Article

Birds of the National Park of Banc d'Arguin, Mauritania: A Panel on Ecosystem Services

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ABSTRACT

Background: The National Park of Banc d'Arguin (PNBA, Mauritania) was founded in 1976 to preserve the largest West African wintering area for shorebirds. In the face of increasing pressures, the PNBA's authorities have launched an appeal to determine the park's socio-economic value to adjust its management plan better.

Methods: In this context, we have created an exhaustive inventory of known characteristics of bird species present in the PNBA to investigate their potential in terms of ecosystem services for local populations. Two regulating and supporting services were also valued based on data availability: nutrients input and carcasses removal.

Results: We found that 53% of the 233 bird species associated with the PNBA are highly dependent on the park and its coastal and marine ecosystems for their life cycle. We were also able to identify services with a high potential for the park, such as nutrient cycling and bird-watching. We finally valued nutrients input and carcasses removal at € 1.8 to € 133.7 million/year and € 2900 to € 4800/year, respectively.

Conclusion: This study highlights the importance of protecting the PNBA's birds beyond the sole ornithological interest behind its creation and reinforces the argument about the importance of this protected area in terms of conservation.

KEYWORDS: conservation; protected area management; biodiversity; land-sea interface; shorebirds

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INTRODUCTION

In the current context of environmental change and ecosystem degradation [1–3], the importance of protected areas in the conservation of these ecosystems and their biodiversity has been now widely recognized beyond the aesthetic considerations that almost exclusively motivated their creation in the past. However, the effectiveness of these areas can only be achieved by implementing appropriate management measures for the ecosystems and species concerned while also taking into consideration human well-being [4–6].

The need for policies that better incorporate environmental considerations has thus become increasingly urgent in recent years. In these circumstances, the concept of "ecosystem services" provides a theoretical framework for bridging the gap between science, society, economics and politics [7]. Ecosystem services have been defined as "the benefits that humans derive from ecosystems" [8], or more precisely as "the ecological features, functions or processes that contribute directly or indirectly to human well-being" [8,9]. The evaluation of ecosystem services has been put forward as a powerful tool for conservation. Indeed, their monetary valuation allows showing that an ecosystem or a species can have value beyond ethical or aesthetic considerations [10] as this value is expressed in a "tangible" unit understood by all and easy to incorporate into policies and decision-making processes [11]. The use of a currency metric helps raise decision-makers' awareness of services often neglected for lack of knowledge and information, such as supporting services [12]. Though the approach has been criticized for its weaknesses, mainly related to the novelty of the discipline, it remains a useful conservation tool as long as these weaknesses are kept in mind and that assessments are accompanied by other physical and biological indicators reflecting the non-economic value of nature [13–15].

Although the ecosystem services concept can be adapted to an ecosystem as well as to a species or group of species, most studies to date have focused on ecosystems as a whole [15] such as coral reefs, mangroves, seagrass beds, salt marshes, or tropical forests for instance [16–20]. In comparison, the literature related to ecosystem services provided by wildlife is still limited and birds, in particular, represent only about 3% of the annual number of publications on ecosystem services (according to research on ISI Web of Science on October 22, 2018, with the keywords "ecosystem services", then refined with the keyword "bird"). Nevertheless, work by Şekercioğlu, Whelan, Wenny and their collaborators [10,21–24] showed that birds are one of the most diverse groups providing the four categories of ecosystem services defined by The Economics of Ecosystems and Biodiversity [25] that are: provisioning services, regulating services, habitat or supporting services, and cultural services. Indeed, birds produce provisioning services through their meat and eggs for food and sport hunting, their feathers and bones for the manufacture of clothing, duvets, and other handicrafts, their guano used as a fertilizer, or the pharmacological molecules of interest that they can harbor. They also provide a wide variety of cultural services such as bird-watching and ecotourism, a source of inspiration for culture, arts or religion, as well as an object of study for research and education as sentinel species of their environment. Often less known are the ecosystem services provided by birds in the form of regulation and maintenance services and supporting and habitat services, through seed dispersal, pollination, carrion consumption and disposal of organic waste, pest control, nutrients deposition and cycling, and soil formation and engineering. These services

are harder to study and often overlooked, and consequently rarely considered in birds ecosystems services evaluations (but see, for instance, [26,27]). This wealth of services is primarily due to the diversity of birds' ecological characteristics and functions [22,28–30]. In particular, considering birdlife as a whole, birds are able to feed virtually on anything [23,31–34]. Şekercioğlu and its collaborators have thus established a correspondence between ecosystem services and functional groups of birds, based on their feeding behavior [21,22]. For instance, insectivorous bird species provide a regulating service through the biological control they exert on harmful insect species, therefore acting as "natural pesticides", while scavengers also provide a regulating and maintenance service through the removal of carcasses that limits the risk of disease outbreaks.

The National Park of Banc d'Arguin (PNBA) was founded in 1976 to preserve the most important wintering area in West Africa for migratory shorebirds [35,36]. The ornithological importance of the area also led to its inscription as a Ramsar site in 1982 and on the UNESCO World Heritage List in 1989 [36]. Indeed, the PNBA is home to up to 2.5 million shorebirds every year, including more than two-thirds of the world population of Bar-tailed Godwits, *Limosa lapponica*, and half of the world population of Red Knots, *Calidris canutus* [36]. The park is also home to two endemic and emblematic sub-species, the Mauritanian Grey Heron, *Ardea cinerea monicae*, and the Mauritanian Eurasian Spoonbill, *Platalea leucorodia balsaci*, along with numerous threatened species such as the Rüppell's Vulture, *Gyps rueppellii*, the Egyptian Vulture, *Neophron percnopterus*, the Saker Falcon, *Falco cherrug*, or the Black-legged Kittiwake, *Rissa tridactyla*. With the general acknowledgment of the park's importance for its associated bird species, a great effort has been made to understand better the ecology of shorebird species in particular (e.g., population trends and life history in [37–39]; feeding ecology in [40,41]; physiology in [42–44]). However, little is still known about the other equally important species present in the PNBA, such as seabirds or raptors and vultures (but see [39,45], for instance), and to our knowledge, no study exists on ecosystem services provided by birds within the PNBA.

