Sara Nujo Veríssimo

The Role of Fisheries in Yellow-Legged Gulls' Diet

Dissertação de Mestrado em Ecologia, orientada pelo Professor Doutor Jaime Albino Ramos e pelo Doutor Vítor Hugo Paiva e 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 Vitor Hugo Paiva (Universidade de Coimbra)

Sara Nujo Veríssimo

Departamento de Ciências da Vida

Universidade de Coimbra

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Abstract

In the Iberian Peninsula, fishing activities are of great importance for the economy. These practices can play an important role in seabirds' livelihood, mostly through fisheries' discards which represent a predictable food source for some seabird species. Gulls are among the most opportunistic seabirds, benefiting from these rejections. Taking this into account, our aim was to understand the role of fisheries in the diet of diverse yellow-legged gull populations (*Larus michahellis*). Using diet samples and stable isotopes analysis, we studied and compared the diet of gulls from four different colonies along the southwest coast of the Iberian Peninsula (Deserta, Pessegueiro, Berlenga and Sálvora islands), during the breeding and non-breeding seasons of 2016 and 2017. In addition, we compared the diet with fish landing data in order to analyse the gulls' dependence on food subsidies provided by fishery discards.

Fish was the main food source for Deserta and Pessegueiro gulls, in contrast with crustaceans for Sálvora and Berlenga gulls. Stable isotopes also revealed differences among the dietary choices of birds from the four distinct colonies. Chicks of the four different colonies presented similar stable isotope values (2017 samples), while the stable isotope values for adults changed among colonies, seasons and years. In the breeding season of 2016, Deserta and Berlenga gulls exhibited a restricted isotopic niche, respectively with prey of high and low trophic level. This trophic segregation was shaped by the presence of fish and crustaceans in the diet of birds from Deserta and Berlenga, respectively. However, during the 2017 chick-rearing, only gulls from Pessegueiro colony site showed a specialist diet. For the incubation and post-breeding season, the results were similar to those of the chick-rearing period, with Pessegueiro gulls revealing a more specialist diet. Overall, the diet and stable isotopic values from the four distinct colonies suggest a large foraging plasticity of yellow-legged gulls, as shown by previous studies. The diet of Pessegueiro gulls, although restrict, also presented seasonal changes, mostly noticed during the post-breeding season with a great consumption of *Corema album* fruits. As for the annual changes, during the pre-breeding of 2016 gulls from Pessegueiro ate mostly crustaceans, in contrast with the high fish intake in 2017. The opposite happen with Berlenga gulls which increased their fish consumption during the 2017 pre-breeding season, diverging from a diet rich in crustaceans, as observed in other seasons. Regarding fish discards, gulls from Deserta and Pessegueiro showed a significant correlation between the percentage of occurrence of the main fish prey items in the diet and their amount landed in the nearby fishing port. However, this relationship varied between years and seasons. This meaning, Deserta gulls presented a significant relationship with fish landings during the pre-breeding period of each year, whereas Pessegueiro gulls exhibited a significant relationship during the post-breeding season, the period when more fish was landed in the nearby fishing port.

With this study, we were capable to discern, not only the annual and seasonal shifts in yellow-legged gulls' diet and trophic ecology during 2016 and 2017, but also how much the different gull populations rely on fishing discards. Moreover, our results provide some insights about the influence that the new discard ban policy, imposed by the European Commission, might have on these gull populations. Yellow-legged gulls are highly plastic and generalist seabirds. They are capable of using other human activities as a source of food, thus minimizing energetic constraints. These traits, alongside with our conclusions, suggest that in the long-term, the discard ban should not affect notoriously the populations of this gull species. Nonetheless, further studies should help better understand the effect of the discard ban on *Larus michahellis* populations.

Key-words: Yellow-legged-gull, diet, trophic ecology, fisheries

Resumo

Na Península Ibérica, as atividades pesqueiras são de grande importância económica. Estas práticas podem desempenhar um papel importante na subsistência de aves marinhas, principalmente através das rejeições da pesca que representam uma fonte previsível de alimento para algumas espécies destas aves. As gaivotas estão entre as aves marinhas mais oportunistas, beneficiando destas rejeições. Tendo isso em conta, o nosso objetivo foi perceber o papel das pescas na dieta de diversas populações de gaivotas-de-patas-amarelas (*Larus michahellis*). Com o uso de amostras de dieta e análise de isótopos estáveis, estudámos e comparámos a dieta de gaivotas de quatro colónias distintas ao longo da costa sudoeste da Península Ibérica (ilhas Deserta, Pessegueiro, Berlenga e Sálvora), durante as épocas reprodutoras e não reprodutoras de 2016 e 2017. Além disso, comparámos a dieta com os dados do peixe desembarcado na lota de portos que se situam nas redondezas de cada colónia, a fim de analisar a dependência destas gaivotas pelo alimento fornecido pelas práticas pesqueiras.

A principal fonte de alimento das gaivotas da Deserta e do Pessegueiro foi peixe, em contraste com os crustáceos encontrados na dieta das gaivotas de Sálvora e da Berlenga. Os isótopos estáveis também revelaram diferenças entre as escolhas alimentares das aves das quatro colónias. As crias de todas as colónias apresentaram valores semelhantes de isótopos estáveis (amostras de 2017), enquanto os valores de isótopos estáveis para os adultos variaram entre colónias, épocas e anos. Durante a época reprodutora de 2016, as gaivotas da Deserta e da Berlenga apresentaram um nicho isotópico restrito, respetivamente com presas de alto e baixo nível trófico. Esta segregação trófica foi formada pela presença de peixes e crustáceos na dieta das gaivotas da Deserta e da Berlenga, respetivamente. No entanto, durante a época de alimentação das crias de 2017, apenas as gaivotas da colónia do Pessegueiro apresentaram uma dieta especializada. Para as épocas de incubação e pós-reprodutora, os resultados foram semelhantes aos do período de alimentação das crias, com as gaivotas do Pessegueiro a exibirem uma dieta mais especializada. No geral, a dieta e os valores isotópicos das quatro colónias sugerem uma grande plasticidade por parte das gaivotas-de-patas-amarelas na procura de alimento, como mostrado em estudos anteriores. A dieta das gaivotas do Pessegueiro, embora restrita, também apresentou mudanças sazonais, notadas principalmente durante a época pós-reprodutora com o grande consumo de frutos de

Corema album. Quanto às mudanças anuais, durante a época pré-reprodutora de 2016, as gaivotas do Pessegueiro consumiram maioritariamente crustáceos, em contraste com a alta ingestão de peixe em 2017. O oposto aconteceu na dieta das gaivotas da Berlenga que aumentaram o consumo de peixe durante a época pré-reprodutora de 2017, divergindo da dieta rica em crustáceos observada nas outras épocas. Em relação às rejeições da pesca, as gaivotas da Deserta e do Pessegueiro apresentaram uma correlação significativa entre a percentagem de ocorrência das principais espécies de peixes presentes na dieta e a quantidade desembarcada dos mesmos no porto de pesca mais próximo. No entanto, esta relação variou entre anos e épocas. Neste sentido, as gaivotas da Deserta apresentaram uma relação significativa com os peixes desembarcados durante o período pré-reprodutor de cada ano, enquanto as gaivotas do Pessegueiro apresentaram uma relação significativa durante a época pós-reprodutora, período com maior quantidade de desembarques perto da colónia.

Com este estudo, fomos capazes de discernir, não apenas as mudanças anuais e sazonais na dieta e ecologia trófica das gaivotas-de-patas-amarelas durante 2016 e 2017, mas também o quanto as diferentes populações de gaivotas dependem das rejeições da pesca. Além disso, os nossos resultados fornecem alguma informação sobre a influência que a nova política de rejeições, imposta pela Comissão Europeia, poderá ter nas populações desta gaivota. As gaivotas-de-patas-amarelas são aves marinhas altamente plásticas e generalistas nas práticas de procura de alimento. São capazes de usar outras atividades humanas como fonte de alimento, minimizando assim os custos energéticos. Estas características, juntamente com as nossas conclusões, sugerem que, a longo prazo, a proibição de rejeições não deverá afetar de forma notória a população desta espécie de gaivota. No entanto, mais estudos deverão ajudar para melhor entender o efeito desta proibição nas populações de *Larus michahellis*.

Palavras-chave: Gaivota-de-patas-amarelas, dieta, ecologia trófica, pescas

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1. Introduction

Photo: Hugo Guímaro

1.1. The effect of fisheries on marine ecosystems

Human activities can deeply affect ecosystems, changing the population dynamics of many species (Shochat *et al.* 2006). Anthropogenic actions range from air and water pollution, resources overexploitation (like overfishing) to introduction of invasive species, which will impact native species. Climate change, a source of great concern nowadays, is also a consequence of human activities. Fisheries are important for the economy and livelihood of many countries (Smith *et al.* 2010) and may affect many organisms and habitats in different ways (Agardy 2000). The major problem with fisheries is when they are poorly managed (Bicknell *et al.* 2016), leading to a decline or collapse of fish stocks (Myers & Worm 2003), bycatch of untargeted species (Lewison *et al.* 2004) and seabed destruction by bottom trawls (Buhl-Mortensen *et al.* 2016). Overfishing is the unsustainable fish removal, in other words, fish is caught at such high rates that fish populations cannot endure, and this will contribute to stock declines and changes in the trophic structure and prey-predator relationships (Coleman & Williams 2002).

Bycatch is the most serious fisheries' impact and the first to capture people's attention, since it represents the incidental catch of non-target marine species, such as turtles, seabirds and sharks (scavenger species) (Dayton *et al.* 1995; Coleman & Williams 2002; Bellido *et al.* 2011). At an alarming pace, this situation increases the mortality rate of those species (Belda & Sanchez 2001) in purse seiners, trammel nets (Borges *et al.* 2001) and longlines (Barcelona *et al.* 2010). "Slippage" is a related concept but, in this case, fish is immediately released from the net, alive but impacted by the net confinement or moribund (Marçalo *et al.* 2010; Marçalo *et al.* 2013). This is a common practice in pelagic purse seine net fishing (Huse & Vold 2010).

Regarding deep-sea fishing disturbance, bottom trawling can have a very strong impact on the seabed (Buhl-Mortensen *et al.* 2016) especially due to the removal of biota and sediment turn-over (Hall–Spencer *et al.* 2002). In this practice, a fishing gear is dragging across the seabed (Wright *et al.* 2015) affecting, mostly, marine benthonic communities, which, among other things, get exposed to predators (Jenkins *et al.* 2004), and also species with a slow recovery rate (e.g. corals and sponges) (Pitcher *et al.* 2015). However, Pham *et al.* (2014) showed that in some areas this practice can be replace by bottom longline, reducing the negative effects of deep-sea fishery (Pham *et al.* 2014).

According to the Food and Agriculture Organization of the United Nations (FAO), fishery discards are described as “fish stocks elements that are rejected after capture and, normally, do not survive”. Daily, a huge amount of unwanted fish is rejected, surpassing seven million tonnes a year (Kelleher 2005). There are EU regulations set by the EU Common Fisheries Policy (CFP), aiming to ensure that fishing and aquaculture provide food with sustainable and economic practices (Bicknell *et al.* 2013). This means that fish can only be rejected if it does not fit the regulated parameters, such as size, quality, market value (Condie *et al.* 2014), or even if the catch is damaged (Bellido *et al.* 2011). Discards can also vary in time and space according to socio-economic demands (Catchpole *et al.* 2005) and in relation to the target species, for instance shrimp fishing presents one of the highest amounts of discards, approximately 27% of the total discards (Kelleher 2005).

Therefore, due to the global fish demand and the threats to fish stocks, this practice is not sustainable (Bicknell *et al.* 2013), because it is nothing more than an unnecessary death (Bellido *et al.* 2011), reason why the European member states following CFP are gradually stopping at-sea discards with the implementation of the discard ban policy (European Commission 2018). There is a large number of species affected by discard practices. Fish populations are negatively affected, because unwanted fish is thrown to the sea often dead (Condie *et al.* 2014), however other species may benefit, such as seabirds (Furness 2003), marine mammals and some fish species. Species that benefit from discards are often marine scavengers that use the rejected fish as food source (Bicknell *et al.* 2013), which may improve their body condition and breeding output (Furness *et al.* 2007).

In Portugal, fishing activities are very important for the economy. In this activity, purse seine and multi-gear fishing, are more common, since there are few licences for trawling. The fish caught is very diverse but there are three species that are the mostly caught: sardine (*Sardina pilchardus*), the atlantic chub mackerel (*Scomber colias*) and the atlantic horse mackerel (*Trachurus trachurus*) (Leitão *et al.* 2014).

1.2. How fisheries influence coastal seabirds

Coastal seabirds (e.g. gannets and gulls) are organisms that inhabit coastal areas (Lewison *et al.* 2012), and usually breed in dense colonies (Jovani *et al.* 2008). Some are considered flagships species (Oro *et al.* 2009), charismatic species that catch people's attention and can be used in conservation programs (Walpole & Leader-Williams 2002), or used as indicators of ecosystem health (Mallory *et al.* 2006). Furthermore, seabirds are easier to monitor in relation to other marine top predators (Lewison *et al.* 2012), and can even give information about terrestrial and marine environment (Grémillet & Charmantier 2010), which make them ideal to study. They are K-strategists characterized by delayed reproduction, low reproductive rate and long lifespan (Ricklefs 1990). Such characteristics make them very vulnerable to Human related stress factors such as contamination (e.g. persistent organic pollutants (POPs), found in gulls eggs (Morales *et al.* 2012)), plastic presence, and fishing activities (González-Solís & Shaffer 2009; Ramos & González-Solís 2012). Climate change can also influence these marine predators. Climatic phenomena, such as the North Atlantic Oscillation (NAO), can alter the foraging activity by changing the seasonal availability of their main food source (Paiva *et al.* 2013).

Although population dynamics are affected by pollution, habitat destruction and invasive species (Libois *et al.* 2012), there has been an increase in some opportunistic seabird species in the last decades (Arizaga *et al.* 2013) due to other human activities, such as fishery discards or refuse dumps (Navarro *et al.* 2010). Focusing on fisheries' impact, these can compete with seabirds because both occupy the same temporal and spatial place and depend on the same resources (González-Solís & Shaffer 2009). Overfishing may starve seabirds through the depletion of their major food resources (Grémillet *et al.* 2016). Additionally, fisheries can decrease seabird numbers by increasing mortality rate through bycatch (i.e. unwanted species which are caught in the nets (Barcelona *et al.* 2010)). Seabirds, among other species, follow the trawlers in an attempt to eat the caught fish, getting themselves trapped or colliding with the fishing gears (Bicknell *et al.* 2013).

On the other hand, fish discards can provide a superabundant source of food (Louzao *et al.* 2011), predictable in time and space (Davoren *et al.* 2003), which can be advantageous for seabirds to obtain their food requirements without spending too much energy (Cama *et al.* 2012). There are several studies reporting empirical proof of this behaviour, for instance Votier et al. observed, mostly in male gannets *Morus bassanus*, an extensive overlap between feeding areas and fishing boats, showing the importance of fisheries for these seabirds (Votier *et al.* 2013).

1.3. The effects of fisheries on yellow-legged gull populations

Yellow-legged gulls (YLG, *Larus michahellis*), are generalist predators (Ronconi *et al.* 2014) with a breeding distribution through almost all Southern Europe and North Africa (BirdLife International 2017). This species is very plastic in terms of foraging habitat and environmental adaptation (Cama *et al.* 2012), being able to adapt, not only to human-altered environments (Ramos *et al.* 2009b), but also to changes in the availability of prey (Arcos & Oro 1996), whether due to annual variations or to changes in fishing activities. These traits are the main reasons for the exponential population increase of several gull species in the last fifty years, which caused some concern due to the disturbances at harbours and urban areas, requiring management control activities in some situations (Oro & Martínez-Abraín 2007).

Although this gull species can prey on eggs, chicks and adults of other seabirds (Sanz-Aguilar *et al.* 2009; Pedro *et al.* 2013), it is considered a scavenger species (Alonso *et al.* 2015) because it uses products from Human activities as a main food source, such as general waste (Duhem *et al.* 2005) and/or fishery discards (Arizaga *et al.* 2013). The breeding site is also related to this dependence, because discards can increase the ecosystem carrying capacity and, consequently, increase reproduction and survival of individuals (Ramos *et al.* 2009a), which means that, if this source of energy decreases or disappears, it is also likely to cause a decrease in the number of individuals, especially by a reduction of their reproductive output (Pons 1992). However, due to the plastic nature of this species, it is expectable that they will adapt to the new conditions and will explore new feeding resources.

