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ABSTRACT - Each year, millions of Palearctic waterbirds migrate between Eurasia and the wintering wetlands of the Sahel-Sahara region. International censuses show these populations are declining. Although hunting is recognised as the second cause of decline after habitat degradation along flyways, waterbird harvesting in the African wintering region remains overlooked. To fill this information gap, we conducted a hunting survey in the seven main Sahel-Saharan wetlands during the wintering season. Based on a socioeconomic, knowledge and off-take questionnaire, we estimated an annual harvesting level proxy per respondent. The results indicated that waterbird harvesting is a widespread practice in the research areas. Based on site, harvesting occurred from opportunistic and food off-take to specialised and commercial hunting. Rallidae and Anatidae were the targeted families, and Afrotropical species were more hunted than Palearctic species. More- over, most of the targeted species had a “least concern” status in the IUCN red list of threatened species. Despite the high harvesting levels of the Malian and Egyptian sites, the total off-take seemed to occur at a lower level than at sites in Europe. This first survey conducted on this scale underlined that migratory waterbirds represent only a limited part of the food or income of the Sahel-Saharan human population. In order to secure both sustainable harvesting and environmental justice, international conservation efforts at the flyway level should implement a meaningful integration of Sahel-Saharan population cultural and subsistence needs and should engage all countries in a collaborative conservation and management approach across the entire migratory range.

Keywords: Palearctic migratory waterbirds Sahel Wetlands Hunting and harvesting practices Wildlife management Environmental justice

1. Introduction

For conservation biologists (Vickery et al., 2014) and NGOs (BirdLife International, 2007), the message widely reported in the media[1] has been clear for several years: bird migration to Africa has always been risky, but in recent decades, the pressure of illegal and indiscriminatory capture, especially with mist nets along the coastline, is threatening the existence of many species because of its unprecedented magnitude. Is it to the point of making the African migration a journey to hell? If this is a well-documented process for the North African coast and migratory land birds (Emile and Dereliev, 2014), what is the process like for waterbirds?

Every year, billions of birds link Europe and Africa by migrating between their breeding areas in the Palearctic region and their wintering areas in the Sahel-Sub-Saharan region (Hahn et al., 2009). It is estimated that among the 1593 Palearctic migratory species,[2] 360 species are waterbirds (Kirby et al., 2008). This subgroup includes many Anatidae (ducks, geese, swans), waders (godwits), Ciconiidae (storks and cranes), Rallidae (rails, coots, crakes, gallinules), Gruidae (cranes), Ardeidae (herons, egrets), and Pelecanidae (pelicans). Migration between Europe and Africa occurs along three migratory axes: the East Atlantic, the

[1] The Guardian (2015). *Conservationists appalled at illegal killing of 25 m birds a year in the Mediterranean.* August 26, 2015.
[2] According to the Convention of the Migratory Species (CMS) and BirdLife International definitions, excluding marine and coastal, nomadic species and altitudinal migrants

Central Europe-Black Sea-Mediterranean and the West Asian flyways (Folliot et al., 2018). This African-Eurasian connection provides benefits for humans and ecosystems (Bagstad et al., 2018; Bellisario, 2018; Green and Elmberg, 2014; Holopainen et al., 2018). Nevertheless, for the period between 1970 and 2000, the Afro-Palearctic long-distance migratory species wintering in the Sahelian drylands have sharply or severely declining populations, more than those of short-distance or resident migrants (Kirby et al., 2008; Vickery et al., 2014). The mainthreatened families are Rallidae (28%) and Anatidae (19%). The African region has the second highest level of declining populations of Afrotropical and Palearctic waterbirds (181), with less than Asia (193) but more than Europe (98) (Wetlands International, 2012). To explain this decrease, much of the literature has highlighted physical and human drivers such as habitat degradation and loss due to climate variabilityand land-use change in connection with development policies and governance impacts from local to global scales (Amano et al., 2017; Gaget et al., 2018; Holopainen et al., 2018; Lemoine et al., 2007; Ramírez et al., 2018). These environmental concerns are a key issue of international waterbirds conservation coordinated by the African Eurasian Waterbirds Agreement (AEWA). However, the migration corridors are still barely properly identified and the national contexts are very diverse from both a social-economic and law perspectives. Wetland loss or quality degradation due to anthropogenic pressures such as ur- banisation or farming development along the migration corridors necessary for stopovers are major threats (Merken et al., 2015; Vickery et al., 2014). More specifically, for example, it has been shown that the critical decline in black tailed godwit populations is due to habitat change related to intensive agriculture in European breeding areas. This led to increased predation on chicks but also to a decrease in food re- sources, thus increasing juvenile mortality (Schekkerman et al., 2009). However, there is very little evidence that habitat changes in the wintering areas have had a negative impact on these populations, particularly water and rice developments in the DFS and DIN (Gill et al., 2007). Studies in African part are very rare and non-specific. Based on a study in Senegal considered to be representative of the Sahelian rangelands as a whole, Zwarts et al. (2018) show that 1.5 to 2.0 billion birds of all types have lost their habitat in half a century. Also, harmonizing national regulatory frameworks for land-use planning and biodiversity protection in the North and South, in line with multilateral agreements,is a huge challenge (Johnson et al., 2018).

