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RESEARCH ARTICLE

Shorebird subsistence harvest and indigenous knowledge in Alaska: Informing harvest management and engaging users in shorebird conservation

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ABSTRACT
Limited data on harvest and population parameters are impediments to assessing shorebird harvest sustainability. Because of sharp declines in shorebird populations, timely conservation efforts require approaches that account for uncertainty in harvest sustainability. We combined harvest assessment and ethnographic research to better understand shorebird conservation concerns related to subsistence harvest in Alaska and to support culturally sensible conservation actions. Our objectives were to (1) estimate the Alaska-wide shorebird subsistence harvest and (2) document shorebird indigenous knowledge on the Yukon-Kuskokwim Delta. Harvest estimates were based on surveys conducted in 1990–2015 ($n = 775$ community-years). Key respondent interviews conducted in 2017 ($n = 72$) documented shorebird ethnotaxonomy and ethnography. The Alaska-wide shorebird harvest was 2,783 birds per year, including 1,115 godwits per year—mostly Bar-tailed Godwits (*Limosa lapponica baueri*), whose population has low harvest potential. The egg harvest was 4,678 eggs per year, mostly small shorebird eggs. We documented 24 Yup'ik shorebird names and 10 main ethnotaxonomic categories. Children learning harvesting skills focused on small birds and adults also occasionally harvested shorebirds, but shorebirds were not primary food or cultural resources. Older generations associated shorebirds with a time when people were closer to nature and their cultural roots. Shorebirds connected people with the environment as well as with Yup'ik traditions and language. Our results can inform improvements to harvest assessment and management, as well as outreach and communication efforts to engage subsistence users in shorebird conservation.

Keywords: ethnotaxonomy, harvest management, harvest surveys, local and traditional knowledge, shorebird conservation, shorebird egg harvest, shorebird hunting, subsistence

Colecta de subsistencia de aves playeras y conocimiento indígena en Alaska: Asesorando el manejo de la colecta e involucrando a los usuarios en la conservación de las aves playeras

RESUMEN
La disponibilidad limitada de datos de colecta y de parámetros poblacionales impiden evaluar la sustentabilidad de la colecta de aves playeras. Debido a una marcada disminución en las poblaciones de aves playeras, los esfuerzos de conservación requieren enfoques que consideren la incertidumbre de la sustentabilidad de la colecta. Combinamos estudios de evaluaciones de colecta y etnográficos para entender las preocupaciones sobre la conservación de las aves playeras relacionadas a la colecta de subsistencia en Alaska y para apoyar acciones de conservación culturalmente sensibles. Nuestros objetivos fueron (1) estimar la cosecha de aves playeras en toda Alaska y (2) documentar el conocimiento indígena de las aves playeras en el Delta de Yukon-Kuskokwim. Las estimaciones de colecta se basaron en entrevistas realizadas entre 1990–2015 ($n = 775$ comunidades-años). Las entrevistas a los encuestados claves realizadas en 2017 ($n = 72$) registraron la etnotaxonomía y la etnografía de las aves playeras. La cosecha de aves playeras en toda Alaska fue de 2783 aves por año, incluyendo 1115 individuos de *Limosa* por año—mayormente *L. lapponica baueri*, cuya población tiene bajo potencial de colecta. La colecta de huevos fue de 4676 huevos por año, mayormente de huevos pequeños. Documentamos 24 nombres Yup'ik de aves playeras y 10 categorías etnotaxonómicas principales. Las habilidades de colecta aprendidas por los niños se enfocaron en las aves pequeñas y los adultos ocasionalmente también colectaron aves playeras, pero las aves playeras no fueron alimentos primarios ni recursos culturales. Las generaciones más viejas asociaron a las aves playeras con un momento en el que la gente estaba más cerca de la naturaleza y de sus raíces culturales. Las aves playeras conectaban a la gente con el ambiente y con las tradiciones y el lenguaje Yup'ik. Nuestros resultados pueden brindar información para mejorar las evaluaciones y el manejo de las colectas, así como los esfuerzos de divulgación y comunicación para involucrar a los usuarios en la conservación de las aves playeras.

Palabras clave: caza de aves playeras, colecta de huevos de aves playeras, conocimiento indígena, conservación de aves playeras, encuestas de colecta, etnotaxonomía, manejo de colecta, subsistencia

INTRODUCTION

Alaska is the terminus of 5 migratory bird flyways and one of the world's most important regions for shorebirds (Alaska Shorebird Group 2019). Migratory shorebirds rely on healthy ecological conditions in multiple sites along their annual journeys. Shorebird populations have sharply declined across the globe, and especially in the East Asia–Australasia Flyway, due to habitat loss, climate and environmental changes, harvest, and other factors (Melville et al. 2016, Pearce-Higgins et al. 2017, Studds et al. 2017). Seventeen of 41 shorebird populations regularly occurring in Alaska are of high conservation concern, increasing the need for knowledge and collaboration among researchers, managers, and stakeholders along their migratory routes (Johnston et al. 2015, Alaska Shorebird Group 2019).

