Synthesis of the current knowledge of the Bijagós archipelago as a key non-breeding area for migratory shorebirds of the East Atlantic Flyway, with recommendations for future research and conservation actions

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Summary

Migratory shorebird populations are declining worldwide. Their conservation and the preservation of the habitats they depend on is a matter of shared responsibility between several countries through which they migrate along the flyways crossing a wide range of latitudes. They breed in Northern temperate zones and then fly south to their wintering areas. One of the most important wintering areas across the East Atlantic Flyway (EAF) is the Bijagós archipelago, a group of 88 islands and islets located off the coast of Guinea-Bissau, in West Africa. It is the second most important gathering of wintering shorebirds in West Africa, receiving hundreds of thousands of shorebirds annually. For its exceptional value, it has been recognised as a Biosphere Reserve, an Important Bird Area and a Ramsar Site.

Between 1982 and 2001, there were several expeditions to the Bijagós archipelago that resulted in population estimates for migratory shorebirds there. These varied between 699 120 and 871 750, depending on the estimation method and the percentage of the area covered by the counts. Nonetheless, these estimates confirmed the international importance of the Bijagós archipelago for wintering shorebirds. After this, only in 2014 another full estimate was produced, following an International Waterbird Count wielding an estimate of 481 395, half of the previous attempts. This, together with much lower estimates in other important wintering sites in the EAF, raised a generalised concern on the status of migratory shorebird populations in the flyway. Most of these birds were apparently 'lost' in their European wintering ranges (2 million), and many fewer from their African wintering ranges (200,000), but the reasons for these decreases remain unknown. Nonetheless, since these drops may be either reflecting real permanent changes in the populations or temporal fluctuations, there is an urgent need for research and well-structured monitoring programs.

The Bijagós archipelago features a wide variety of ecological traits that seem to be important for shorebirds, given such high yearly concentrations. It is located at the south of a large upwelling zone and it has one of the fifteen most vast and important mudflats in the world. Despite having an apparently low benthic macroinvertebrate density, the community of macroinvertebrates is highly diverse, which may reduce the interspecific competition between shorebirds species. Also, the Bijagós offer a wide variety of safe roost sites, ranging from dense mangrove forests to vast open and undisturbed beaches, fulfilling the different needs of each species. Another important ecological feature is related to the demanding energetic requirements of shorebirds during the pre-migration period, which appears to be met there with the increasing in the abundance of macrozoobenthic prey during that period. Moreover, human activities appear to have a low impact on shorebirds and their prey, as the local culture of human communities allowed to keep this place near to its pristine state until presently.

Very few threats to shorebirds in the Bijagós are known, and they appear to show a much lower perceivable impact there than what is known for the northern range of their distribution. However, the future impacts of the expected sea level rise on shorebird' habitats and food have never been addressed. This is a significant knowledge gap that should be addressed to better anticipate and prevent such impacts. Recently, there has been a bilateral agreement, between Guinea-Bissau and Senegal, aiming to develop oil prospections in their shared marine areas, and the risks of negative impacts for the Biosphere Reserve may be very high. This is an emergent and eminent threat that can direct and indirectly affect shorebirds and their environment.

Recently, the increasing number of conservation and research projects in the Bijagós has been improving the knowledge available about its biodiversity and ecological traits. Nonetheless, there are still important knowledge gaps that need to be addressed and much more to learn to better define conservation and management strategies. This may only be achieved by associating researchers, local communities, governmental and non-governmental organizations, always under a continuous investment in awareness, capacity raising and education of national human resources. Such dynamic and integrative conservation model could be the key to preserve this amazing place and the biodiversity occurring there.

1. Introduction

In this document, we summarize the existing knowledge on the status of wader populations wintering in the Bijagós Archipelago, Guinea-Bissau, especially by providing an overview on the important ecological traits for wintering shorebirds in that area and discussing its role in the conservation of the migratory wader populations at a Flyway scale. It has been commissioned by the Wadden Sea Flyway Initiative and the geographic range considered in this study is limited to the Bijagós Archipelago.

The objectives pursued in this document are:

a) A review of the existing baseline knowledge on the status of the migratory shorebird populations in the geographic scope of this work.
b) A synthesis of the importance of the Bijagós Archipelago as shorebird wintering site along the East Atlantic Flyway, highlighting the main ecological features and key threats for waders in this area.
c) A summary of the main knowledge and conservation gaps based on existing information and on past and ongoing conservation and research initiatives.
d) A set of recommendations for an improved management and conservation of shorebird populations and their key habitats in this archipelago

This study was conducted by reviewing the most important sources of available data, both by searching for online information, and by using more ancient print-out reports and books. The most recent information was also included by conducting informal inquiries with relevant researchers and conservationist currently developing work in the Bijagós archipelago. The consultants recognize that not all information is consulted and included in this work, as the aim here is to summarise the most relevant studies in order to provide a good state-of-the-art on the subject and frame the recommendations featured in this document.

2. Description of the Bijagós Archipelago

The Bijagós Archipelago is a group of 88 islands and islets located off the coast of Guinea-Bissau, in West Africa, ranging between the mean latitude of 11º14'N and mean longitude of 16º02'W (Campredon & Catry 2016; Fig.1). It is under the influence of a tropical climate, with two well marked seasons, the dry season (from December to April) and the rainy season (from May to November). The islands are separated by three large channel groups of shallower depth (10-30 m), maintained by tidal streams (Campredon & Catry 2016). This archipelago takes a triangular shape, typical of estuarine delta archipelagos, and its sedimentary origins are mainly associated to the Geba and Buba rivers (Pennober, 1999).

Figure 1. Satellite image of a low-tide moment of the Bijagós Archipelago, Guinea-Bissau. Satellite image from Landsat-8 from USGS Earth Resources Observation and Science (EROS) Centre, courtesy of the U.S. Geological Survey.