This study follows the Mauritanian and the PNBA authorities' joint call to determine the economic and social value of the PNBA to adjust better conservation and management actions of the park. Valuing bird ecosystem services contributes to a more robust estimate of the full value of the PNBA and a strengthened argumentation as to its consequent role as a protected area. The study objective is to draw up a general list of the ecosystem services the avifauna of the PNBA provides to humans as the first step towards understanding their use to the local communities. The study also values two regulating and supporting services, nutrient input and carcasses removal, based on data availability and proposes research avenues to quantify these services and others accurately as a path towards an in-depth economic valuation of birds within the PNBA. To this end, we

used existing literature and databases to create an original inventory of the known characteristics of the bird species present in the PNBA before investigating the potential of these birds in terms of ecosystem services to inform better the park's management.

MATERIAL AND METHODS

Study Area

The National Park of Banc d'Arguin (PNBA; 19.35°N–20.83°N, 15.95°W–16.75°W) stretches over 180 km along the Mauritanian coast between Cape Minou and Cape Timiris (Figure 1). Its 12,000 km^2 surface area is almost equally divided between land and sea and encompasses a wide variety of terrestrial and coastal landscapes ranging from desert sand dunes to seagrass beds by way of coastal sand dunes, mangroves, mudflats, and small islands, among others. Besides, its coastal waters are enriched through the permanent upwelling off Cap Blanc, sustaining a rich marine life [46]. The PNBA is one of the largest parks in West Africa and plays a crucial role in maintaining the bird biodiversity it shelters. The park also protects and contribute to the productivity of the marine ecosystems and halieutic resources of the Mauritanian Exclusive Economic Zone (EEZ; [47]), from which the country derives up to 10% of its Gross Domestic Product through fisheries [48]. Furthermore, the park is home to the Imraguen, a local ethnic population living in harmony with its environment for several centuries and whose ancestral fishing techniques are also part of the park's immaterial heritage.

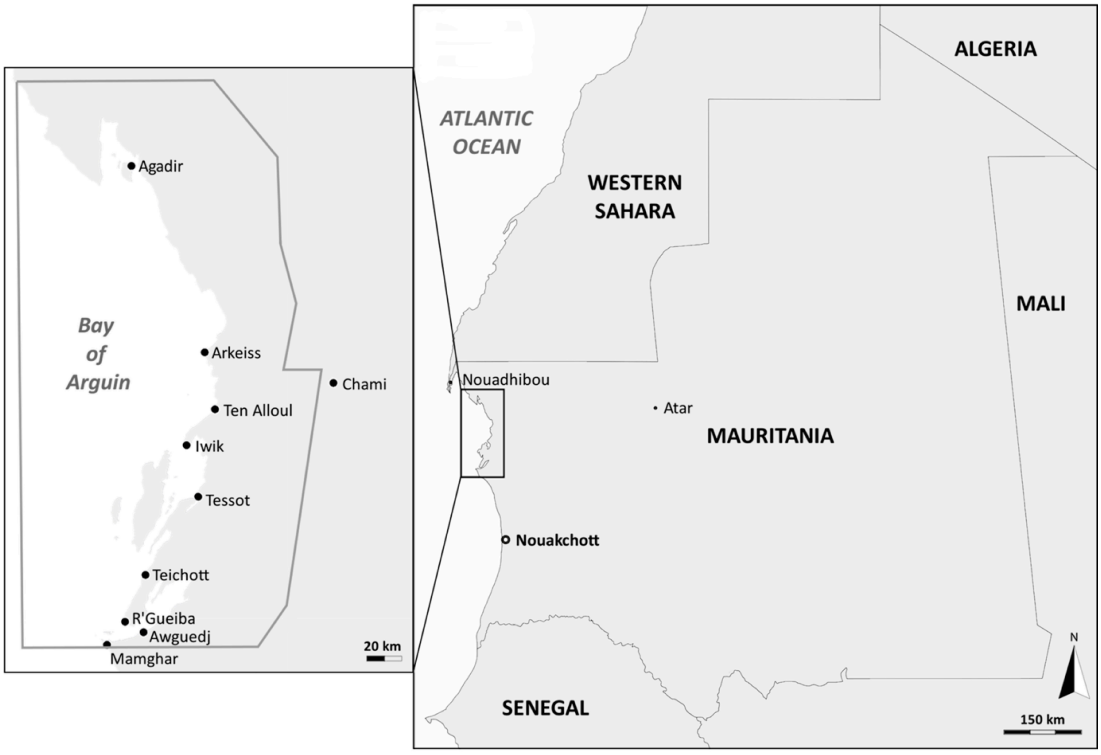

Figure 1. Localization of the National Park of Banc d'Arguin. The thick grey line on the left panel defines the limits of the park.

Characterization of Bird Species of the PNBA

In this study, we analyzed the literature on ecosystem services provided by birds and available ecological data on species present in the PNBA. As a first step, the list of bird species associated with the PNBA was defined from BirdLife International [49] spatial distribution data and Isenmann [50]. Then, still from BirdLife International [49] and Isenmann [50], or, where information was missing, from del Hoyo et al. [51], Oiseaux.net (http://www.oiseaux.net) and aerien.ch (http://www.aerien.ch), the following criteria were collected for each identified species: the status of the species within the PNBA regarding its life cycle, the status of the species on the IUCN Red List [52], the global population trend of the species, the biome(s) to which the species is associated with, the habitats within the PNBA to which the species is associated with and the relative importance of these habitats for the species, the consumption uses identified for the species, and finally the functional group(s) associated with the diet of the species. These different characteristics were defined as follows.

Status of the species within the PNBA

Five different statuses were defined according to the species life cycle stage when it is found in the PNBA. Consequently, species breeding within the PNBA and observed within the PNBA all year long were classified as "Resident"; species breeding within the PNBA but absent the rest of the year, although some individuals may be observed outside the breeding season, were classified as "Breeding"; species wintering within the PNBA were classified as "Wintering"; species whose presence does not correspond to any pattern related to reproduction or migration, often a species present in the PNBA for food prospection, were classified as "Non-breeding"; and finally species whose presence in the PNBA is transitory (often a step on the migratory route) were classified as "Transient".

Status of the species on the IUCN red list of threatened species

Birds species associated with the PNBA identified here have all been evaluated in the IUCN Red List of Threatened Species [52]. As of the last evaluation of July 2019, they were classified in one of the five following categories at the global scale, from the least to the most endangered: Least Concern (LC), Near Threatened (NT), Vulnerable (VU), Endangered (EN), and Critically Endangered (CR).

Population trend

The four categories of population trend defined by the IUCN [52] according to the evolution of the population's size at a global scale (depending on the number of individuals or on the number of mature individuals) were used here: Increasing, Stable, Decreasing, and Unknown.

