Potential title: A national assessment of waterbird hunting in coastal wetlands of Suriname, south America

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Abstract

Introduction: The central northern coast of South America has extensive wetlands critical for waterbird conservation. While waterbird harvest occurs in the region, the impact on species population dynamics remains unclear. This study assesses waterbird hunting in the coastal wetlands of Suriname, addressing: (i) the extent of waterbird harvest, (ii) changes in harvest magnitude over time, and (iii) the motivations and methods of hunters.

Methods: We collected data via a national survey of licensed hunters in 2006 and 2016 using structured interviews. A Bayesian hierarchical model was used to analyze the data.

Results: We estimated harvest levels for 11 species and three groups (small herons, small shorebirds, large shorebirds). For most species, mean harvest per hunter significantly decreased from 2006 to 2016, except for blue-winged teal and migratory shorebirds. Most hunting was for non-commercial purposes (personal consumption and recreational).

Discussion: This is the first national assessment of waterbird hunting in Suriname. Harvest levels vary by species, and the sustainability of these levels remains uncertain. Managing hunting in Suriname requires addressing both legal and illegal hunting. Given Suriname's importance for waterbirds, particularly species like the scarlet ibis and migratory shorebirds, it should be a priority for conservation efforts.

Keywords: harvest management, scarlet ibis, shorebirds, Western Atlantic Flyway, western hemisphere, wildlife management

1. Introduction

Wetlands are biologically productive ecosystems that have sustained humans globally. The use of wetlands has included the harvesting of plants and animals, such as fish and waterbirds, with multiple purposes (e.g., cultural, subsistence, recreational, commercial). However, following increased pressure on the environment during the second phase of the Anthropocene (i.e., the Great Acceleration), the exploitation of some species may have contributed to population declines, and in some cases, extinction (Steffen et al. 2011; Benitez-Lopez et al. 2017; Cornford et al. 2023). Additionally, for long-distance migratory species, such as birds, harvest at specific locales can be compounded over large spatial scales and become unsustainable (e.g., Gallo-Cajiao et al. 2020). Hence, evaluating the magnitude of harvest, corresponding population-level impacts, and human dimensions of wetland-dependent species is crucial for informing conservation policy and action. There is a strong need to assess waterbirds harvest in the tropics, where people's livelihoods often rely on natural resources, governance capacity for their management may be weak, and research is relatively limited (Amano et al. 2018; Brotherton et al. 2020).

The central northern coast of South America has extensive wetlands crucial for waterbird species conservation (Butler et al. 2001; Murray et al. 2019). These ecosystems comprise mangrove forests, brackish lagoons, freshwater swamps, and the most extensive mudflats of South America that have been formed by sediments from the Amazon River, a flat coastline, and the Guiana Current. Noteworthy, this region has a low human footprint with little intertidal wetland losses (Murray et al. 2022), so threats associated with land use change are generally not prevalent (Allan et al. 2023). These coastal wetlands serve as important non-breeding and stopover areas for migratory shorebirds (e.g., *Scolopacidae, Charadriidae*) along the Western Atlantic Flyway. Additionally, over 100 species of waterbirds, many of which are non-migratory, occur in these coastal wetlands, including ducks (*Anatidae*), flamingoes (*Phoenicopteridae*), and herons (*Ardeidae*). Along the central northern coast of South America, Suriname has the largest concentration of some waterbird species (Spaans 1978; Morrison & Ross 1989) including scarlet ibis (*Eudocimus ruber*), semipalmated sandpiper (*Calidris pusilla*), greater yellowlegs *(Tringa melanoleuca*), lesser yellowlegs (*Tringa flavipes*), and short-billed dowitcher (*Limnodromus griseus*). The importance of this region has been recognized through the designation of Important Bird Areas by BirdLife

International, Ramsar wetlands of international importance, and sites of hemispheric importance under the Western Hemisphere Shorebird Reserve Network.

Waterbird population trajectories in this region are generally unknown with some exceptions. For instance, the central northern coast of South America is not surveyed as part of the International Waterbird Census, hindering long-term monitoring of populations. This data gap has also impeded assessments of protected area effectiveness, which is essential for management (Wauchope et al. 2022). However, some species are declining across their entire range, such as the scarlet ibis, wood stork (*Mycteria americana*), and white-cheeked pintail (*Anas bahamensis*; BirdLife International 2025). Similarly, several migratory shorebirds species (e.g., semipalmated sandpiper, lesser yellowlegs, and short-billed dowitcher) have shown a significant decline of over three decades along the central northern coast of South America (Morrison et al. 2012), consistent with overall declines observed in North America (Smith et al. 2023).

Harvest, whether for commercial, recreational or subsistence purposes, can significantly contribute to mortality and influence population dynamics of some waterbird species. Harvest assessments can play a crucial role in the development of sustainable harvest management frameworks and to inform conservation objectives (Watts et al. 2015; Koneff et al. 2017; Cox et al. 2024) but to date, there is no ongoing systematic monitoring of waterbird harvest in central northern South America. These concerns are especially important for shorebirds, as they typically have slow life history traits, such as small clutch sizes and only one breeding attempt per season, making them highly vulnerable to high harvest levels or even to seemingly low harvest levels when populations are declining (Watts et al. 2015). For migratory bird species, harvest assessments must also occur in multiple countries to allow for data aggregation across these species' full life-cycle. Recent studies from Guyana (Andres et al. 2022), French Guiana (Taylor 2017), and Brazil (Bosi de Almeida et al. 2018) show widespread shorebird hunting in the central northern coast of South America and along the Western Atlantic Flyway in parts of the Lesser Antilles (Watts & Turrin 2016; Gebauer 2018; Reed et al. 2018). In the United States and Canada, the extent of hunting remains unclear, as part of illegal harvest during recreational hunting (Katzner et al. 2020) and subsistence hunting (but see Naves et al. 2019).