Indigenous subsistence harvest of most birds has occurred in Alaska for millennia (Wolfe et al. 1990). Shorebirds are likely a fraction of the subsistence bird harvest in Alaska (~400,000 birds per year), but some shorebird species that are harvested are imperiled (Paige and Wolfe 1998, Alaska Shorebird Group 2019, L. C. Naves personal observation). Shorebird conservation concerns related to subsistence harvest in Alaska refer mostly to Bar-tailed Godwits (*Limosa lapponica baueri*) because their population size and adult survival have declined, and some annual harvest estimates in Alaska seem high (Conklin et al. 2016, Studds et al. 2017, Naves and Keating 2019a). Shorebird conservation goals in Alaska have included harvest assessment and communication with subsistence users (Johnston et al. 2015, Alaska Shorebird Group 2019).

Harvest surveys conducted in the 1980s–1990s in Alaska often did not include enough species categories to fully document shorebird harvests (Wolfe et al. 1990, Paige and Wolfe 1997, 1998). Since the 2000s, the Harvest Assessment Program of the Alaska Migratory Bird Co-Management Council (AMBCC-HAP) and other research entities in Alaska have produced a large body of data including more detail on shorebird harvest (e.g., Kawerak 2004, Alaska Migratory Bird Co-Management Council 2019a, Community Subsistence Information System 2019). However, harvest estimates have been available only at the regional and community levels, and large annual variation in estimates make it difficult to depict the Alaska-wide shorebird harvest.

Limited data on harvest and population parameters are impediments to the evaluation of shorebird harvest sustainability (Watts et al. 2015, Atlantic Flyway Shorebird Initiative 2016, Turrin and Watts 2016). Multiyear datasets are needed for many sites along migratory routes and the acquisition of such data is challenging (Woodley 2009). Yet, identifying and ranking population threats is crucial for prioritizing conservation actions (Pearce-Higgins et al. 2017). Because of ongoing declines in shorebird populations, timely conservation efforts require approaches that account for uncertainty in harvest sustainability.

Consideration of human (e.g., socio-economic and cultural) dimensions is an effective approach to answer research questions, solve management and conservation issues, and support community well-being (Decker et al. 2012, Atlantic Flyway Shorebird Initiative 2016, North America Bird Conservation Initiative 2019). In this study, we combined harvest assessment and ethnographic research to better understand shorebird conservation concerns related to subsistence harvest in Alaska and to support culturally sensible conservation actions. Our objectives were to estimate the Alaska-wide shorebird subsistence harvest using a comprehensive dataset and updated analytical approaches and document shorebird indigenous knowledge in the Yukon-Kuskokwim Delta region. This information is needed to (1) put subsistence harvest in Alaska in perspective with factors affecting shorebird populations, (2) provide context to harvest estimates, (3) include indigenous knowledge and engage subsistence users in management and conservation efforts, and (4) protect sustainable subsistence harvest opportunities.

METHODS

Study Area

Alaska's vast geography (1.72 million km^2) includes coastal, estuarine, wetland, boreal forest, and other ecosystems in Arctic and Subarctic western North America. More than half of the state's human population (~740,000 people) is concentrated in a few urban centers and the remainder lives in >200 remote communities accessible only by aircraft, boat, or in winter by snowmobile. Fifty-five percent of the population in remote communities belong to 5 large indigenous groups (U.S. Census Bureau 2011). The remote communities largely follow a subsistence way of life, with a mixed economy based on cash income and harvest of wild resources (hereafter subsistence communities). Subsistence harvests in Alaska amount to 16.7 million edible kilograms per year including fish (53%), land and marine mammals (23% and 14%, respectively), plants (4%), shellfish (3%), and birds and eggs (3%) (Fall 2016).

Bird harvests in the subsistence communities add diversity to the diet, enhance food security, and are culturally and socially important. Harvest of wild birds in Alaska does not involve sale between individuals or in markets. Most harvest regulations in Alaska do not refer to ethnicity; eligibility for participation in the subsistence harvest of migratory birds and their eggs is based on region of residency and excludes urban areas (U.S. National Archives and Records Administration 2019a). The eligible area is divided into 12 management regions (Figure 1), including 202 communities with population of ~87,000 people (U.S.