Biomes

The systems to which the species is associated during its life cycle for its different biological functions (e.g., reproduction, food prospection) as defined by the IUCN [52] were also used here: Terrestrial, Freshwater, Marine. It is to be noted that a species can be associated with several biomes at the same life stage or for different life stages. This criterion is defined worldwide.

Habitats within the PNBA

Only habitats, as defined by IUCN [52], which can be found in the PNBA have been retained here. A species can be found in one or several of these habitats within the PNBA: “Urban areas”; “Rocky areas” such as inland cliffs, mountains, talus, etc.; “Hot deserts”; “Dry caves” defined as underground spaces produced naturally by the weathering of rock; “Sandy shorelines” and/or beaches, sand bars, spits, etc., defined as intertidal shores composed mainly of sandy sediments; “Rocky shorelines” defined as intertidal shores composed mainly of consolidated rock or boulders; “Sea cliffs and rocky offshore islands”; “Mud shorelines” and “Intertidal mud flats” defined as intertidal shores composed mainly of mud or sandy-mud sediments; “Coastal sand dunes”; “Subtidal sandy bottoms” defined by substrate areas consisting of loose particles of rock or mineral sediments; “Subtidal sandy-mud bottoms” defined by substrate areas consisting mainly of a mixture of small pebbles, mineral sediments, wet clay and silt-rich sediments; “Macroalgal beds/kelps forests” defined by substrate areas covered mainly by large algae which often forms dense macroalgal beds or forests; “Seagrass beds” defined by substrate areas covered mainly by grass-like marine flowering plants; “Pelagic” defined as the area of neritic marine environment composed of the entire water column; “Epipelagic” defined as the oceanic pelagic environment from the surface to a depth of around 200 m; “Salt marshes” defined by a grassy area that extends along the shores of estuaries and sheltered coasts in temperate and subpolar regions with emergent vegetation rooted in soils alternately inundated and drained by tidal action; “Tidepools” defined by an intertidal depression in rocks or in sandy beaches that continues to hold water during low tide; “Subtropical/tropical mangroves”. Some species associated with the PNBA could not be tied to any of these habitats due to a lack of information.

Relative importance of these habitats for the species

This criterion determines the adequacy of the habitat(s) within the PNBA, defined above, for the species in question. Three categories were defined: major, suitable, or marginal.

Identified consumption uses

The categories of uses defined and identified in the BirdLife International database [49] have been retained here: Pets or display animals; Sport hunting or specimen collecting; Food for humans; Medicine for humans or animals; Handicrafts, jewelry, decoration and other curios; Other household goods; Fuels. Up to four different uses have been identified for a same species.

Functional group

We used here the same functional groups related to the diet of species as used by Şerkercioğlu and his collaborators [21,22] to establish a correspondence with specific categories of ecosystem services. Thus, all species consuming fruits, seeds, roots, and other vegetal material were defined as "Frugivores"; all species consuming insects and other invertebrates were defined as "Insectivores"; all species consuming fish and other marine organisms were defined as "Piscivores"; all species consuming vertebrates mainly (e.g., mammals, birds, reptiles) were defined as "Raptors"; all species consuming mainly or exclusively carrions were defined as "Scavengers". Because of the lack of information on its diet, we could not determine the functional group of one species that was thus defined as "Miscellaneous". Since none of the species studied could be classified as "Nectarivores", this group is not presented here. Each species was associated with a primary functional group according to the most prominent items in the species diet, and one or several secondary functional groups according to the other significant items of its diet if there were any.

All data collected are available in Supplementary Table S1.

Monetary Valuation

Mainly because of the lack of data availability, we were able to quantify and value only two regulating and supporting services provided by the birds of the PNBA: nutrients input by seabirds and shorebirds and the removal of carcasses by vultures.

Nutrients input

The daily guano or feces production for seabirds and shorebirds was extracted from the literature. Wainright et al. [53] estimated that large seabirds corresponding to murres and cormorant species produced individually on average 185 g of guano (wet mass) per day, while medium seabirds that corresponded to kittiwake, puffin and fulmar species produced 80 g, and small seabirds that corresponded to auklet species produced 46 g. We then used the average size and body mass of the seabird species associated with the PNBA to classify them in one of these categories and attribute them the corresponding guano production rate. A similar relationship between individuals' stature and their daily guano

production could not be established for shorebirds. We thus used the lowest and highest values we found in the literature for this type of species for all the shorebirds associated with the PNBA: 6.65 g of wet mass/day for Black-tailed Godwits, *Limosa limosa* [54], to 510.37 g of wet mass/day for Red Knots, *Calidris canutus* ([55]—provided as a dry mass we converted to a wet mass considering an average water content in birds feces of 70%; [54,56,57]). Next, we calculated the global production of these species using the last global count carried out in the PNBA in 2017 [39], and Issenmann [50] or Observation.org [58] when data were not available for a species. Finally, still using Issenmann [50] or Observation.org [58], we determined the average number of days a species can be observed during the year to report this global production on an annual basis.

In the next step, we used the replacement cost method to evaluate this service's potential monetary value, i.e., we established how much it would cost locally to provide the park's ecosystems with an equivalent amount of nutrients through fertilizer, and artificial replacement, in order to sustain the productivity of the PNBA. As no data were available for Mauritania, the average price per ton of fertilizer was determined through a regression between the average price per ton of fertilizer [59] and the Gross Domestic Product at Purchasing Power Parity per capita [60] per African country in 2017 (Supplementary Figure S1). We then considered that 1 ton of wet mass of guano was equivalent to 1 ton of fertilizer and multiplied the production of guano of the park's birds by the country's price of fertilizer.

Removal of carcasses

From Margalida and Colomer [27], we determined that individual vultures consume, on average, 2.28 to 3.45 kg of bones/year and 95.52 to 143.30 kg of meat/year, which was valued as providing a benefit of € 15.62 to € 26.62/individual/year. We brought back these prices in 2017 € considering the inflation rate based on consumer prices [60] in Spain where the study was conducted to obtain a value comparable to the 'nutrients input' service, and therefore considered a benefit of € 16.01 to € 27.29/individual/year in 2017. Two of the vulture species found in Spain in Margalida and Colomer's study [27] can also be found in the PNBA, the Griffon Vulture, *Gyps fulvus*, and the Egyptian Vulture, along with a third species, the Rüppell's Vulture. While no vultures were counted in 2017, according to Issenmann [50], these three species can be observed in the PNBA all year round by groups of up to 40, 15 and 43 individuals, respectively, while up to 124 Griffon vultures have been observed in the same day according to Observation.org [58].