In addition to evaluating harvest from an ecological standpoint, understanding the human dimensions of hunting is crucial for informing conservation policy. These dimensions include parameters such as demographics of resource users (e.g., age, gender, income), hunting's

contribution to livelihoods, and attitudes toward hunting and regulations (Vaske & Manfredo 2012; Eriksson et al. 2023). For instance, hunting of migratory shorebirds in Southeast Asia can make a considerable contribution to household income (Zöckler et al. 2010; Gallo-Cajiao et al. 2020). In Guyana, shorebird hunters are typically fishermen supplementing their income when fishing conditions are poor (Andres et al. 2022). Understanding these parameters in the context of the central northern coast of South America could help inform more effective and equitable harvest management policies.

Here, we present a case study on a national assessment of waterbirds harvested in coastal wetlands of Suriname. Our aim is to contribute to the evaluation of the sustainability of harvest for waterbird species in Suriname within the context of central northern South America and the Western Atlantic Flyway. Specifically, we ask: (i) what is the recent extent of waterbird harvest in coastal wetlands of Suriname?; (ii) has magnitude of waterbird harvest changed over time?; and, (iii) what are the motivations of waterbird hunters and, what harvest methods they use? Our assessment, based on surveys of hunters, indicates that harvest of waterbird species is pervasive across coastal wetlands of Suriname, has significantly declined over time except for shorebirds and blue-winged teals, and is primarily practiced for non-commercial purposes with firearms.

2. Methods

2.1 Study area

Suriname, located on the central northern coast of South America, covers 163,800 km² and has a 386 km coastline. It borders the Atlantic Ocean, Guyana, French Guiana, and Brazil. The country has a tropical climate with two dry and two wet seasons. Major rivers include the Courantyne, Coppename, Saramacca, Suriname, Commewijne, and Marowijne Rivers. Most of Suriname's population (87%) lives in the coastal area, where the economy is driven by mining and agriculture. The coastal zone, mostly low and flat, comprises the lower and upper coastal plains, which are key waterbird habitats (Spaans et al. 2018). Wetland ecosystems in the lower coastal plain include mudflats, beaches, estuaries, mangroves, salt pans, coastal marshes, swamp forests, and shallow brackish lagoons. The upper coastal plain includes herbaceous and peat swamps. Our study focused on all coastal districts except Marowijne, where hunting pressure is low and hunters were difficult to reach (Figure 1).

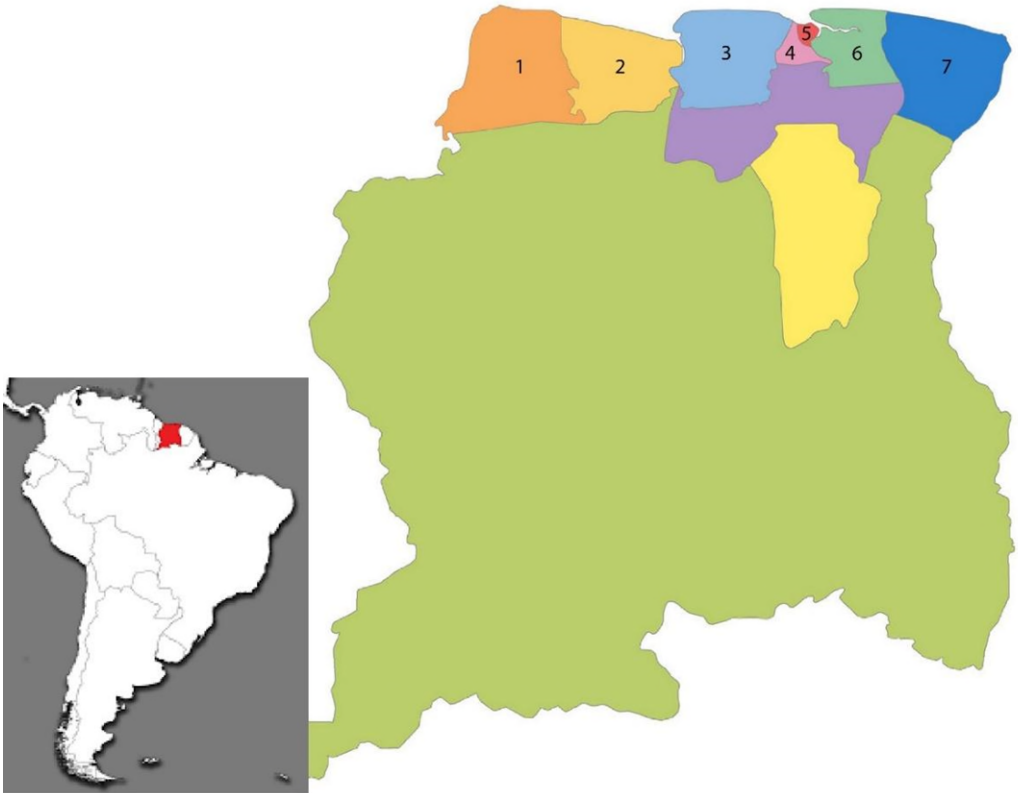

Figure 1: Map of Suriname with district borders, showing coastal districts numbered: 1) Nickerie, 2) Coronie, 3) Saramacca, 4) Wanica, 5) Paramaribo, 6) Commewijne, and 7) Marowijne. Note: the Marowijne district was not surveyed during this study.