However, very few studies have focused on the second factor, hunting, particularly in the main nonbreeding grounds, i.e., the Sahel-Saharan Region (Kirby et al., 2008; Madsen et al., 2015; Salafsky et al., 2008; Vickery et al., 2014). The existing studies in Egypt (Elha- lawani, 2015; Goodman and Meininger, 1989; Meininger and Mullié, 1981; Mullié and Meininger, 1983), Mali (Kone et al., 2007, 2006; Maiga et al., 2012; Wymenga, 2003), Senegal (Vincke et al., 1985) and West Africa (Roux, 1990) are relatively old, have not been updated, and some lack detailed data on harvesting levels by species, socioeconomic di- mensions and drivers. However, these previous studies showed that hunting and trapping practices and harvest intensities were highly variable and diverse and that the social-ecological context mattered (Ostrom, 1990). Even if we know through these studies that some spe- cies are specifically harvested in distinctive areas (Vickery et al., 2014), no recent global study has measured the level of harvesting and demonstrated its impact on wintering populations, especially at the local to regional levels, mainly due to the lack of reliable data. This infor- mation is key to achieving the twin objectives of transboundary biodi- versity conservation and human well-being through the sharing, wise use and management of these renewable natural resources between European and African countries (Kark et al., 2015; López-Hoffman et al., 2010). However, in this context, it is also critical to consider this southern subsistence activity in the framing of local, national and in- ternational access rules in relationships with northern recreational hunting or population control activity. The development, implementa- tion and enforcement of any management plan, regulations and policies are environmental justice issues (Lehtinen, 2009; Kipriyanova et al., 2021; Schlosberg, 2004), as they need fair treatment and the meaningful involvement of the local people involved in the harvest, consumption or trade of waterbirds.

In this paper, our aims were to (*i*) characterise waterbird harvesting in terms of quantities by species and ultimately by type (Palearctic or Afrotropical) and conservation status and (*ii*) describe hunting and trapping (techniques, seasons, reasons). First, we briefly present our case study sites and the methods used to collect data in each country. Second, we explore the main outcomes of our first analysis of the harvest levels for each species and wetland along the Sahel-Saharan strip. Finally, we discuss the main implications of our results for both national and international public policies of adaptive management and conser- vation of migratory waterbirds.

2. Methodology

2.1. Case study areas

The study was implemented in 2018 and 2019 in seven main wintering wetlands in five countries (Fig. 1 and Appendix A.1). These wetlands are the Senegal River Delta (SRD) in Senegal, the Inner Niger Delta (IND) in Mali, the lakes Chad and Fitri (LD and LF) in the LakeChad basin (LCB) in Chad, the Khor Abu Habil (KAH) floodplain in Sudan, and the lakes Burullus and Manzala (LB and LM) in the Nile Delta (ND) in Egypt. Five of these sites belong to the Sahel, a semiarid region situated between hyper-arid Sahara in the north and the Africansavannah also called the “Sudan zone” in the south (Sinclair and Fryxell, 1985).

2.2. Hunting definition and typology

According to Roulet (2004), we can define four main types of hunting: (*i*) self-consumption hunting as “*local hunting* (*all species*, *espe- cially medium and small game*), *for consumption within the family and close circle* (*food and sociocultural value*)”; (*ii*) local commercial hunting as “*hunting by villagers for supplemental income* (*often part of the same action as self-consumption hunting*)”; (*iii*) tourism hunting as “small hunting” as “*tourist hunting of game birds*, *warthog is often associated with it*”; and (*iv*) living animal sale as “*harvest of animals for sale for the purpose of captive breeding*”.

The importance of tourism hunting that occurs in the SDR and LC is negligible for a variety of reasons (Degez et al., 2018). To our knowl- edge, two commercial hunting units for tourists have been running in Lake Chad since the increasing actions of the jihadist terrorist organi- sation of Boko Haram. In the SRD, 13 land leasing agreements are included in 8 hunting units, but despite the limited data collected on this hunt, it does not seem to exceed approximately 7000 individuals perseason for an average of 300 tourist hunters (Degez et al., 2018). InEgypt, there is one commercial sport hunting on Lake Nasser, but this was not integrated in the study due to feasibility within the time frame of the study. Moreover, in the context of insecurity, as in Chad and Mali, hunting tourism is very low.

2.3. Sampling strategy and effort

To match the waterbird wintering season, surveys were conducted from January to April 2018 in sub-Saharan countries (equivalent to the dry season) and from July to October 2019 in Egypt. Each study area was defined according to previous studies for the sake of comparison or administrative limit layers, including wetlands. In this survey, we added a limit based on the distance from which we considered that harvestingin the area no longer takes place or is no longer connected to the wetland. For the IND in Mali, access to the villages was difficult due the high level of insecurity. For Egypt, the spatial configurations of villages within and around the lakes made the initial basic sampling by village