There are also several studies that illustrate the interaction fisheries-YLG diet. Ramos *et al.* (2009a) analysed chicks' regurgitates from four yellow-legged gull colonies along the Western Mediterranean coast of Spain and observed that the main source of food for those chicks were products of human activities, such as refuse dumps and fishing discards. Another example is the study by Cama *et al.* (2012), where the highest density of yellow-legged gulls matched the highest density of trawlers. Furthermore, yellow-legged density was higher around 16h, when fish discards were available, confirming not only that these gulls depended on nearby fishing activities, but also that they anticipated in space and time the presence of food.

1.4. The diet and feeding ecology of yellow-legged gull in relation to fisheries

Diet identifications from pellets of hard remains regurgitated by seabirds, describe a short-term diet of the individuals (Hobson *et al.* 1994), based on the identification of otoliths, bones, squid beaks (Barrett *et al.* 2007) and/or vertebras. It is a non-invasive technique because the pellets are collected from the breeding area after the birds regurgitate, once after every meal in the case of gulls (Barrett *et al.* 2007). Like every method, regurgitation analysis show some disadvantages, not only because it can overestimate the importance of certain species in the gull's diet (Duffy & Jackson 1986), but also due to the difficulty in identifying some samples that are more damaged. Despite all this, it is a valid technique used through direct observation of preys' remains that are, when possible, identified to species-level.

Since the 1970s (Kelly 2000) a stable-isotope analysis (SIA) have been used to complement bird diet studies (Ramos *et al.* 2015). SIA does not identify the specific prey (Arizaga *et al.* 2013), but instead takes into account the assimilated food (Ramos *et al.* 2009b) and using the carbon (expressed by $\delta^{13}C$) and nitrogen ratio ($\delta^{15}N$) allows to identify the consumer's foraging habitat (terrestrial or marine/freshwater) and the predator trophic level, respectively (Barrett *et al.* 2007). This is only possible since the two isotopes increase in the consumer tissues at each trophic level (Bearhop *et al.* 2004; Bearhop *et al.* 2006; Caron-Beaudoin *et al.* 2013) in a predictable manner (Barrett *et al.* 2007), being that carbon suffers an increase of 0‰ to 1‰ (Phillips *et al.* 2011), while nitrogen has a greater increase of 3‰ to 5‰ at each trophic level (Bearhop *et al.* 2004).

In order to successfully perform this technique, blood and/or feathers samples are collected. Although both represent short-term diet (Bearhop *et al.* 2002), feathers can give a clue about the diet composition during a larger period (one year), even the non-breeding period, because specific feathers provide isotopic information for the moulting period, when they are growing, and thus irrigated by blood (Barrett *et al.* 2007). Nitrogen and carbon are the most used isotopes but, when in presence of a complex food web, it is also recommended the use of a third isotope, the sulphur ($\delta^{34}S$), which allows, as carbon, to distinguishing the prey origin (Hebert *et al.* 2008) but can better discriminate not only different marine prey origins but also between marine/terrestrial prey (Moreno *et al.* 2010). Carbon presents low values for both marine and terrestrial prey, making difficult to distinguish between these two types of prey, while sulphur presents higher values for terrestrial prey and low values for marine prey. Nevertheless, it is also worth mention that stable isotopes are not the only methods that can be used in diet studies (Ramos & González-Solís 2012), trace elements and some organic pollutants such as mercury (Hg), arsenic (As), cadmium (Cd) and selenium (Se), can also specify the consumer trophic level (Becker *et al.* 2002).

We used diet identification from prey hard remains in pellets and stable isotope analysis to evaluate how fisheries are related with the feeding and trophic ecology of four gull populations. We used data from gulls breeding in Sálvora Island (Galicia, Spain), Berlenga Island, Pessegueiro Island and Deserta Island (Portugal), which differ markedly in the amount of fish landed (and discarded), and in the diversity of fishing activities. In Galicia for instance, the amount of fish landed is far superior to any Portuguese study site and it is also worth mention that the target fish are different among the two countries. Galicia fishing sector represents 9% of the European Union (EU) fishing activity (343 thousand tonnes, (European Commission 2017)), and the most important species landed there are blue whiting (*Micromesistius poutassou*); european hake (*Merluccius merluccius*); horse mackerel (*Trachurus* sp.); megrims (*Lepidorhombus boscii* and *Lepidorhombus wiffiagonis*), anglerfish (*Lophius budegassa*) and Norway lobster (*Nephrops norvegicus*) (Valeiras 2003; Vázquez-Rowe *et al.* 2010). In contrast Portugal, for the last two years, landed in Peniche harbour (near Berlenga) around 12000 tonnes of fish each year. Sines harbour, close to Pessegueiro, gathered each year more or less 7000 tonnes of fish, while the lowest amount of fish landed was in Olhão harbour (close to Deserta) with about 4400 tonnes of fish a year. Indubitably, fish caught/landed vary during the year, not being available for gulls in the same amount through all seasons (see Figure A1).

Previous diet identification studies (from pellets) have shown that the Henslow's swimming crab *Polybius henslowii* is the main prey for yellow-legged gulls breeding both in Galicia (Munilla 1997; Moreno *et al.* 2010) and in Berlenga Island (Alonso *et al.* 2015). Nevertheless, in both places there were also fish prey present in the diet. At Berlenga, YLG seems to feed also on sardine (*Sardina pilchardus*), chub mackerel (*Scomber colias*), horse and blue jack mackerel (*Trachurus* sp.). Gulls ate also chicken (*Gallus*

gallus), pork/cow (*Sus domesticus/Bos taurus*), plastic, metal, paper and glass, as refuse tips (Alonso *et al.* 2015). There are also recent studies in Algarve showing that, although there is some refuse waste and insect consumption, the main YLG food prey at this site, during the breeding season, is fish (Calado *et al.* 2018). The fish species found were sardine (*Sardina pilchardus*), mackerels (*Scomber* sp. and *Trachurus* sp.), seabreams (*Diplodus* sp.), blue whiting (*Micromesistius poutassou*), bogue (*Boops boops*) and, occasionally, garfish (*Belone belone*).

Previous studies were made during the breeding period, when gull pellets are easier to find and collect (Barrett *et al.* 2007), but there are few studies examining seasonal variations in diet. During the winter occurs a decrease in fishing activities, reason why usually gulls shift their food source (Hüppop & Wurm 2000), and, therefore, we also expect variation in the diet between different periods of the year.

We evaluated seasonal, annual and spatial variations in the diet of yellow-legged gulls and how this is related to fishery activities and discards. The main goal of this work was to determine how *Larus michahellis* are dependent on fisheries. Two hypotheses were formulated: 1) the composition of diet and isotopic niche of the 4 different colonies should reflect the fishing activities around those colonies and, based on this, it is expected that the amount of fish in the diet is proportional to the fish landings in the nearby ports. It is also expected that the fish diet composition is partially a reflection of the diversity and amount in fish landings, because, often the mostly caught fish species are also discarded in considerable numbers (e.g. injured fish from the purse-seine fishing gear (Marçalo *et al.* 2010)). Furthermore, the isotopic niche will be larger where gulls ingest a larger diversity of prey types. 2) The second hypothesis states that gulls' diet and isotopic niche should vary seasonally in response to changes in fishery intensity and breeding duties. According to this hypothesis, we expect marine food, mainly fish, to be more important during the breeding season, in order to meet the chicks' nutritional needs (Alonso *et al.* 2015). On the other hand, terrestrial prey should be more relevant during the non-breeding period, because during winter fishing intensity is lower and the climate conditions are unpredictable (Arizaga *et al.* 2013), which means that gulls will try to find other food sources, thus enlarging their isotopic niche (Calado *et al.* 2018).

2. Methods

Photo: Manuela Rodrigues

2.1. Study sites

This study was carried out in four different places along the Portuguese coast and Galicia (Spain): Sálvora Island (Galicia), Berlenga Island (Peniche), Pessegueiro Island (Sines) and Deserta Island (Algarve), between 2016 and 2017. Yellow-legged gull colony in Sálvora is located at Atlantic Islands of Galicia National Park, more exactly at Ria de Arousa, a place characterized by a high productivity due to its upwelling regime (Álvarez-Salgado *et al.* 2002). Delimited by two peninsulas, Barbanza at north and Salnés at south, Ria de Arousa is the biggest of Rias Bajas group. Sálvora Island (42° 28′ 25″ N, 9° 00′ 42″ W) has 190 ha of surface and is located approximately 3 km from the coast (Velando *et al.* 2017), holding around 25000 yellow-legged gull breeding pairs.

Berlenga Island (39° 24′ 55″ N, 9° 30′ 34″ W) is a Biosphere UNESCO Reserve located in the continental shelf, about 9 km off the Portuguese coast. With 78.8 ha and 11 km along the coast, it is positioned in an upwelling zone with consequent high productivity (Sousa *et al.* 2008). Approximately 8500 YLG adults bred in Berlenga in 2014 (Ceia *et al.* 2014). Pessegueiro Island (37° 50′ 1″ N, 8° 47′ 52″ W) is the smallest of the studied sites. This rocky island has 7 km^2 of surface area and belongs to the Sudoeste Alentejano e Costa Vicentina Natural Park, a coastal strip of 110 km length and 2 km width, extending from S. Torpes, Sines, to Burgau, Lagos. This YLG population was detected in 2008 and has been growing exponentially since then, numbering today around 500 breeding pairs. In Algarve, our study was conducted at Ria Formosa National Park (southern Portugal), more exactly at Deserta (Barreta) Island (36º 57’ 40’’ N, 7º 53’ 20’’ W). The Ria Formosa National Park, with 60 km coastline and 18.400 ha, is composed by two peninsulas and five barrier islands, and is a Ramsar Site as well as part of the Natura 2000 network as a Special Protection Area under the Birds Directive. Deserta Island, which was artificially separated from the Farol/Culatra barrier Island, is located approximately 5.5 km from the mainland and presents a length of 7 km. At Deserta there are 1300 YLG breeding pairs, which breed in sympatry with Audouin gull (*Larus audouinii*; ~2900 breeding pairs).

The fishing activities and the corresponding landings (and discards) differ strongly among the 4 sites. Galicia has the largest amount of landings, as well as the largest amount of fishing trawlers operating, which also implies different species caught (https://www.pescadegalicia.gal/). Berlenga (Peniche) presents the second highest amount of fish landings, followed by Pessegueiro (Sines) and the Algarve (Olhão). Olhão presents a large amount of fishing activities, but these are focused in the chub mackerel capture with purse seine fishing (Carvalho 2017).

2.2. Study species

The yellow-legged gull is characterized by a generalist and scavenging feeding behaviour (Arcos *et al.* 2001). It feeds mostly from common and abundant food sources like landfills organic waste or fish discards (Valeiras 2003), but it can also present an active predatory behaviour (Matias & Catry 2010; Alonso *et al.* 2015). It is present throughout the year in southern Europe, including along the coasts of the Mediterranean, Black Sea and Caspian Sea, as well as in Portuguese and Spanish islands , however, it may also winter in the southwest of Asia and the north coast of Africa (BirdLife International 2017). With an average body mass of 800-1500 g, a length of 52-58 cm and 120-140 cm of wingspan, this coastal seabird is a long-lived gull with the capability to breed in different habitats, from rocky shores to sandy beaches. The breeding season is from mid-March to June, with the eggs (generally three) incubating for 27-31 days and chicks fledging after 35-40 days.

2.3. Fishing activities data

Data on fish landings was acquired from the General Direction of Natural Resources, Safety and Maritime Services (DGRM) (https://www.dgrm.mm.gov.pt/web/guest) which present updated fishing information. Therefore, it was possible to obtain data from the seasonal and annual fluctuations in fish landings and to obtain rough measures of fish discards (Arizaga *et al.* 2013).

2.4. Sample collection

In order to study the YLG diet, regurgitations were collected randomly in each colony 2/3 times a week during the breeding (May-June), post-breeding (September-October) and pre-breeding period (February-March). This process had to be executed the fastest way possible to minimize disturbance and only fresh pellets were considered in order to ensure they were from the studied period (Duhem *et al.* 2003). The collected samples were then put into identified plastic bags and kept frozen until later analysis.

To study the trophic ecology, we collected chicks' feathers and blood and feathers from adults for stable isotope analysis. Samples were collected in 2017. Adults were caught using nest traps (Weaver & Kadlec 1970), and around 0.5-1 ml of blood was collected from the tarsal vein. The blood was kept in a cold box and centrifuged within 2-3h to separate plasma (chick-rearing period) from red blood cells (RBC, incubation). After centrifugation, samples were preserved frozen until stable isotopes analysis (SIA). Samples from 3 types of feathers were also collected from each individual: 1) chicks breast feathers (4-5 random feathers), 2) 1st primary (P1, about 2-3 cm from the tip), for the breeding period characterization, and 3) the 8th secondary, which represents the non-breeding season (S8, about 2-3 cm from the tip), that were kept sealed in plastic bags until later analysis.

2.5. Diet sampling analysis

The comparison of the diet between the four colonies was the major goal of regurgitates analysis. For that purpose, the collected pellets were sorted under a steromicroscope to separate all hard prey remains such as vertebrae, otoliths and crab chelae. All prey were identified to the lowest taxon possible using our own reference collection and published identification guides (Assis 2004; Tuset *et al.* 2008). The samples also contained inorganic material, such as glass, paper and plastic, and other hard parts, mostly broken bones and vegetal matter. The birds' bones are likely from some predatory behaviour by the yellow-legged gulls, but the inorganic material and the vegetal matter should be, almost all, ingested accidentally, however, it also provides valuable information about the studied species diet, so it was kept for analysis.

2.6. Stable isotopes analysis

The stable isotopes analysis was performed in the laboratory and it was used the $\delta^{13}C$ and $\delta^{15}N$. The carbon isotope ($\delta^{13}C$) provides information about the preys' origin (marine/terrestrial), in other words the foraging habitat of the consumer (Ceia *et al.* 2012), while the nitrogen isotope ($\delta^{15}N$) gives the predator' trophic position (Ceia *et al.* 2012; Ceia *et al.* 2014). All isotopes were measured in feathers and blood samples since plasma and RBC can give short-term information on diet, while feathers can provide a long-term diet information (up to one year) because keratin is metabolically inert so the diet information is related to the moult period (Ceia *et al.* 2012). The feathers are related to different seasons from previous year to which they are collected, in other words, P1 feather is replaced in the end of the breeding season so it represents this season, while the S8 replacement takes place at the middle of the post- breeding period (Ramos *et al.* 2011), giving information from this period.

Possible contaminants present in the feathers were cleaned using a 2:1 chloroform-methanol solution. After an oven-dried period (24h to 48h at 50ºC), they were cut into small fragments. Blood samples were freeze-dried, homogenised (Bearhop *et al.* 2006; Ceia *et al.* 2014) and then had the lipids removed from the plasma samples by successive rinses in a 2:1 chloroform-methanol solution since high lipid concentrations in plasma can lead to depleted $\delta^{13}C$ values (Cherel *et al.* 2005).

For this analysis, approximately 0.35 mg of sample was weighed in a microbalance. The samples were then combusted in a tin cup so that the isotopes ratios could be determined by continuous-flow isotope ratio mass spectrometry (CF-IRMS). According to the equation $\delta X = [(Rsample / Rstandard) - 1] \times 1000$, results were expressed in the common delta (δ) notation as parts per thousand or per mil (‰). In this equation, X is ^{13}C or ^{15}N, Rsample is the corresponding ratio: $^{13}C/^{12}C$ or $^{15}N/^{14}N$ and Rstandard is the ratio for the international references PeeDee Belemnite (PDB) for carbon and atmospheric N2 (AIR) for nitrogen. The analytical precision for the measurement was 0.2 ‰ for both carbon and nitrogen.

2.7. Data analysis

The food items found in regurgitations were separated in different groups according to the prey category (pelagic and demersal fish, crustaceans, insects, molluscs and other prey, including refuse (all organic and inorganic material from human origin), vegetal matter, birds, mammals or others animal species, gull eggs and unidentified items). Those pellets' contents were described as species' frequency of occurrence (FO, %) in relation to the total number of diet samples, calculated from a binary matrix of presence/absence. To calculate FO, it was used the formula FO*i* = *ni*/*n*total x 100%, where *i* represents a specific prey or prey group, *ni* the number of samples in which *i* is present and *n*total corresponds to the total number of samples analysed. The numeric frequency of individuals of each species (NF, %) in relation to the total number of individuals was additionally calculated with NF*i*= *ni*/*n*total x 100% formula. In this formula *i* also represents a specific prey or prey group but, differently from the previous formula, *ni* represents the number of individuals of *i* present while *n*total corresponds to the total number of individuals. From the frequency of occurrence was obtain the percentage of occurrence for each prey type which was expressed in pie charts.