The coastal zone of Suriname has various designations under different international institutional frameworks, including one Ramsar site, three hemispherically important sites under the Western Hemisphere Shorebird Reserve Network, and four Important Bird Areas under BirdLife International. Domestically, there are four Multiple-Used Management Areas (MUMAS) and four nature reserves as well (Spaans et al. 2018). Some of these areas have overlapping designations.

The Hunting Act 1954 and the corresponding implementing legislation (i.e. Hunting Decree 2002 as amended in 2009), determine the species of wildlife that may be hunted and when. All bird species occurring in Suriname are fully protected, except those designated as ‘game’, ‘cage birds’, and ‘predominantly harmful species’. Waterbird species without full protection under Suriname regulations and mentioned in this paper are: black-bellied whistling-duck (*Dendrocygna autumnalis*), muscovy duck (*Cairina moschata*), white-cheeked pintail (*Anas bahamensis*), blue-winged teal (*Spatula discors*), Neotropic cormorant (*Nannopterum brasilianum*), and anhinga (*Anhinga anhinga*; Table 1).

Table 1: Species and species groups of waterbirds included in the hunter survey conducted in six districts of Suriname in 2006 and 2016.

Common name	Scientific name
blue-winged teal	*Spatula discors*
white-cheeked pintail	*Anas bahamensis*
black-bellied whistling-duck	*Dendrocygna autumnalis*
muscovy duck	*Cairina moschata*
American flamingo	*Phoenicopterus ruber*
cocoi heron	*Ardea cocoi*
great egret	*Ardea alba*
wood stork	*Mycteria americana*
jabiru	*Jabiru mycteria*
scarlet ibis	*Eudocimus ruber*
roseate spoonbill	*Platalea ajaja*
Small herons (e.g., little blue heron, snowy egret, cattle egret, tricolored heron, black-crowned / yellow-crowned night-herons, boat-billed heron)	*Egretta caerulea, Egretta thula, Bubulcus ibis, Egretta tricolor, Nycticorax nycticorax, Nyctanassa violacea, Cochlearius cochlearius*
Small shorebirds (e.g., semipalmated and least sandpiper, semipalmated plover)	*Calidris pusilla, C. minutilla, Charadrius semipalmatus*
Large shorebirds (e.g., lesser yellowlegs, short-billed dowitcher, willet, whimbrel, black-bellied plover)	*Tringa flavipes, Limnodromus griseus, Tringa semipalmata, Numenius phaeopus, Pluvialis squatarola*

2.2 Study design and data collection

This is a cross-sectional and longitudinal single case study based on surveys conducted at two points in time that are ten years apart. Travel is difficult, particularly on unpaved roads during the rainy season in Suriname, so data were collected in April 2006 and 2016, during what is typically the short dry season, to improve our chances of reaching hunters in their communities. The survey questions in 2006 focused primarily on hunting frequency, magnitude and purpose, and species or group of species of waterbirds harvested (Appendix 1). For some taxa, species reporting was not possible, or at least not accurately, so for these we present data for groups of species which share broad morphological and ecological traits (Table 1). The 2016 survey used all the same questions used in 2006 but included additional questions to improve our understanding of the hunter community (e.g., age, family members, hunting purpose), hunting seasonality, and hunting method (Appendix 2). All surveys were

administered in Dutch, the official language of Suriname. The survey instruments were designed with input from the Suriname Forest Service/Nature Conservation Division.

To recruit survey participants, we used licensed hunter rolls from each district and contacted hunters with current information. The participant pool consisted of those who could be reached and agreed to participate. Due to challenges in contacting hunters, we could not create a stratified sample proportional to the number of hunters in each district. For instance, the Paramaribo District, despite having the largest population of licensed hunters, had the fewest participants (Table 2). Additionally, we were unable to recruit the same number of hunters from each district over the two years or interview any hunters from the 2006 survey in 2016. Surveys were conducted in six districts in 2006 and five districts in 2016, with the highest number of participants from Nickerie, Saramacca, and Commewijne (Table 2).

Table 2: Numbers of hunters interviewed about their harvest of waterbirds per districts in Suriname in 2006 and 2016

District	2006	2016
Nickerie	115	186
Coronie	8	21
Saramacca	100	29
Wanica	3	11
Paramaribo	3	0
Commewijne	47	42
Total	**276**	**289**

Survey respondents self-reported their harvest, a common method for assessing waterbird hunting (Geissler 1990; Smith et al. 2022). However, this approach has potential limitations, including recruitment bias and underreporting of mortality, such as instances of crippling. In 2006, we piloted group surveys with hunters, but found that participants were conferring with each other, making the results unreliable. As a result, we switched to individual one-on-one interviews at hunters' homes, continuing this method in 2016. If interviewers suspected dishonesty, they cross-checked answers with game wardens familiar with the hunters' activities. Data deemed unreliable were excluded from analyses. All data were considered anonymous and confidential, and participation was voluntary.

