Larus audouinii*. *Oecologia*, *118*(4), 438-445.

Paiva, V. H., Geraldes, P., Rodrigues, I., Melo, T., Melo, J., & Ramos, J. A. (2015). The Foraging ecology of the endangered Cape Verde Shearwater, a sentinel species for marine conservation off west Africa. *PloS one*, *10*(10), e0139390.

Paiva, V.H., Geraldes, P., Ramirez, I., Meirinho, A., Ramos, J.A. & Garthe, S. (2010). Oceanographic characteristics of areas used by Cory’s shearwaters during short and long foraging trips in the North Atlantic. *Marine Biology* 157: 1385-1399.

Parnell, A. C., Inger, R., Bearhop, S., & Jackson, A. L. (2010). Source partitioning using stable isotopes: coping with too much variation. *PloS one*, *5*(3), e9672.

Pauly, D., & Maclean, J. (2003). In a perfect ocean: the state of fisheries and ecosystems in the North Atlantic Ocean. *Island Press*, ISBN 1-55963-324-7 (Vol. 1), pp.206.

Pauly, D., Christensen, V., Guénette, S., Pitcher, T. J., Sumaila, U. R., Walters, C. J., & Zeller, D. (2002). Towards sustainability in world fisheries. *Nature*, *418*(6898), 689-695.

Pedro, P. I., Ramos, J. A., Neves, V. C., & Paiva, V. H. (2013). Past and present trophic position and decadal changes in diet of yellow-legged gull in the Azores Archipelago, NE Atlantic. *European journal of wildlife research*, *59*(6), 833-845.

Pedrocchi, V., Oro, D., González-Solís, J., Ruiz, X., & Jover, L. (2002). Differences in diet between the two largest breeding colonies of Audouin's gulls: the effects of fishery activities. *Scientia Marina*, *66*(3), 313-320.

Phillips, R. A., Xavier, J. C., & Croxall, J. P. (2003). Effects of satellite transmitters on albatrosses and petrels. *The Auk*, *120*(4), 1082-1090.

Post, D. M. (2002). Using stable isotopes to estimate trophic position: models, methods, and assumptions. *Ecology*, *83*(3), 703-718.

R Core Team (2015). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/.

Ramos, J. A., Fagundes, A. I., Xavier, J. C., Fidalgo, V., Ceia, F. R., Medeiros, R., & Paiva, V. H. (2015). A switch in the Atlantic Oscillation correlates with inter-annual changes in foraging location and food habits of Macaronesian shearwaters (*Puffinus baroli*) nesting on two islands of the sub-tropical Atlantic Ocean. *Deep Sea Research Part I: Oceanographic Research Papers*, *104*, 60-71.

Ramos, J. A., Pedro, P., Matos, A., & Paiva, V. H. (2013). Relation between climatic factors, diet and reproductive parameters of Little Terns over a decade. *Acta oecologica*, *53*, 56-62.

Ramos, J. A., Solá, E., Porteiro, F. M., & Monteiro, L. R. (1998). Prey of yellow-legged gull, roseate tern and common tern in the Azores. *Seabird, 20*, 31.

Ramos, R., Ramírez, F., & Jover, L. (2013). Trophodynamics of inorganic pollutants in a wide-range feeder: the relevance of dietary inputs and biomagnification in the yellow-legged gull (*Larus michahellis*). *Environmental pollution*, *172*, 235-242.

Ramos, R., Ramírez, F., Carrasco, J. L., & Jover, L. (2011). Insights into the spatiotemporal component of feeding ecology: an isotopic approach for conservation management sciences. *Diversity and Distributions*, *17*(2), 338-349.

Ramos, R., Ramírez, F., Sanpera, C., Jover, L., & Ruiz, X. (2009). Diet of yellow-legged gull (*Larus michahellis*) chicks along the Spanish Western Mediterranean coast: the relevance of refuse dumps. *Journal of Ornithology*, *150*(1), 265-272.

Ruiz, X., Oro, D., Martinez-Vilalta, A., & Jover, L. (1996). Feeding ecology of Audouin's Gulls (*Larus audouinii*) in the Ebro delta. *Colonial Waterbirds*, 68-74.