Data Analysis

All data collected were analyzed and graphically represented using the R software [61] and the "ggplot2" package [62].

RESULTS

The PNBA, An Ornithological Hotspot

We identified a total of 233 bird species as associated with the PNBA among the 538 species present on the Mauritanian territory. It is to be noted that for numerous bird species, no spatial distribution data are available. Consequently, there are probably more species associated with the PNBA than what we could define here. Among these 233 bird species identified within the PNBA, 31.3% are wintering, 20.6% are residents, and 1.7% are only breeding in the park. The proportion of non-breeding and transient species then reaches 10.3% and 35.2%, respectively (Figure 2a). We could not confirm the status within the PNBA for two species, the Abyssinian Roller (*Coracias abyssinicus*) and the Northern Bald Ibis (*Geronticus eremita*), and it was thus considered *NA*. Furthermore, 27.5% of bird species associated with the PNBA depended only on the terrestrial biome, while 72.5% of the remaining species depended on at least one water-related biome or even both in addition to the terrestrial biome during their life cycle (Figure 2b).

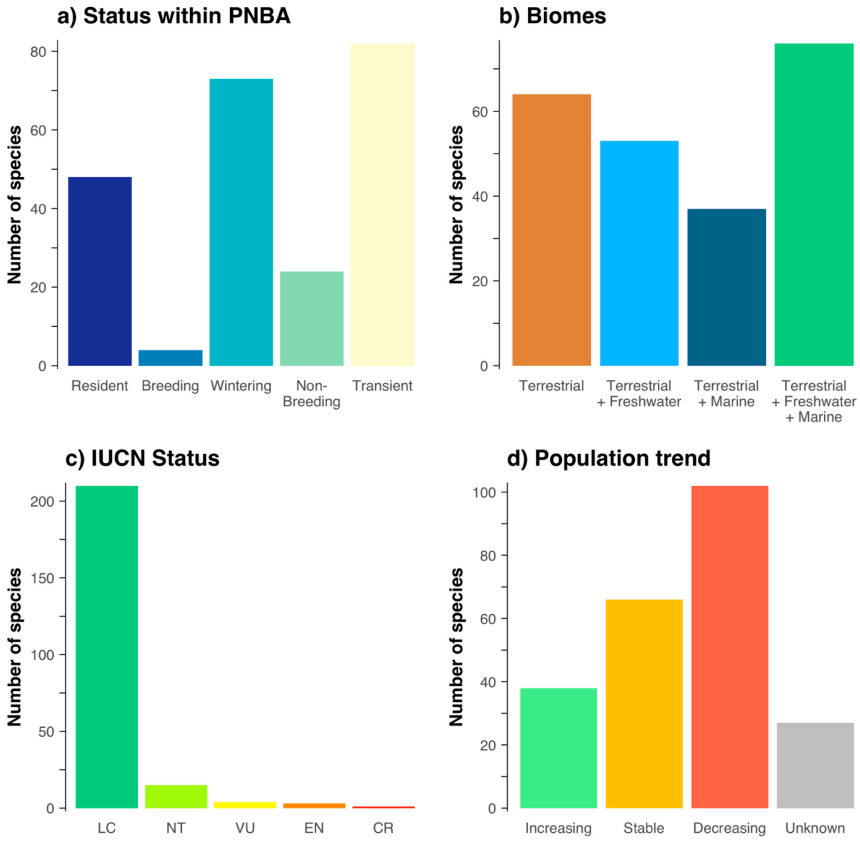

Figure 2. Characterization of the bird species associated with the PNBA through (**a**) their status within the PNBA, *n* = 231 observations; (**b**) the biome(s) to which they are associated, *n* = 230 observations; (**c**) their status on the IUCN Red List of Threatened Species (2019), with LC: Least Concern, NT: Near Threatened, VU: Vulnerable, EN: Endangered, CR: Critically Endangered, *n* = 233 observations; and (**d**) trend of the global population, *n* = 233 observations.

This last trend is reflected in the habitats in which these species are present in the PNBA and the importance of these different habitats for them (Table 1). Indeed, of the 17 identified habitats, 13 relate to water directly or indirectly. In the absence of river and surface freshwater reservoirs, only the marine biome is concerned in the case of the PNBA. Thus, most bird species in the PNBA are found in subtidal sandy and sandy-mud bottoms, macroalgal beds, seagrass beds, and the pelagic zone.

Table 1. Distribution of bird species in different habitats within the PNBA and relative importance of these habitats for the species considered. N = 627 observations on k = 167 species.

Habitats within the PNBA	**Relative importance for *x* bird species**			**Total**
	major	**suitable**	**marginal**	
Urban areas	3	36	4	43
Rocky areas	25	10	-	35
Hot deserts	8	22	1	31
Dry caves	-	3	-	3
Sandy shorelines	15	23	2	40
Rocky shorelines	8	27	1	36
Sea cliffs & rocky offshore islands	21	15	-	36
Mud shorelines	7	29	-	36
Coastal sand dunes	1	6	1	8
Subtidal sandy bottoms	25	26	1	52
Subtidal sandy-mud bottoms	25	26	1	52
Macroalgal beds/kelps forests	25	26	1	52
Seagrass beds	25	26	1	52
Pelagic	26	17	2	45
Epipelagic	17	12	3	32
Salt marshes	1	27	1	29
Tidepools	2	23	1	26
Subtropical/tropical mangroves	-	18	-	18

Although the vast majority of these species are classified as 'Least Concern' by the IUCN (2019), 44.2% of them have seen their populations decline in recent years (Figures 2c and 2d). Furthermore, among the eight most endangered species associated with the PNBA (Figure 2c), one is resident within the PNBA: the Rüppell's Vulture (*Gyps rueppellii*, CR); 3 species are wintering within the PNBA: the Saker Falcon (*Falco cherrug*, EN), the Egyptian Vulture (*Neophron percnopterus*, EN) and the Black-legged Kittiwake (*Rissa tridactyla*, VU); and finally, two species are transient: the Aquatic Warbler (*Acrocephalus paludicola*, VU) and the European Turtle-dove (*Streptopelia turtur*, VU); and finally one species is non-breeding: the Leach's Storm-petrel (*Hydrobates leucorhous*, VU). The

eighth species' status within the PNBA, the Northern Bald Ibis (*Geronticus eremita*, EN), could not be confirmed as stated previously.