2.3 Data analysis

2.3.1 Estimation of licensed hunters in 2016

In 2006, there was no centralized database, so the total number of licensed hunters that year is unknown. For 2016, we used the Suriname hunter license database, which tracks only license registrations. According to Suriname law, hunting licenses are valid for up to five years, from January 1st to December 30th. We considered the total number of licensed hunters in 2016 as the unique registrations between January 1, 2011, and December 30, 2016. This method does not account for licenses that may have been suspended before 2016, as the database lacked records on renewals or suspensions, and no corrective measures were applied.

2.3.2 Estimation of hunting levels

We used a Bayesian hierarchical model to analyze the harvest survey data (Appendix 3). We modelled harvest data for 11 waterbirds species and four taxa (small herons, small shorebirds,

large shorebirds, and all shorebirds). Because of the limited number of respondents in each region, we pooled all the data together and assumed that harvest would be similar across all regions. In 2006, survey respondents were asked to provide estimates for all shorebird species combined. In 2016, respondents were asked to distinguish between harvest of large and small shorebird species. Therefore, the survey of small and large shorebirds was set to zero for 2006 and we modeled the harvest of all shorebirds directly. For 2016, we instead modelled the harvest of small and large shorebirds and derived the harvest of all shorebirds from those two categories.

During the interview process, hunters reported the number of birds they harvested that year via 8 categories (either 0; 1; 2 – 10; 11 – 50; 51 – 100; 101 – 500; 501 – 1000; or > 1000 birds). We therefore modeled the reported harvest of each species i by each individual hunter interviewed j via a categorical distribution:

$$Harvest_{i,j} \sim Categorical(\pi_{1:8\,j,t}) \quad (1)$$

where $\pi_{1:8}$ represents the vector of probabilities that the hunter will report their harvest in that category for a given species *j* in year *t*.

We assumed that the underlying distribution of harvest of each species would follow a negative binomial distribution, which allows for over dispersion that we observed in harvest data. We parametrized the negative binomial distribution via the mean and variance (Lindén & Mäntyniemi 2011) and modelled the mean harvest $(\mu_{j,t})$ for a given species *j* in year *t* such as:

$$log(\mu_{j,t}) = \eta_t + \varepsilon_{j,t} \quad (2)$$

$$\varepsilon_{j,t} \sim Normal(0, \sigma_t) \quad (3)$$

where η_t is the average harvest across all species on the log scale and a $\varepsilon_{t,j}$ is species specific derivation from this mean in this given year. The species-specific derivations are drawn from a normal distribution with year specific standard distribution. This hierarchical formulation allowed us to share information across species (i.e. 'borrowing the strength' from the ensemble) but to also consider the change in harvest level across years. We then parametrized the variance $({\sigma^2}_{j,t})$ of the model in function of the mean such as:

$${\sigma^2}_{j,t} = \mu_{j,t} + \theta {\mu_{j,t}}^2 \quad (4)$$

where θ is the overdispersion parameter for the quadratic mean–variance relationship of the classic negative binomial regression (Lindén & Mäntyniemi 2011). We used moment matching to link estimates of the mean and variance to the species-specific and year specific

probability $\left(p_{j,t} = \frac{\mu_{j,t}}{\sigma^2{}_{j,t}}\right)$ and size parameter $\left(r_{j,t} = \frac{\mu_{j,t}{}^2}{(\sigma^2{}_{j,t} - \mu_{j,t})}\right)$ and then linked the probability of the harvest categories with the cumulative probability distribution (CDF; $F(k, p_{j,t}, r_j)$) of the negative binomial distribution. The first category of harvest represents the probability that harvest for a given species each year is exactly zero and can be derived directly from the CDF:

$$\pi_{1_{j,t}} = F(0, p_{j,t}, r_j) \tag{5}$$

The probability of the harvest for categories 2 to 7 can be derived by subtracting the CDF at the lower bound of the category from the CDF at the upper bound of category. For example, for the probability that harvest is between 2 to 10 birds (i.e., Category 3) for a given species in a given year can be estimated via:

$$\pi_{3_{j,t}} = F(10, p_{j,t}, r_j) - F(2, p_{j,t}, r_j) \tag{6}$$

The last harvest category ($\pi_8; > 1000\ birds$) is the probability that the harvest is larger than the lower bound of the category:

$$\pi_{8_{j,t}} = 1 - F(1000, p_{j,t}, r_j) \tag{7}$$

Hunters did not always complete the survey and did not report their harvest for all the species. In those cases, we used a data augmentation scheme and let the model assign a harvest category for the hunter. Because of the hierarchical formulation of the model, the category of harvest assigned to this hunter by the model will tend to be close to the most frequent category of harvest observed for that species during that year.

Finally, we derived the total annual harvest in 2016 by multiplying the number of registered hunters with the mean annual harvest ($\mu_{j,2016}$) for a given species j. Since the Suriname hunter license database was incomplete for 2006, we were not able to estimate the number of registered hunters and total annual harvest in 2006.