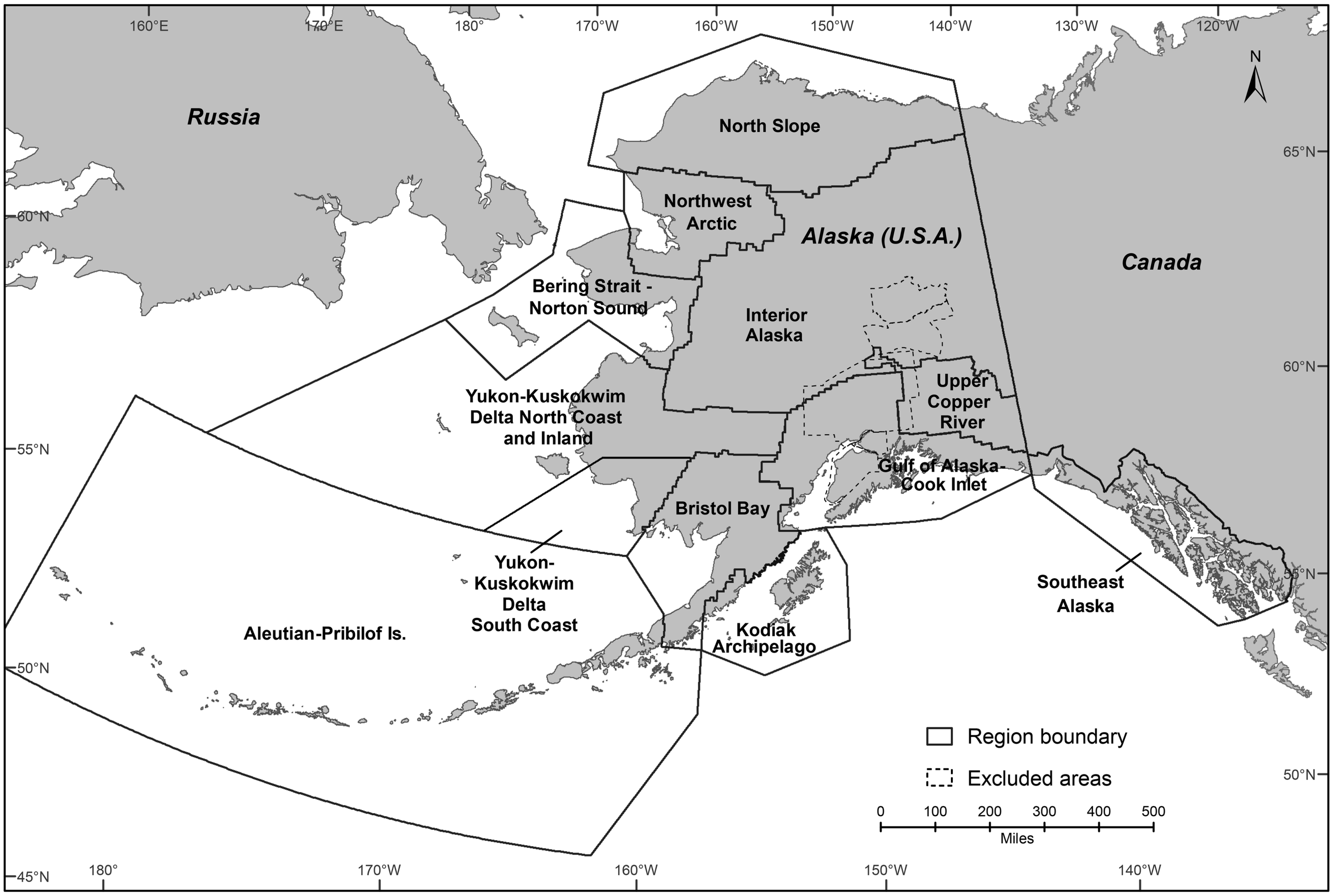

FIGURE 1. Alaska's regions used to calculate shorebird harvest, adapted from management regions for the subsistence harvest of migratory birds (U.S. National Archives and Records Administration 2019a).

Census Bureau 2011; Supplemental Material Table S1). In this study, the Yukon-Kuskokwim Delta region was divided into "South Coast" and "North Coast and Inland" because of their distinct shorebird harvest patterns, and the Gulf of Alaska and Cook Inlet regions were combined. Our harvest estimates accounted for all households of communities in the regions eligible to participate in the subsistence harvest of migratory birds.

Our indigenous knowledge research focused on the Central Yup'ik culture of the Yukon-Kuskokwim Delta because this extensive wetland supports the highest densities of breeding shorebirds in the United States and provides critical migratory staging habitat for millions of shorebirds (Gill and Handel 1990, McCaffery et al. 2012). This region also accounts for about one-third of the Alaska-wide subsistence bird harvest due to its high bird abundance and relatively large indigenous population as compared to other regions in Alaska (Wolfe et al. 1990, Paige and Wolfe 1998, U.S. Census Bureau 2011, Naves and Keating 2019a).