The tidal regime is semi-diurnal, with two tide cycles per day. Due to the extension of the continental shelf, the tidal range in the archipelago is the highest in West Africa, with spring tides reaching 4.5 m in amplitude (Campredon & Catry, 2016). The hydrology is highly influenced by the Canary current, mostly felt during the dry season, and by the Guinea current, mostly felt during the rainy season. As trade winds reach the area, they give rise to coastal upwelling, increasing the overall productivity (Campredon & Catry 2016). However, the levels of nutrient and chlorophyll concentrations in the waters of the Bijagós are considered relatively low when compared to coastal ecosystems further north. It is hypothesised that this may be partly compensated in some form by the input of nutrients through the mangrove forest (Henriques et al. unpub. data), as 30% of the surface area of this archipelago is covered by mangrove (Vasconcelos et al., 2015; Temudo and Cabral, 2017; Cardoso, 2017).

This archipelago comprises a relatively important diversity of habitats, including a set of wetland ecosystems:

- **Channels and Shallow shelfs**

These environments are permanently submerged by marine waters and composed mostly by mobile seabeds but also some rocky reefs, which are both often covered by algae (*Caulerpa* sp., *Sargassum sp*., *Vaucheria* sp., *Dictyota* sp.), attracting fish and marine turtles.

- **Intertidal flats**

With an area of ca. 100,000 ha, these habitats represent the majority of the marine habitats (Campedron & Catry, 2016). Most of the tidal area is composed by a mixture of fine and coarse sediments (Zwarts, 1988; Pennober, 1999; 2003), supporting a high diversity of benthic invertebrate such as polychaetes, bivalves (e.g. *Senillia senillis*) and crabs (e.g. *Afruca tangeri;* Lourenço et al. 2018). During the low tide period, a huge number of migratory waders feed in these mudflats (Zwarts, 1988, Salvig et al., 1994). There are also records of other bird species

feeding within the tidal flats (e.g. Sacred Ibis, Palm-nut Vultures, some Tern species and even Starlings; Carneiro et al., 2017; Correia et al., 2020; Author pers. obs).

- **Mangroves**

Mangrove forests occupy a large portion of the archipelago (ca. 42 480 ha; Cardoso 2017). In fact, the mangrove importance goes beyond its extension in the archipelago, as they provide a wide variety of ecosystem services, including as potential contributors to the carbon and nutrients cycle (Alongi 2014). Many species of waders use mangroves as a roosting site (e.g. *Numenius phaeopus*, *Actitis hypoleucos;* Altenburg & van Spanje 1989) and they also act as important nurseries and growing areas for various fish and crustacean species (Arkhipov et al., 2015).

This mosaic of different habitats supports high levels of biodiversity, including 155 species of fish (Campredon & Cuq 2001), more than 28 species of sharks and rays (Jung et al., 2011; Cross 2015), the most important breeding colony of green turtles in the Atlantic (Catry, 2002; 2010; Patrício, 2017), several critical sites for colonial seabirds (Zwarts et al., 2009; Birdlife International, 2013) and the second most important wintering population of shorebirds in West Africa (Salvig et al., 1994; 1997; Underhill et al., 2001; Dodman & Sá, 2005; Delany et al., 2009). The undisputable ecological value of this place led to the recognition as a Biosphere Reserve by UNESCO in 1996 (Biai, 2015), followed by a classification as an Important Bird Area (IBA) in 2001 by Birdlife International (Biai, 2015). After 2001, three Marine Protected Areas were created and implemented (Biai, 2003; INEP, 2006; IBAP, 2008; Nacional, 2018). In 2014, the recognition of importance of the wetlands of the Bijagós for waterbirds was reinforced by labelling it as a Ramsar Site (Campredon & Catry, 2016).

Such levels of biodiversity can only be supported by the conservation and sustainable use of the natural resources by local human communities. In fact, of the 88 islands and islets in the Bijagós, only 21 are permanently inhabited by communities of the Bijagós ethnic group (Campredon *et al*. 2010). These communities rely on natural resources on their everyday life, provided by the ecosystem around them (INEP, 2006; Biai, 2015). The main economic activities are fishing, upland rice agriculture, cashew plantations and other small horticulture activities (INEP, 2006).

3. The migratory shorebird populations in the Bijagós

Shorebirds are a large group of small to medium-sized birds that occur in coastal or wetland habitats. Shorebirds are an inclusive term which refer to birds from the Recurvirostridae, Charadriidae, Haematopodidae and Scolopacidae families. Many of these species migrate through flyways, linking their high latitude breeding grounds to low latitude wintering areas. The East Atlantic flyway (EAF) is one of the major flyways, being travelled by millions of shorebirds every year. The Bijagós archipelago receives hundreds of thousands of shorebirds annually during the non-breeding period (Zwarts et al., 1988; Dodman & Sá, 2005) and it is among the most important wintering sites along the EAF. The seasonal fluctuations in abundance occurring there, derived from the arrival and stay of migrants during the northern winter, and their departure and absence during spring and summer seasons, lead to a variable predation pressure over the benthic macroinvertebrates inhabiting the mudflats where they feed (Mercier & McNeil, 1994; Mendonça et al., 2007; Lourenço et al., 2017a; 2017b). This may have a structuring effect over intertidal food webs, of which much remains unstudied (Trush, 1999; Gaston & Fuller, 2008; Horn et al., 2017).

Table 1 – The 13 most abundant migratory shorebird species wintering in the Bijagós archipelago, with description of their most common prey items in this area and their short- and long-term population trends along the East Atlantic Flyway. The information regarding the prey items were based on Lourenço et al. (2017a, ;2018) and Coelho et al. (2019). The information regarding the long- (over 10 years) and short-term (last 10 years) trends were extracted from Van Roomen et al. (2018).