Subsequently, diet composition was tested using a Generalized Linear Model (GLM), which tested the influence of (1) colony site (Sálvora, Berlenga, Pessegueiro and Deserta islands), (2) annual seasons (pre-breeding, breeding and post-breeding), (3) years (2016 and 2017) and (4) their interaction (explanatory variables) on the species' frequency of occurrence present in diet (response variables). Due to lack of data for Pessegueiro and Sálvora in some seasons or years, GLM analyses with all independent variables were only run for Berlenga and Deserta colonies. Nonetheless, the site influence was tested for the breeding season of 2017. Lastly, all these analyses were graphically represented by Non-Metric Multidimentional Scalling (NMDS), once again, one for the 2017 breeding period for all sites and two others for each year but only taken into account Berlenga and Deserta colonies.

GLM with quasipoisson family was used to evaluate the effects of (1) colony site (Sálvora, Berlenga, Pessegueiro and Deserta), (2) season (breeding (P1 feathers), non-breeding (S8 feathers), chick-rearing (plasma) and incubation period (red blood cells)) and (3) their interaction (independent variables) on (1) δ^{13}C and (2) δ^{15}N values (response variables). Nevertheless, carbon and nitrogen isotopic signatures from adults feathers present enriched values relative to blood so, in order to perform this analysis, this values were adjusted with a discriminant factor, 1.8‰ and 0.6‰ for carbon and nitrogen, respectively (values for the same species obtain from Calado (2015)). Additionally, metrics available within SIBER (Stable Isotope Bayesian Ellipses in R) were used in order to establish the isotopic niche for each tissue. The comparison of isotopic niches amongst annual seasons (pre-breeding, breeding and post-breeding) and the differences between sites were also performed, for the first, the area of the standard ellipse (SEA_C) was determined, whereas for the second the Bayesian estimate of the standard ellipse and its area (SEA_B) was done (Jackson *et al.* 2011). In this analysis chicks' breast feathers were also used. All results were then presented as mean ± SD and C:N ratio.

The potential association between fisheries (explanatory variable) and diet (response variable) was tested, when possible, with a Pearson's correlation coefficient. For these analyses, we only considered prey present in the diet with a FO (%) higher than 2.5%, (data was arcsine transformed in order to fit a normal distribution).

The R statistical program (R Core Team 2017) was used in all analyses, with a significance level of $P < 0.05$.

3. Results

3.1. Comparing main diet items among colony sites

The yellow-legged gull population from Deserta Island fed mostly on fish, irrespective of season, and at a much higher proportion than yellow-legged gull populations at the other three study sites (mean for 2016/2017: Sálvora – no data/13.8%, Berlenga – 12.5/26.7%, Pessegueiro – 20.9/44.5%, Deserta – 67.8/63.8%, See Figure 1). Most of the fish taken by Deserta birds at all seasons was pelagic fish, with the exception of the pre-breeding period in both years, when mostly demersal fish was consumed (FO > 60%, Table A1 and A4). Refuse was also highly consumed by this population (2.5 to 25.5%, Figure 1), followed by Insecta (1.7 to 10.0%, Figure 1) and other items such as vegetal matter (0.0 to 9.4%, Figure 1) and Mollusca (0.8 to 5.6%, Figure 1) in fewer quantities. These last items presented higher amounts in the other three sites, in comparison with a lower consumption of refuse (0.0 to 18.3%, Figure 1). Birds from Pessegueiro Island fed mostly on fish (20.9 to 56.0%, Figure 1) and crustaceans (5.3 to 69.8%, Figure 1), with a higher proportion of *Boops boops* and *Scomber* sp. (e.g. FO > 30% in the 2017 breeding and post-breeding seasons, respectively, Table A5 and A6) and *Polybius henslowii* (e.g. FO > 50% in the 2016 pre-breeding season, Table A1). Nonetheless, in the 2017 post-breeding season, seeds of *Corema album* were very important in the diet (> 30%, Figure 1). Gulls' diet in Berlenga was dominated by crustaceans, particularly by Henslow's swimming crab (*Polybius henslowii*), ranging from 14 to 71.6 % of the diet. The 2017 pre-breeding season was an exception, because fish was the most consumed item (> 42%, Figure 1). Gulls from Sálvora Island consumed frequently Henslow's swimming crab (FO > 50%, Table A5), but vegetal matter, refuse and fish were also highly consumed (14.9%, 12.1%, 13.8%, respectively. Figure 1).

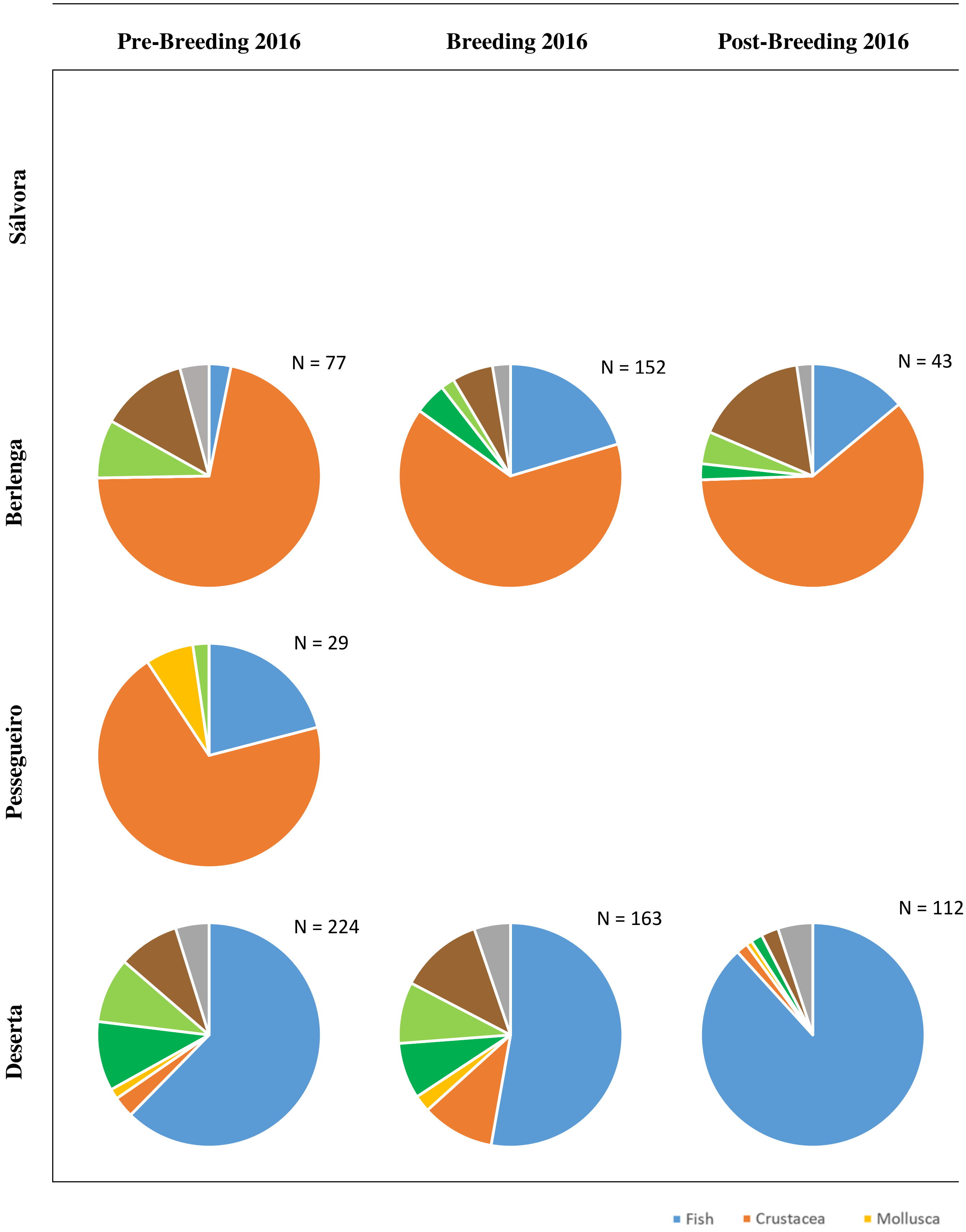

Figure 1: *Pie charts with the percentage of occurrence (PO %) of the main diet items for Sálvora, Berlenga, Pessegueiro and Deserta during the pre-breeding, breeding and post-breeding seasons of 2016 and 2017, (sample size (number of pellets) presented in the topright of each chart).*

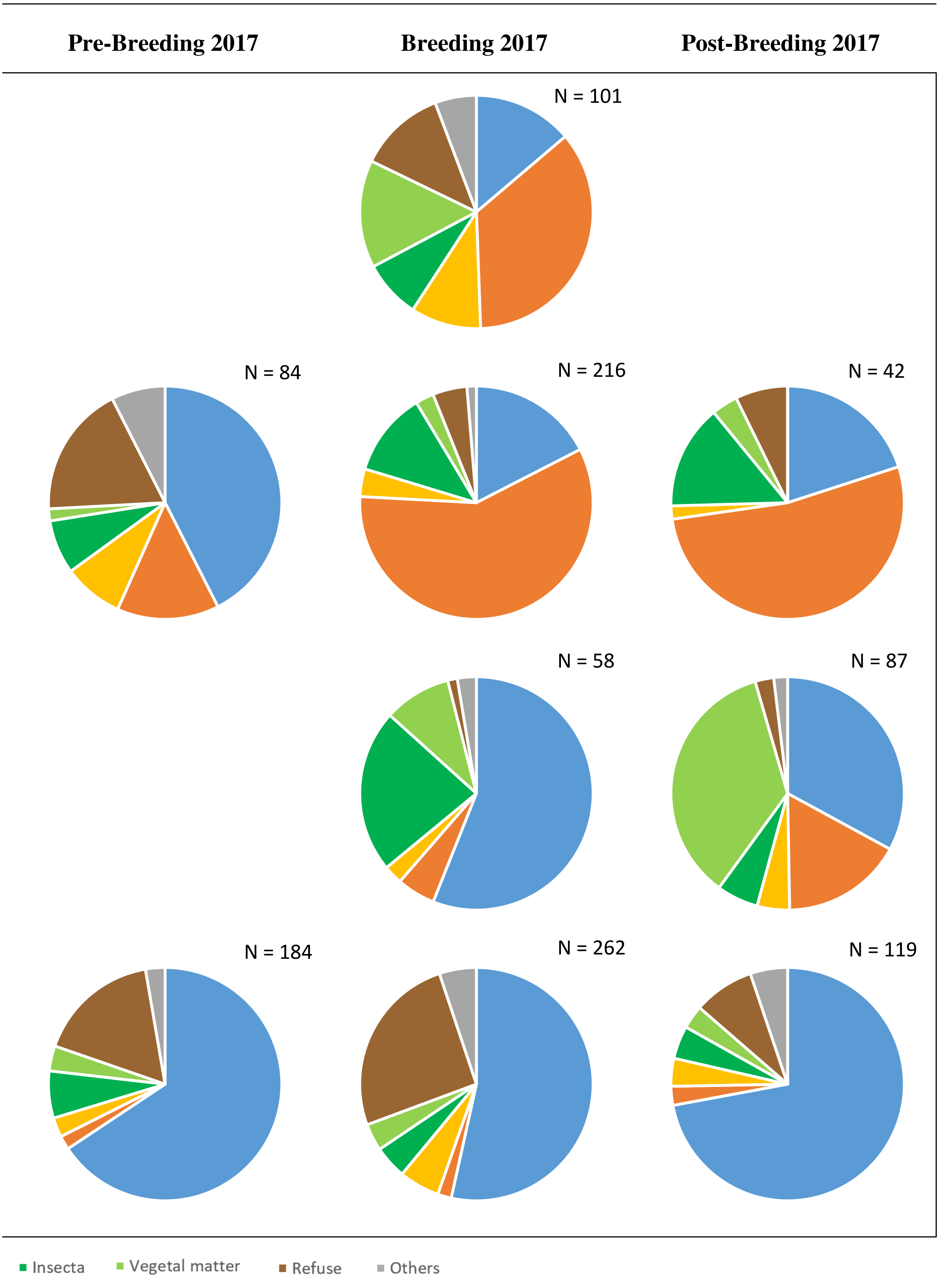

Figure 1: *Continued.*

3.2. Comparing gulls' diet from Deserta and Berlenga among seasons and years

GLM results testing the effect of year (2016 and 2017), season (pre-breeding, breeding and post-breeding) and site (Berlenga and Deserta) on the diet of gulls showed that many diet items varied significantly among years, seasons, and sites (Table 1). Most species had a higher occurrence in the diet in 2017 than in 2016, although this tendency was not observed for vegetal matter. Also, the main diet items were more important during the breeding season. During the pre-breeding period, demersal fish, *Sardina pilchardus*, *Diplodus* sp. and vegetal matter were the main items. Moreover, *Trisopterus* sp. was more important for the post-breeding season. Finally, fish, refuse and vegetal matter were significantly more important at Deserta than at Berlenga, while *Polybius henslowii* was the most important diet item at Berlenga.

The interaction Year*Season showed that most diet items were more consumed during the breeding period of 2017. Notwithstanding, *Scomber* sp. was higher in the pre-breeding of 2017, *Scomberosox saurus* in the breeding season of 2016 and vegetal matter was more relevant during the pre-breeding of 2016. The interaction Year*Site showed that most diet items were more important in the diet of gulls from Deserta in 2017, although demersal fish, S*comber* sp. and S*comberosox saurus* were significantly higher for Deserta in 2016, and *Polybius henslowii* and Insecta were the main diet items for Berlenga gulls in 2017. The Season*Site interaction showed that gulls presented a greater consumption of the main diet items during the pre-breeding and breeding period at Deserta Island, which may be partially a reflection of the larger sample size for this period. Nonetheless, *Trisopterus* sp. was the most important prey for the post-breeding of Deserta, while *Polybius henslowii* was most consumed in Berlenga's breeding.

The interaction between all variables (Year*Season*Site) showed that some of the main diet components (demersal fish, *Boops boops* and vegetal matter) were more consumed during the pre-breeding period by gulls from Deserta in 2016. Despite this, pelagic fish and Mollusca species had a higher importance for the 2017 breeding period at Deserta, while in the same season, Berlenga gulls consumed more *Polybius henslowii* and Insecta species.

Table 1: *Generalized Linear Model (GLM) testing the effect of year (2016, 2017), season (PBre- Pre-Breeding; Bre- Breeding; PTBre- Post-Breeding), site (Berl-Berlenga: Des- Deserta) and their interaction in the presence of the main prey in gulls' pellets (FO > 10%) from 2016 and 2017 in Berlenga and Deserta.*

	Year			***Season***			***Site***		
Prey	$F_{1,1673}$	***P***	***Main Effects***	$F_{2,1674}$	***P***	***Main Effects***	$F_{1,1676}$	***P***	***Main Effects***
Pelagic fish	19.34	<0.001	2016 < 2017	11.36	<0.001	Bre > Others	271.92	<0.001	Berl < Des
Micromesistius poutassou	7.70	0.005	2016 < 2017	43.12	<0.001	Bre > Others	135.65	<0.001	Berl < Des
Sardina pilchardus	2.55	0.110	--	8.11	<0.001	PBre > Others	38.32	<0.001	Berl < Des
Scomber sp.	1.41	0.236	--	4.45	0.117	--	18.14	<0.001	Berl < Des
Scomberosox saurus	0.88	0.349	--	3.03	0.048	Bre > Others	1.26	0.262	--
Trachurus sp.	1.63	0.201	--	0.16	0.852	--	69.00	<0.001	Berl < Des
Demersal fish	0.26	0.609	--	42.55	<0.001	PBre > Others	319.54	<0.001	Berl < Des
Boops boops	0.10	0.757	--	1.48	0.227	--	16.30	<0.001	Berl < Des
Diplodus sp.	2.84	0.092	--	34.05	<0.001	PBre > Others	222.82	<0.001	Berl < Des
Trisopterus sp.	12.06	0.006	2016 < 2017	4.43	0.012	PTBre > Others	0.41	0.522	--
Refuse	28.20	<0.001	2016 < 2017	13.68	<0.001	Bre > Others	23.00	<0.001	Berl < Des
Vegetal matter	11.13	<0.001	2016 > 2017	6.66	0.001	PBre > Others	8.79	0.003	Berl < Des
Polybius henslowii	8.89	0.003	2016 < 2017	25.36	<0.001	Bre > Others	918.61	<0.001	Berl > Des
Mollusca	23.08	<0.001	2016 < 2017	1.97	0.140	Bre > Others	0.43	0.512	--
Insecta	2.31	0.128	--	2.73	0.065	--	0.70	0.403	--