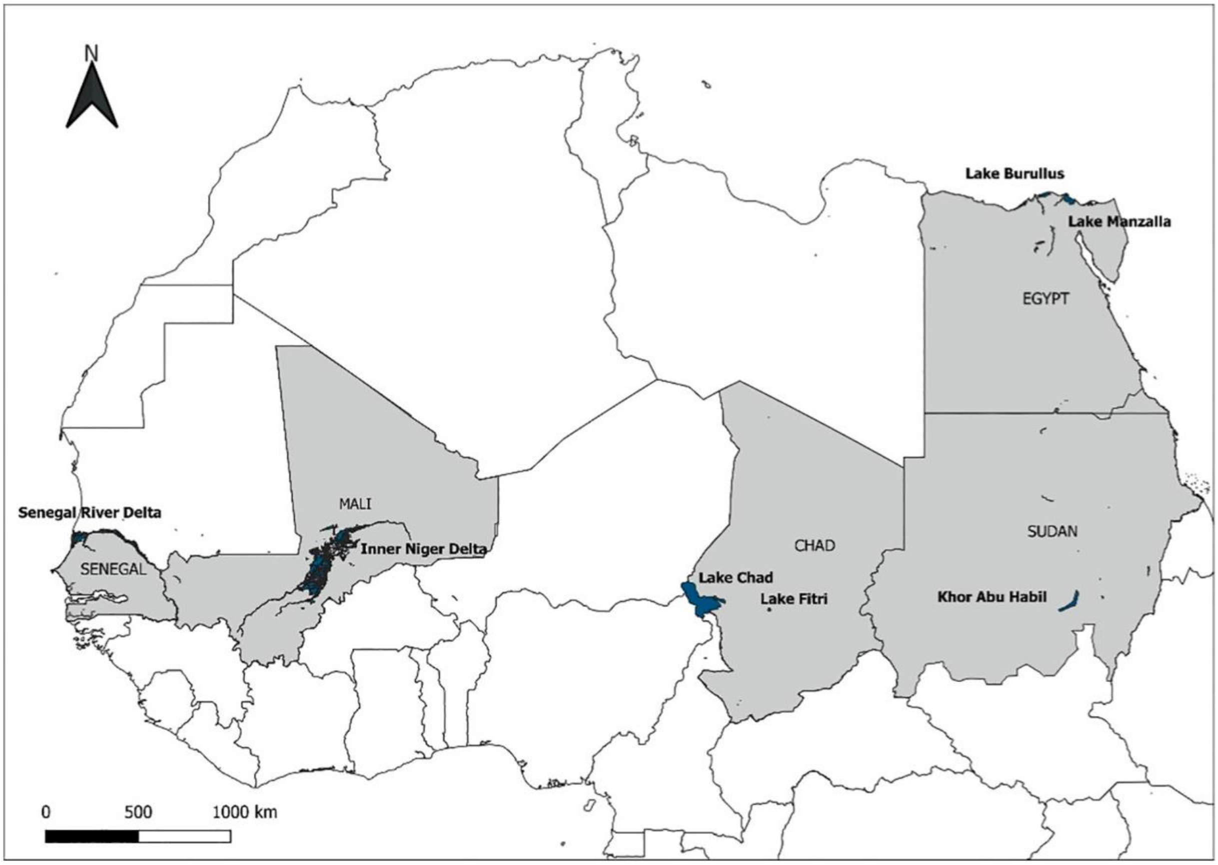

Fig. 1. The seven studied wetlands in the Sahel-Sub-Saharan African Region.

difficult. Many family settlements (not considered villages) are scattered on islands. Therefore, a total of 118 villages and more than 50 Egyptian settlements were sampled for a total of 2240 people interviewed in 206 days. After cleaning, 2189 interviews were usable (Appendix A2).

According to the geospatial data available and the logistical and funding constraints, we decided to choose 20 villages per site by crossing the available population census, existing academic fieldwork and studies, and the connection to the lake. As a result, we randomly selected 20 villages where we were sure the activities were connected, oriented, and shaped by the wetland within a radius of 10 km (for KAH, SRD, LB, LM) to 30 km (for LC and LF) depending on the geographical configu- ration of the region. Then, for each selected village, we carried out an exhaustive census of households with the customary authorities and then randomly drew households to interview; we interviewed the headof household regardless of whether he was a hunter or gatherer (i.e., as we do not know the population of hunters or the importance of the practice within the society, and in order to understand the hunting pressure in a context of high diversity and multi-fold activities within a family according to seasons, we did this random selection within the general population without stratification, Elmqvist and Olsson, 2006).To make it easier to answer the questionnaires, the survey remained anonymous. Each national ministry of environmental affairs in the five countries authorised these survey campaigns. In each village, the research team met the chief, sultan and all local authorities to presentthe objectives of the survey and obtain their authorization. The names of the villages were also anonymised to avoid any conflict with any public agency.

2.4. Questionnaire and harvest intensity proxy estimate

Data collection was based on a standardised questionnaire. The survey mixed a qualitative and quantitative approach and was split into two main parts: the characteristics of actors and their hunting practices/ trapping and the harvesting level. The first part contained a set of basic sociodemographic, socioeconomic, dietary and cognitive questions. Questions on food habits and representations of waterbirds were used as a means to obtain information on waterfowl use. If the respondents mentioned waterbirds in their diet list or if his social representation of waterbirds was food or income, we questioned the origin of the game meat, and if it was from its own harvesting, we used the second part of the questionnaire related to off-take per species. This part included the following questions (per species): harvested species name, harvested reason, species choice reason, harvesting period, moment of the day, harvesting frequency, quantity harvested per session, and harvest techniques. We extrapolated this off-take information over a year through the average session frequency per unit of time and then adjusted it to the duration of the practice in the year. So, these memory-based estimates are an approximation of what is taken in the year 2017 ±1 year. Also, in the question relative to hunting production activity, we ask them if they perceive an increasing or decreasing of harvesting for the last ten years. Despite a legal national framework for hunting in all countries, waterbird harvesting through hunting or trapping remains an informal and illicit activity for many people, whether for commercial purposes or for family consumption. Because we asked questions about activities that may have been illegal that could lead to fear, suspicionand incrimination, the interviews mixed direct and indirect questions (Whytock et al., 2018) and used triangulation (e.g., questions about social representation of waterbirds and household food habits). Old and recent literature has listed other sources of bias, such as memory bias or prestige bias (Atwood 1956 in Vernon, 1978), the rounding up of the respondent estimation of his seasonal bag (approximately 5%), or a nonresponse bias due to a null harvest that drives the potential hunter to not answer (Aubry and Guillemain, 2019). For all these reasons (representativeness, memory bias and nonresponse), for this exploratory study, we aimed to estimate a proxy of harvest intensity relative to our sample size and not a spatially extrapolable and exhaustive estimate of the overall harvesting at the regional scale. This proxy allowed us tomake relative intersite comparisons in obtaining information on the species mainly harvested, the relative intensity of harvesting composed by the quantity, frequency and duration of harvesting. Because these wetlands provide habitats for Palearctic and Afrotropical waterbirds, a conservation approach must focus on both (Green 1996 in Williamson et al., 2013), and our survey integrated both. The questionnaire was designed according to a collaborative and iterative process where project members drafted, reviewed and tested the final questionnaire.