Species	Most common prey items in the Bijagós	Short-term trend	Long- term trend
Curlew Sandpiper *Calidris ferruginea*	Polychaeta	Steep decline	Moderate decline
Red Knot *Calidris canutus*	Bivalvia	Moderate decline	Moderate decline
Sanderling *Calidris alba*	Crustacean and Polychaeta	Moderate increase	Moderate increase
Little Stint *Calidris minuta*	No information	Steep decline	Moderate decline
Common Ringed Plover *Charadrius hiaticula*	Polychaetes	Stable	Moderate decline
Kentish plover *Charadrius alexandrinus*	No information	Stable	Moderate decline
Grey Plover *Pluvialis squatarola*	Crustacean and Polychaeta	Moderate decline	Moderate increase
Ruddy Turnstone *Arenaria interpres*	No information	2 populations: Neartic/W Europe and NW Africa- Both populations are: Stable N Europe/ W Africa- Stable	Neartic/W Europe and NW Africa- Moderate increase N Europe/ W Africa- Moderate decline
Redshank *Tringa totanus*	Crustaceans (Fiddler-crabs)	Moderate decline	Stable
Bar-tailed Godwit *Limosa lapponica*	Polychaeta, Crustacean and Bivalvia	Moderate decline	Moderate decline
Whimbrel *Numenius phaeopus*	Crustacean (Fiddler-crabs)	Moderate increase	Moderate increase
Eurasian Curlew *Numenius arquata*	No information	Moderate decline	Moderate decline
Eurasian Oystercatcher *Haematopus ostralegus*	No information	Stable	Stable

Historical and present population trends

Over the last four decades, there have been several shorebird counts in the Bijagós archipelago. A summary of the available data is presented in Table 2. In Dodman & Sá (2005), there is a description regarding the first counts conducted in the Bijagós archipelago, as well as comparisons between different years. These efforts were conducted together with international organizations (e.g. Wetland International and the Trilateral Wadden Sea Cooperation) and Guinea-Bissau organizations (Coastal Planning Office – GPC- and later with the cooperation of the Institute of Biodiversity and Protected Areas Dr. Alfredo Simão da Silva – IBAP). After 2001, there were no published or available data on shorebird numbers until 2009, when IBAP set in place a three-year shorebird monitoring program in two marine protected areas of the archipelago – Orango National Parc and João Vieira and Poilão Marine National Park (JVPMNP). In January 2014, the International Waterbird Count (IWC) included the most important wetlands of Guinea-Bissau, especially focused in the Bijagós, and from there on the country was always included in these international censuses. These counts were coordinated by national coordinators of the IWC (namely GPC and the Wetland Protection NGO – ODZH), in conjunction with the

Wadden Sea Initiative and the Conservation of Migratory Bird Project (CMB), coordinated by BirdLife International in cooperation with the Wetlands International (van Roomen et al., 2015).

Trends of population estimates in the Bijagós are presented in Figure 2. Note that Van Roomen et al. (2015) estimated shorebird numbers for the whole intertidal area of the Bijagós and the shore of Guinea-Bissau, and only the total national figures were made available. Moreover, the methods used in different years were not standardized, which makes them nearly impossible to compare confidently. This constitutes an enormous limitation when trying to interpret populations trends from the available data in the Bijagós archipelago. The inconsistency of the data is partly a consequence of the difficulties that the Bijagós present to count birds, in comparison to other important wetlands. For most species, roosts are impossible to count as they are placed in dense mangrove areas. Thus, the most reliable method to count have been in-situ low-tide counts, which nonetheless poses great methodological challenges in terms of estimating the numbers for each species, due to the extensive intertidal areas and the low densities shorebirds occur when foraging. Despite this, the numbers highlight the importance of the Bijagós archipelago for migratory shorebirds at an international level, with several shorebird species attaining numbers eligible for Ramsar Site criteria (Table 2).

Table 2 – Summary of shorebird counts and population estimates in the Bijagós archipelago to date, with distinction between the count method, estimation method and the source of information. * counts did not produce a global population estimate; ** Estimates for all Guinea-Bissau coastal mudflats and Bijagós Archipelago

Year	Period of count	Areas covered	Area covered (%)	Count method	Estimation method	Population estimate	Literature source
1982-1983 **1986-1987**	December-February	Bubaque, Bolama, Bijagós	28.1	In situ low-tide counts	Density extrapolation	699 120	Poorter & Zwarts (1984) Zwarts (1988)
1992-1993	October-May	16 areas in 14 islands	64	In situ low-tide counts	Density extrapolation	710 000	Salvig et al. (1994)
1994	December	Full coverage	54	Aerial survey & ground counts	Detection Rate	750 000	Salvig et al. (1997)
1994 **1995** **1997**	February-November April-September January-March	Bubaque, Soga	NA	In situ low-tide counts	Maximum total count	15 000*	Salvig et al. (1997)
2001	January-February	44 areas in 18 islands	64	In situ low-tide counts	Density extrapolation	871 750	Frikke et al. (2002) Dodman & Sá (2005)
2009	May, July September, December	9 counts in 2 marine protected areas	NA	In situ low-tide counts	Maximum total count	23 241*	Monteiro (2011)
2010	August, October, December	9 counts in 2 marine protected areas	NA	In situ low-tide counts	Maximum total count	31 092*	Monteiro (2011)

2011	August, October, December	9 counts in 2 marine protected areas	NA	In situ low-tide counts	Maximum total count	17 979*	Monteiro (2011)
2014	January	171 points in all Bijagós	58	In situ low-tide counts	Density extrapolation	481 395 **	Van Roomen et al. (2015)
2017	January	56 points in all Bijagós	NA	In situ low-tide counts	Maximum total count	62 150* **	Van Roomen et al. (2018)
2020	January	108 polygons in all Bijagós and shore of Guinea-Bissau	NA	In situ low tide-counts	Maximum total count	56 521* **	Van Roomen et al. (2020)

Shorebird species assemblages are diverse in the Bijagós, with the counts conducted during the non-breeding period typically wielding 16 migratory species. Salvig et al. (1997) assessed the variation in numbers with monthly counts in 10 pre-defined foraging areas. September and November constituted the major influx periods, attaining the peak in numbers in November (ca 15 000 birds), and suggesting similar values for December and January. During spring until May, numbers remain fairly constant (ca 7,000-8,000 birds) but they decrease from June to August (ca. 2,000 birds). Monteiro (2011) also reported similar trends in the Marine Protected Area of João Vieira and Poilão and Orango National Parc.