Table 1: C*ontinued.*

	Year*Season			***Year*Site***			***Season*Site***		
Prey	$F_{2,1668}$	***P***	***Main Effects***	$F_{1,1670}$	***P***	***Main Effects***	$F_{2,1671}$	***P***	***Main Effects***
Pelagic fish	9.92	<0.001	2017 Bre > Others	34.55	<0.001	2017 Des > Others	3.41	0.03	Bre Des > Others
Micromesistius poutassou	1.40	0.247	--	4.19	0.041	2017 Des > Others	5.28	0.005	Bre Des > Others
Sardina pilchardus	1.94	0.144	--	9.74	0.002	2017 Des > Others	6.68	0.001	PBre Des > Others
Scomber sp.	4.42	0.012	2017 PBre > Others	24.80	<0.001	2016 Des > Others	0.27	0.760	--
Scomberosox saurus	8.56	<0.001	2016 Bre > Others	23.94	<0.001	2016 Des > Others	13.20	<0.001	Bre Des > Others
Trachurus sp.	8.45	<0.001	2017 Bre > Others	18.13	<0.001	2017 Des > Others	0.73	0.481	--
Demersal fish	1.44	0.237	--	11.38	<0.001	2016 Des > Others	9.54	<0.001	PBre Des > Others
Boops boops	0.08	0.926	--	1.49	0.222	--	0.68	0.505	--
Diplodus sp.	2.51	0.081	--	0.05	0.822	--	0.32	0.723	--
Trisopterus sp.	0.96	0.381	--	1.75	0.186	--	5.15	0.006	PTBre Des > Others
Refuse	0.02	0.980	--	4.00	0.045	2017 Des > Others	23.69	<0.001	Bre Des > Others
Vegetal matter	4.56	0.010	2016 PBre > Others	1.38	0.240	--	3.10	0.045	PBre Des > Others
Polybius henslowii	51.00	<0.001	2017 Bre > Others	6.83	0.009	2017 Berl > Others	7.83	<0.001	Bre Berl > Others
Mollusca	0.58	0.560	--	10.88	<0.001	2017 Des > Others	2.46	0.086	--
Insecta	3.08	0.046	2017 Bre > Others	29.64	<0.001	2017 Berl > Others	5.34	0.005	PBre Des > Others

Table 1: *Continued.*

		Year*Season*Site	
Prey	***$F_{2,1666}$***	***P***	***Main Effects***
Pelagic fish	5.31	0.004	2017 Bre Des > Others
Micromesistius poutassou	2.23	0.108	--
Sardina pilchardus	2.55	0.078	--
Scomber sp.	0.00	1.000	--
Scomberosox saurus	0.00	1.000	--
Trachurus sp.	2.15	0.116	--
Demersal fish	7.95	<0.001	2016 PBre Des > Others
Boops boops	3.82	0.022	2016 PBre Des > Others
Diplodus sp.	2.51	0.082	--
Trisopterus sp.	0.09	0.917	--
Refuse	2.01	0.134	--
Vegetal matter	4.28	0.014	2016 PBre Des > Others
Polybius henslowii	4.34	0.013	2017 Bre Berl > Others
Mollusca	0.00	1.000	2017 Bre Des > Others
Insecta	1.82	0.162	2017 Bre Berl > Others

The NMDS for 2016 showed a notorious division among seasons. NMDS 1 revealed a notorious separation of the breeding period from Berlenga, together with the pre-breeding and post-breeding periods from Deserta (characterize by fish prey, Insecta and Mollusca) from all other seasons. *Trisopterus* sp. along with the remaining diet items was important to characterize the remain seasons (Figure 2).

NMDS 2 clearly divided the two colonies, with Insecta, Mollusca and demersal fish characterizing the diet of gulls from Berlenga, while pelagic fish was more prevalent on the diet of birds from Deserta.

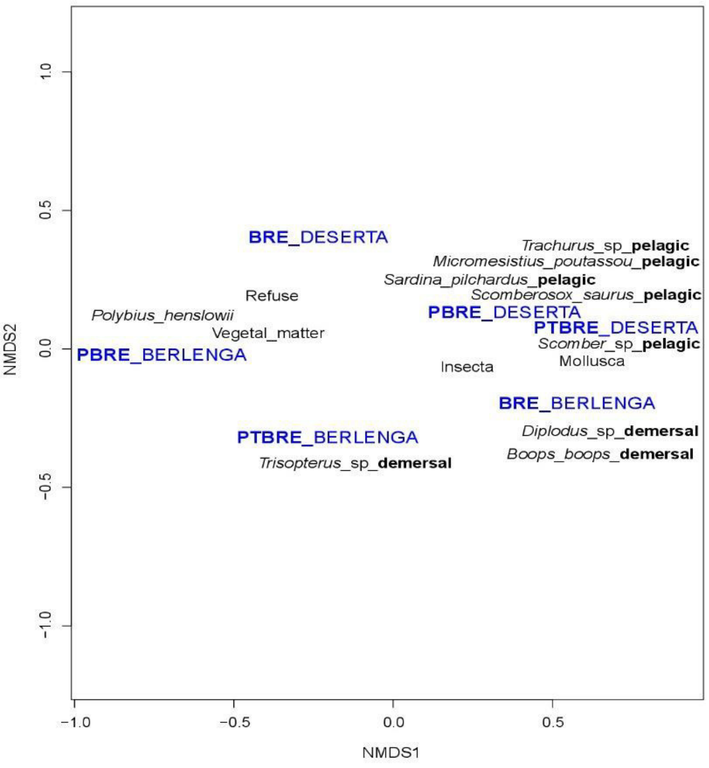

Figure 2: *Non-metric multidimensional scaling (NMDS) with the main consumed prey (> 10% percentage of occurrence) in Berlenga and Deserta during 2016. Demersal and pelagic fish and different seasons (PBre- Pre-Breeding; Bre- Breeding; PTBre- Post-Breeding) are identified in bold.*

In 2017, and according to the NMDS 1, Berlenga's breeding and pre-breeding along with Deserta's pre/post-breeding were clearly separated from the other seasons. The diet of gulls from these colonies were characterized by fish, namely *Scomberosox saurus*, *Trisopterus* sp., *Trachurus* sp., *Micromesistius poutassou* and *Diplodus* sp., whereas the others food items characterized the remain seasons (Figure 3).

NMDS 2 did not present a clear distinction among seasons/sites. It indicates that the diet for the breeding season of all colony-sites as well as the Deserta's pre-breeding season were mostly characterize by fish (*Scomberosox saurus* and *Trisopterus* sp., were an exception), apart from refuse and vegetal matter (Figure 3).

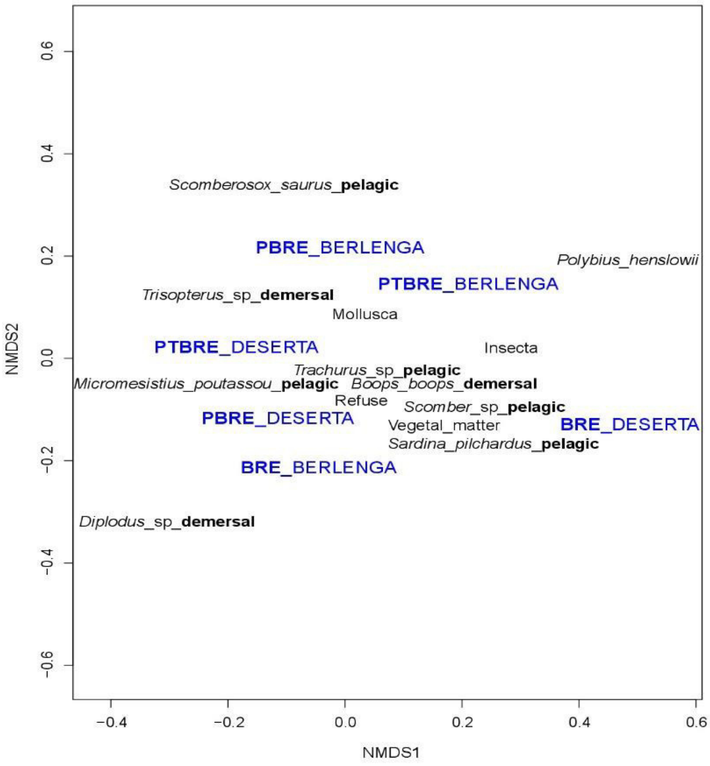

Figure 3: *Non-metric multidimensional scaling (NMDS) with the main consumed prey (> 10% percentage of occurrence) in Berlenga and Deserta during 2017. Demersal and pelagic fish and different seasons (PBre- Pre-Breeding; Bre- Breeding; PTBre- Post-Breeding) are identified in bold.*

3.3. Comparing the diet of gulls during the breeding period among sites

During the breeding season of 2017, most prey items differed significantly among colony sites (Table 2). With a few exceptions, fish species, along with refuse and Mollusca, were significantly more important for Deserta birds than for the other three colony sites. On the other hand, *Polybius henslowii* and Insecta showed greater importance for Berlenga gulls while *Boops boops* and vegetal matter were important in Pessegueiro and Sálvora colony sites, respectively.

Table 2: *Generalized Linear Models (GLM) testing the effect of site (Salv- Sálvora; Berl- Berlenga; Pes- Pessegueiro; Des- Deserta) in the presence of the main prey in gulls' pellets (FO > 10%) during the 2017 breeding season.*

Prey	$F_{3,633}$	***P***	***Main Effects***
Pelagic fish	22.89	<0.001	Des > Others
Micromesistius poutassou	14.63	<0.001	Des > Others
Sardina pilchardus	4.46	0.004	Des > Others
Scomber sp.	2.54	0.055	--
Scomberosox saurus	1.17	0.318	--
Trachurus sp.	4.01	0.007	Des > Others
Demersal *fish*	22.06	<0.001	Des > Others
Boops boops	14.60	<0.001	Pes > Others
Diplodus sp.	22.61	<0.001	Des > Others
Trisopterus sp.	0.49	0.689	--
Refuse	28.19	<0.001	Des > Others
Vegetal matter	12.97	<0.001	Salv > Others
Polybius henslowii	145.07	<0.001	Berl > Others
Mollusca	4.12	0.006	Des > Others
Insecta	6.97	<0.001	Berl > Others

The NMDS comparing all four sites in terms of the gulls' diet preferences during the breeding season of 2017 revealed a distinct separation of Berlenga and Deserta from Sálvora and Pessegueiro along NMDS axis 1. However, a distinguish pattern in diet is not clear in this axis. Axis 2 on the other hand presents a notorious separation between fish and other diet items (Figure 4).

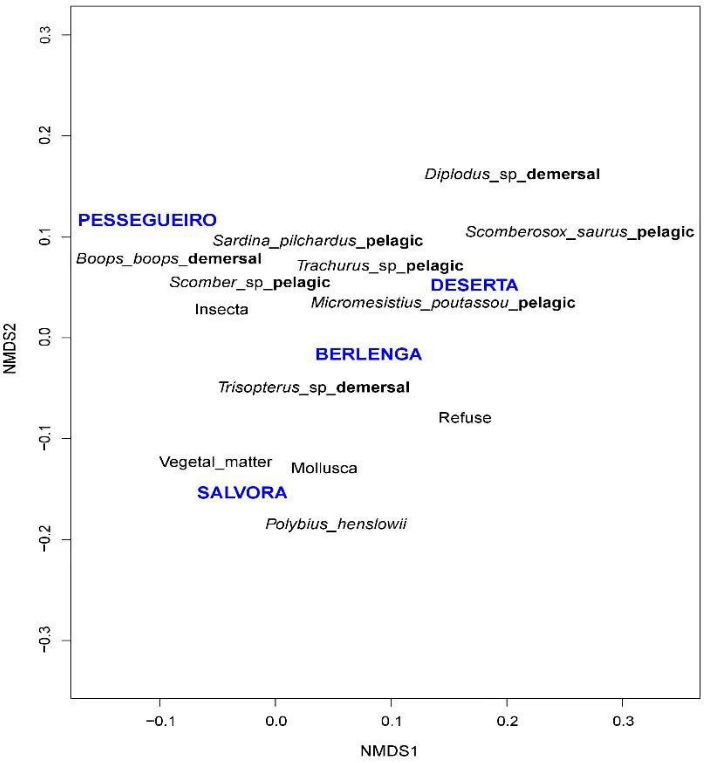

Figure 4*: Non-metric multidimensional scaling (NMDS) with the main consumed prey (> 10% percentage of occurrence) in all yellow-legged gull colonies (Sálvora, Berlenga, Pessegueiro and Deserta) during the breeding season of 2017. Demersal and pelagic fish and different seasons (PBre- Pre-Breeding; Bre-Breeding; PTBre- Post-Breeding) are identified in bold.*

3.4. Trophic Niche

The ratio C/N was approximately 3 for all tissues which means lipid removal was effective (Post *et al.* 2007). Moreover, carbon and nitrogen stable isotope values differed among sites and seasons (Table 3). As showed by the GLM analysis (Table 4), stable carbon isotope values differed significantly among sites (GLM, $F_{3,172} = 7.89$, P = <0.001), with the highest effect for Berlenga which had lower carbon values in all tissues (Figure 5). Carbon values were also significantly influenced by season (GLM, $F_{3,169} = 6.28$, P = <0.001), with the non-breeding season (S8 feathers) exhibiting higher values (Figure 5).

Site and season had a significant effect on the stable nitrogen isotope values (Table 4). The main effect was observed for Pessegueiro (GLM, $F_{3,172} = 3.69$, P = 0.013, Figure 6), while the breeding season (P1 feathers) showed the highest values (GLM, $F_{3,169}$ =

14.82, P = 0.001, Figure 6). Nitrogen was also highly influenced by site*season interaction (GLM, $F_{3,169} = 3.46$, P = <0.001), where Deserta showed the highest values during the breeding season (P1 feathers) (Figure 6).

Table 3: *$\delta^{15}N$ and $\delta^{13}C$ (mean ± SD; ‰) values and C:N ratio of feathers and blood for yellow-legged gulls (YLG) from Sálvora, Berlenga, Pessegueiro and Deserta islands collected in 2017 (sample size (N) presented).*

Tissues	N	δ13C ± SD	δ15N ± SD	C:N
		Sálvora		
P1	10	-16.5 ± 0.8	14.5 ± 0.8	3.1
S8	10	-16.1 ± 1.3	13.6 ± 1.2	3.1
Br	15	-16.9 ± 0.5	13.4 ± 0.6	3.1
RBC	10	-18.7 ± 0.9	12.7 ± 0.7	3.3
Plasma	10	-18.8 ± 0.8	13.6 ± 1.1	3.1
		Berlenga		
P1	16	-17.2 ± 0.4	13.7 ± 0.7	3.0
S8	16	-16.8 ± 1.1	14.4 ± 0.7	2.9
Br	10	-17.0 ± 0.6	12.8 ± 0.7	3.2
RBC	16	-18.8 ± 0.7	12.6 ± 0.7	3.4
Plasma	16	-19.3 ± 0.5	12.1 ± 1.4	3.7
		Pessegueiro		
P1	7	-16.1 ± 1.0	14.3 ± 0.9	3.1
S8	7	-16.1 ± 0.5	14.8 ± 0.7	3.1
Br	13	-16.7 ± 0.3	13.7 ± 0.2	2.9
RBC	7	-18.0 ± 0.4	13.5 ± 0.6	3.2
Plasma	7	-18.4 ± 0.4	13.0 ± 0.7	3.5
		Deserta		
P1	11	-15.7 ± 0.4	14. 9 ± 0.8	3.1
S8	11	-16.7 ± 1.4	14.2 ± 1.1	3.1
Br	15	-16.6 ± 0.9	13.2 ± 0.7	2.9
RBC	11	-18.5 ± 0.8	12.0 ± 1.3	3.2
Plasma	11	-19.1 ± 1.2	12.1 ± 1.5	3.7

Table 4: *Generalized Linear Model (GLM) testing the effect of the site (Des-Deserta, Pes-Pessegueiro, Berl-Berlenga and Sálv-Sálvora), season (NBre - Non-breeding (S8), Bre - Breeding (P1), CR - chick-rearing (plasma) and IP - incubation period (red blood cells)) and their interaction in the trophic niche. Values were adjusted with a discriminant factor 1.8‰ for carbon and 0.6‰ for nitrogen isotopes. Only significant variables are represented.*

	Site			**Season**			**Site*Season**		
	$F_{3,172}$	**P**	**Main Effects**	$F_{3,169}$	**P**	**Main Effects**	$F_{9,160}$	**P**	**Main Effects**
C	7.89	<0.001	Berl < Others	6.28	<0.001	NBre > Others	1.75	0.081	--
N	3.69	0.013	Pes > Others	14.82	0.001	Bre > Others	3.46	<0.001	Bre Des > Others