We used R version 4.2.0 for data processing (R Core Team 2020) and JAGS version 4.3.0 (Plummer 2003), called via the R package jagsUI (Kellner 2021) for analyses. We used non-informative priors for all parameters and ran three chains with randomized initial start values for 69,500 iterations, using the first 2,000 iterations as burn in and thinning the chains to save every 12th iteration, with 1,000 iterations of adaption yielding 45,000 posterior samples for each parameter. We assessed model convergence visually and by making sure that the Gelman-Rubin statistic ($\hat{R}$) was less or equal than 1.1 (Gelman et al. 2013). We also used a posterior predictive check to evaluate the performance of the model. All results are reported

as the median with 90% Bayesian Credible Intervals, calculated as high-density intervals using *bayestestR* package (Makowski et al. 2019)

3. Results

3.2 Hunters in Suriname

In 2006, 276 licensed hunters answered the survey (Table 2) but only 73% (n=202) of the hunters reported their harvest of all species included in the survey. Hunters completed the survey and reported their harvest most frequently for black-bellied whistling-duck (93%) and muscovy duck (92%), white-cheeked pintail (91%), while hunters were less inclined to answered questions about their harvest of jabiru (84%) and American flamingo (83%).

In 2016, 289 hunters answered the survey (Table 2) and 99% (n=286) of the hunters reported their harvest for all species included in the survey. Hunters completed the survey for all species except one hunter who did not report his harvest of black-bellied whistling-duck (99%) and cocoi heron (99%). Of the surveyed hunters, 202 hunters indicated that they did not harvest a species, 76 hunters reported harvesting 5 species or less, 8 hunters harvested between 5 and 10 species, and 3 hunters harvested more than 10 species.

In addition to the 11 species and four taxa that we modelled, hunters also reported the harvest of Neotropic cormorant (*Nannopterum brasilianum*), anhinga (*Anhinga anhinga*), brown pelican (*Pelecanus occidentalis*), black skimmer (*Rynchops niger*), and Laridae (*gulls, and terns*). However, because the harvest levels for these species were too low for statistical modeling, they were excluded from the analysis.

3.3 Estimated waterbirds harvest in Suriname

3.3.1 Average harvest for 2006 and 2016

In both 2006 and 2016, mean harvest per hunter of all shorebirds was higher than for any other species or group (Figure 2). Results from the 2016 survey indicate that hunters harvested on average more small shorebirds than large shorebirds. At the individual species level, the most harvested species in 2006 were the black-bellied whistling-duck, the scarlet ibis, and the cocoi heron; the jabiru and American flamingo were the least harvested species (Figure 2). In 2016 the most harvested species was the blue-winged teal followed by the black-bellied whistling-duck, and the American flamingo and the jabiru were still the two least harvested species (Figure 2).

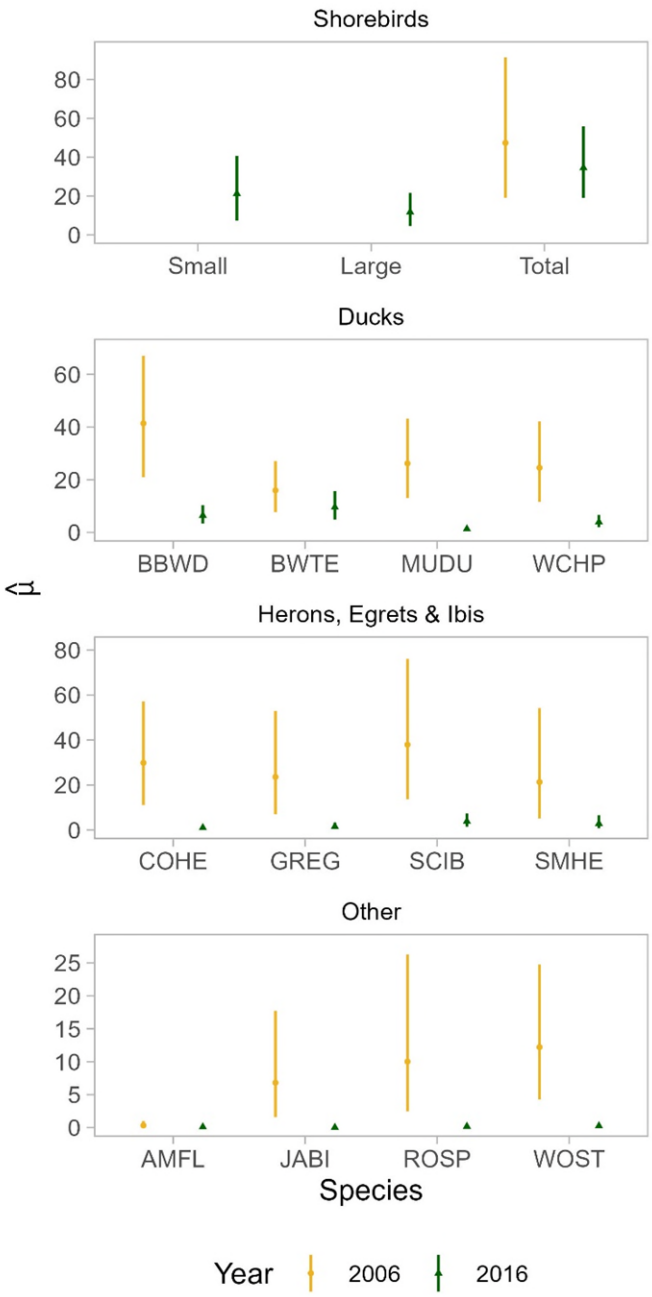

Figure 2: Mean annual harvest (μ) per hunter based on surveys conducted among hunters in Suriname in 2006 and 2016. Data points represent the median, with error bars indicating the 90% high-density intervals. American Ornithological Society species code are presented in Table 3.