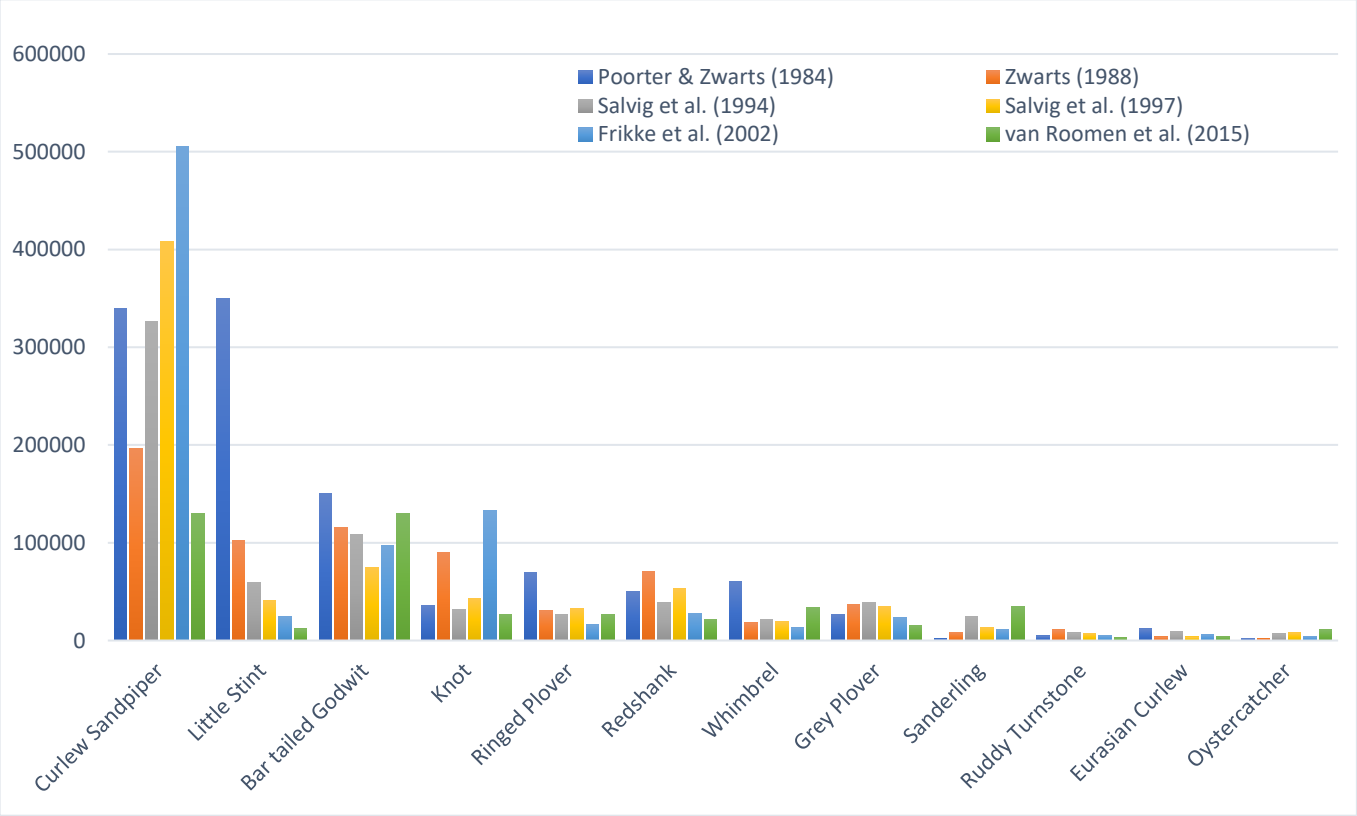

Figure 2 – Comparison between the estimates of the 11 most abundant species for all the years in which counts were conducted. References are presented in the plot.

In a general way, the trends assessed for the EAF populations (Table 2) are in agreement with those found for the Bijagós (Figure 2), revealing concerning patterns. For the methodological issues and characteristics of the data available, as mentioned above, trends in the Bijagós archipelago should be analysed carefully. However, there are patterns that suggest steep declines, for instance for the Curlew sandpiper and the Little Stint. The data on other species also suggest a downward trend, although in a lower degree than the previous two species, such as the Red Knot, Redshank, Common Ringed Plover and Grey plover. Regarding the numbers of the Whimbrel and the Bar-tailed godwit, they seem to have decreased since the first count conducted (longer-trend) but when looking closely to more recent counts, the numbers of both species seem to be increasing. The Sanderling numbers seem to be also increasing.

4. The importance of the Bijagós archipelago for shorebirds

Most of the extent of the tidal flats in the Bijagós archipelago is explored by the hundreds of thousands of shorebirds that spend more than half of their yearly cycle foraging there. The Bijagós archipelago is, in fact, the third most important non-breeding site for the migratory wader population of the EAF, sustaining ca. 10% of the entire population of the Flyway (van Roomen et al., 2015). This suggests that there, shorebirds benefit from a set of unique environmental and ecological conditions that allows them to recover from the post-breeding migration, to avoid the harshness of the northern winter and to fuel up in preparation for the pre-breeding migration. These are key parts of the shorebird's life cycle, that are being sustained by key habitat features in the Bijagós archipelago, which will be summarised in the next paragraphs.