Consumption Uses

We found that 190 of the 233 bird species associated with the PNBA were related to at least one consumption use. Among the seven categories of consumption uses identified by BirdLife International [49], three categories account for 96.5% of all the uses made of the bird species of the PNBA: pets and/or display animals, sport hunting and/or specimen collection, and food for humans (Figure 3). Thus, 73.7% of these species are used for companionship and/or exposure, 71.6% for sport hunting and/or specimen collection, and 59.5% for food. Furthermore, 70.0% of the birds found in the PNBA were associated with more than one category of consumption use, and three species even cumulated up to four different types of uses (Figure 3): the Grey Heron, *Ardea cinerea*, the Squacco Heron, *Ardeola ralloides*, and the Cattle Egret, *Bubulcus ibis*.

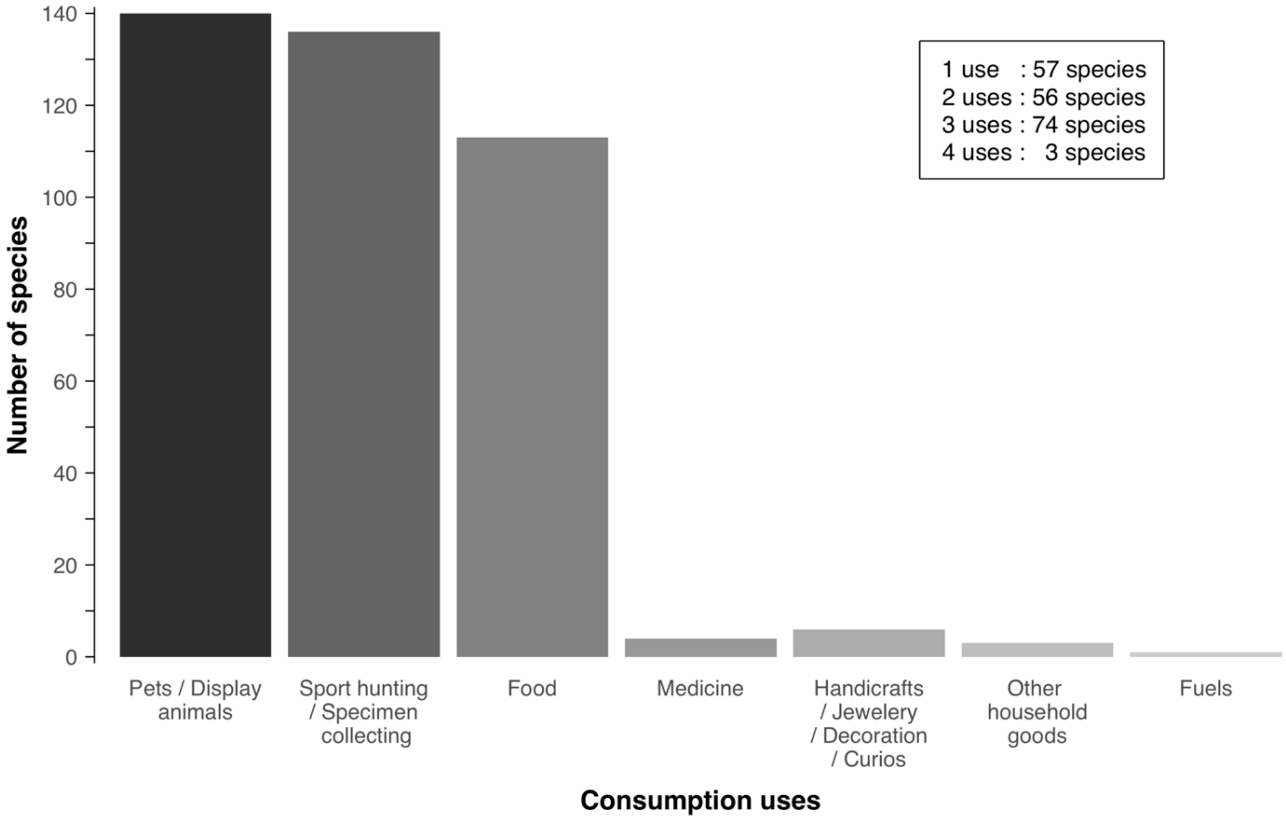

Figure 3. Consumption uses of PNBA bird species identified in the BirdLife International database [49], and number of species with one or several uses. N = 403 observations on k = 190 species.

Feeding Behavior and Functional Group

Among the bird species associated with the PNBA, we found that 55.6% have a primarily insectivorous diet, 22.8% a piscivorous diet, 10.3% a raptor-like diet, 9.9% a frugivorous diet, and 1.3% a scavenger-like diet

(Figure 4). When considering both primary and secondary functional groups, the percentage of insectivorous bird species associated with the PNBA reaches 73.0%, while piscivorous birds reach 45.1%, raptor-like species reach 28.3%, frugivorous birds reach 32.6%, and scavengers reach 6.9%. A small majority of these species have a relatively generalized diet, as 58.6% could be associated with more than one functional group (Figure 4). Ten of these species even have a very omnivorous diet as nine have been linked to four different functional groups and one, the Sabine's Gull (*Xema sabini*), to five different functional groups. It should also be noted that species with a raptor-like diet generally have a fairly diverse diet with insects, other invertebrates and carrions supplementing the main vertebrate diet (Supplementary Table S1).