2.5. Data collection, processing and analysis

In each country, a national consultant was recruited to finalize the adaptation of the questionnaire to the local context (multiple choice items, lexicon and translation in local languages). Then, the first author trained a team of interviewers in the same way in all the sites to preserve the homogeneity and consistency of the study over the entire Sahelo- Saharan strip (objective and interest of the questions, translation of questions and key words, way of interviewing, method used to deter- mine the quantities of birds used, etc.). The teams were mainly composed of alumni from social sciences and natural sciences. Experienced officers from the national administration partners were also selected to complete the teams.

The collection protocol was based on the use of the KoBoCollect smartphone application (https://www.kobotoolbox.org/). A specific one-week training was organized for interviewers, aiming to present the key topics and to describe and adapt the questionnaire to the local context. A test phase was organized, giving rise to a second version that was retested before validation and its field deployment. In addition tothe digital questionnaire downloaded on the smartphone, they used a notebook for specific quotations. They corrected and completed all forms before sending them on the KoBoToolBox web platform where the data could be downloaded. A final cleaning was performed using the free software RStudio, and correspondence tables were used to record the raw data.

To estimate bird harvesting at each site, an elementary method was developed according to the context of the study. The quantities per species and session estimated by the interviewees were multiplied by the frequency of sessions according to the unit of this frequency (day, week, month, year) and reported to the duration of harvesting time (annual or specific seasons) to adjust the different annual harvesting levels. This method allowed us to obtain a harvesting intensity proxy by species but also per individual involved in this practice at different scales, i.e., intra-site and inter-site scales.

To ensure the accuracy of the bird name quoted, we systematically used the images of the West African WB ornithological guide (Girard, 2003) with the respondents. We also elaborated a nomenclature of all local names in the different languages (French, English, Arabic). Finally, tests for normal distribution and homogeneity of variances of raw and transformed data indicated a need to use nonparametric tests (Siegel and Castellan, 1988). Harvest levels were statistically compared between places using chi-square tests or Kruskal-Wallis tests (R core team, 2018).

3. Results

We present the global harvest intensity estimated, the harvesting intensity proxy estimated per species and wetland, and the main features of hunting practices.

3.1. Global waterbird harvest intensity estimates

Hunting bags were very different according to each site (Appendix A.3). The harvests could be nearly marginal (SRD, KAH) to thousands of off-take (IND, LF, LC). The estimated annual total of harvested waterbirds in our sample was c.185,000 individuals. The wetlands with the most important hunting harvests were LB and LM in Egypt, with c.73,000 and c.47,500 individuals, respectively, followed by IND with c.29,000 individuals and LF with c.23,500 individuals. In the SDR, only two people out of 296 answered our questionnaire. Food hunting is almost non-existent in this area, excluding the occurrence of sporadic harvesting. Hunting concerned more tourists and commercial huntingunits.

In terms of harvesting pressure (Table 3), there was also a difference between sites: those with a high level of harvesting and a low number of respondents (IND, LM, LF), those with a high level of harvesting and a high number of practitioners (LB), and wetlands with a low level of harvesting and a low number of respondents (LC, KAH). In terms of number, the highest level of respondents for hunting questions was from the ND with 53% of the sample in LB and 15% for LM, followed by LCB with 16% for LC and 13% for LF and finally 4.4% for IND and KAH with very different harvesting rates.

3.2. Main harvested waterbird families and species

Forty-three bird species were declared harvested (Appendix B). LB presented the highest diversity of birds (22), followed by LM (18), LC (11), LF and IND (10), and KAH (7). Rallidae (3 species, 45.1% of thetotal harvest bag, mostly common moorhen) and Anatidae were the most harvested families (16 species, 39.3%, mostly garganey, *Anas querquedula*), followed by Phalacrocoracidae (2 species, 4.9%, cormo- rant sp.), Ardeidae (6 species, 4.1%, cattle egret, *Bubulcus ibis*) and Scolopacidae (3.9%, godwit) (Table 1). Species from the family Pho- nenicopteridae (0.01%, greater flamingo, *Phoenicopterus roseus*) were marginally harvested. As expected, there was specificity between sites. Rallidae represented c.75% and c.50% of the off-take in LB and LM, respectively, while Anatidae accounted for over 90% of the off-take in LC and LF and was the main harvested family in the IND and KAH.

Table 2 shows that most of the harvested species were of low biodiversity conservation concern according to IUCN status (90%). There was one Afrotropical "vulnerable" species in the KAH (African woollyneck, *Ciconia episcopus*) and one in LC and LF (black crowned crane, *Balearica pavonina*); additionally, there was one Palearctic species in LB and LM (common pochard, *Aythya ferina*). The black tailed godwit (*Limosa limosa*) in the IND was the only "near threatened" species of global off-take. Moreover, 34% of the harvested species populations were estimated to be "increasing" and 29% were "decreasing" (accord- ing to the IUCN red list). It was in the IND where a large part of the off-take (more than 80%) was from a decreasing population, in contrast to LC and LF where 80% to 85% of the populations are increasing. For LB and LM, the distribution of the harvested population trend was more variable, with nearly 50% stability in LB and 36.6% increasing in LM.

Palearctic species represent c.40% of the total harvested quantity

Table 1
Percentage per site of waterbirds harvested per family (quantity of individuals).