Among the first potential important ecological features of the Bijagós archipelago is its location. The fact that it is situated south of a large upwelling zone (Cuq et al., 2001) may be one of the reasons why these tidal flats attract so many shorebirds, as it has been suggested that shorebirds aggregations can be driven by high levels of productivity (Butler et al., 2001). The size of its intertidal area is also important. This archipelago holds one of the fifteen largest and most important mudflats in the world, where shorebirds find vast foraging areas and may avoid spatial competition (Piersma et al., 1993; Hickey et al., 2015). Despite its enormous extent, tidal flats of the Bijagós Archipelago present a much lower density of invertebrate prey when compared to the temperate mudflats (Lourenço et al., 2017a; 2018). At the first sight, this seems to contrast with the tremendous numbers of wintering shorebirds, as the abundance of foraging shorebirds has been reported to be highly correlated to the patterns of benthic macroinvertebrate distribution and abundance (Goss-Custard, 1970; Yates et al., 1993). However, the low density of invertebrate prey seems to be attenuated by the high diversity of prey found within these mudflats. Ultimately, a higher diversity can lead to trophic partitioning (i.e., better distribution of prey types among shorebird species, according to their biological and behavioural traits) and therefore, reduce interspecific competition (Catry et al., 2016). This way, shorebird species can even share the same foraging areas, by diversifying and differentiating their diet, which results in a low overlap of the trophic niches of the different species (Lourenço et al., 2017a). The areas occupied by the fiddler crab *Afruca tangeri* are a good example of this trophic partitioning. This fiddler crab is widespread throughout the tidal flats of the archipelago and it is part of the diet of almost all the species of shorebirds (Lourenço et al., 2017a; Coelho et al., 2019). In fact, it seems that some species (like the Whimbrel, the Common Sandpiper and the Common Redshank) may be fiddler crab specialists during their stay in the Bijagós (Lourenço et al., 2017a; Paulino, 2019). Similar crab species from other parts of the globe have been described as ecosystem engineers, as their burrowing activity alter habitat characteristics such as the biogeochemistry and topography of the sediment (Botto & Irribane, 2000; Kristensen, 2008). A recent unpublished study conducted in the Bijagós archipelago in 2019 showed that areas with high density of fiddler crabs feature a much less abundant and diverse macrozoobenthic prey community than areas with low density of fiddler-crab, while also showing very different shorebird assemblages using these two habitats, as previously noted by Zwarts (1988). This clearly indicates that in the Bijagós archipelago, areas occupied by fiddler crabs constitute different habitats that may promote shorebird segregation while foraging, therefore reducing the potential for competition for resources (Paulino, 2019).

Another key ecological trait of the Bijagós archipelago is the availability of different and widespread high tide roosts for shorebirds. In this archipelago, shorebirds are only able to forage during low tide, and use the high tide period to rest while waiting for the tidal flats to be once more available. Shorebirds in the Bijagós have been showing signs of a high fidelity to foraging areas (NIOZ, University of Lisbon and University of Aveiro unp. data) and therefore depend largely on the availability of good roost sites near their preferred foraging grounds. Among the most important roost types are the dense mangrove forests. These provide a relatively safe place for roosting, as predation risk and perturbation from human activities are lower in these areas (author pers. obs). Some shorebird species roost over or inside the mangrove dense roots and branches, such as the common Redshank and the Whimbrel, while many species choose to use the large clearings inside mangrove forests created from the hyper salinization. The vast area covered by sandy beaches is also used as roost site by other species, such as the Bar-tailed Godwit, the Sanderling and the Curlew Sandpiper. The low human disturbance in these vast beaches opens the opportunity for large roosting areas, where shorebirds concentrate in large flocks. During neap tides, many shorebirds even choose to remain in the tidal flats, congregating in the nearest elevated areas and waiting off the high tide.

Shorebird feeding patterns depend on the balance between the availability of food resources and energetic requirements. During the non-breeding season, it is expected that species specific diet and the trophic network will vary across different periods (winter and pre-migration) in order to fulfil shorebird's energetic demands. For instance, right before migrating northwards to their breeding grounds, shorebirds need to fuel up, i.e., to increase their prey intake rate and shift their diet to more energetically profitable prey, storing fat for their long and dangerous migration. However, this is only possible if the wintering areas provides adequate conditions for that to happen. Recently, Coelho et al. (2019) explored the phenology of the feeding patterns of the most common migratory shorebirds in the Bijagós archipelago. They compared the prey availability, species specific diet and macrozoobenthic community variation between two periods: winter (October to January) and pre-migration (February to April). Preliminary results indicate that prey availability increased for all groups (Bivalves, Crustaceans, Polychaetes and Gastropods) from winter to pre-migration period, and the main consumed prey during the winter became increasingly important throughout the pre-migration period. Moreover, the size class of all consumed prey items tended to increase across bird species. Regarding the diet variation from winter to pre-migration, shorebirds consumed fewer prey species but in higher frequencies. The authors pointed out the higher consumption of the polychaete *Nereis sp*., fiddler crabs and the bivalve *Tellina nymphalis* by shorebirds, which indicate that these prey items may be key to fuel the northwards migration. Thus, the demanding energetic requirements to fuel up for migration seems to be met by the productivity of the intertidal flats of the Bijagós Archipelago, within the timeframe needed, through the increase of prey availability and size of food items along the pre-migration period.