For thousands of years, the Yukon-Kuskokwim Delta and the Bristol Bay, to the south, have been the homeland of the Central Yup'ik people (Fienup-Riordan 1994). Euro-American settlement in the Yukon-Kuskokwim Delta started in the late 1800s, but the Yup'ik have maintained close ties to their cultural heritage, land, and the animals and plants they depend upon (Brandt 1943, Fienup-Riordan 2000). The current human population in this region (~32,000 people) is divided into 47 communities ranging from a few dozen to ~6,000 people, 90% of whom are indigenous (U.S. Census Bureau 2011). Government services and commercial fishing are the main employment activities, but jobs are scarce and often seasonal (Abrahamson 2013). Nevertheless, this land has historically provided its people with seasonally abundant fish, wildlife, and plants that support the subsistence component of the local economy.

Harvest Estimates

Data sources. We summarized existing Alaska-wide shorebird subsistence harvest data to portray an average annual harvest in the 1990–2015 period. The sampling effort unit is a community-year, which refers to a harvest survey conducted in a specific community and year. The dataset (775 community-years) included 2 databases, the AMBCC-HAP (2019a; n = 410 community-years) and the Community Subsistence Information System (2019; n = 307), as well as other sources (Webb 1999, Stovall 2000, Kawerak 2004, Ahmasuk and Trigg 2008, Bacon et al. 2011, Tahbone and Trigg 2011, and Reedy-Maschner and Maschner 2012). Most data (698 community-years) referred to 1990–2015 and limited data from 1984–1989 supplemented information for regions less-often surveyed (Supplemental Material Table S1). Of 202 communities in the sampling universe, only 12 communities spread across 5 regions were not represented in the dataset. In all sources, data were collected in household interview surveys conducted in partnership with indigenous organizations, and household participation was typically >80%.

Data treatment. We did not include some available sources of data because of incompatibility and other constraints: (1) 65 AMBCC-HAP community-years affected by missing data issues (Naves 2018); (2) surveys conducted in the Yukon-Kuskokwim Delta and Bristol Bay in the 1980s–1990s, which only reported results at the region level (Wentworth 2007a, 2007b); (3) surveys conducted prior to 1984, which did not ask enough detail to characterize shorebird harvest; and (4) 33 community-years surveyed in 1989–1992 in the Gulf of Alaska-Cook Inlet and Kodiak Archipelago, when usual harvest patterns were disrupted immediately following the 1989 Exxon Valdez Oil spill (Fall 1999).

Subsistence harvest surveys in Alaska use multi-species categories because of diverse study foci, challenges in species identification, limited understanding of ethnotaxonomies, and a need for conciseness in surveys that include dozens to hundreds of animal and plant species. Because shorebirds as a group contain many look-alike species and are only a fraction of the total bird harvest (Paige and Wolfe 1998), harvest surveys have used broad and often incomplete multi-species categories to document shorebird harvest (see also the Discussion section "Harvest Management"). For this study, we standardized categories in the original sources as follows: Black-bellied/Golden plovers (*Pluvialis* spp.), Whimbrel/Bristle-thighed Curlew (*Numenius* spp.), godwits (*Limosa* spp.), Black Oystercatcher (*Haematopus bachmani*), small shorebirds (*Calidris* spp., *Arenaria* spp., and *Phalaropus* spp.), and unidentified shorebirds (including birds labelled in surveys as "common snipe") (Table 1).

Following AMBCC-HAP methods, we divided annual harvests into spring (April–June), summer (July–August), and fall–winter (September–March), broadly reflecting seasonal availability of biological resources and bird phenology (arrival at breeding grounds and egg laying, chick rearing, and post-breeding migration). For sources that did not document season of harvest, we used "unknown season." Only annual egg harvest estimates were presented because eggs are available for only about a month in any given location during spring–summer.

Harvest estimation. We followed analytical methods developed in previous harvest studies involving multiple data sources (Naves 2018). We calculated community-level harvest estimates from AMBCC-HAP household raw data (Supplemental Material Appendix A, Equation 1) and integrated these estimates with the other data sources to assemble the complete dataset. Although we used a large dataset, data were insufficient to calculate Alaska-wide harvest estimates for individual years while properly accounting for geographic harvest patterns. For communities surveyed more than once, annual estimates of harvest and variance were averaged at the community level before calculating region-wide estimates. Thus, harvest estimates represent an average annual harvest in the 1990–2015 period (i.e. harvest was not calculated cumulatively over years). For each region, community estimates were extrapolated to account for the few communities not represented in the dataset (Supplemental Material Appendix A, Equation 2). Region estimates were summed into Alaska-wide estimates. Harvest estimates did not account for crippling (birds struck but not retrieved).