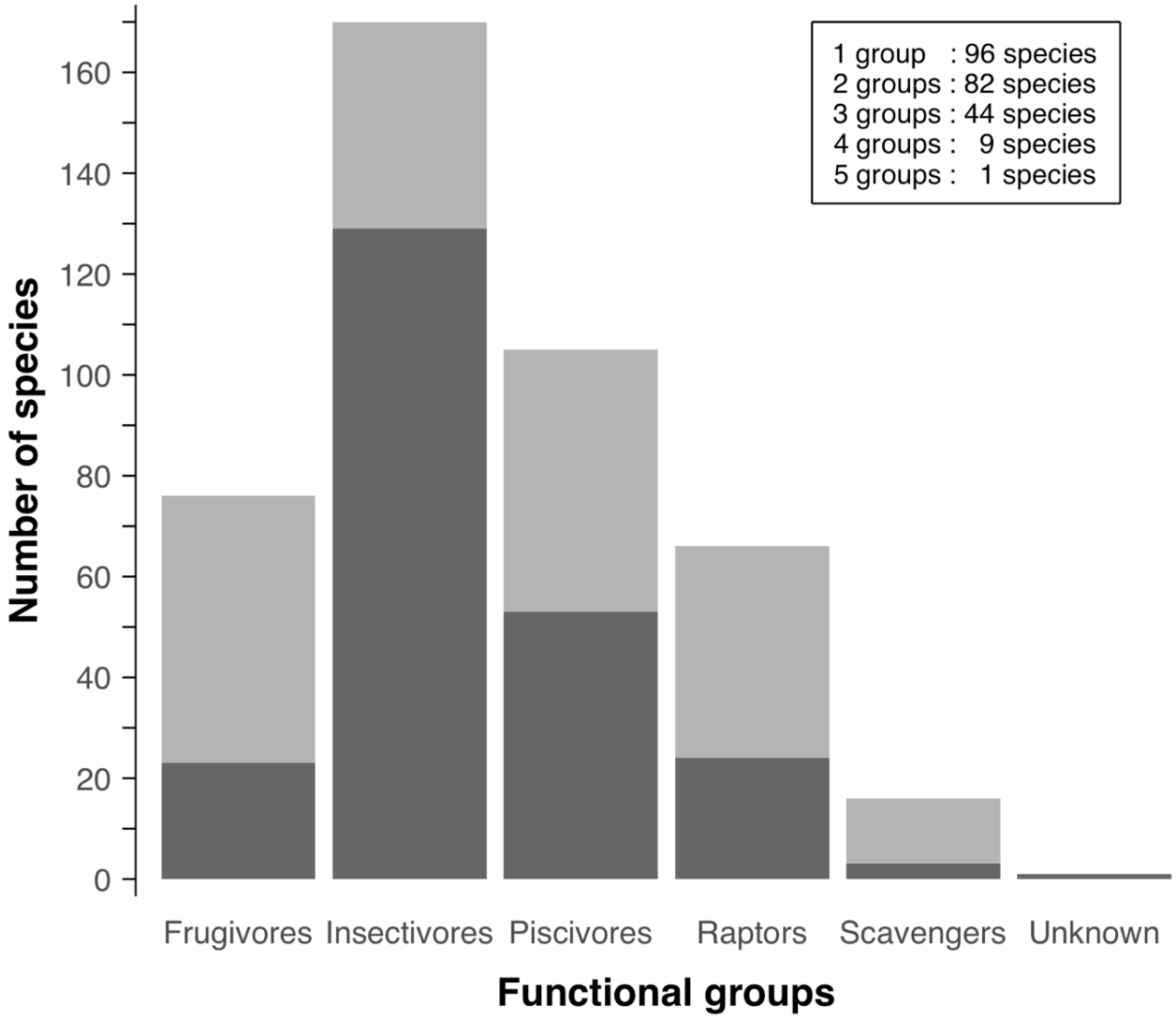

Figure 4. Distribution of PNBA's bird species according to their primary (dark grey) and secondary (light grey) functional groups defined by Şekercioğlu and his collaborators [21,22], and number of species associated within one or several groups. The primary functional group was defined from the most prominent items in the species diet, and the secondary functional group(s) was defined from the other significant items, if any. N = 345 observations on k = 233 species.

The Value of PNBA's Birds

We estimated that the seabird species associated with the PNBA produced between 1565 and 2370 tons of wet mass of guano/year (Supplementary Table S2), while the shorebird species produced between 2571 to 307,185 tons of wet mass of guano/year. According to its GDP PPP Per capita in 2017, we calculated that the average price of fertilizer in Mauritania was € 431.85/ton, or MRU 17,428.68/year. The 'nutrients input' regulating and supporting service associated with the PNBA's seabirds and shorebirds was consequently valued at € 1.79 to € 133.68 million/year in total, or MRU 72.08 to 5395.14 million /year (see Supplementary Table S2 for the detailed calculation).

Finally, the removal of carcasses by the park's vulture population (*N* = 182 individuals according to our estimations) was valued at up to € 2914–€ 4780 /year in total, or MRU 109,861–180,194 /year based on Margalida and Colomer [27] estimations for the same species.

DISCUSSION

Provisioning Services

In this study, we identified at least one consumption use at a global scale for a little more than 80% of the bird species associated with the PNBA. Within the PNBA, on the other hand, it is prohibited by law to hunt, trap, capture, injure or kill any wild animals, including birds, but also to move, damage, or take nests or eggs, and to damage or destroy the habitats and shelters of these animals (Article 10 of Mauritanian Law number 2000–24 of January 19, 2000, relative to the National Park of Banc d'Arguin). Therefore, no provisioning services should be associated with the bird population of the park that represents a refuge from the anthropogenic pressures associated with provisioning services elsewhere. In practice, though, the reality is highly likely to be different. While the literature on birds' consumption uses within the PNBA is almost non-existent, probably due to the illicit nature of such uses, Campredon ([35], p. 37) has already observed that: "When [waders] arrive in Africa, they are almost all in a state close to exhaustion. This is the time when we can see the children of Nouadhibou running on the beaches and sebkhas to capture them: it is not uncommon then to come across them holding in their hands a bundle of Bar-tailed Godwits, or a Grey Heron flapping its wings". Isenmann ([50], p. 139) also mentioned that "[…] since the creation of the National Park of Banc d'Arguin […] eggs and chicks harvesting by foreign fishermen no longer exists […]", suggesting that harvesting of eggs and chicks by local populations might still take place. It can be reasoned then that the uses identified for the Grey Heron and the Bar-tailed Godwit (sport hunting/specimen collection and food) at the international scale could still be applicable at the PNBA scale, despite being illegal, and that this may be the case for many other species.

Provisioning services rendered by birds, i.e., nutritional or non-nutritional material and energetic outputs, may be particularly important for local populations heavily dependent on only a few subsistence means, such as Imraguens. It could explain why such practices persist despite their illegality, as it is observed with sharks and rays [63]. On the other hand, many of the species involved also offer other forms of services that may potentially have more value. Furthermore, they are subject to other environmental and anthropogenic pressures that may threaten these species in the long run. For instance, the Grey Heron is used as a pet/display animal, for sport hunting/specimen collection, food, and finally, for handicrafts. The species is also piscivorous, which means it can also provide supporting services through nutrients deposition around rookeries or cultural services such as sentinel of their environment through their position as top predators, as further discussed later in this chapter. Resident in the PNBA, the Grey Heron is for now classified as 'Least Concern' by the IUCN [52]. However, the population seems to be declining in the park [39], and the combined pressure of these consumption uses and other pressures of anthropogenic origin, such as habitat destruction or the decrease of fish stocks due to overfishing, could eventually threaten the species [39,64,65].