The ecosystem in the Bijagós is considered to be relatively pristine. This is mostly a result from the local community cultural traits, who's beliefs include animist-based religious regulations that kept the resources and the environment from being overexploited until this point. Also, there is no large-scale industry and very little build infrastructures, and the tourism has a low impact on the environment. Large scale fishing is not a problem yet, as the fishing areas around each island are only used by the local communities. Recent studies have shown that the levels of pollutants in the environment, namely heavy metals and organic pollutants in the intertidal soft sediments, water and macroinvertebrates, are in general much lower than the reference levels (Coelho et al., 2016; Catry et al., 2016; Mullié, 2017). These factors all together are the main reasons of such low human disturbance upon the environment, which in turn leaves space for the amazing concentrations of shorebirds.

5. Main threats for migratory shorebirds in the Bijagós archipelago

As previously noted, shorebird populations are declining worldwide and the populations along the EAF are no exception. In the Bijagós Archipelago, there are few studies about threats for shorebirds and more information is needed. However, from our many years of observations in the site and on-ground experience, it is fair to consider that threats there appear to be of a much lower magnitude when compared to their breeding grounds or other wintering areas, as the intertidal and coastal ecosystems in the Bijagós are still considerably pristine.

The Bijagós communities' ancient practices and culture are responsible for the regulation of the access to these ecosystem services, promoting the sustainable use of marine resources (Biai et al., 2003; Campredon et al., 2010; Rachid et al., 2011). However, the increasing global interactions are promoting the growth of international trade and exchange of cultural ideas, and Guinea-Bissau is no exception. People will have to adapt their own ways of living, which can lead to the substitution of the otherwise sustainable use of resources for more unstainable practices, as a consequence of globalization. For instance, it has been recently reported the overexploitation of macroinvertebrates by the local communities, namely, the Bloody Cockle *Senilia Senilis*, in the mudflats of the Island of Bubaque. The main driver behind this is the high demand of Senegal for this type of resource (P. Campredon pers. comm).

Despite its slow growth rate and although having a potential to be the most beneficial activity to promote both the development of local communities and the conservation of that natural environment, poorly managed and unregulated tourism in the Bijagós may also present a serious potential threat to shorebirds and shorebirds' habitats. Tourism may alter the land use in these islands, and ultimately may result in habitat loss and degradation and, increasing pollution and perturbation levels, which may negatively affect shorebird populations wintering in this amazing place (Davenport & Davenport, 2006; Polet, 2011). Moreover, because the conservation and protection of the unique ecological traits of shorebird habitats in this archipelago has been promoted by the ancient rules of the local culture (Maretti 2001), unregulated tourism also present the potential to disturb the fragile balance of the Bijagós communities' cultural structure, jeopardising many centuries of community-based conservation (Ozorio & de Lima, 2019), which will ultimately bear negative impacts on the ecological quality of this site for shorebirds.

Hunting and prosecution of shorebirds do not seem to have a relevant expression in the Bijagós archipelago. However, some hunting activities targeting all kinds of bird species have been reported recently, though considered to be isolated events yet. Despite not having enough impact presently, local conservation organizations should keep an eye on this potential threat, in order detect immediately these events and deliver a rapid and effective response.

Global warming and human induced climate change may constitute the major threats in our study area. In fact, together with land reclamation, sea-level rise led to the decline of global intertidal areas by ca. 16% between 1984 and 2016 (Murray et al., 2019). Global warming is accelerating the rate of sea-level rise, which negatively affects the availability of suitable foraging habitats for shorebirds, as well the availability of food resources for these birds (Kam et al., 2004; Piersma & Lindstorm, 2004; Zwarts et al., 2009; Lourenço et al., 2013). The mudflats and sandbanks of the Bijagós archipelago require particular attention as these areas have a low coastal slope and present areas with low elevation range (Granadeiro et al., 2021). In addition, the Bijagós archipelago present the highest tidal range in West Africa (Campredon & Catry, 2016). These factors are of extreme importance when assessing the risk to erosion and sea-level rise of coastal areas (Boruff et al., 2005; Karymbalis et al., 2014). Sea-level rise is predicted to reach up to 20 cm in the coast of Guinea-Bissau by 2050 (Republic of Guinea-Bissau, 2018), which may have very deep impacts in the intertidal area extent of the Bijagós archipelago. Sea level rise may also affect the distribution of benthic macroinvertebrate prey for shorebirds. As mentioned above, the effects of such a diversity of prey, results in trophic partitioning for shorebirds, reducing their interspecific competition (Catry et al., 2016). With the sea-level rise, these prey species will be forced to change their

distribution, as they are distributed through intertidal gradients, which will change, according to their ability to cope with physical and biotic factors (Rafaelli & Hawkins, 1999). The potential impacts on wintering wader populations are still unknown and, to our knowledge, no studies have been conducted on the subject.

There is an emerging and eminent threat that may affect the integrity and health of the Bijagós Biosphere Reserve. Recently, the governments of Guinea-Bissau and Senegal signed a protocol which aims to start an oil exploitation located within the shared marine areas of both countries. Oil exploitation impacts go beyond the area of effective extraction and may affect ecosystems and biodiversity around it. In this case, oil spills may affect intertidal areas within the Biosphere Reserve of the Bijagós, resulting in the accumulation of hydrocarbons in the sediment and in the macroinvertebrate fauna that inhabit intertidal systems. As shorebirds feed upon these organisms, they will be the final recipient of a chain of bioaccumulation which ultimately will affect their fitness and probably have impacts on breeding success. To the best of our knowledge, nothing is being done to stop such exploration and there is no transparent environmental assessment of the impacts that may result from oil spills and exploration. Additionally, other activities that surround the installation of an oil exploitation, like the industrialization and development of infrastructures to support the activity (like warehouses and ports) and the increased marine traffic may also have important indirect impacts that need to be considered.