3.3.2 Has hunting of waterbird species changed over time?

For most waterbird species, mean harvest per hunter declined between 2006 and 2016 (Figure 2). The exceptions were the blue-winged teal and migratory shorebirds, for which harvest did not decrease significantly between 2006 and 2016. In particular, wood stork, roseate spoonbill, jabiru, and American flamingo harvest declined below one bird per hunter in 2016.

Hunters surveyed in 2016 generally agreed that their overall harvest had declined. The large majority of the respondents (78%) who hunted in both 2006 and 2016, reported hunting less in 2016 and a minority (6%) reported hunting more than in 2006. When asked why they had changed their hunting practices, the most common response was that there were fewer birds available for harvest than there were in the past. Some individuals also cited the increase in hunting regulations and the increased enforcement and associated costs.

3.3.3 Total derived harvest 2016

Shorebirds were the most harvested group in general in 2016 with a total harvest of about 163 thousand birds (90-264 thousand; Table 3). Small shorebirds (100 [35-192] thousand) were harvested nearly twice as much as large shorebirds (55 [21-102] thousand). Ducks were the next group of species with the most harvest with the blue-winged teal being duck species with the highest total harvest (45 [23-74] thousand), followed by herons, with the scarlet ibis (18 [7- 35] thousand; Table 3) having the highest total harvest. Finally, the wood stork, roseate spoonbill, American flamingo, and jaribu were less frequently harvested species with only the wood stork (1230 [419- 2530]; Table 3) harvest exceeding a thousand birds.

Table 3: Predicted total waterbird harvest by all registered hunters in Suriname in 2016. Estimates are presented as medians with 90% Bayesian Credible Intervals (BCI). IUCN 2023. The IUCN Red List of Threatened Species. Version 2022-2. <https://www.iucnredlist.org>

Family/Species	Species code	IUCN listing	Migratory	2016 Annual harvest (90% BCI)	Hunting status according to Suriname's law
Anatidae					
black-bellied whistling-duck (*Dendrocygna autumnalis*)	BBWD	LC	No	30403 (15919 – 48782)	Game species
blue-winged teal (*Spatula discors*)	BWTE	LC	Yes	45248 (23099 – 73789)	Game species
muscovy duck (*Cairina moschata*)	MUDU	LC	No	6277 (3251 – 10240)	Game species
white-cheeked pintail (*Anas bahamensis*)	WCHP	LC	No	18578 (9265 – 31365)	Game species
Phoenicopteridae					
American flamingo (*Phoenicopterus ruber*)	AMFL	LC	No	501 (75 – 1500)	Protected
Ardeidae					
cocoi heron (*Ardea cocoi*)	COHE	LC	No	4911 (1874 – 9180)	Protected
great egret (*Ardea alba*)	GREG	LC	No	7267 (2240 – 15549)	Protected
Small herons	SMHE			13204 (3684 – 30918)	Protected
Ciconiidae					
jabiru (*Jabiru mycteria*)	JABI	LC	No	116 (10 – 411)	Protected
wood stork (*Mycteria americana*)	WOST	LC	No	1227 (419 -– 2532)	Protected
Threskiornithidae					
roseate spoonbill (*Platalea ajaja*)	ROSP	LC	No	860 (162 – 2313)	Protected
scarlet ibis (*Eudocimus ruber*)	SCIB	LC	No	18155 (6942 – 34640)	Protected
Charadriidae, Recurvirostridae, Scolopacidae					
Large shorebirds	Large		Yes	55485 (21411 – 102122)	Protected
Small shorebirds	Small		Yes	100269 (35172 – 192417)	Protected
Total shorebirds	Total		Yes	163230 (90113 – 263944)	Protected

3.3.4 What are the motivations of waterbird hunters and what hunting methods do they use?

The primary purpose of hunting was non-commercial, which includes personal consumption and recreational. Though there is overlap, the majority of hunters reported hunting for the former (75%) and only a small proportion for the latter (17%). Additionally, a fifth of hunters (19%) reported selling the birds inferring a commercial purpose. Across both survey years, 63% of respondents travelled to their hunting location with the intention of engaging in another activity, generally fishing or recreation. In 2016, nearly all hunters reported also hunting primarily with a firearm (99%), while a small proportion reported using a net (5%) or a choking wire (4%).

4. Discussion

Harvest of waterbird species is pervasive across coastal wetlands of Suriname, has declined over time, and is primarily practiced for personal consumption. To the best of our knowledge, this is the first national assessment of waterbird harvest from Suriname, part of a region of importance to shorebirds conservation in central northern South America and the Western Atlantic Flyway. While the importance of waterbird harvest in Suriname has been internationally recognized for many years (Ottema & Spaans 2008; AFSI Harvest Working Group 2017, 2020), no structured assessment has been previously conducted. Waterbird harvest occurs along the entire coast of Suriname and includes species across a wide range of taxonomic groups. Amongst all waterbirds hunted in Suriname, the scarlet ibis and migratory shorebirds are of particular conservation concern due to higher hunting levels, declining populations, and slow life history traits. Harvest management strategy and compliance promotion efforts will need to consider a broader context of wetland use, livelihoods, and governance capacity.