For AMBCC-HAP data, community harvest variances were calculated from raw data (Supplemental Material Appendix A, Equations 3.a and 3.b). For other data sources, community variances were retro-calculated based on reported confidence intervals assuming that all surveys used simple random sampling (Supplemental Material Appendix A, Equation 3.c). Variances for region estimates were calculated using formulas for 2-stage sampling: communities were primary sampling units and households were secondary sampling units (Cochran 1977; Supplemental Material Appendix A, Equations 4.a–4.c). Region variances were summed into Alaska-wide variances. Confidence intervals were calculated as percentages of harvest estimates (Supplemental Material Appendix A, Equations 5.a and 5.b).

Yup'ik Indigenous Knowledge

Key respondent interviews. We were interested in cultural and ecological aspects of indigenous knowledge, including intertwined elements of ecology, ethics, and history, with application to shorebird research and conservation while supporting the well-being of local communities (e.g., Blanchard 1994, Lyver et al. 2015). Participation in the indigenous knowledge interviews was voluntary for Yup'ik communities and individuals. We initially planned to conduct 6 interviews in each of 5 participating communities. We identified 12 candidate communities near important shorebird sites (Gill and McCaffery 1999, Marks et al. 2002, McCaffery et al. 2005). Five communities declined to participate or did not respond to

TABLE 1. Shorebird population sizes and 1990–2015 estimated Alaska-wide shorebird subsistence harvest.

				Alaska subsistence harvest	
Shorebird species that regularly breed or occur in Alaska	Total Population	Number in Alaska	PBR*	Birds per year	Eggs per year
Black Oystercatcher *Haematopus bachmani*◆‡	11,000	6,710	–	27	446
Black-bellied/Golden plovers				61	417
Black-bellied Plover *Pluvialis squatarola* (North America)◊‡	362,700	261,144	4,110	–	–
American Golden-Plover *P. dominica*◆	500,000	290,000	–	–	–
Pacific Golden-Plover *P. fulva* (North America)◆	42,500	42,500	10,580	–	–
Whimbrel/Bristle-thighed Curlew				215	112
Bristle-thighed Curlew *N. tahitiensis*◆	10,000	10,000	–	–	–
Whimbrel *Numenius phaeopus hudsonicus* (Alaska, Southwest Yukon Territory)◆	40,000	38,000	1,312	–	–
Godwits				19	248
Bar-tailed Godwit *L. lapponica baueri*◆‡	90,000	90,000	1,184	1,096**	–
Hudsonian Godwit *Limosa haemastica* (Alaska)◆	21,000	21,000	–	–	–
Marbled Godwit *L. fedoa beringiae*◆	2,000	2,000	–	–	–
Small shorebirds				609	1,962
Semipalmated Plover *Charadrius semipalmatus*†	200,000	38,000	15,000	–	–
Killdeer *C. vociferous vociferus*	2,000,000	20,000	250,100	–	–
Upland Sandpiper *Bartramia longicauda*	750,000	7,500	71,380	–	–
Ruddy Turnstone *Arenaria interpres interpres* (Alaska)◊‡	20,000	20,000	959	–	–
Black Turnstone *A. melanocephala*◆	95,000	95,000	–	–	–
Surfbird *Calidris virgata*◊	70,000	56,000	–	–	–
Rock Sandpiper *C. ptilocnemis ptilocnemis*◆	19,800	19,800	–	–	–
Rock Sandpiper *C. p. couesi*	75,000	75,000	–	–	–
Rock Sandpiper *C. p. tschuktschorum*	50,000	50,000	–	–	–
Red Knot *C. canutus roselaari*◆	21,800	21,800	995	–	–
Sanderling *C. alba* (North America)◊	200,000	20,000	–	–	–
Semipalmated Sandpiper *C. pusilla* (Alaska)◆‡	1,450,000	1,450,000	–	–	–
Western Sandpiper *C. mauri*◊‡	3,500,000	3,500,000	238,600	–	–
Least Sandpiper *C. minutilla*‡	700,000	266,000	133,400	–	–
White-rumped Sandpiper *C. fuscicollis*	1,694,000	16,940	–	–	–
Baird's Sandpiper *C. bairdii*‡	300,000	30,000	–	–	–
Pectoral Sandpiper *C. melanotos*◆	1,680,000	1,260,000	–	–	–
Sharp-tailed Sandpiper *C. acuminata*‡	160,000	24,000	–	–	–
Dunlin *C. alpina pacifica*◊‡	550,000	550,000	–	–	–
Dunlin *C. a. arcticola*◆‡	500,000	500,000	26,490	–	–
Stilt Sandpiper *C. himantopus*	1,243,700	124,370	94,300	–	–
Buff-breasted Sandpiper *C. subruficollis*◆	56,000	14,560	1,371	–	–
Spotted Sandpiper *Actitis macularius*‡	660,000	132,000	83,960	–	–
Solitary Sandpiper *Tringa solitaria cinnamomea*	63,000	49,770	–	–	–
Wandering Tattler *T. incana*†	17,500	9,975	–	–	–
Red-necked Phalarope *Phalaropus lobatus*◊‡	2,500,000	1,250,000	47,890	–	–
Red Phalarope *P. fulicarius*◊‡	1,620,000	583,200	225,600	–	–
Short-billed Dowitcher *Limnodromus griseus caurinus*◆†	75,000	60,000	–	–	–
Long-billed Dowitcher *L. scolopaceus*◊‡†	650,000	637,000	52,420	–	–
Wilson's Snipe *Gallinago delicata*‡†	2,000,000	500,000	398,100	–	–