Family	Inner Niger Delta	Lake Chad	Lake Fitri	Khor Abu Habil	Lake Burullus 2019	Lake Manzala
Anatidae	42,1	91,8	95,9	69,2	17,7	30,9
Anhingidae	9,0	0,2	0,0	0,0	0,0	0,0
Ardeidae	9,2	1,7	0,0	0,0	6,2	0,5
Ciconidae	0,0	0,0	1,6	18,8	0,0	6,1
Gruidae	0,0	3,7	0,1	0,0	0,0	0,0
Pelecanidae	0,0	0,6	0,0	0,0	0,0	0,5
Phalacrocoracidae	14,0	2,0	0,0	0,0	0,1	9,9
Phoenicopteridae	0,0	0,0	0,0	0,0	0,0	0,0
Podicipedidae	0,0	0,0	0,0	0,0	0,0	4,0
Pteroclidae	0,0	0,0	0,0	6,1	0,0	0,0
Rallidae	0,1	0,0	2,4	0,0	75,3	47,7
Scolopacidae	25,2	0,0	0,0	0,0	0,0	0,0
Threskiornithidae	0,4	0,0	0,0	5,9	0,7	0,3

Table 2

Proportion of species and birds harvested according the IUCN status and population trend estimation and the proportion of migratory waterbirds.

Status	Description	n species	%	IND n	IND %	LC n	LC %	LF n	LF %	KAH n	KAH %	LB n	LB %	LM n	LM %	TOTAL n	TOTAL %
LC	Low concern	39	90,7	18.751	65,2	8.526	87,7	23.318	99,0	1.762	89,1	69.180	94,9	45.912	96,6	167.449	**90,8**
VU (P)	Vulnerable (Palearctic)	1	2,3									3.735	5,1	1.632	3,4	5.367	2,9
VU (A)	Vulnerable (Afrotropical)	2	4,7			361	3,7	12	0,1	190	9,6					563	0,3
NT	Near threatened (M)	1	2,3	7.264	25,2											7.264	3,9
Decreasing		19	44,2	23.440	**81,5**	656	6,7	3.820	16,2	190	9,6	10.470	14,4	14.718	31,0	53.294	28,9
Increasing		13	30,2	2.425	8,4	8.231	**84,7**	18.934	**80,4**	1.438	**72,7**	14.478	19,9	17.418	**36,6**	62.924	**34,1**
Stable		5	11,6	150	0,5			576	2,4	324	16,4	35.463	**48,6**	9.942	20,9	46.455	25,2
Unknown		6	14,0									12.504	17,1	5.466	11,5	17.970	9,7
Percentage of palearctic species cited					15,4		14,3		9,1		25,0		77,3		55,6		
Percentage of palearctic individuals harvested (intra-site)					59,9		1,8		0,8		9,6		41,8		54,9		
Percentage on the total of palearctic WB harvested (inter-site)					23,2		0,2		0,3		0,3		41,0		35,1		

(inter-site). We observed a clear distinction between sites according to Palearctic and Afrotropical proportions (Table 2). LB and LM showed the highest proportions of Palearctic waterbirds in the species choice (more than 50%). The IND presented the same proportion as LC, was less than the KAH with 25% of the species choice, and the Malian site had the highest proportion of Palearctic individuals harvested intra-site (60%), followed by LM (55%) and LB (42%). However, more than 75% of the total Palearctic waterbirds were harvested in LB and LM and 23% were harvested in the IND. In contrast, the LC, LF and KAH off-takes targeted more Afrotropical species (between 90 and 100%).

The main harvested species are common moorhen (*Gallinula chloropus*) (24%), common coot (*Fulica atra*) (12%), garganey (10%), white-faced whistling duck (*Dendrocygna viduata*) (9%) and spur-winged goose (*Plectropterus gambiensis*) (7%) (Appendix C.1). There were also specific hunted species based on sites. More than 90% of the total harvestedwhite-faced whistling ducks (i.e., a total of c.14,600 birds) and spur- winged geese (i.e., c.12,200 birds) were hunted in Lake Chad and Lake Fitri. Almost all vulnerable black crowned cranes (i.e., 376 ind.)were harvested at LC and LF. In IND, the main hunted species were Palearctic, e.g., garganay with 9972 individuals (96% of the total har- vested Garganeys), followed by black-tailed godwit (7264 ind., 99%), sedentary African darter (2580 ind., 99%) and western cattle egret (2280 ind., 83%). In Egypt, LB and LM hunted most of the Palearctic ducks, e.g., 45.5% of the total harvested garganeys, 100% of the 5574 northern pintails, 5367 of the common pochards, 3540 of the northern shovelers (*Spatula clypeata*) and 2208 of the mallards (*Anas platyrhyn- chos*). LB and LM harvested 93% of the total harvested Rallidae (i.e., 54,935 birds and 22,689 birds, respectively). Common moorhen was mainly harvested at LB (78%, 35,324 ind.) and LM (21%, 45,027 ind.) like common coots and purple swamphen. LB harvested 60% of the hunted Ardeidae of the region, e.g., 100% of the 2454 squacco herons (*Ardeola ralloides*) and 1821 of the grey herons (*Ardea cinerea*), while LM harvested 77% of the hunted Ciconidae, e.g., 91% of the 3154 white storks; and 52% of the total harvested Phalacrocoracidae of the region (e.g., 98% of the 4788 great cormorants (*Phalacrocorax carbo*)). Most of the spoonbills were harvested in Egypt (72%, 600 ind.). In KAH, the main harvested species were white-faced whistling ducks (1016 ind.), Ciconidae (all 190 harvested African woollynecks and 112 African openbills (*Anastomus lamelligerus*)), 352 spur-winged geese and 117 spoonbills.

3.3. Hunting and trapping characteristics

The techniques used for hunting were very diverse according to the sites and species (Table 3). The number varied between 3 (KAH) and 9 (LM). The main technique used was trapping, particularly in KAH, LM and LC. Exceptions were for the IND with nets and the LF with hooks, even if traps were the second technique cited. Call device was only usedin Egypt as poison in LF. Trapping was the technique used for a large

Table 3

Percentage of techniques used by sites.