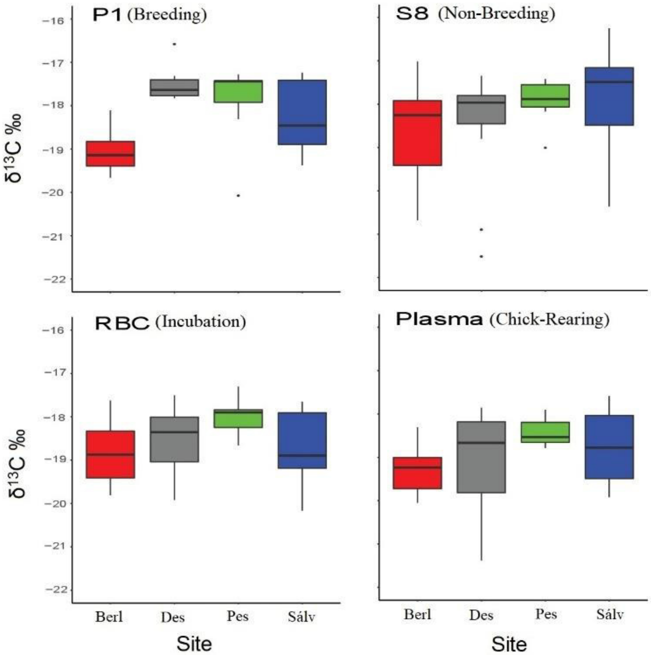

Figure 5*: Carbon isotopic values (median, 25-75% inter-quartile range, non-outlier range and outliers) for Berlenga (Berl-red), Deserta (Des-grey), Pessegueiro (Pes-green) and Sálvora (Sálv-blue) in breeding (P1 feather), non-breeding (S8 feather), incubation (RBC) and chick-rearing (plasma) seasons. To compare among different tissues, isotopic values of feathers were enriched with 1.8‰ according to Calado (2015) and following a method described by Cherel et al. (2014).*

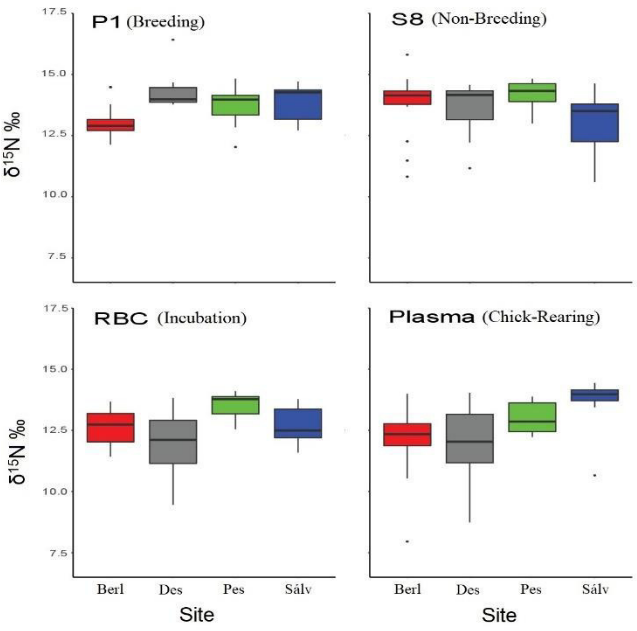

Figure 6: *Nitrogen isotopic values (median, 25-75% inter-quartile range, non-outlier range and outliers) for Berlenga (Berl-red), Deserta (Des-grey), Pessegueiro (Pes-green) and Sálvora (Sálv-blue) in breeding (P1 feather), non-breeding (S8 feather), incubation (RBC) and chick-rearing (plasma) seasons. To compare among different tissues, isotopic values of feathers were enriched with 0.6‰ according to Calado (2015) and following a method described by Cherel et al. (2014).*

Regarding the niche width (SEA_C, Table 5 and Figure 7), primarily, Berlenga exhibit the highest value in S8 feather, suggesting a more varied diet, whereas Pessegueiro presented the lowest values, implying a more specialist diet. More specifically, chicks exhibited a wider niche in Deserta in relation to the others sites, and the overlap varied between 54% to approximately 0% (Deserta-Berlenga, Berlenga-Pessegueiro, respectively). For the breeding period, both Sálvora and Pessegueiro had a similar isotopic niche, which was wider than those of the others sites. Furthermore, Pessegueiro in the breeding season was the only site showing significant differences in the niche width in relation to Berlenga (SEA_B, $P = 0.034$). About the niche overlap, this varied from 0% (Deserta-Berlenga) to 56% (Pessegueiro-Sálvora). In the non-breeding, Berlenga revealed a significantly larger niche, as well as the highest nitrogen values (Figure 6). The overlap in this period was very high for all sites with the exception of Sálvora, which had an almost null overlap with Deserta and Pessegueiro.

For the incubation period, results revealed a larger niche width for Sálvora, in opposition to Pessegueiro's narrow niche. Moreover, Sálvora also presented the largest overlap with Berlenga, while Deserta and Pessegueiro had almost no overlap. The chick-rearing period revealed the larger niche in Deserta and, similarly to the incubation, Pessegueiro with a narrow niche. Concerning the niche overlap, Deserta presented high values in relation to the other sites while Berlenga and Pessegueiro presented the smallest overlap.

Table 5: *SIBER outputs: area of the standard ellipse (SEAc) for Sálvora, Berlenga, Pessegueiro and Deserta in each tissue (season).*

	SEA_C			
	Sálvora	Berlenga	Pessegueiro	Deserta
P1	1.5	0.7	1.5	0.5
S8	2.7	4.3	1.0	2.3
Br	0.7	0.7	0.1	1.5
RBC	1.6	1.4	0.5	1.0
Plasma	2.9	2.4	0.6	3.9

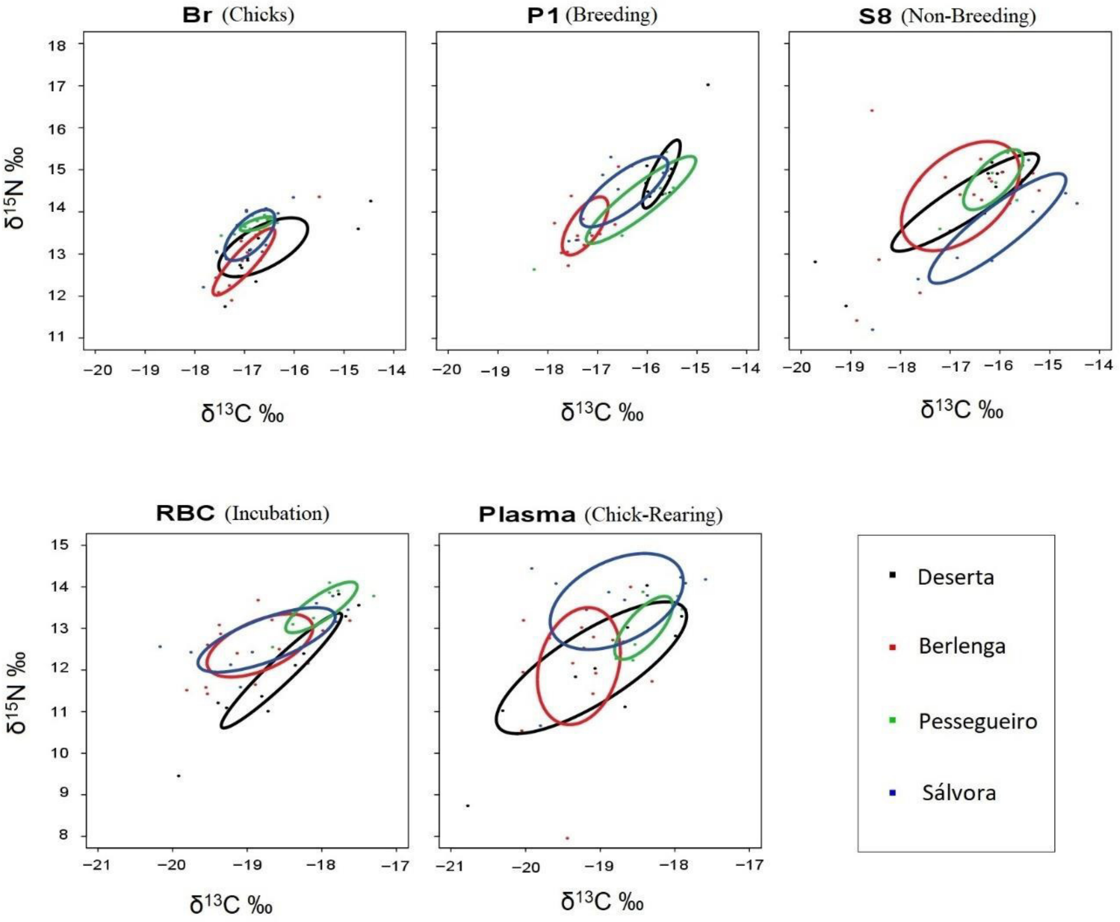

Figure 7: *Isotopic niche comparison between chicks (Br), breeding (P1), non-breeding (S8), incubation (RBC) and chick-rearing (plasma) seasons, for all sites: Berlenga (red), Deserta (grey), Pessegueiro (green) and Sálvora (blue). It is represented the standard ellipses areas (SEA$_C$).*

3.5. The influence of fisheries in the diet

Concerning the relationship between fish landed (explanatory variable) and fish consumed (response variable), only a few significant values were obtained. There was a significant correlation between the main consumed fish species by gulls from Deserta during the pre-breeding and the percentage of fish landed in the nearby port during the same period, for both 2016 (r = 0. 83, P = 0.001; Figure 8) and 2017 (r = 0.55, P = 0.03, Figure 9). These suggest an influence of fisheries in the gulls' diet of Deserta Island. Data from the 2017 post-breeding for Pessegueiro also showed a significant correlation (r = 0.94, P = 0.01, Figure 10). Berlenga did not show any relationship between the proportion of fish in the diet and that in the fish landings, although the correlation for the pre-breeding period of 2017 show a P value close to 0.05 (r = 0.57, P = 0.07). It should be noted that for Sálvora (breeding of 2017) and Berlenga during the pre and post-breeding periods of 2016 and 2017 breeding and post-breeding periods the diet was mainly composed by Crustacea, Mollusca species or vegetal matter (Table A1, A3, A5, A6), and thus we could not correlate it with fish landings.

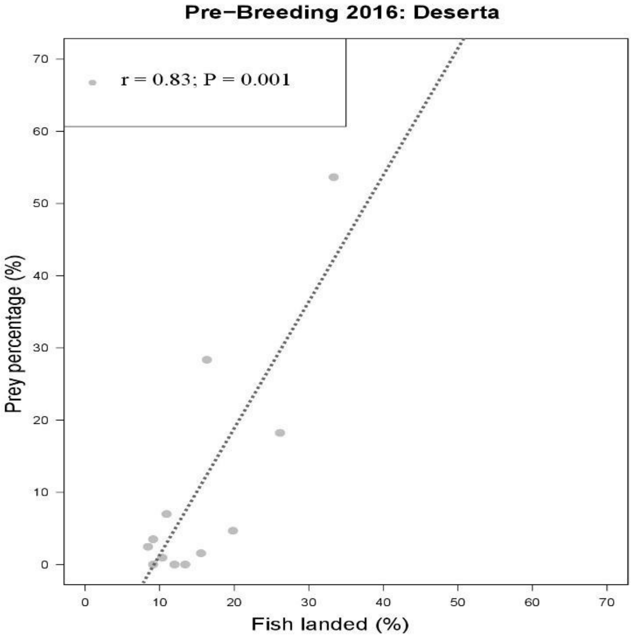

Figure 8: *Pearson correlation between prey percentage of occurrence (PO%) in the pellets from Deserta colony site and the percentage of prey landed in Olhão harbour during the pre-breeding period of 2016, (only prey present in diet with a frequency of occurrence (FO%) superior to 2.5% were considered).*

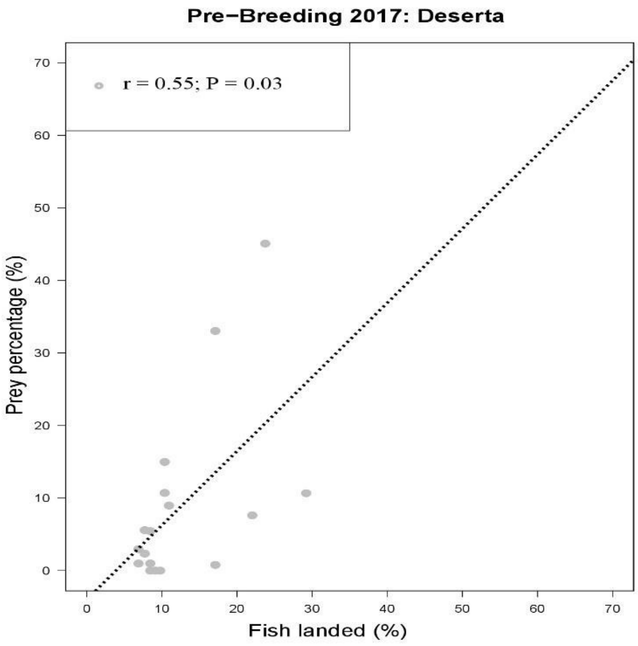

Figure 9*: Pearson correlation between prey percentage of occurrence (PO%) in the pellets from Deserta colony site and the percentage of prey landed in Olhão harbour during the pre-breeding period of 2017, (only prey present in diet with a frequency of occurrence (FO%) superior to 2.5% were considered).*

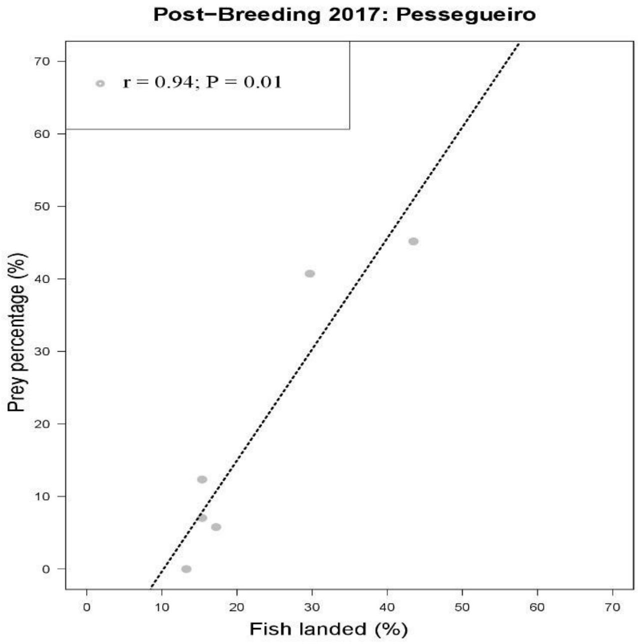

Figure 10: *Pearson correlation between prey percentage of occurrence (PO%) in the pellets from Pessegueiro colony site and the percentage of prey landed in Sines harbour during the post-breeding period of 2017, (only prey present in diet with a frequency of occurrence (FO%) superior to 2.5% were considered).*

4. Discussion

Photo: Hugo Guímaro

With this study, we were able, not only to characterize the diet of yellow-legged gulls from four different coastal populations in the Iberian Peninsula, but also to distinguish trophic shifts in these colonies amongst distinct seasons and years. Although there are many studies on the diet of gulls, most were conducted during the breeding season only and on one colony site per study. Therefore, this study provides a more comprehensive framework of the spatial, seasonal and annual shifts in the diet of gulls. Moreover, we were able to evaluate how gulls rely in fishing activities as a source of food.

We observed an overall generalist diet for the gulls from different colony sites. Nonetheless, diet components exhibited notorious seasonal differences, which may be related with seasonal changes in food availability, reproductive demands, and chicks' nutritional needs as showed by differences in stable isotopes values and isotopic niche width. In addition, only Deserta presented a diet mainly composed by fish, whereas, in the other colony sites, the diet comprised mostly crustaceans, insects, vegetal matter and/or refuse. As for gulls' dependence on fishing activities, Deserta Island, where fish was the main consumed item, exhibited a strong relationship with fisheries, especially during the pre-breeding period. Pessegueiro's gulls also relied on fisheries for food during the post-breeding season.

4.1. Dietary and trophic shifts among colony sites during the breeding season

As it is characteristic for this species, our results presented an overall generalist diet for all populations during the breeding season, yet, distinct patterns in diet were also perceptible when comparing the different colony sites. According to diet samples there was a notorious separation of Deserta and Pessegueiro, where the diet was rich in fish, from Berlenga and Sálvora, where gulls consumed mostly crustaceans (see Table 1). We expected that, during the breeding period, diet would be of better quality, mostly due to chicks' nutritional needs, being constituted predominantly by fish (Annett & Pierotti 1989; Bukacińska *et al.* 1996) and, consequently, colonies would display a narrow trophic niche due to this specialist diet. Overall, the diet of gulls from both Deserta and Pessegueiro seem to agree with our hypothesis. However, we have to take into consideration that a diet characterization using regurgitations, although adequate, cannot describe all diet items, since it takes into account only prey hard parts that are partially digested and some items, particularly those with soft parts, will not be assessed with this method (Barrett *et al.* 2007). Therefore, a complementary use of isotopic analysis was helpful to better characterize the yellow-legged gull trophic ecology (Hobson *et al.* 1994; Karnovsky *et al.* 2012), be it from adults or chicks.