In Suriname, waterbirds are primarily harvested using firearms, with only a small proportion using alternative methods, such as nets and choking wires. This pattern is quite similar to French Guiana (Taylor 2017). In contrast, it is quite different from neighboring Guyana, where choking wires are most commonly used (Andres et al. 2022), and Brazil where fishing nets and night lighting are the most common methods (Bosi de Almeida et al. 2018). This spatial heterogeneity in the use of hunting methods is similar to the case of Southeast Asia, where harvest of waterbirds involves a variety of methods (Gallo-Cajiao E et al. 2020). In line with broader understanding of wetland use by humans, waterbird harvest did not happen in isolation in our study but rather alongside other resource uses, such as fishing.

The purpose of waterbird harvest in Suriname presented variation when compared to other countries within the region as well as to other regions. Waterbird harvest was primarily non-commercial in Suriname and included both personal consumption and recreational harvest. Unfortunately, disentangling these two from one another is challenging as they can overlap. Despite this caveat, harvest for personal consumption was overrepresented in our surveys. Some of this harvest may have cultural dimensions, as suggested by the consumption of scarlet ibis at social celebrations. This is in contrast with Guyana, where commercial harvest, of migratory shorebirds at least, happens at a relatively larger scale (Andres et al. 2022). Indeed, the small proportion of waterbird harvest that happens for commercial purposes in Suriname is likely transported into Guyana and then sold in markets near the border with Suriname.

Species hunted represented a wide variety of taxonomic groups and harvest levels varied between species. Wide taxonomic breadth of harvested species has also been reported for waterbird harvest in tropical wetlands elsewhere, such as northern Brazil (Bosi de Almeida et al. 2018), the Sahel (Deniau et al. 2022), southern India (Ramachandran et al. 2017), and Southeast Asia (Iskandar & Karlina 2004). Duck species were amongst the species with highest levels of harvest, a pattern shared with other tropical wetlands. This pattern may reflect hunter preferences for large bodied species. Of all the duck species hunted, only the blue-winged teal is considered migratory. This species breeds in North America where it is also harvested, with the harvest levels from Suriname were modest and represented about 1.68% of the combined harvest estimated for the US and Canada during the same year (Raftovich et al. 2018). Notably, the scarlet ibis was also amongst the species with highest levels of hunting and, while this species is hunted elsewhere in the tropics (Deniau et al. 2022), this hunting level has not been reported elsewhere in recent times. In contrast, waterbirds with relatively low levels of hunting in Suriname, such as the American flamingo, the wood stork, the jabiru, and the roseate spoonbill, all have species counterparts elsewhere that are harvested at similar levels, such as the Sahel (Deniau et al. 2022).

Current estimates of migratory shorebird harvest in Suriname are higher than estimates available from any other country in the central northern coast of South America and the Lesser Antilles. We estimated that migratory shorebirds harvest in Suriname was ≈ 163,230 birds in 2016 but this is a conservative estimate as it does not consider factors such as crippling loss and hunters that are hunting without a license. The true value could also be higher due to the limitations of the survey we conducted. Nevertheless, this figure is markedly

greater than a minimum estimate of 37,000 birds per year for neighboring Guyana (Andres et al. 2022), 24,000 birds per year for Barbados, Guadeloupe, and Martinique combined (AFSI Harvest Working Group 2020) and the current estimate of at least 2,000 birds per year for Brazil (Bosi de Almeida et al. 2018). These results are similar to other regions of the world waterbird distributions spans multiple countries, as it is the case of Southeast Asia, where harvest has been recorded along coastlines involving seven countries (Gallo-Cajiao et al. 2020). These similar patterns may signal underlying ecological conditions that are widely shared across far-distant regions, such as high concentration of migratory shorebirds associated with productive wetlands but may also be due to anthropogenic factors such as weak governance capacity to manage biodiversity, and socio-economic contexts related to intensive direct use of wild animal populations.

The sustainability of waterbird harvest in Suriname remains largely unknown, but some inferences can be made based on ecological theory and species life history traits. The population-level effects of harvest range from compensatory to additive, or even super-additive mortality, modulated by the level of hunting and the species life history (Anderson & Burnham 1976). Additive mortality occurs when harvesting reduces survival, while compensatory mortality happens when harvesting does not affect survival due to density dependence or targeting individuals that would have died naturally (Sandercock et al. 2011; Cooch et al. 2014). Generally, species with large clutch sizes, high natural mortality, and large populations experiencing density dependence allow for higher harvest rates without inducing additive mortality compared to species with small clutch sizes, high annual survival, and small populations (e.g., most shorebird species; Nichols et al. 1984; Cooch et al. 2014). The timing of harvest relative to natural mortality is also important, with hunting timed after, or during, periods of natural mortality more likely to be additive (Kokko 2001; Blomberg 2015). For many species, migration represents a period of exceptionally high natural mortality particularly for juveniles (Lok et al. 2015; Rushing et al. 2017; Sergio et al. 2019).