	Inner Niger Delta	Lake Chad	Lake Fitri	Khor Abu Habil	Lake Burullus	Lake Manzala
Net	38,6	18,6	15,3	1,7	4,5	1,4
Shotgun	18,1	22,2	0,5	5,1	34,8	3,9
Hook	2,3	20,4	25,4		10,9	11,2
Trap	20,5	25,7	16,3	93,1	10,1	28,9
Slingshot	4,5	5,3	5,3			0,6
Call device					3,9	15,1
Poison			0,5			
Torch and stick	6,8		16,3		3,6	14,2
Hand/ Moult	6,8	2,7	9,6			2,6
Mansaab					12,7	2,1

number of species, between 4 (IND) and 15 (LM). Poison in LF seemed to be the main technique due to the use of traditional rifles. Except forKAH, people used a variety of techniques per species even if some allowed them a higher harvested quantity according to the species, such as trapping for the spur-winged goose and rifle for the white-faced whistling duck in LC. In LF, hooks were the technique with the highest level of harvesting for these two species. The highest level of individual harvest resulted from the use of nets for harvesting black-tailed godwits, cormorants and garganays in the IND (20), nets and rifles for white≥- faced whistling ducks in LC (20), nets for white-faced whis≤tling ducks in KAH (25) and hooks for moorhens in LM≥ (8). ≤

Most of the time, hunting occurred during the daylight for Sahelian wetlands in the IND (50%), LC (74.8%), LF (60%), and KAH (80%) but largely at night in Egypt, LB (80%) and LM (66%). The hunting season was different according to the sites and species, particularly between the IND and LC and LF. In the IND, black-tailed godwit was hunted mainly during December, January and February, the wintering season. Usually, no hunting occurred during the lowest levels of the Niger River (from March to July), except for the harvest of spur-winged geese. In LC, the hunting of the white-faced whistling ducks occurred during this periodof low water levels. In LF, the nonhunting season extends from August to October for the spur-winged and fulvous ducks. However, during the low-water season, July was a key hunting period for both Chadian lakes. Concerning the KAH, the only period mentioned for hunting was from April to August, and high rainfall may increase the hunting period as well as the cropping and harvesting period for the main agricultural productions, such as sesam, sorghum, peanut, and bean (October,November). Finally, in Egypt, the main hunting season for all specieswas from September to October for the two lagoons, even if huntingoccurred year-round.

According to the answers, hunting was driven first by the necessity of food at all sites (>70%). The marketing dimension followed this motivation (ranging between 28% in LC to 53% in the IND). Per species, we obtained the same tendencies with more details for 3 sites (IND, LC and LF). For the IND, the main reason for species choice was the low cost of the main harvested species (garganey, black-tailed godwit and cormorant). Garganay was also defined as “nutritive”. These last two charac- teristics seem to stimulate the “demand” that can drive harvesting. In LC, “demand” also seemed to be a strong driver for harvesting, particularly for the two main species used, spur-winged goose and white-faced whistling duck. Interviewees mainly underlined that nutritive and taste were the reasons for this demand. Moreover, symbolic andaesthetic dimensions must be considered. For instance, the black crowned crane is trapped and breeds as an ornamental waterbird that brings happiness to people. Finally, in LF, despite the higher diversity of answers, accessibility and availability were largely mentioned as facilitating hunting activity.

The majority of the interviewees practiced agriculture and fishing, generally self-consuming and marginally selling killed birds. In the vast wetland areas of the sites in Mali and Sudan, probably due to low human densities and infrastructure availability, self-consumption prevailed. Wild meat constituted more than 20% of the meat consumption of interviewees in the IND but also in LC and LF. Nevertheless, approximately 20% of the people who hunted were exclusively commercial hunters.

4. Discussion and future directions

This work was the result of a major empirical survey and is unprecedented in terms of its geographical scope and means used to collect the information. Below, we first discuss the methodological limitations, the waterbird harvest assessment results, and the main practices in use; additionally, we focus on North-South harvesting-level comparisons before ending with a set of recommendations.

First, from a methodological point of view, it is important to high- light three limits. The first is based on the fact that hunting is often an informal and illegal activity that remains difficult to explore and understand (Mathevet and Mesléard, 2002; Nuno et al., 2013). Information based on self-reported data is therefore difficult to collect and cross-check. Moreover, Jihadism in the Sahel and political tensions hamper scientific monitoring and biodiversity conservation. This socio- political situation hinders the knowledge of harvesting and consumption chains in many regions important for waterbirds. Second, many pa- rameters could not be considered because either the relative data do not exist or they are not sufficiently reliable, updated or available (human demography and village census, ratio of hunters or gatherers, population dynamics of palearctic and Afrotropical species, period of presence onthe study sites). Despite these limitations, we designed a basic method adapted to each site but standardised at the regional level to produce the targeted information and to be able to make comparisons. As we aredealing with an estimated average, we assume that what has been estimated at time *t* is extrapolable and adjustable to the duration of the activity in the year, as detailed by the interviewee of each site. However, as we investigated in the main wintering wetlands with high concen-trations of waterbirds, we cannot robustly extrapolate in space (i.e., at each country level). These biases make any North-South comparison along the flyway difficult. We are therefore talking about the currentsituation for a given sample without being able to reflect any trend for the moment. We were starting from almost zero, particularly for four sites (DFS, LT, LF and KAH) for which we had no basic data. Our results now make it possible to set up and coordinate appropriate monitoring with a more precise view of the dynamics of harvesting for each site and for the whole Sahelo-Saharan Region. The third limitation relies on the choice of a standardised questionnaire approach; it tends to erase the details of the social and cultural practices and relationships that could be determining drivers in consumption patterns and choices. Such quantitative surveys should be systematically combined with qualitative socio-ethnological surveys.