Regulating and Supporting Services

The data we presented in this study support the status of the PNBA as an ornithological biodiversity hotspot. Because of the genetic diversity it underpins, this species richness can also be considered a supporting service as defined by the TEEB [25]. Furthermore, as we established in the introduction of this paper, the diversity of ecological characteristics and more particularly of foraging and feeding behavior exhibited by bird species is also associated with a great diversity of regulating and supporting services.

Indeed, birds provide a valuable biological control service. On the one hand, by controlling harmful invertebrate populations, insectivorous species reduce damages to plants [21,22]. Mainly associated with agriculture, this service would seem to have little interest in the PNBA where agriculture is non-existent. However, pests can affect plant species that have a direct or indirect interest for humans outside of agriculture. For instance, seeds of the Umbrella thorn acacia (*Vachellia tortilis raddiana*), which have many potential uses in the PNBA, are the target of the seed beetle *Bruchidius raddianae* [66]. Indeed, this variety of acacia helps fight against desertification, has many therapeutic virtues (anti-bacterial, deworming, antidiarrheal), and can be used for consumption (e.g., wood for construction and as a combustible, seeds for human food, leaves and fruits for livestock food, bark as a source of dye) [67]. The 73% of insectivorous species found in the PNBA can thus have a significant role in protecting this acacia among other vegetal species present in the park. In the state of Washington, USA, for instance, the harmful invertebrate

control service provided by birds, and particularly the Evening Grosbeak (*Hesperiphona vespertina*) in northern conifer or mixed forests, has been estimated to amount at least $ 1820/km^2/year [68].

On the other hand, species with a raptor-like diet offer a control service for harmful vertebrates [21,22]. For instance, Brown et al. [69] showed that the Common Barn-owl (*Tyto alba*) reduced the foraging activity of 3 species of rodents of the family Heteromidae in North America's deserts. The Common Barn-owl is also present in the PNBA, among other species with a raptor-like diet, where it is likely to provide the same service. The regulation of harmful mammals is of significant importance in the park too, given the presence of rodent species such as the Fat Sand Rat (*Psammomys obesus*) carrying a species of parasite responsible for leishmaniasis in humans, *Leishmania major* [70,71]. Furthermore, scavenger species, by their particular diet, have a primordial role in the disposal of carcasses, and therefore in hygiene and sanitation services [21,22,27,72]. In the PNBA, this service has a relatively modest value of about € 2900 to € 4800 because of the small population of vultures compared to other regions such as northern Spain, where this service's value was about ten times higher [27]. However, in the absence of domestic waste treatment facilities in the park, these species offer a vital health service to local populations by treating their biological waste and thus limiting the proliferation of other potentially harmful species, as was the case in India, where populations of stray dogs and rats (vectors of disease) exploded with the collapse of vulture populations [73].

By disposing of carcasses, scavengers also have a role in the recycling of nutrients [21,22] though this supporting service is more complicated to assess and estimate. Piscivorous species participate as well in the nutrients cycle and the maintenance of soil fertility through the deposition of nutrients around their colonies [21,22]. Indeed, it has been estimated that seabirds contribute 104 to 105 tonnes of phosphorus to the soil each year and that waterfowl contribute to up to 40% for nitrogen and 75% for phosphorus to nutrient inputs in wetlands ([22] and references within). In the PNBA, the value of this nutrients input service was high, ranging from € 1.8 to € 133.7 million/year. Despite the relatively high uncertainty due to the lack of specific data for the species associated with the park and the use of simplistic valuation method that resulted, this value still put forward the essential role of these birds, as "fertilizer" species, in the mechanisms ensuring the productivity of the PNBA and more particularly of the PNBA's marine ecosystems.

Birds provide another service that is also essential in ensuring the productivity of the PNBA's ecosystems: seed dispersal. Indeed, frugivorous species, through the seed dispersion associated with their diet and foraging behavior, can improve the genetic flow between plant species, but also help to recolonize and restore disturbed ecosystems [21,22]. It has been shown, for instance, that the Lesser Scaup (*Aythya affinis*), a duck species, has the greatest dispersal distance of the seeds of the Eelgrass,

Zostera marina, out of 5 species known to feed on this marine phanerogam's seeds, the four other species being fish and a turtle [74]. Given the importance of seagrass beds in the productivity of the PNBA, and to a lesser extent of salt marshes and mangroves [75], and given the fragmentation of vegetated areas in the terrestrial part of the park, this ecosystem service offered by these birds is far from being negligible. Though we did not have the data for a monetary evaluation of this service within the PNBA, as an example, it has been shown elsewhere that a couple of Eurasian jays, *Garrulus glandarius*, were worth between $ 4900 and $ 22,500 for its seed dispersal service only [26]. Furthermore, it has been hypothesized that piscivorous bird species and species with a raptor-like diet could also provide a secondary seed dispersal service through preys they can consume in complement to fish and other marine organisms for the former, and through the usual type of prey consumed by the latter that could be frugivores themselves ([22], and references within).

The great diversity of bird species present in the PNBA, therefore, offers a wide range of regulating and supporting services both as a whole and as individual species, and both within the park and beyond its borders. Furthermore, this bundle of services could even be more important as many of these species' ecology is still poorly known.

Cultural Services

Birds offer a wide variety of relatively well-identified cultural services, but these services are complex to value with a few exceptions. Indeed, among the cultural services, recreational activities such as bird-watching and ecotourism (which can also be considered as non-consumptive provisioning services) are the most studied services to date. For instance, the recreational value of bird-watching has been valued at $ 1,100,000–1,200,000/year in Israel's Gamla Nature Reserve [76], and at least $ 103,000,000/year in Turkey's Kuşcenneti National Park [77]. Within the PNBA, although the value of the ornithological heritage is widely recognized by both the local community and the international community, no evaluation of this service could be made. Indeed, despite its relative simplicity, the evaluation of any form of tourism within the park is today difficult in practice, as highlighted by Boide [78].