The waterbird species harvested in Suriname are along a continuum of life history traits and demographic parameters that allow inference of vulnerability relative to the levels of harvest and some sustainability reference points available. Hence, while duck hunting could be considered as having relatively low conservation concern based on ecological theory, some empirical data may call for a more precautionary approach since the population status of resident ducks harvested in Suriname are largely unknown. Beyond waterfowl, the scarlet ibis population is declining in Suriname, a consistent pattern across the species' range (Matheu et

al. 2020), and habitat alteration throughout it range is thought to have played in the observed declines. However, the level of harvest estimated for scarlet ibis remains high given this species exhibits slow life history traits (i.e., small clutch size, delayed sexual maturity). An increased compliance promotion campaign could help. However, lack of hunter education has been cited as a reason for non-compliance, but research shows that poachers are often aware of regulations but comply only in the presence of law enforcement (Jacoby 2014; von Essen et al. 2014). A more reliable assessment of the scarlet ibis population could also encourage better adherence to regulations, as hunters may use uncertainty as a justification to dismiss the need for the law (i.e., neutralization theory; Eliason 1999).

In the case of migratory shorebirds, though harvest levels were not estimated at a species level, some inference can be made using relative population abundances and reference points for sustainable harvest. Among all the species that are harvested, the semipalmated sandpiper is of particular concern given it is a species globally listed as Near Threatened (BirdLife International 2024) with likely population declines at a flyway level, and likely accounts for a large percentage of the small shorebirds harvested in Suriname given its prevalence in the region. The harvest estimated for shorebirds presents high very levels, and up to 44% of the flyway-wide sustainable hunting levels could be already being taken from neighboring Guyana (Watts et al. 2015; Andres et al. 2022).

At a national level, our study predominantly focuses on species that were harvested illegally under Suriname's Hunting Act (1954). With the exception of the four duck species, which are legal game species, the harvest of flamingoes, herons, storks, ibises, and shorebirds in this survey were illegal. The observed declines for the harvest of flamingoes, herons, storks, ibises are encouraging and is likely due in part to an increase in compliance promotion and enforcement of the harvest regulations. The current level of shorebirds harvest remains problematic. The status of shorebirds as protected species also complicates the engagement of hunters over species identification and precludes assessment of shorebird harvest sustainability (Solomon et al. 2015). This situation is not unique to Suriname however and has been observed elsewhere such as in Guyana (Andres et al. 2022) and the East Asian-Australasian Flyway (Gallo-Cajiao et al. 2020).

Furthermore, a patchwork approach to understanding hunting of migratory shorebirds can blur its full effects until data are aggregated at a full life-cycle scale (Gallo-Cajiao et al. 2020). Regulatory frameworks for shorebird harvest in particular are variable across the north coast of South America (Watts & Turrin 2016). For instance, these species are also totally protected

from harvest in Brazil, while they can be legally harvested for sport purposes in French Guiana but not for commercial purposes. By contrast, harvest of shorebirds in Guyana is entirely unregulated, including commercial hunting. This heterogeneity of regulatory frameworks can create incentives for laundering, whereby shorebirds could be illegally harvested in some jurisdictions and sold in others where commercial harvest is legal or unregulated. Despite the relevance of at least two international agreements to help address hunting, such as the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) and the Convention on Migratory Species (CMS), neither presents tangible possibilities. Suriname is a party to CITES but not to the CMS, whilst relevant migratory shorebird species are listed by the CMS but not by CITES.

To be efficient a multi-jurisdictional approach to harvest regulations would require an improvement of harvest assessments at a species level. An improved understanding of population-level effects of harvest will also need to be coupled with an improved monitoring system of the populations so that harvest can be related to the populations being harvested. It will also be important to improve a better understanding of the human dimensions related to shorebirds harvest in the Western Atlantic Flyway, particularly in relation to equity, contribution of harvest to livelihoods, and perceptions of regulatory frameworks and conservation interventions. Noteworthy, conservation policies that are not accepted by resource users will likely be ineffective. Both lines of research on harvest effects and human dimensions will need to be further integrated into the policy process balancing conservation and human needs. More specifically, outputs from this research agenda could inform institutional arrangements already in place that have incorporated harvest mitigation as a priority, such as the Atlantic Flyway Shorebird Initiative (AFSI Harvest Working Group 2017, 2020), which could in turn influence additional conservation policies and actions.

5. Conclusion

Our study contributes to the understanding of wetland use more generally and to the consumptive use of waterbirds more specifically, both in the tropics as well as in Suriname within the context of central northern South America and the Western Atlantic Flyway. In doing so, we discovered that harvest could be happening at unsustainable levels both for resident and migratory species, supporting global analyses on the importance of overharvesting as a threat to biodiversity (Maxwell et al. 2016). Illegally hunted species are typically those that are of greatest conservation concern. The issue of waterbird harvest, and

shorebirds in particular, has been recognized for decades in the central northern coast of South America and the Lesser Antilles (Hutt, 1991). However, structured and systematic assessments have only recently become available, highlighting the challenges involved in addressing this issue. More dedicated resources to monitor the status of the population and the level will greatly help develop more effective regulatory frameworks in the region. However, while enhancing existing regulatory frameworks is important, it is crucial to also prioritize efforts in promoting compliance, engaging with local communities, and developing alternative livelihoods. Given the importance of Suriname for waterbirds in the Americas, developing a cost-effective approach to Suriname's harvest management of species with international conservation concern, such as the scarlet ibis and migratory shorebirds, should remain a priority for the international community.

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