Regarding the recognition of WBs by the respondents, the results show a consistency that validates the identification of species (we remove some obvious mistakes from the analysis). The only bias thatmay remain is that respondents could only cited the main species they remembered. It is likely that they forget some species. This is a usual problem for this type of exercise as Guillemain et al. (2016) have faced during their survey for the 2013–2014 hunting season in France based on a memory-based questionnaire. Overall, we observed that the respondents had their own knowledge of WBs, and that this knowledge is not hierarchical in relation to other knowledge of different natures. Of course, an ethno-linguistic study would allow us to learn more about the local classification and categorization of species (Garine et al., 2013) and to characterise local ornithological knowledge (LOK). For instance, in Lake Fitri, three Palaearctic species were grouped together under the same name “Norgorno”, but this did not affect the results, since it islargely the Afro-tropical species that are collected there and distinctly named. Aiming to assess if the respondents deliberately avoided naming protected species, we also questioned the legal knowledge of the interviewees. The main outcome is that the rules of positive law are notwell known on the ground. Moreover, our results are consistent with the limited existing data. Finally, because of the organization of the questionnaire, the explanations and the attitude of the interviewers, few people were afraid to answer. Those who were afraid to talk were not forced to answer to the questionnaire and were not included in (which does not affect the percentage of respondents to the questions on collection practice, or prevalence).

Second, we observe great diversity in the levels of harvest and hunting pressure between sites. Our results are in line with those from the existing literature for Egypt and Mali (Mullié and Meininger, 1983; Kone et al., 2007; Wymenga, 2003) but are new for Chad and Sudan. If some mean harvesting estimate per individual (and their standard deviation) seems too overestimated, particularly in the IND, LF and LM, we must remember that we are addressing year-round hunting activity more or less focused on food and commercial needs. However, they do not consider the off-take from existing commercial hunting units for foreign tourists, which may constitute the bulk of the hunting harvest in Senegal (Degez et al., 2018) with c. 7000 waterbirds and in Egypt but without a specific study (BirdLife International, 2006).

Concerning the main species collected, our results are in line with pre-existing studies (Elhalawani, 2015; Goodman and Meininger, 1989; Meininger and Mullié, 1981; Mullié and Meininger, 1983; Kone et al., 2007; Wymenga, 2003). We can highlight that Palearctic species represent more than 55% - or 42% depending on the site – of the hunted species in the ND and 60% of those in the IND. Seventy-six percent of the total harvest of Palearctic waterbirds is carried out only in the ND and 23% is in the IND, underlining the importance of these two sites for these migrants. Several lessons can be drawn from these results: (1) the existence of two migratory flyways along which people take the available species (Kirby et al., 2008) is well observed. Thus, in the central zone (Chad and Sudan), mainly Afrotropical Anatidae are taken, whose populations are increasing, while in the eastern migratory axis (in Egypt) mainly Palearctic Anatidae are hunted, whose populations are decreasing; (2) Egyptian sites are thus the main places for the hunting of Palearctic ducks, in particular garganeys, common teals and pochards, northern pintails and shovelers; (3) the IND is also the main site for the taking of two important Palearctic species: garganey and black-tailed godwit; (4) the Chad and Sudan sites mainly harvest Afrotropical (resident or short migrants) species whose populations are increasing; (5) 90% of the harvested species have a "Least Concern Conservation" status according to the IUCN. A set of recommendations could therefore be proposed. In general, the 19 harvested species whose populations were declining and the 6 species whose trends were not clearly identified could be specifically monitored in the main wintering wetlands. More specifically, awareness-raising campaigns could be combined with more detailed studies of both garganey and black-tailed godwit hunting at the IND to rapidly restore a more favourable conservation status. Similarly, efforts should be made to assess, reduce or stop the taking of species classified as vulnerable by the IUCN, such as the black-crowned crane in Chad, the African wollyneck in Sudan, and the common pochard, northern pintail and shoveler in Egypt, whose population sizes are declining.

Third, according to Petrozzi (2018), bird taxa do not represent an important proportion of the bushmeat in general in Africa and our results are in line with this statement. There are very few if any studies of terrestrial or water bird hunting in general in the Sahel. Guinea fowls and quails are the main terrestrial species harvested (pers. obs.). In the context of wetlands, the main taken or exposed species are anatidae and rallidae. As everywhere, availability, capturability, accessibility, nutritional and gustatory qualities may contribute to local hunting pressure on land and waterbirds. This "hunting" practice seems to be determined by many factors. Our results show situations shifting between two use systems: (*i*) an opportunistic use of a variable natural resource (Palearctic or Afrotropical) according to climatic, hydrological and economic drivers to answer in a complementary or substitutional manner to food needs; (*ii*) an organized and specialized hunting system supplying markets and the function of a demand. Overall, the summary study of the drivers is to be developed, but we can already emphasize that the main reason for harvesting is self-consumption, even though sales are very widespread. The choice of species is explained by a compromise among abundance, catchability, weight and food interest. In general, in line with the FAO studies,[3] the interviewed people would consume wild duck because there would not be enough meat, such as chicken, from domestic breeding on the local market in the Sahel region or because it is considered too expensive. Furthermore, bird catches with fishing nets are easy opportunities to obtain wild bird meat in addition to fish. Defining the cultural, sociodemographic and economic drivers of these practices by multivariate analysis is the next step of our study. The challenge could be to identify common patterns in a multisite study across the Sahel-Saharan region and its multicultural, economic and legal contexts.