Rutz, C., & Hays, G. C. (2009). New frontiers in biologging science. *Biology letters*, *5*(3), 289-292.

Sanderson, E. W., Jaiteh, M., Levy, M. A., Redford, K. H., Wannebo, A. V., & Woolmer, G. (2002). The Human Footprint and the Last of the Wild The human footprint is a global map of human influence on the land surface, which suggests that human beings are stewards of nature, whether we like it or not. *BioScience*, *52*(10), 891-904.

Sanz-Aguilar, A., Martínez-Abraín, A., Tavecchia, G., Mínguez, E., & Oro, D. (2009). Evidence-based culling of a facultative predator: efficacy and efficiency components. *Biological conservation*, *142*(2), 424-431.

Shamoun-Baranes, J., van Loon, E. E., Purves, R. S., Speckmann, B., Weiskopf, D., & Camphuysen, C. J. (2011a). Analysis and visualization of animal movement. *Biology letters*, rsbl20110764.

Shamoun-Baranes, Judy Bouten, W., Camphuysen, C. J., & Baaij, E. (2011b). Riding the tide: intriguing observations of gulls resting at sea during breeding. *Ibis*, *153*(2), 411.

Shapira, I., Sultan, H., & Shanas, U. (2008). Agricultural farming alters predator–prey interactions in nearby natural habitats. *Animal Conservation*, *11*(1), 1-8.

Smith, G. C., & Carlile, N. (1993). Methods for population control within a silver gull colony. *Wildlife Research*, *20*(2), 219-225.

Tomkiewicz, S. M., Fuller, M. R., Kie, J. G., & Bates, K. K. (2010). Global positioning system and associated technologies in animal behaviour and ecological research. *Philosophical Transactions of the Royal Society of London B: Biological Sciences*, *365*(1550), 2163-2176.

Tuset, V. M., Lombarte, A., & Assis, C. A. (2008). Otolith atlas for the western Mediterranean, north and central eastern Atlantic. *Scientia Marina*, *72*(S1), 7-198.

Vitousek, P. M., Mooney, H. A., Lubchenco, J., & Melillo, J. M. (1997). Human domination of Earth's ecosystems. *Science*, *277*(5325), 494-499.

Votier, S. C., Bearhop, S., MacCormick, A., Ratcliffe, N., & Furness, R. W. (2003). Assessing the diet of great skuas, Catharacta skua, using five different techniques. *Polar Biology*, *26*(1), 20-26.

Votier, S. C., Bearhop, S., Witt, M. J., Inger, R., Thompson, D., & Newton, J. (2010). Individual responses of seabirds to commercial fisheries revealed using GPS tracking, stable isotopes and vessel monitoring systems. *Journal of Applied Ecology*, *47*(2), 487-497.

Votier, S. C., Bicknell, A., Cox, S. L., Scales, K. L., & Patrick, S. C. (2013). A bird's eye view of discard reforms: bird-borne cameras reveal seabird/fishery interactions. *PLoS One*, *8*(3), e57376.

Washburn, B. E., Bernhardt, G. E., Kutschbach-Brohl, L., Chipman, R. B., & Francoeur, L. C. (2013). Foraging ecology of four gull species at a coastal-urban interface: Ecología de forrajeo de cuatro especies de gaviota en una interface costera-urbana. *The Condor*, *115*(1), 67-76.

Weimerskirch, H., Le Corre, M., Jaquemet, S., & Marsac, F. (2005). Foraging strategy of a tropical seabird, the red-footed booby, in a dynamic marine environment. *Marine Ecology Progress Series*, *288*, 251-261.

Wilhelm, S., I., Rail, J., F., Regular, P., M., Gjerdrum, C., Robertson, G., J. (2016). Large-scale changes in abundance of breeding Herring gull (*Larus argentatus*) and Great black-backed gulls (*Larus marinus*) relative to reduced fishing activities in Southeastern Canada*. Waterbirds,* 39 (special publication1), 136-142.

Zuur, A. F., Ieno, E. N., & Elphick, C. S. (2010). A protocol for data exploration to avoid common statistical problems. *Methods in Ecology and Evolution*, *1*(1), 3-14.