6. Research, conservation and management in the Bijagós archipelago

Past and present conservation and management, monitoring and research initiatives

Conservation actions focusing on shorebirds in the Bijagós have been going on since the 1980's. Several international organizations, such as the IUCN, Wetlands International, the Trilateral Wadden Sea Cooperation, the MAVA Foundation and others, have worked together with local institutions to create the Coastal Planning Office (GPC), which later supported the rise of the governmental Institute for Biodiversity and Protected areas (IBAP), under the leadership of Dr. Alfredo Simão da Silva. Until recently, information about shorebird ecology within the Bijagós dated back to the 80s/90s, namely due to expeditions of researchers from the Wadden Sea and supported by the Wetlands Trilateral Wadden Cooperation. During these expeditions, a group of Guinea-Bissau technicians and collaborators was trained in the identification and monitoring of shorebirds (Dodman & Sá, 2005). Both the GPC and IBAP have been a hub for conservation activities since then, with several small-scale training and awareness raising initiatives taking place throughout the years, although limited in duration.

The Marine Protected Areas Network in the Bijagós, comprising the Marine National Parks of João Vieira and Poilão, National Park of Orango and the Community Marine Protected Area of Urok, have been the strongest conservation points in the archipelago. There, IBAP, the NGO Tiniguena, the international NGO CBD Habitat and others have been managing a long-term implementation of a set of conservation measures and regulation of access and use of marine resources, together with local communities, and with the financial support of the European Union, the MAVA Foundation, among other international partners. The success of these marine protected areas in conserving both the natural resources, including the areas used by shorebirds, and the local culture and identity, which was already mentioned as an important part of the conservation of the Bijagós archipelago' ecological traits, has deserved international recognition (Equator Initiative, Global Program on Nature for Development, 2019).

More recently, IBAP, with the support of MAVA Foundation, developed several projects in straight collaboration with European universities and research institutes (MAVA Foundation, 2018). Shorebirds have been the focus of one of this large research projects, in which intertidal ecosystems of the Bijagós were and continue to be studied. This research project is within the scope of MAVA's Action Plan entitled Plan of Action for Coastal Wetlands and Bird Populations in West Africa (http://zoneshumidescotieres.prcmarine.org/en). This

extremely important international project has already produced results such as the filling of knowledge gaps on shorebird ecology in this archipelago (e.g. Coelho et al., 2018; 2019; Belo, 2019; Paulino, 2019; Henriques et al., 2019; 2020; Mathijsssen, 2020; Parente, 2020), key factors regarding the hydrology and intertidal sediment (e.g. Granadeiro et al., 2021), sensibilization and training of the local community members, and more is still ongoing. Before this major project, other research initiatives, lead by researchers from the University of Lisbon, funded by the Portuguese Foundation for Science and Technology (FCT), had already started to address some of the research questions that were taken on further during the MAVA funded project, with important findings being published (Catry et al., 2016; 2017; Coelho et al., 2016; Lourenço et al., 2017a; 2017b; 2018).

Knowledge gaps

The first and most prominent knowledge gap in the Bijagós archipelago currently is related to the lack of adequate methods to reliably assess shorebirds numbers. Because the Bijagós archipelago is particular in the sense that it is not possible to count shorebirds while they are congregated, due to how and where they roost (as addressed earlier in this case study), counts must be undertaken during low tide, when birds are extremely scattered. This makes it very difficult to properly cover the entire Bijagós, and also entails technical difficulties in the replicability of the counts in a way that they can be reliably compared, due to potential variations in the area sampled in each count, which is very difficult to estimate. Furthermore, recent studies have already shown that shorebirds are not equally distributed throughout the intertidal flats of the Bijagós, as they occur in much lower densities in fiddler crab dominated areas compared to other areas (Paulino, 2019). Henceforth, the development of adequate sampling methods that can account for these important variations and improve the quality of data is of upmost importance for the conservation of shorebirds in this site.

The absence of regular seasonal monitoring of shorebird numbers and community compositions is also an important knowledge gap hindering a comprehensive understanding of how these birds use this site throughout the year, namely regarding the proportion of immature birds (which do not migrate in the first year) depending on the ecological traits of this site during the northern spring and summer.

Despite the increasing number of studies and reports for this area that were only possible due to funded projects (e.g. MAVA foundation, FCT, Wetlands International, SOVON), the trophic ecology is still poorly studied for some species. The diets of the Eurasian Curlew *Numenius arquata*, the Eurasian oystercatcher *Haematopus ostralegus* and the Little Stint *Calidris minuta*, in the Bijagós Archipelago, are yet to be described. Without a sound knowledge of dietary preferences along the year-round distribution of migratory shorebirds, it is difficult to understand the reasons behind demographic changes.

The role of the fiddler-crab *Afruca tangeri* in the intertidal systems of the Bijagós is yet to be clarified. It can be of major importance for shorebird conservation as it is a common prey-item identified in birds' diet and it is widespread within the mudflats of the whole archipelago. The potential effects of this crab in the intertidal system should feature in future research priorities, as it has the potential of modifying the areas in which they inhabit and therefore, act as ecosystem engineers (Paulino, 2019).

Predation levels over shorebird wintering populations in the Bijagós archipelago are considered to be low but are still yet to be studied. However, a few attacks from raptors to feeding shorebird have been recorded (Belo, 2019). Interestingly, species not yet described as shorebird predators there, such as the Palm-nut Vulture *Gypohierax angolensis*, were found attacking and/or eating them (Belo, 2019).

The effects of global changes on the Bijagós intertidal ecosystem in regard to shorebirds have not been addressed yet to the best of our knowledge and may constitute one of the main threats in the future. We urgently need to understand how intertidal areas in the Bijagós will be affected in relation to their total area, as sea level

rise will imply habitat loss for foraging shorebirds and may lead to shifts in distribution of macrozoobenthic prey.