TABLE 1. Continued

Shorebird species that regularly breed or occur in Alaska	Total Population	Number in Alaska	PBR*	Alaska subsistence harvest	
				Birds per year	Eggs per year
Lesser Yellowlegs *T. flavipes*◆‡†	660,000	158,400	79,450	–	–
Greater Yellowlegs *T. melanoleuca*‡†	137,000	36,990	10,210	–	–
Shorebirds (unidentified)				756	1,493
Total		12,328,059		2,783	4,678

Population size data: U.S. Shorebird Conservation Partnership (2016a), Alaska Shorebird Group (2019).
* PBR: Estimated potential biological removal for entire population (maximum sustainable human-caused mortality, as annual number of animals; Watts et al. 2015, Turrin and Watts 2016).
**: All godwits harvested in the Yukon-Kuskokwim South Coast assumed to be Bar-tailed Godwits.
–: Species-specific data not available.
◆: Species of greatest or high conservation concern (U.S. Shorebird Conservation Partnership 2016b).
◊: Species of moderate conservation concern (U.S. Shorebird Conservation Partnership 2016b).
‡: Subsistence harvest in Alaska is legally authorized (U.S. National Archives and Records Administration 2019a).
†: Not represented in harvest survey materials.

requests; to meet the sampling goal, alternate communities within the candidate set were invited to participate.

We refined interview structure and materials based on 2 pilot interviews with Yup'ik subsistence users and input from ad hoc consultants experienced in ethnographic and shorebird research (Nakashima 1991). In 2 communities, we contracted a Yup'ik-fluent research assistant for data collection. Indigenous leaders identified individuals knowledgeable about birds as potential key respondents. Using chain referral, we asked respondents to indicate other interview candidates (Singleton and Straits 2010, Neuman 2011). Our sample included indigenous men and women, older generations, and active harvesters (Figure 2). All respondents spoke English and most spoke Yup'ik. Two respondents preferred to communicate in Yup'ik; these interviews were facilitated by the local research assistant and translated into English.

As we conducted interviews, it became clear that a small proportion of people knew about shorebirds, thus we eventually conducted a total of 72 interviews including 80 respondents. Sixty-eight interviews were conducted in 2017 in the communities of Quinhagak (February 10–17; n = 11), Toksook Bay (April 16–20; n = 12), Platinum (May 21–28; n = 9), Hooper Bay (November 6–11; n = 19), and Bethel (December 4–8; n = 17). Four interviews were conducted in Anchorage and Dillingham with Yup'ik respondents from the Bristol Bay region. Most interviews were individual, and 6 interviews included 2–3 respondents. Interviews were conducted at respondents' houses or public spaces, were audio-recorded, and averaged 58 min (Supplemental Material Table S2). We offered respondents a $50 per hour honorarium in recognition of their time.

Interview structure. We used 3 activities to collect ethnotaxonomy data. First, we briefly explained what birds we were interested in learning about ("the small, brownish birds that use the coast and mudflats") while showing a 13 × 10 cm card with color photographs of 9 shorebird species. Setting this card aside, in a free-listing activity we asked respondents to share "bird names and Yup'ik names for this kind of birds."

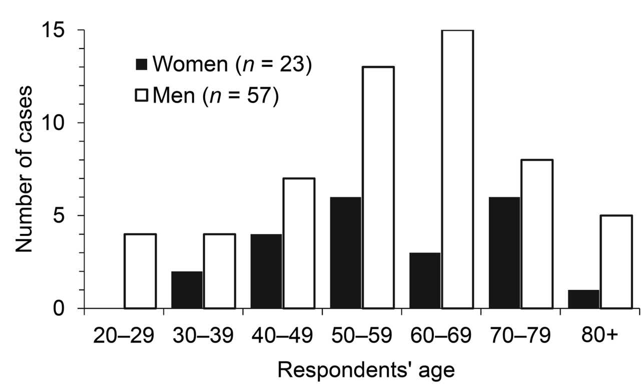

FIGURE 2. Sample for shorebird indigenous knowledge interviews.

Free-listing helps to identify significant words in a cultural domain, in this case the shorebird names most widely known (Thompson and Juan 2006, Souza and Begossi 2007).