Fourth, not only it is difficult to obtain good estimates of Palearctic and Afrotropical population size and trends in the North and South, but it is more difficult to obtain unbiased and precise estimates on hunting pressure through the total amount of harvest numbers in Europe (Johnson et al., 2018; Guillemain et al., 2016; Hirschfeld et al., 2019; Mathevet and Mesléard, 2002) and the number of people involved (Hirschfeld et al., 2019) (Appendix C.2). Thus, obtaining robust data in southern countries, especially in the Sahel, remains challenging, as we have experienced in this work. We are confronted to the problem of spatial extrapolation, especially for important sites such as IND, LF, LB and LM as described above. Determining the sustainability of harvesting was one of our initial objectives using the Maximum Population Growth Rate method (Lormée et al., 2020; Niel and Lebreton, 2005), which is well suited for data-poor contexts. This is one of the limitations of our study and certainly an unattainable goal in such study area. Therefore, a long-term participatory monitoring of harvesting should follow our exploratory study. The first phase of participatory management can thus be the determination of the size of the resource withdrawn by involving local and national actors in order to dispel any fear of repression or punishment. Numerous methods exist today, such as the Management- Oriented Monitoring System or MOMS method (Mbaiwa, 2015). This would allow us to estimate local removals more comprehensively and realistically, to identify trends and to evaluate the harvesting sustain- ability. Our study shows the limits of an initiative involving only "exogenous" experts who have no control over the dynamics of local resource use.

Nevertheless, we can observe that the Palearctic species targeted in Europe are not the same as those in the SSWW (appendix C.2): if the Europeans seem to hunt more mallard and common teal, with increasing or stable population, it is the garganey, with a decreasing population, that is mainly caught exclusively in the IND, LB and LM. In addition, although it is difficult to define for each species the precise reason for its population decline, hunting pressure along migration flyways and on breeding and wintering sites is the second most important threat after habitat change (Kirby et al., 2008). Almost half of the populations of huntable species in Europe are in decline (Madsen et al., 2015) as well as in our study areas. Indeed, 45% of species harvested in SSWW have populations estimated by the IUCN to be in decline, while the trend is reversed in terms of numbers of individuals harvested per species. In addition, more than half of the Palearctic species caught in the surveyed SSWW belong to populations estimated to be declining (almost entirely caught in IND and ND), while almost three quarters of the Afrotropical species caught belong to stable or increasing populations (mainly in LCB). So, should conservation efforts be concentrated in Europe, where Palaearctic birds breed, or in the SSWW or along the entire flyway? Should efforts be concentrated on habitat conservation or hunting regulation?

Due to the variability of inter- and intra-site contexts and variables influencing the practice, it is difficult to extrapolate our estimate to the whole population. However, it seems difficult to imagine that there could be as many hunters in Sahelian areas as in Europe. From these points, our first outcomes lead us to think that the hunting harvest level in the South appears low compared to the Afrotropical and Palearctic waterbird populations of the main targeted species, at least not more than the North off-takes. Therefore, before imposing or building any new constraints on the use of waterbirds on local human populations that are vulnerable in terms of health and economics in difficult environments, it is advisable to reflect on the recreative hunting practices of European countries (including Russia, a country that has not ratified the AEWA and hosts a large proportion of Palaearctic breeding birds). Of course, quantifying hunting sustainability is complex and challenging (Boere et al., 2006; Brochet et al., 2016; Lormée et al., 2020), and this work does not assess all parts of this topic. Because waterbirds are obviously an important source of protein for locals, we should avoid

[3] http://www.fao.org/3/ak771f/ak771f00.pdf.

basic assessment of hunting sustainability, as any overly conservative rules may rapidly impact the livelihoods and wellbeing of local resource users. However, we should also avoid any overexploitation in the context of both human demography and social inequitable growth. To meet the objectives of the AEWA, we need to address the issue of environmental justice in terms of recognition, access and sharing of a borderless resource. This creates a link notably by responding in the North to the mainly recreational needs of a formal hunt, mainly using guns, and in the South to the needs of food and/or economic subsistence through an informal if not illegal hunt, mainly using nets and traps.

Finally, we recommend a set of future studies to build a more robust picture of the situation in each key wetland. It is crucial to better characterise the practices, revenues and off-take of private hunting in Chad and Egypt. It is also important to locally assess food hunting in relation to the regulation of species that can cause crop damage, especially in rice fields, as identified in Senegal (Elphick, 2010). In the context of the AEWA, a participatory science mechanism could be implemented for each site to (1) better understand the local stake- holders' interplay and characterise the economic sectors based on wa- terbirds and (2) better measure the level of harvesting with a participatory monitoring mechanism. It would also be interesting to study local ornithological knowledge and assess the level of species recognition error and (3) better integrate hunting activity and wetlands into land-use planning policies. Such an approach would make itpossible to foresee the development of adaptive management of exploited populations in Europe and Africa as recommended by the AEWA (Boere et al., 2006) and fair management leading to wise use of wetlands in general, in line with the recommendations of the Ramsar Convention.

5. Conclusion

Overall, our main results suggest that the migration from the Palearctic to the Sahelo-Saharan wintering wetlands is probably not a flyway to hell. The answer to our open question is much more nuanced. Our results show that waterbird harvesting is widespread and occurs at high levels in Egypt and Mali. The results also reveal that most of the harvested species are not Palearctic or that they involve stable or increasing populations of species of less concern to the IUCN. This work also shows the importance of waterbirds for the livelihood and wellbeing of some local people. From that perspective, some species, such as garganey, black-tailed godwit, black-crowned crane and common pochard, appear to be potentially impacted by local hunting, although this result remains to be studied in detail. It remains important and urgent to quantify hunting sustainability to further assess the conservation status of the species and populations affected as well as the contribution of the African hunting harvest and its socioeconomic, cognitive and cultural drivers. Biodiversity and livelihood are threatened by current harvesting trends mainly in Egypt but also in Europe. It is necessary to implement participatory monitoring programs for the hunting levels and numbers of species and populations in each of the studied sites to foster the development of genuine adaptive and wise management at the scale of the sites and of all the countries concerned by the migratory routes. We believe that this paper will be a step toward a stewardship approach based on greater international collaboration to meet the numerous challenges of conservation at a flyway level (Johnson et al., 2018; Mathevet et al., 2018).

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