Among the cultural services provided by birds that are more complex to value, the function of environmental sentinel is well recognized in birds [79–83]. As top predators, seabird populations reflect the state of resources, including stocks of some fish species of commercial interest [79,80,82]. Given the intense fishing activity in the Mauritanian EEZ's productive waters [84], this sentinel function is particularly relevant and can be used to inform the management of the PNBA and the Mauritanian EEZ. Being highly studied in scientific communities, this function of environmental sentinel also underpins research and education services. The monetary evaluation of these two latter categories of services would require, among other things, to compile the budgets allocated to the

research and education programs on the birds of the PNBA. As a guide, a search in ISI Web of Science dated 22/10/2018 with the keywords “Banc d’Arguin” and “birds”, highlighted 26 scientific publications, the oldest dating back to 1993. It is to be noted that among these publications, only one [85] investigated the relationship between seabirds and fish stocks in the Mauritanian EEZ. Furthermore, fishers have historically used piscivorous birds as indicators of high productivity fishing areas [86]. Imraguens are known to use dolphins to locate mullet schools [35] and are highly likely to use seabirds in the same capacity, though this has not been documented yet.

Finally, birds also offer many other cultural services, which are even more challenging to evaluate with current methods, such as the source of inspiration they represent for arts, culture and religion [72]. In the literature, birds’ non-use value estimated through “Willingness to Pay” or “Consent to Pay” methods, which is commonly used to evaluate this type of services, usually range from $ 7.57 to $ 42/person/year depending on the species [14,87–91]. Given the Imraguen’s proximity to their environment and tourists’ profile within the PNBA [36,78], there is no doubt that birds play an important spiritual role in the PNBA too, although the recognition of this role is more qualitative than quantitative.

CONCLUSION

This study revealed the wealth of possible ecosystem services provided by the PNBA’s birds and the potentially substantial value of some of them, like the nutrient input valued to about € 2 million/year at least in the lowest range of the valuation. It emphasizes the social and economic interest of these species, in addition to their ecological interest at the origin of the PNBA. Listing these services is a first important step to accurately assessing their total value and to ensure they are recognized by decision-makers [9]. This first attempt at valuing these services has also highlighted the still considerable gaps in the ecological knowledge of this avifauna within the PNBA and the economic value that can be attributed to it. Raw data on these species’ ecology are essential for quantifying these services and developing specific monetary valuation methods. Therefore, it will be important to continue the scientific and economic research effort to fill these gaps and improve the evaluation of these services in the future (i.e., reducing the uncertainty). The ecosystem services provided by the birds of the PNBA are likely to extend beyond the park’s borders as many of these birds are highly mobile and will provide these services elsewhere, benefiting the Imraguen and the Mauritanian communities as well as the international community.

While this study is a first step towards valuing birds’ ecosystem services, a more robust and exhaustive study can be achieved by exploring the following avenues. First of all, it seems important to set up a scientific research program to deepen the knowledge of PNBA’s piscivores populations given their role as environmental sentinels and indicators of

fish stocks [45]. The study of foraging behaviors coupled with the study of population dynamics of some of these species residing in the PNBA, such as the Slender-billed Gull, the Long-tailed Cormorant or the Great White Pelican, will assess their potential as an indicator of the state of fish stocks and, therefore, as a management tool. Studying the composition and amount of guano produced by piscivorous species present in the park (including shorebirds species) may also make it possible to quantify more accurately their contribution to enriching their environment. In the same vein, another avenue is to study the foraging behavior of scavenger species resident in the PNBA. Indeed, by quantifying their consumption of carcasses and other organic waste within the park, it will then be possible to estimate more accurately their participation in the waste treatment in the PNBA, which remains to this day one of the park's weaknesses [78]. Furthermore, the re-establishment of rigorous statistical monitoring of tourism in the PNBA will make it possible to assess bird-watching's contribution to the economic value of birds in the PNBA. Surveys of tourists (national and international) and local populations would also allow estimating these birds' non-use value through "Willingness to Pay" methods, for instance. Finally, the evaluation of the budgets allocated to education and science research projects dedicated to the birds of the PNBA will make it possible to estimate an additional share of their value for a more robust and complete estimate of the value of birds in the PNBA.

Revealing the value of birds is a promising avenue to spur the development of an ecotourism inclusive of local communities of the PNBA for sustainable exploitation of the park that will further enhance the conservation of these birds in a virtuous circle. As stated previously, bird-watching's recreational value can be high, as it is the case in the Gamla Nature Reserve of Israel, for instance, where the activity is mainly related to the presence of the Griffon Vulture, *Gyps fulvus* [76]. This vulture species is also found in the PNBA, along with several rare, endemic, endangered and/or emblematic species, and an exceptional specific richness, all being as many assets for the park's attractiveness to ornithology enthusiasts. Furthermore, it has been shown in Namibia and Botswana, the success of natural reserves where local communities have the freedom to manage wildlife harvesting and conservation measures by themselves [92–94]. Non-consumptive wildlife tourism was the form of tourism with the most important economic benefits in these natural reserves, which could even ensure their financial autonomy and sustain effective conservation measures with healthy wildlife populations. The development of this type of ecotourism within the PNBA would allow the Imraguen populations to diversify their livelihood activities beyond fishing. In the current context of overfishing in the Mauritanian EEZ (and the PNBA) [84], diversifying the Imraguen communities' activities could relieve the pressure on fish stocks and promote their resilience. Numerous testimonies underlined the Imraguen's sensitivity to the protection of their environment and their desire to see this form of tourism develops within the PNBA (e.g., [36]). The

PNBA seems then to be a good candidate to become an ecotourism destination.

ETHICS STATEMENT

No birds were handled during this project and no ethics protocols were required.

SUPPLEMENTARY MATERIALS

The following supplementary materials are available online: https://doi.org/10.20900/jsr20230009. Supplementary Table S1: List of bird species associated with the National Park of Banc d'Arguin (PNBA) and their associated characteristics. Supplementary Table S2: Annual guano production of the (a) seabird and (b) shorebird species associated with the National Park of Banc d'Arguin (PNBA) and associated monetary value of the subsequent nutrients input. Supplementary Figure S1: Linear regression between the Gross Domestic Product at Purchasing Power Parity (GDP PPP) per capita and the average price of 1 ton of fertilizer in African countries in 2017. Grey shades indicate the standard error around the regression line. Sources: [59,60].

DATA AVAILABILITY

Analyses reported in this article can be reproduced using the data provided in Supplementary Table S1 and Table S2.

AUTHOR CONTRIBUTIONS

CCC and PF conceived the project idea. CCC collected and analyzed the data and wrote the manuscript with input from PF and ET.

CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

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