Our results for chicks' diet agreed with our hypothesis, because all colonies presented a specialist diet, some highly overlapped, suggesting that chicks from all colonies were fed with similar diet items (Bearhop *et al.* 2004), which is predominantly fish according to several studies (Moreno *et al.* 2010; Alonso *et al.* 2015). The isotopic niche for Deserta´s chicks, however, was larger when compared to that of other colonies, which could suggest an intake of different groups of fish (demersal and pelagic), as reported by Calado *et al.* (2018) and Navarro *et al.* (2010).

Regarding adults isotopic niche, this could present some variations in relation to chicks, as observed by Navarro *et al.* (2010). Moreover, it cannot be forgotten that P1 (breeding period) and plasma (chick-rearing) tissues, although representing similar periods, characterize different years (Ceia *et al.* 2014). Taking this into account, Deserta's gulls presented, during this season, a narrow isotopic niche, suggesting a more specialist diet, and high values for nitrogen, which characterize diets rich in fish. This can be explained with a potential relation with nearby fishing activities, as observed in previous studies. Valeiras (2003) and Arcos *et al.* (2001) described fishing activities as beneficial for various seabird species, including YLG, specifically in foraging practices. Cama and others also observed that the peak density of gulls coincided, both in time and space, with the higher amount of fishing vessels (Cama *et al.* 2012; Cama *et al.* 2013). Moreover, Navarro *et al.* (2010) reported that high values of nitrogen matched with demersal prey coming from fisheries, which could also explain our results. Nonetheless, another explanation to our results could be a possible shift in gulls' foraging selection to provide chicks with a more nutritious and easy to swallow food items, as we hypothesised. Similar results were reported by other studies where gulls fed mostly on fish, but other prey items were also found (Pedro *et al.* 2013; Calado *et al.* 2018). In Pessegueiro, the pattern was distinct with gulls presenting a generalist diet. Diet samples from 2016 were not collected, however, their trophic niche also presented a substantial overlap with Sálvora gulls' diet. Our samples of Sálvora's diet suggested a generalist diet, which could denote not only similarities between the two colonies but also that a generalist diet is maintained in both colonies during the breeding period. Our results for Sálvora's gulls (and possibly

Pessegueiro colony site) could be relate with Moreno *et al.* (2010) observations, where a diverse diet, even though rich in fish, was provided to chicks, according to nearest food source. Notwithstanding, during the chick-rearing period, gulls from Deserta presented a larger trophic niche, suggesting that adults selected different food resources for their offspring and, due to parental constrictions, choose a closer and predictable source of food to feed themselves. This result is similar to what was reported by Alonso *et al.* (2015) for Berlenga island, which observed this change in the breeding period, where adult gulls consumed mostly crustaceans, but fed their chicks with fish, a more energetic and easier to ingest food resource. These results and the specialist diet exhibit by Pessegueiro's gulls are related with the chicks' feeding niche (Deserta with a more generalist diet and a restricted diet for Pessegueiro), suggesting, as reported by Arizaga *et al.* (2013), a similar diet between adults and chicks and, consequently, that gulls select food of better quality, as stated in our hypothesis.

Sálvora and Berlenga colonies both presented Henslow's swimming crab (*Polybius henslowii*) (see Table A2 and A5) as main food source. This crab species occurs in high numbers during upwelling events (Sousa *et al.* 2005) which can vary between years, yet that was not the case in our study. Even though this is a food resource with low caloric value, it is very abundant and allows gulls to feed without losing energy in their foraging activities. Alonso *et al.* (2015) also reported a high consumption of crabs by gulls from Berlenga, which becomes an advantage mostly during the reproductive season, when gulls are central place foragers. Berlenga´s gulls presented a more restricted diet during the breeding season, according to the narrow niche that was recorded. Additionally, because more than 60% (see Table 1) of the gulls' diet was composed by crabs, it also explains the low nitrogen values (Navarro *et al.* 2010) observed in our results. Carbon values also suggest differences in the foraging habitat from Berlenga in relation to the other colonies, because lower values imply a more pelagic foraging behaviour (Ramos *et al.* 2015). Moreover, gulls from this colony showed a high overlap in terms of stable isotopic values with Deserta gulls during the chick-rearing period, suggesting a similarity in prey isotopic signatures consumed at the two sites (Bearhop *et al.* 2004). Gulls from Sálvora presented a large niche, in accordance with diet samples, suggesting a large spectrum of diet items, in other words, gulls probably fed on resources more abundant and predictable near the colony. This outcome matches with previous observations also performed in Galicia (Munilla 1997; Moreno *et al.* 2010), were *Polybius henslowii* was the main prey. Nonetheless, we cannot neglect the significant amount of vegetal matter and refuse also present in the diet of gulls (see Table A5), which, as stated by Duhem *et al.* (2005) reveal advantages for adult gulls, who would perform short foraging trips in order to minimize the time chicks spend alone and see their chances of predation decreased (Bukacińska *et al.* 1996). These results suggest different and also predictable food sources near the colony sites, which adult gulls would select due to parental constrains.

4.2. Comparing annual and seasonal variations in diet and trophic ecology among colonies

Overall, yellow-legged gulls presented similar diets for the two years. Notwithstanding, some changes in diet could be witness in Pessegueiro and Berlenga colonies, between the two years. Gulls from Pessegueiro, during the pre-breeding season (2016), presented a higher intake of crustaceans, contrasting with the other 2017 periods with a large consumption of fish. These results could suggest, not only, a shift in diet among seasons/years, but also a greater relevance of terrestrial food during the non-breeding season, as stated in our hypothesis. The pre-breeding season is a period with high energy demands, especially for females (Mills 1979). Crabs, as well as molluscs, are reported as a good source of calcium, which can be beneficial for the egg formation or even for chicks' bones structure (Schwemmer & Garthe 2005). This assumption could suggest a preference for this food items during the pre-breeding season as reported by Navarro *et al.* (2010), that observed a greater intake of American crayfish in female gulls' diet during the incubation period. However, according to stable isotopes analysis, this outcome appears to be a singular situation, because during the incubation period a specialist diet with high values of nitrogen was observed, which owing to the opportunistic feature of this gull species, suggest the presence of demersal fish from discards (Navarro *et al.* 2010). Nonetheless, we have to take into account that diet samples from the pre-breeding in Pessegueiro were only collected in the previous year and that some changes in food availability may be the cause for this shift between years, as reported for Berlenga in 2011 (Ceia *et al.* 2014; Alonso *et al.* 2015). Regardless, this shift in foraging behaviour was described in other studies (Lindsay & Meathrel 2008), including with different species, as reported by Paiva *et al.* (2010) in Cory's shearwaters (*Calonectris borealis*). Our study was not the first to present differences between years.

Similarly, Arizaga *et al.* (2013) also reported differences among colonies and years. Ceia *et al.* (2014) also observed slight differences between years, though these were an apparent consequence of a shift in prey availability.

Diet of gulls from Berlenga also exhibited a shift between years, with 2017 pre-breeding diet representing an exception in the overall crustacean based diet. In this season it was noticeable some influence from fisheries, even thought this was not meaningful. These results can suggest different interpretations. First, it is possible that gulls alter their diet selection in order to prepare for chicks' arrival, specifically gathering caloric energetic food for the egg laying and territory protection, as reported in other *Larus* species' (Mills 1979; Lindsay & Meathrel 2008). Second, as mentioned before, there could have been a seasonal decrease in the abundance of *Polybius henslowii*, as observed during the 2011 breeding season (Ceia *et al.* 2014; Alonso *et al.* 2015), which forced gulls to search for other food sources. Third, the high amount of fisheries (see Figure A1), and consequent discards, could provide a predictable and stable food source, as Cama and others perceived in yellow-legged gulls, as well as with Audouin's gulls (Cama *et al.* 2012; Cama *et al.* 2013). However, we cannot forget the generalist diet observed during the incubation period, similar for all colonies (except in Pessegueiro), as well as the notorious overlap among colonies, which suggests that, without parental duties of the breeding phase, gulls were able to feed in similar habitats and consumed the same species, or species with similar isotopic values (Bearhop *et al.* 2004).

Concerning seasonal changes in diet, these were more noticeable during the post-breeding season for Pessegueiro. Terrestrial items were of great importance in this colony's diet, agreeing with our hypothesis (terrestrial prey more important during the winter due to the decrease of fishing practices and the unpredictability of weather conditions). Nevertheless, it is important to highlight the presence of *Corema album* (Portuguese crowberry) seeds. This plant can be found in dunes or rocky shores through all Iberian coast and its fruits mature between August and September (Calviño-Cancela 2002), providing a low energy food resource, but that is highly predictable and can be obtained with a minimum energy cost, as stated by the optimal foraging theory (MacArthur & Pianka 1966). These results are in accordance with a previous study performed in Vigo, where young gulls, with less foraging skills, appeared to use the abundant *Corema album* fruits as a main food source. Regarding the large amount of fish consumed during this period, it is worth mentioning that fishing activities were higher in this season in relation to other study periods (see Figure A1), suggesting some opportunistic behaviour in this gulls' foraging activities. These results agree with the stable isotope analysis, where birds from Pessegueiro differed from the other colonies, because Pessegueiro gulls' diet was composed mainly by *Corema album* fruits and/or fish, presumably from fisheries discards (high nitrogen values).

All other colonies presented a similar diet throughout the year. Although, it is important to highlight the difference between the diet of Deserta gulls from that of other colony sites. Deserta gulls fed almost exclusively on fish, which suggests a high dependence on fishing activities. However, we cannot disregard the differences observed, among years/seasons, in their trophic ecology, specifically the variation detected between breeding and chick-rearing, as already mention, as well as the changes in the niche width between the breeding and non-breeding period. Furthermore, it is also worth mention that we are in presence of a complex food web, which can cause some misinterpretation of gulls' trophic ecology, because carbon present low values for marine and terrestrial prey. Therefore, it would be beneficial to use a third isotope, sulphur, which can better distinguish between the two foraging areas, presenting high values for prey of terrestrial origin and low values for marine prey.

4.3. Role of fisheries in gulls' diet

Regarding fishing activities, we expected that the amount of fish present in diet to be proportional to the landings in the harbours near the colonies. Moreover, it was also predicted that the fish intake was higher during the breeding season, mostly due to chicks' nutritional needs. Nonetheless, this was not always observed in our study. Although all colonies presented some fish intake, only Deserta and Pessegueiro gulls exhibit significant correlations with fishing activities, even though that relationship was not constant the whole year. Through diet samples, we were able to observe a close relationship between the gulls' diet of these two sites and the amount of fish landed in the nearby ports. However, in Deserta's gulls, this correlation was presented in the pre-breeding season of each year (2016 and 2017), while for gulls from Pessegueiro Island it occurred during the post-breeding period (2017). Curiously, the post-breeding season in Pessegueiro matched with the period with highest fishing activities near the colony (see Figure A1), suggesting by itself a cause for the observed relationship. Even though gulls' foraging strategies from Pessegueiro' colony site are less studied, previous studies corroborate the previous assumption, for instance Hüppop and Wurm (2000) that observed, in gulls from the North Sea, a higher fish intake during fishing days and a shift from marine to terrestrial food items on days without fisheries. Votier *et al.* (2013) and Cama *et al.* (2012) also observed fisheries-bird interaction on northern gannets and gulls, respectively, once again evidencing seabirds strong connection with fisheries. Studies like these, not only validate our hypothesis but also allow us to better understand possible differences between distinct colonies, as it is shown by Ramos *et al.* (2009a), where gulls from Columbretes Island (more distant to the mainland) had a higher intake of fish in relation to the other colony sites.

For both Deserta and Pessegueiro colony sites, the main species consumed by gulls were the pelagic species *Scomber* sp. (mackerels), *Micromesistius poutassou* (blue whiting), *Sardina pilchardus* (sardine) and *Trachurus* sp. (horse mackerels), together with the demersal *Diplodus* sp. (seabreams), *Boops boops* (bogue) and *Chelon labrosus* (mullet) (see Table A1, A4 and A6). The pelagic fish presence could suggest a predatory behaviour by yellow-legged gulls, however, the opportunistic foraging behaviour in this species has been reported in many studies, be it in relation with fishing activities (Oro & Ruiz 1997; Arcos *et al.* 2001; Cama *et al.* 2012) or with refuse dumps (Duhem *et al.* 2003; Real *et al.* 2017). Plus, the assumption that gulls use fisheries as a food source provider, was also corroborated by the presence of demersal fish in their diet. Gulls are not capable to dive to depths where demersal fish occur (Votier *et al.* 2010), and thus such prey were unquestionably obtained from fisheries (Arizaga *et al.* 2010).

Even though our hypothesis states that the amount of fish in gulls' diet should reflect the fish landed near the colony, we cannot forget that gulls do not feed directly from the fish caught, instead they exploit fish and its offal rejected from fishing activities (Valeiras 2003). From the main consumed species, *Sardina pilchardus, Scomber* sp., *Trachurus* sp. and *Diplodus* sp. are amongst the main target species in Portuguese fisheries (Cabral *et al.* 2003; Costa *et al.* 2008), however, its presence in gulls diet is owed to the fact that even target species can be rejected if they do not meet the necessary requirements impose by the EU Common Fisheries Policy (CFP), reason why our hypothesis is valid. Discard of target species is not the only way gulls can feed on it. Stratoudakis and Marçalo (2002) reported in sardine purse seine practices the "slipping" phenomenon were fish is release with the lowering of the net; yet this practice can also injure fish, increasing its mortality and making it more accessible to gulls. As for the remain species, *Micromesistius poutassou* and *Boops boops* can also be found among the fish landed, although in lower quantities, because they are not targeted but can have some commercial value (Costa *et al.* 2008), *Chelon labrosus,* on the contrary, presents a 100% discard rate (Cabral *et al.* 2003). Despite this, all target and non-target species appear as greatly discarded (Borges *et al.* 2001; Gonçalves *et al.* 2008), which could explain its presence in yellow-legged gulls' diet.

However, we cannot forget that these fisheries-diet association was analysed taking into account diet samples. Because this type of analysis, as referred before, can cause some bias in our results, it is possible that other correlations passed unnoticed. This could be the case for Pessegueiro Island, during the breeding season, where a large volume of *Boops boops*, a demersal fish, was consumed (see Table A5) yet, no relationship between diet and fishing activities was found. The diet of gulls from Berlenga and Sálvora can also be related with fisheries discards, given the high importance of *Polybius henslowii* in the diet, a highly discarded species (Batista *et al.* 2009; Ordóñez-Del Pazo *et al.* 2014). However, as Arizaga *et al.* (2013) suggested, the use of fish landed as indicator of discarded species could imply some inconsistencies in diet-fisheries correlations, so in order to better discern the previous assumptions, concrete data on discarded items for each site would be important.

4.4. Conclusions and final remarks

Through this work, we were able to better understand shifts in yellow-legged gulls' diet over the years. Moreover, we observed the opportunistic and generalist foraging behaviour of this gull species. Taking into account our results, yellow-legged gulls did not exhibit a major dependency on fisheries, instead, they use this human activity as provider of high nutritional and energetic value type of food, together with other predictable and abundant food sources, such as refuse dumps (Moreno *et al.* 2010) and/or crustaceans (Munilla 1997; Alonso *et al.* 2015). Additionally, our hypothesis was only partially confirmed, because only Deserta and Pessegueiro colony sites, where gulls had a greater intake of fish, exhibited a meaningfully relationship with fisheries, whereas Peniche, the harbour near Berlenga colony, presented the higher amount of fish landed (see figure A1). Nevertheless, we cannot exclude the possibility that fisheries around Deserta and Pessegueiro islands produce high amounts of discards, as reported by Costa *et al.* (2008), which could justify our results.