Conservation and protection gaps

As mentioned before, the Protected Area network in the Bijagós archipelago has been developing a very important work that has been promoting the conservation of shorebird habitats together with local communities. Nonetheless, several challenges raise with the increased fragility of the local communities regarding their basic development needs, which has been the motive of some conflicts between conservation efforts and human activities. Such conflicts take the form of augmented pressure over the resources in the Bijagós, weather by local communities and foreigner fishermen or tourist businesses, with the need of economical revenue potentially leading to unsustainable practices of exploitation of shells, fish and mangroves. To counter this, more resources need to be made available for conservation institutions to develop adequate projects that may create alternative revenues and avoid the destruction of the natural environment, and to support a stronger surveillance and protection.

A weak presence and virtually inexistent investment of the government of Guinea-Bissau in the protection and funding of conservation is another big gap, that has been causing local conservation institutions to work with very limited resources and authority, having to depend on international funds to support their work. Likewise, the authority of the government still needs to be put to a better use for the conservation of coastal areas in the country, and more awareness needs to be raised among the political actors to change this.

The integration of local communities and national technicians and authorities in the research efforts has been ongoing for many years now, which has resulted in the clear increase of the number of national human resources with improved capacity to undertake conservation activities with adequate knowledge and know-how. Nonetheless, there is still need to improve the level of exchange between international researchers and monitoring partners and national conservationists and researchers and students, which can be extremely important in securing future competent and knowledgeable human resources to manage the natural habitats and resources of which shorebirds depend on.

7. Recommendations for an improved conservation of shorebirds and management of the key ecological traits in the Bijagós archipelago

Shorebirds find in the Bijagós archipelago an amazing wintering paradise. However, there is need to keep building knowledge to better understand the ecological processes behind the choice of such large numbers of shorebirds in spending half of their year there, and to understand, prevent and anticipate current and future changes in such processes that may affect these birds. Thus, we recommend bellow a set of guidelines to improve shorebird conservation and management in the Bijagós archipelago.

Development of an improved count and monitoring method: This is of major importance as it will allow to have more clear interpretations of the trends of the different shorebird species and to identify with higher certainty the most important areas for shorebirds, which may need to be taken in consideration regarding the protection zonation in the current protected area network.

Increased support and involvement of the government: Governmental authorities should increase the efforts in supporting the Biosphere Reserve and its three protected areas, and incorporate the conservation of the Bijagós archipelago and its biodiversity as a national priority.

Training and capacity raising of national human resources: Conservation organizations, together with international partners, should strongly invest in the capacity raising of national technicians, and promote the engagement of younger generations in the protection of the environment, as a condition for sustainable development. This can be done through partnerships with international organizations in providing workshops, webinars, talks, courses and such, through close exchanges and collaboration with ongoing and future research

projects in the field, and investment from national institutions in their human resources. Scholarships to support national students to follow advanced studies (Bachellor's, Master and PhD) in universities outside the country are also key for the future of conservation in the Bijagós archipelago.

Assessment of the impact of potential threats to shorebirds habitats and identification of detection and mitigation strategies: Threats must be conveniently assessed, by generating scenarios of potential global changes effects in the ecosystem. For instance, developing a Coastal Sensitivity Index (CSI) to understand the magnitude of the risk to erosion and sea-level rise and thus, predict possible impacts on shorebirds. Also, and since it is in an early phase, authorities should consider legislating more strongly and clearly the rules and criteria for tourism development, pursuing a sustainable and ecological strategy. The emerging oil exploration should be properly evaluated in terms of possible impacts on coastal ecosystems and protection, mitigation and compensation measures should be defined for the Bijagós archipelago Biosphere Reserve.

Long-term ecological monitoring: We recommend the development of a long-term ecological monitoring of the Bijagós archipelago, in which several ecological parameters would be measured along the years as proxies of the ecosystem health in the perspective of shorebirds, and as means for an early detection of changes with negative impacts on the habitats and its biodiversity. This could be done by measuring parameters like the sediment composition (including organic and heavy metal contaminants), the intertidal area surface (through remote sensing techniques), the evolution of macroinvertebrate communities, and shorebird numbers, allowing long-term assessments, and ecological alert systems. This meaningful exercise can be expanded for other important groups of species, such as sea turtles, fish and terns, and may motivate very profitable exchanges between international researchers and conservationists and local technicians, students and local communities.

Conservation works best with the engagement of all parties involved. In João Vieira and Poilão Marine National Park (JVPMNP), a dynamic conservation model was implemented with a very positive overall outcome (**https://sites.google.com/site/projectopnmjvp/**). We believe that this framework should be applied to every protected area in the Bijagós archipelago, as it involves a straight collaboration between researchers, students, staff from conservation authorities and community members, while ensuring funding for conservation, monitoring and research and promoting the presence of teams on field almost constantly. The research aims are related to the specificity of the protected area, and the different parties contribute for the conservation and improvement of the protected areas:

- **Researchers** supervise students, transmitting their knowledge and experience. They develop the existing knowledge and locally adjust conservation and management guidelines. They provide important knowledge that can be used for environmental education and for promoting ecotourism, and therefore bring wealth in a sustainable way for Guinea-Bissau.
- **Local students** learn how to work in the field and to develop knowledge about ecosystem functioning, ecology and biology of the study species and their habitats. They gain conservation awareness and at the same time, their qualities are valued which may lead conservation authorities to hire them. As students rise the national qualification levels, they will also increase the quality and resilience of the dynamic conservation at the country level.
- **Conservation authorities** actively participate in research activities as technicians and develop their knowledge. In the other hand, they transmit their local knowledge to researchers and guide them through the specificities of each site, improving the efficiency. Also, by working with specialists, they learn monitoring techniques and a set of skills that are important for conservation actions.
- **Local communities** benefit from work opportunities related with research and conservation. They transmit their empirical and factual knowledge about the species and ecosystems to researchers and conservation authorities. In exchange, they receive information that allow them to better understand the aims and functions of protected areas, which will be probably passed to the rest of the community.

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