In the second ethnotaxonomy activity, we asked respondents to name shorebirds in 47 color photographs and 14 sound recordings, which were numbered for reference, randomly sorted, and presented one at a time in the same order to all respondents (first all photographs, then sounds). Three card sizes (22 × 9, 22 × 19, and 23 × 22 cm) roughly depicted small, medium, and large shorebirds. Most photographs presented birds in breeding plumage. Several species were represented by more than one photograph or sound, providing diverse species identification clues.

We then provided a 14-page printout presenting photographs of shorebirds and Yup'ik names found in the literature, and asked respondents if they were familiar with names, if names matched photographs, and missing names (Wentworth 2007a, Jacobson 2012, Keim 2018). However, being familiar with a name does not necessarily mean respondents knew to which bird the name applied (e.g., "*This name is familiar, but I can't place it.*").

We next asked 24 open-ended questions on past and current shorebird harvest methods and uses, cultural importance (place names, stories, songs, objects), ecology, changes in abundance, and local concerns (Bernard 2011, Naves and Keating 2019b).

Analysis of ethnographic and ethnotaxonomic data. Interview recordings were listened to at least twice for accuracy in their transcription. Transcription respected respondents' word choices; word order and sentence structure were slightly edited favoring conciseness while communicating the original meaning (Fienup-Riordan et al. 2017). To summarize ethnographic information, a comprehensive compilation of quotes from transcripts was sorted by topics elicited from interview questions and emergent topics.

We followed Jacobson (2012) for Yup'ik orthography, and contracted a Yup'ik translator to assist in orthography, pronunciation, and use. Because Yup'ik remains primarily a spoken language, fluidity and variant words are common. We combined dialectal forms, synonyms, and variants for data analysis. We used FLAME (Pennec et al. 2012) to calculate the Smith's salience index. This index simultaneously considers the frequency of occurrence of names mentioned by respondents in a set of free-lists and the average order (rank) in which they were listed (Smith and Borgatti 1997, Sutrop 2001). We also calculated the frequency of occurrence of names mentioned during the 3 ethnotaxonomy activities to portray use of all documented words.

We quantified familiarity with shorebird names for each interview by combining accuracy in use and number of known names (familiarity index = average naming accuracy × total number of names identified in the 3 ethnotaxonomy activities; Bailenson et al. 2002, Reyes-García et al. 2013). We ranked accuracy in naming each photograph and sound in a weighted scale: (0) the respondent did not know the bird or a name for it; (1) a name at a high (more general) taxonomic level (e.g., *iisuraar/iiyuraar*, phalarope) was incorrectly used; (4) a name at a high taxonomic level was correctly used; (6) a name at a low (more specific) taxonomic level (e.g., *curemraq*, Red-necked Phalarope) was incorrectly used; and (10) a name at a low taxonomic level was correctly used.

The ethnotaxonomy activities seemed to underestimate respondents' ability to identify shorebirds due to communication challenges and a disconnect between theoretical knowledge (ability to name species) and practical knowledge (ability to apply knowledge in a realistic setting) (Godoy et al. 2005). When people encounter live birds in nature, information on size, shape, color, sounds, behavior, and habitat are integrated for species identification (Diamond and Bishop 1999). Some respondents did not understand the free-listing activity, and some had vision or hearing impairments that affected communication.

RESULTS

Harvest Estimates

The estimated Alaska-wide harvest of shorebirds was 2,783 birds per year over the period 1990–2015. The harvest was mostly composed of godwits (40%), unidentified shorebirds (27%), and small shorebirds (22%) (Table 1, Figure 3A). For harvests with documented seasons, the distribution of harvest was 16% in spring, 44% in summer, and 40% in fall–winter (Table 2, Figure 4). Harvest reported as godwits occurred mostly in summer (46%) and fall–winter (52%). Harvests reported as small shorebirds occurred mostly in spring (40%) and summer (46%).

The Yukon-Kuskokwim Delta South Coast (1,183 birds per year) represented 43% of the Alaska-wide harvest of shorebirds, and harvest in this region was mostly reported as godwits (Table 2, Figure 3A). The Bristol Bay region ranked second in shorebird harvest (522 birds per year), and the main categories were small shorebirds, unidentified shorebirds, and Whimbrel/Bristle-thighed Curlew. The Aleutian-Pribilof Islands ranked third in shorebird harvest (354 birds per year), including harvests documented as Black Oystercatcher and Black-bellied/Golden plovers (Table 2, Figure 3A).

The Alaska-wide estimated harvest of shorebird eggs was 4,678 eggs per year (Table 3, Figure 3B). This harvest was largely from small shorebirds (42%), unidentified shorebirds (32%), Black Oystercatcher (10%), and Black-bellied/Golden plovers (9%). The regions accounting for most of the shorebird egg harvest were Yukon-Kuskokwim Delta North Coast and Inland (38%), Bering Strait-Norton Sound (32%), and Yukon-Kuskokwim Delta South Coast (14%) (Table 3, Figure 3B).