Gulls, as well as other seabirds, benefit with discards by improving their reproduction success (Tasker *et al.* 2000), decreasing chicks mortality (less time away from nests) and/or decreasing energy use in foraging activities (Cama *et al.* 2012). Nonetheless, the exploitation of this predictable food source can lead to seabird bycatch (Lewison *et al.* 2004; Cortés *et al.* 2017). Even though fisheries are advantageous for gulls, the overfishing of stocks would ultimately lead to a reduction in prey availability. Due to this, the European Commission (EU) approved recently a discard ban that has been slowly imposed through all member states, with a full deadline application in 2019. This ban states that all fish that does not meet the necessary requirements and/or it is not target cannot be rejected, instead, it should also be landed in the harbour where it will be used for another proposes, such as animal food (European Commission 2018). Due to the opportunistic nature of yellow-legged gulls and their use of fisheries, the possibility that this discard ban will affect gulls' diet, and consequent survival, has to be considered. According to our results, gulls from Algarve would be the most affected, as well as gulls from Pessegueiro during part of the year. Nevertheless, we cannot forget the plastic nature of gulls and, taking this into account, the most probable scenario is that gulls will suffer some decrease in their numbers as a response to the sudden lack of a predictable food source (Oro *et al.* 1995). However, in time they would adapt to the new conditions, probably by the increase of foraging practices in refuse dumps and/or predation of other species. Moreover, yellow-legged gulls presence in cities has being increasingly reported, showing its high adaptability.

Taking into consideration all the previous information, it is probable that the discard ban will not affect significantly, in the long-term, the yellow-legged gull populations. However, it would be interesting to deepen this research in order to better evaluate gulls' diet and the influence of fisheries, perhaps with the addition of a third isotope (sulphur) to better distinguish gulls' trophic ecology or resorting to the use of GPS data, in order to, more accurately, examine fisheries-gulls interaction, as reported by Cama *et al.* (2012). Nonetheless, this work contribution to gull's research cannot be disregarded, not only due to the description of less studied colonies such as Pessegueiro, but also due to the diversity in diet and foraging strategies demonstrated with the comparison of different yellow-legged gull's colonies.

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Appendix

Table A1: *Frequency of occurrence (FO; %) and Numeric Frequency (NF; %) of all items found in the diet in Berlenga, Pessegueiro and Deserta during the pre-breeding of 2016. Number of samples (FO) and number of individuals (NF) presented below colony sites (*correspond to squid species).*

	Pre-Breeding 2016					
	FO (%)			FN (%)		
	Berlenga N=77	Pessegueiro N=29	Deserta N=224	Berlenga N=201	Pessegueiro N=117	Deserta N=622
Pelagic Fish		13.8	42.0		4.3	25.7
Atherina sp.						
Belone belone		6.9	0.4		1.7	0.2
Chelon sp.			3.1			1.1
Engraulis encrasicolus						
Gadiculus argenteus			0.4			0.2
Micromesistius poutassou			6.7			4.8
Myctophum punctatum			0.9			0.3
Sardina pilchardus		3.4	24.1		0.9	13.2
Scomber sp.		3.4	9.8		0.9	4.3
Scomberosox saurus			0.4			0.2
Trachurus sp.		3.4	14.3		0.9	6.3
Demersal Fish	1.3	13.8	71.9	1.5	3.4	47.6
Ammodytes tobianus						
Anguilla anguilla			0.9			0.3
Arnoglossus laterna			0.9			0.3
Boops boops			8.9			4.2
Callionymus sp.						
Capros aper						
Cepola macrophatalma			0.4			0.2
Chelidonichthys sp.		3.4			0.9	
Chelon labrosus			5.4			2.1
Citharus linguatula						
Coelorhynchus sp.			0.4			0.2
Conger conger			2.7			1.0
Dicentrarchus sp.			0.4			0.2

Table A1: *Continued.*

	FO (%)			FN (%)		
	Berlenga	Pessegueiro	Deserta	Berlenga	Pessegueiro	Deserta
	N=77	N=29	N=224	N=201	N=117	N=622
Diplodus sp.			37.5			21.7
Echiichthys vipera						
Echiodon sp.			0.4			0.2
Galeus sp.			0.9			0.3
Gobius sp.						
Halobatrachus sp.			0.4			0.2
Helicolenus dactylopterus			0.9			0.3
Hoplostethus mediterraneus						
Lepidotrigla cavillone		6.9			1.7	
Lithognathus mormyrus			0.4			0.2
Macroramphosus scolopax			0.4			0.2
Malacocephalus laevis			1.3			1.4
Merluccius merluccius			4.5			1.6
Microchirus sp.		3.4			0.9	
Mullus surmuletus						
Nezumia sp.						
Other Soleidae			6.3			2.4
Pagellus sp.			0.4			0.2
Pagrus sp.			1.3			0.5
Pegusa lascaris						
Phycis sp.			0.9			0.3
Platichthys flesus			0.9			0.3
Sarpa salpa			4.0			1.4
Scophthalmus sp.			0.4			0.2
Scorpaena sp.			2.2			0.8
Serranus sp.			3.1			1.1
Sparus aurata						
Spondyliosoma cantharus			0.9			0.3
Synchiropus phaeton						
Trachinus draco						
Trigla lyra			1.3			0.6
Trisopterus sp.	1.3		0.4	1.5		0.2

Table A1: *Continued.*

	FO (%)			FN (%)		
	Berlenga N=77	Pessegueiro N=29	Deserta N=224	Berlenga N=201	Pessegueiro N=117	Deserta N=622
Zeus faber						
Unidentified fish	2.6	13.8	20.1	1.0	3.4	9.2
Total fish	3.9	31.0	91.5	2.5	11.1	82.5
Crustacea						
Carcinus maenas			0.4			0.3
Polybius henslowii	88.3	51.7		96.0	47.0	
Uca tangeri						
Pachygrapsus marmoratus		3.4			2.6	
Unidentified *Brachyura*		6.9	4.0		1.7	1.4
Procambarus clarkii		3.4			0.9	
Pollicipes pollicipes		37.9			33.3	
Order *Sessilia*						
Mollusca						
Mytilus sp.		10.3			3.4	
Patella sp.						
Sepia officinalis			0.9			0.3
Other Decapodiformes*						
Unidentified Bivalve						
Unidentified Cephalopoda			1.3			0.6
Unidentified Gastropoda						
Insect						
Order Coleoptera			7.1			8.4
Order Hemiptera						
Order Hymenoptera			2.7			1.4
Order Orthoptera						
Unidentified Insect			4.9			4.2
Others						
Corema album				-	-	-
Unidentified vegetal matter	10.4	3.4	13.8	-	-	-
Refuse	15.6		12.9	-	-	-
Bird species	3.9		2.2	1.5		0.8

Table A1: *Continued.*

	FO (%)			FN (%)		
	Berlenga N=77	Pessegueiro N=29	Deserta N=224	Berlenga N=201	Pessegueiro N=117	Deserta N=622
Rat species						
Egg Shell				-	-	-
Asteroidea						
Unidentified Animal						
Fishhook				-	-	-
Unidentified item				-	-	-

Table A2: *Frequency of occurrence (FO; %) and Numeric Frequency (NF; %) of all items found in the diet in Berlenga and Deserta during the breeding of 2016. Number of samples (FO) and number of individuals (NF) presented below colony sites (*correspond to squid species).*

	Breeding 2016			
	FO (%)		FN (%)	
	Berlenga N=152	Deserta N=163	Berlenga N=382	Deserta N=465
Pelagic Fish	5.3	60.7	2.9	50.1
Atherina sp.				
Belone belone		3.7		1.7
Chelon sp.		1.8		0.6
Engraulis encrasicolus		0.6		0.2
Gadiculus argenteus		3.7		2.2
Micromesistius poutassou	1.3	22.1	0.8	17.0
Myctophum punctatum				
Sardina pilchardus	2.6	11.7	1.3	5.2
Scomber sp.		9.8		3.4
Scomberosox saurus		11.7		10.5
Trachurus sp.	1.3	23.9	0.8	9.2
Demersal Fish	8.6	35.0	3.9	20.2
Ammodytes tobianus		1.8		1.5
Anguilla anguilla		0.6		0.4

Table A2: *Continued.*

	FO (%)		FN (%)	
	Berlenga N=152	Deserta N=163	Berlenga N=382	Deserta N=465
Arnoglossus laterna				
Boops boops	2.6	3.7	1.0	1.5
Callionymus sp.				
Capros aper	0.7		0.3	
Cepola macrophatalma				
Chelidonichthys sp.				
Chelon labrosus		3.7		1.3
Citharus linguatula		0.6		0.2
Coelorhynchus sp.				
Conger conger	0.7	2.5	0.3	0.9
Dicentrarchus sp.		0.6		0.2
Diplodus sp.	0.7	10.4	0.5	4.3
Echiichthys vipera		3.1		1.1
Echiodon sp.		1.2		0.4
Galeus sp.		0.6		0.2
Gobius sp.		0.6		0.2
Halobatrachus sp.		0.6		0.2
Helicolenus dactylopterus				
Hoplostethus mediterraneus				
Lepidotrigla cavillone				
Lithognathus mormyrus		0.6		0.2
Macroramphosus scolopax				
Malacocephalus laevis		1.2		0.4
Merluccius merluccius	1.3	1.8	0.5	0.6
Microchirus sp.				
Mullus surmuletus				
Nezumia sp.				
Other Soleidae				
Pagellus sp.				
Pagrus sp.		2.5		0.9
Pegusa lascaris		1.8		0.6
Phycis sp.		0.6		0.2

Table A2: *Continued.*

	FO (%)		FN (%)	
	Berlenga N=152	Deserta N=163	Berlenga N=382	Deserta N=465
Platichthys flesus				
Sarpa salpa		1.2		0.4
Scophthalmus sp.				
Scorpaena sp.				
Serranus sp.	1.3	5.5	0.5	2.4
Sparus aurata		0.6		0.2
Spondyliosoma cantharus		0.6		0.2
Synchiropus phaeton				
Trachinus draco				
Trigla lyra		2.5		1.1
Trisopterus sp.	1.3	0.6	0.8	0.4
Zeus faber				
Unidentified fish	6.6	27.0	2.4	11.4
Total fish	20.4	80.4	9.4	81.7
<u>Crustacea</u>				
Carcinus maenas				
Polybius henslowii	64.5	11.7	85.3	5.2
Uca tangeri				
Pachygrapsus marmoratus				
Unidentified Brachyura		4.3		1.5
Procambarus clarkii				
Pollicipes pollicipes				
Order Sessilia				
<u>Mollusca</u>				
Mytilus sp.				
Patella sp.				
Sepia officinalis		1.2		0.4
Other Decapodiformes*		1.8		0.6
Unidentified Bivalve				
Unidentified Cephalopoda		0.6		0.2
Unidentified Gastropoda				

Table A2: *Continued.*

	FO (%)		FN (%)	
	Berlenga	Deserta	Berlenga	Deserta
	N=152	N=163	N=382	N=465
Insect				
Order Coleoptera	2.0	2.5	1.6	0.9
Order Hemiptera				
Order Hymenoptera				
Order Orthoptera				
Unidentified Insect	2.6	9.8	2.6	7.5
Others				
Corema album			-	-
Unidentified vegetal matter	2.0	13.5	-	-
Refuse	5.9	18.4	-	-
Bird species	2.0	4.9	0.8	1.7
Rat species	0.7	0.6	0.3	0.2
Egg Shell		0.6	-	-
Asteroidea				
Unidentified Animal				
Fishhook			-	-
Unidentified item		1.8	-	-

Table A3: *Frequency of occurrence (FO; %) and Numeric Frequency (NF; %) of all items found in the diet in Berlenga and Deserta during the post-breeding of 2016. Number of samples (FO) and number of individuals (NF) presented below colony sites (*correspond to squid species).*

	Post-Breeding 2016			
	FO (%)		FN (%)	
	Berlenga	Deserta	Berlenga	Deserta
	N=43	N=112	N=84	N=251
Pelagic Fish	14.0	68.8	8.3	58.6
Atherina sp.				
Belone belone				
Chelon sp.		0.9		0.4
Engraulis encrasicolus				

Table A3: *Continued.*

	FO (%)		FN (%)	
	Berlenga N=43	Deserta N=112	Berlenga N=84	Deserta N=251
Gadiculus argenteus		1.8		1.2
Micromesistius poutassou	2.3	40.2	1.2	33.5
Myctophum punctatum				
Sardina pilchardus	7.0	8.9	3.6	5.6
Scomber sp.		8.9		4.0
Scomberosox saurus				
Trachurus sp.	4.7	27.7	3.6	13.9
Demersal Fish		44.6		29.1
Ammodytes tobianus				
Anguilla anguilla				
Arnoglossus laterna				
Boops boops		8.0		4.8
Callionymus sp.				
Capros aper				
Cepola macrophatalma				
Chelidonichthys sp.		0.9		0.4
Chelon labrosus		1.8		0.8
Citharus linguatula		0.9		0.4
Coelorhynchus sp.				
Conger conger		0.9		0.4
Dicentrarchus sp.				
Diplodus sp.		10.7		5.6
Echiichthys vipera				
Echiodon sp.				
Galeus sp.				
Gobius sp.				
Halobatrachus sp.				
Helicolenus dactylopterus				
Hoplostethus mediterraneus				
Lepidotrigla cavillone		0.9		0.4
Lithognathus mormyrus		0.9		0.4

Table A3: *Continued.*

	FO (%)		FN (%)	
	Berlenga N=43	Deserta N=112	Berlenga N=84	Deserta N=251
Macroramphosus scolopax				
Malacocephalus laevis		6.3		4.0
Merluccius merluccius		8.0		3.6
Microchirus sp.		0.9		0.4
Mullus surmuletus				
Nezumia sp.		0.9		0.4
Other Soleidae				
Pagellus sp.				
Pagrus sp.		2.7		1.2
Pegusa lascaris				
Phycis sp.		0.9		0.4
Platichthys flesus				
Sarpa salpa		0.9		0.4
Scophthalmus sp.				
Scorpaena sp.		3.6		1.6
Serranus sp.		0.9		0.4
Sparus aurata				
Spondyliosoma cantharus				
Synchiropus phaeton				
Trachinus draco		6.3		3.2
Trigla lyra				
Trisopterus sp.		0.9		0.4
Zeus faber				
Unidentified fish		17.9		7.6
Total fish	14.0	94.6	8.3	95.2
Crustacea				
Carcinus maenas				
Polybius henslowii	60.5		88.1	
Uca tangeri				
Pachygrapsus marmoratus				
Unidentified Brachyura		1.8		1.2

Table A3: *Continued.*

	FO (%)		FN (%)	
	Berlenga N=43	Deserta N=112	Berlenga N=84	Deserta N=251
Procambarus clarkii				
Pollicipes pollicipes				
Order Sessilia				
Mollusca				
Mytilus sp.				
Patella sp.				
Sepia officinalis				
Other Decapodiformes*				
Unidentified Bivalve				
Unidentified Cephalopoda		0.9		0.4
Unidentified Gastropoda				
Insect				
Order Coleoptera				
Order Hemiptera				
Order Hymenoptera				
Order Orthoptera				
Unidentified Insect	2.3	1.8	2.4	0.8
Others				
Corema album			-	-
Unidentified vegetal matter	4.7		-	-
Refuse	16.3	2.7	-	-
Bird species	2.3	3.6	1.2	1.6
Rat species				
Egg Shell			-	-
Asteroidea				
Unidentified Animal		1.8		0.8
Fishhook			-	-
Unidentified item			-	-

Table A4: *Frequency of occurrence (FO; %) and Numeric Frequency (NF; %) of all items found in the diet in Berlenga and Deserta during the pre-breeding of 2017. Number of samples (FO) and number of individuals (NF) presented below colony sites (*correspond to squid species).*

	Pre-Breeding 2017			
	FO (%)		FN (%)	
	Berlenga N=84	Deserta N=184	Berlenga N=189	Deserta N=504
Pelagic Fish	38.1	58.2	30.7	41.5
Atherina sp.				
Belone belone	3.6	0.5	2.6	0.6
Chelon sp.		3.3		1.4
Engraulis encrasicolus		1.1		0.4
Gadiculus argenteus		4.3		2.4
Micromesistius poutassou	6.0	13.0	2.6	7.9
Myctophum punctatum				
Sardina pilchardus	7.1	21.2	4.2	9.9
Scomber sp.	8.3	13.0	5.3	5.8
Scomberosox saurus	9.5	0.5	9.0	0.2
Trachurus sp.	11.9	24.5	6.9	12.9
Demersal Fish	25.0	62.0	17.5	35.7
Ammodytes tobianus				
Anguilla anguilla				
Arnoglossus laterna		1.1		0.4
Boops boops	4.8	5.4	3.2	2.4
Callionymus sp.		0.5		0.2
Capros aper				
Cepola macrophatalma				
Chelidonichthys sp.	4.8	1.1	2.6	0.4
Chelon labrosus		0.5		0.2
Citharus linguatula				
Coelorhynchus sp.				
Conger conger		3.3		1.4
Dicentrarchus sp.		2.7		1.0
Diplodus sp.	2.4	35.9	1.1	18.5
Echiichthys vipera				
Echiodon sp.				

Table A4: *Continued.*

	FO (%)		FN (%)	
	Berlenga N=84	Deserta N=184	Berlenga N=189	Deserta N=504
Galeus sp.				
Gobius sp.				
Halobatrachus sp.				
Helicolenus dactylopterus				
Hoplostethus mediterraneus				
Lepidotrigla cavillone	3.6	0.5	1.6	0.2
Lithognathus mormyrus				
Macroramphosus scolopax				
Malacocephalus laevis		3.8		2.0
Merluccius merluccius	8.3	4.9	5.3	2.0
Microchirus sp.	1.2	4.9	0.5	2.0
Mullus surmuletus				
Nezumia sp.				
Other Soleidae				
Pagellus sp.		0.5		0.2
Pagrus sp.		2.2		0.8
Pegusa lascaris				
Phycis sp.		0.5		0.2
Platichthys flesus				
Sarpa salpa		0.5		0.2
Scophthalmus sp.				
Scorpaena sp..	1.2	0.5	0.5	0.2
Serranus sp.	2.4	3.3	1.1	1.2
Sparus aurata		0.5		0.2
Spondyliosoma cantharus				
Synchiropus phaeton				
Trachinus draco		2.2		1.0
Trigla lyra				
Trisopterus sp.	3.6	2.7	1.6	1.0
Zeus faber		0.5		0.2
Unidentified fish	16.7	25.5	9.0	11.1
Total fish	60.7	92.4	57.1	88.3

Table A4: *Continued.*

	FO (%)		FN (%)	
	Berlenga N=84	Deserta N=184	Berlenga N=189	Deserta N=504
Crustacea				
Carcinus maenas				
Polybius henslowii	17.9		19.0	
Uca tangeri				
Pachygrapsus marmoratus				
Unidentified Brachyura	1.2	2.7	0.5	1.0
Procambarus clarkii				
Pollicipes pollicipes	1.2		2.1	
Order Sessilia				
Mollusca				
Mytilus sp.				
Patella sp.				
Sepia officinalis		2.2		0.8
Other Decapodiformes*				
Unidentified Bivalve	1.2	1.1	0.5	0.2
Unidentified Cephalopoda				
Unidentified Gastropoda	10.7	0.5	9.0	3.4
Insect				
Order Coleoptera	4.8	2.7	4.2	1.2
Order Hemiptera		0.5		0.2
Order Hymenoptera		1.1		1.6
Order Orthoptera				
Unidentified Insect	6.0	4.9	2.6	2.2
Others				
Corema album			-	-
Unidentified vegetal matter	2.4	4.9	-	-
Refuse	26.2	23.9	-	-
Bird species	3.6	2.7	1.6	1.0
Rat species		0.5		0.2
Egg Shell			-	-
Asteroidea				

Table A4: *Continued.*

	FO (%)		FN (%)	
	Berlenga N=84	Deserta N=184	Berlenga N=189	Deserta N=504
Unidentified Animal	7.1		3.2	
Fishhook		0.5	-	-
Unidentified item			-	-

Table A5: *Frequency of occurrence (FO; %) and Numeric Frequency (NF; %) of all items found in the diet in Sálvora, Berlenga, Pessegueiro and Deserta during the breeding of 2017. Number of samples (FO) and number of individuals (NF) presented below colony sites (*correspond to squid species).*

	Breeding 2017							
	FO (%)				FN (%)			
	Sálvora N=101	Berlenga N=216	Pessegueiro N=58	Deserta N=262	Sálvora N=585	Berlenga N=1103	Pessegueiro N=168	Deserta N=542
Pelagic Fish	17.8	20.4	46.6	51.1	4.8	7.1	26.2	42.8
Atherina sp.								
Belone belone				0.4				0.2
Chelon sp.				6.9				3.9
Engraulis encrasicolus	1.0				0.2			
Gadiculus argenteus		0.5	1.7	3.1		1.0	0.6	1.7
Micromesistius poutassou	7.9	5.6	12.1	25.6	2.2	1.2	4.2	19.0
Myctophum punctatum				1.1				0.6
Sardina pilchardus	4.0	8.3	22.4	9.9	0.7	1.9	11.3	5.7
Scomber sp.	3.0	5.1	12.1	3.1	0.5	1.0	4.8	1.8
Scomberosox saurus		1.4		1.1		0.3		0.7
Trachurus sp.	5.9	9.7	13.8	17.6	1.2	2.6	5.4	9.2

Table A5: *Continued.*

	FO (%)				FN (%)			
	Sálvora N=101	Berlenga N=216	Pessegueiro N=58	Deserta N=262	Sálvora N=585	Berlenga N=1103	Pessegueiro N=168	Deserta N=542
Demersal Fish	12.9	10.2	48.3	34.7	2.9	3.0	25.6	26.4
Ammodytes tobianus								
Anguilla anguilla								
Arnoglossus laterna			1.7	0.8			0.6	0.4
Boops boops	7.9	1.9	31.0	5.0	1.4	0.4	12.5	2.4
Callionymus sp.			1.7					
Capros aper							0.6	
Cepola macrophatalma								
Chelidonichthys sp.	1.0	0.9		1.1	0.2	0.2		0.6
Chelon labrosus				1.1				0.7
Citharus linguatula		0.5		0.4		0.1		0.2
Coelorhynchus sp.								
Conger conger	1.0	2.3	1.7	0.8	0.2	0.5	0.6	0.4
Dicentrarchus sp.				0.8				0.4
Diplodus sp.	1.0		3.4	16.4	0.2		1.2	9.4
Echiichthys vipera								
Echiodon sp.								
Galeus sp.				0.8				0.4
Gobius sp.				0.4				0.2
Halobatrachus sp.				0.4				0.2
Helicolenus dactylopterus								
Hoplostethus mediterraneus								

Table A5: *Continued.*

	FO (%)				FN (%)			
	Sálvora	Berlenga	Pessegueiro	Deserta	Sálvora	Berlenga	Pessegueiro	Deserta
	N=101	N=216	N=58	N=262	N=585	N=1103	N=168	N=542
Lithognathus mormyrus			5.2	0.4			2.4	0.2
Macroramphosus scolopax								
Malacocephalus laevis				2.7				1.7
Merluccius merluccius	1.0	0.9	3.4	5.3	0.2	0.2	1.2	3.0
Microchirus sp.		0.5		1.5		0.1		0.7
Mullus surmuletus								
Nezumia sp.								
Other Soleidae								
Pagellus sp.								
Pagrus sp.				1.1				0.6
Pegusa lascaris								
Phycis sp.				0.8				0.6
Platichthys flesus								
Sarpa salpa				0.4				0.2
Scophthalmus sp.								
Scorpaena sp.		0.5		1.5		0.1		0.7
Serranus sp.		0.5	6.9	1.9		0.1	3.0	1.1
Sparus aurata								
Spondyliosoma cantharus								
Synchiropus phaeton	1.0	0.5			0.3	0.1		
Trachinus draco				2.7				1.3
Trigla lyra								
Trisopterus sp.	2.0	1.9	1.7	0.8	0.3	0.5	0.6	0.6
Zeus faber				0.8				0.4

Table A5: *Continued.*

	FO (%)				FN (%)			
	Sálvora	Berlenga	Pessegueiro	Deserta	Sálvora	Berlenga	Pessegueiro	Deserta
	N=101	N=216	N=58	N=262	N=585	N=1103	N=168	N=542
Unidentified fish	8.9	10.2	20.7	26.0	2.6	2.5	9.5	14.0
Total fish	23.8	25.5	72.4	76.0	9.8	12.6	61.3	83.2
Crustacea								
Carcinus maenas								
Polybius henslowii	50.5	83.3	5.2	1.9	66.5	78.2	1.8	1.1
Uca tangeri								
Pachygrapsus marmoratus								
Unidentified Brachyura	2.0	1.4	1.7	0.8	2.1	0.3	0.6	0.2
Procambarus clarkii								
Pollicipes pollicipes	8.9	0.5			5.1	0.1		
Order Sessilia								
Mollusca								
Mytilus sp.	10.9				6.8			
Patella sp.								
Sepia officinalis				0.8				0.6
Other Decapodiformes*								
Unidentified Bivalve	3.0		1.7	1.5	0.9		0.6	0.9
Unidentified Cephalopoda	2.0	0.5		1.5	0.3	0.1		0.9
Unidentified Gastropoda	1.0	5.1	1.7	4.2	0.2	1.7	1.2	6.3

Table A5: *Continued.*

	FO (%)				FN (%)			
	Sálvora	Berlenga	Pessegueiro	Deserta	Sálvora	Berlenga	Pessegueiro	Deserta
	N=101	N=216	N=58	N=262	N=585	N=1103	N=168	N=542
Insect								
Order Coleoptera	3.0	6.5	10.3	3.1	1.4	2.7	9.5	1.7
Order Hemiptera			1.7				1.8	
Order Hymenoptera	6.9	0.5	6.9		4.4	0.1	18.5	
Order Orthoptera	1.0				0.3			
Unidentified Insect	3.0	10.2	10.3	3.4	0.5	4.0	3.6	1.8
Others								
Corema album					-	-	-	-
Unidentified vegetal matter	25.7	3.7	12.1	5.3	-	-	-	-
Refuse	20.8	6.9	1.7	36.3	-	-	-	-
Bird species		0.9	3.4	2.7		0.2	1.2	1.3
Rat species	1.0				0.2			
Egg Shell		0.5		0.4	-	-	-	-
Asteroidea	1.0				0.2			
Unidentified Animal	7.9	0.5		4.2	1.4	0.1		2.0
Fishhook					-	-	-	-
Unidentified item					-	-	-	-

Table A6: *Frequency of occurrence (FO; %) and Numeric Frequency (NF; %) of all items found in the diet in Berlenga, Pessegueiro and Deserta during the post-breeding of 2017. Number of samples (FO) and number of individuals (NF) presented below colony sites (*correspond to squid species).*

	Post-Breeding 2017					
	FO (%)			FN (%)		
	Berlenga N=42	Pessegueiro N=87	Deserta N=119	Berlenga N=153	Pessegueiro N=236	Deserta N=383
Pelagic Fish	23.8	43.7	71.4	9.2	25.0	46.7
Atherina sp.						
Belone belone						
Chelon sp.			5.0			1.6
Engraulis encrasicolus			0.8			0.3
Gadiculus argenteus			8.4			3.7
Micromesistius poutassou		2.3	45.4		1.3	22.2
Myctophum punctatum						
Sardina pilchardus	16.7	16.1	19.3	5.9	6.4	8.9
Scomber sp.	7.1	31.0	9.2	2.6	15.7	3.7
Scomberosox saurus			3.4			1.6
Trachurus sp.	2.4	4.6	16.0	0.7	1.7	5.0
Demersal Fish	2.4	20.7	51.3	0.7	8.9	35.5
Ammodytes tobianus						
Anguilla anguilla						
Arnoglossus laterna			0.8			0.3
Boops boops	2.4	4.6	6.7	0.7	2.1	2.9
Callionymus sp.			3.4			1.3
Capros aper		1.1				
Cepola macrophatalma						
Chelidonichthys sp.					0.4	
Chelon labrosus						
Citharus linguatula						
Coelorhynchus sp.			0.8			0.3
Conger conger			4.2			1.3
Dicentrarchus sp.		1.1			0.4	
Diplodus sp.		5.7	21.8		2.1	8.4
Echiichthys vipera						
Echiodon sp.						

Table A6: *Continued.*

	FO (%)			FN (%)		
	Berlenga N=42	Pessegueiro N=87	Deserta N=119	Berlenga N=153	Pessegueiro N=236	Deserta N=383
Galeus sp.						
Gobius sp.			0.8			0.3
Halobatrachus sp.						
Helicolenus dactylopterus						
Hoplostethus mediterraneus			0.8			0.3
Lepidotrigla cavillone		3.4	0.8		1.3	0.3
Lithognathus mormyrus			2.5			0.8
Macroramphosus scolopax						
Malacocephalus laevis			4.2			3.1
Merluccius merluccius		1.1	7.6		0.4	3.7
Microchirus sp.			1.7			0.5
Mullus surmuletus						
Nezumia sp.			1.7			2.1
Other Soleidae						
Pagellus sp.						
Pagrus sp.		1.1	0.8		0.4	0.3
Pegusa lascaris						
Phycis sp.						
Platichthys flesus						
Sarpa salpa			0.8			0.5
Scophthalmus sp.						
Scorpaena sp.		2.3	0.8		0.8	0.3
Serranus sp.			6.7			2.9
Sparus aurata						
Spondyliosoma cantharus						
Synchiropus phaeton						
Trachinus draco		2.3	2.5		0.8	1.8
Trigla lyra						
Trisopterus sp.			10.1			4.4
Zeus faber						
Unidentified fish	4.8	10.3	28.6	1.3	3.4	8.6
Total fish	26.2	58.6	93.3	11.1	37.3	90.9

Table A6: *Continued.*

	FO (%)			FN (%)		
	Berlenga N=42	Pessegueiro N=87	Deserta N=119	Berlenga N=153	Pessegueiro N=236	Deserta N=383
Crustacea						
Carcinus maenas						
Polybius henslowii	69.0	2.3	1.7	77.1	1.3	0.8
Uca tangeri			0.8			0.3
Pachygrapsus marmoratus						
Unidentified Brachyura			0.8			0.3
Procambarus clarkii						
Pollicipes pollicipes		25.3			44.9	
Order Sessilia		2.3			0.8	
Mollusca						
Mytilus sp.		2.3			1.3	
Patella sp.		3.4			3.0	
Sepia officinalis		1.1	2.5		0.4	0.8
Other Decapodiformes*						
Unidentified Bivalve						
Unidentified Cephalopoda		1.1	1.7		0.4	0.5
Unidentified Gastropoda	2.4		0.8	5.2		1.6
Insect						
Order Coleoptera	4.8	3.4		2.0	1.7	
Order Hemiptera						
Order Hymenoptera		3.4	2.5		5.9	1.8
Order Orthoptera						
Unidentified Insect	14.3	3.4	3.4	4.6	1.7	1.3
Others						
Corema album		57.5		-	-	-
Unidentified vegetal matter	4.8	5.7	4.2	-	-	-
Refuse	9.5	4.6	10.9	-	-	-
Bird species		3.4	4.2		1.3	1.3
Rat species						
Egg Shell				-	-	-
Asteroidea						
Unidentified Animal			1.7			0.5

Table A6: *Continued.*

	FO (%)			FN (%)		
	Berlenga N=42	Pessegueiro N=87	Deserta N=119	Berlenga N=153	Pessegueiro N=236	Deserta N=383
Fishhook			0.8	-	-	-
Unidentified item				-	-	-

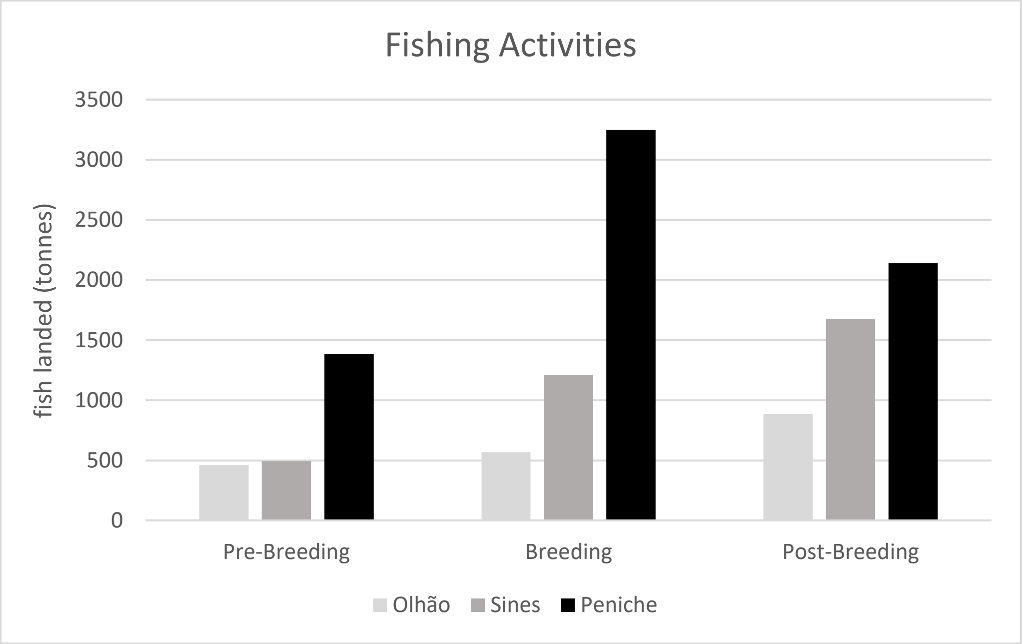

Figure A1: *Graphical representation of Portuguese landings. Each bars represents the mean amount of fish landed (tonnes) for the two years (2016 and 2017) in the harbour nearest to the colony site (Olhão-Deserta, Sines-Pessegueiro and Peniche- Berlenga).*