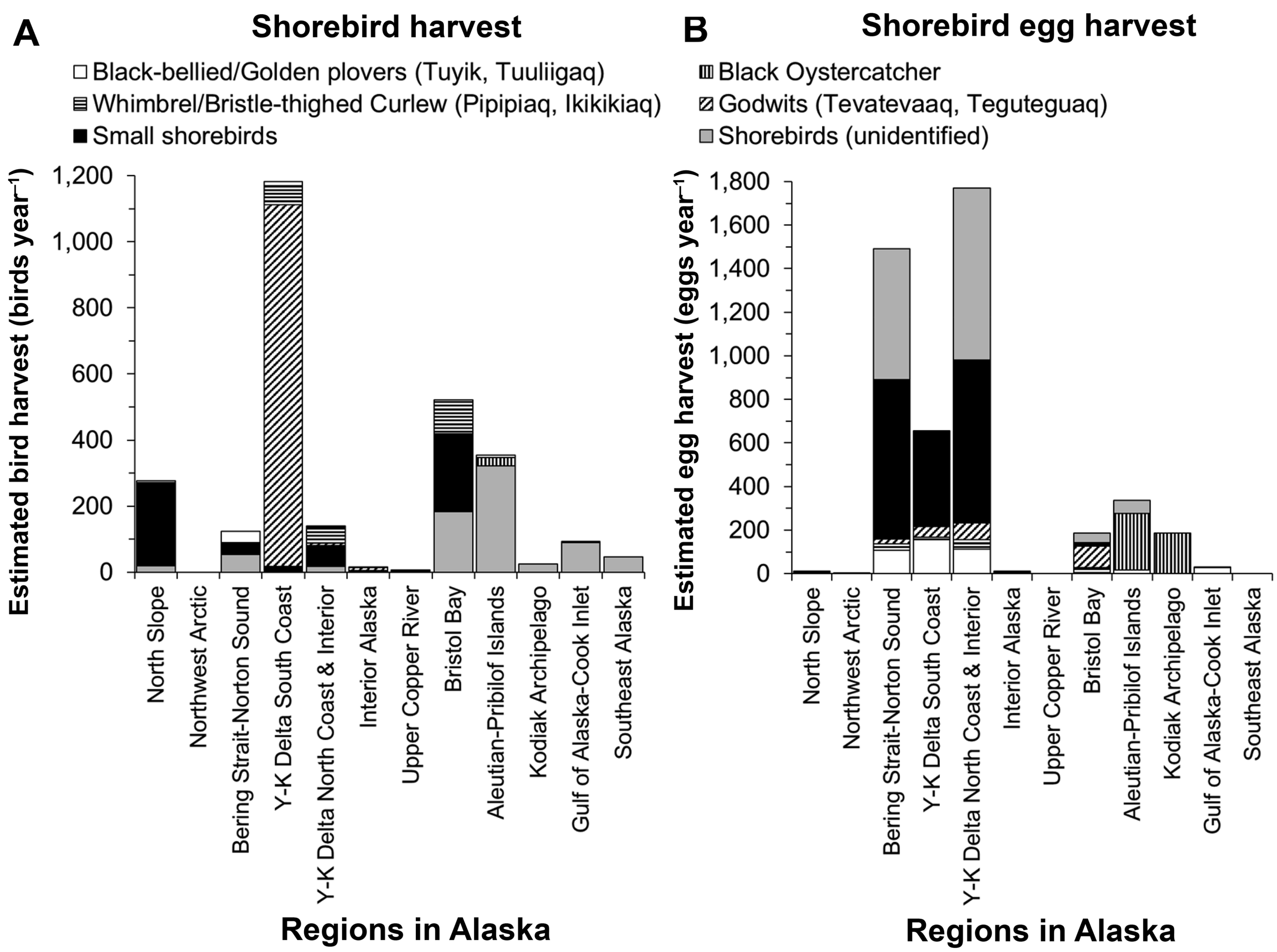

FIGURE 3. Subsistence harvest of shorebirds (**A**) and their eggs (**B**) in Alaska's regions, 1990–2015.

Yup'ik Indigenous Knowledge

Harvesting practices and uses. Respondents reported that shorebirds and their eggs are currently harvested infrequently and in relatively small numbers. Adults harvest shorebirds using shotguns for an occasional meal, especially in fall when birds are fat, and as emergency meals. They also reported that fall harvest of shorebirds is more common along the south coast of the Yukon-Kuskokwim Delta, where communities unfortunately did not consent to interviews in this study. Traditionally, shorebirds and other small birds have been the focus of children learning hunting skills such as patience, observation, stalking, animal behaviors, and use of hunting tools (see also Brandt 1943, Fienup-Riordan 2007). Currently, children hunt birds mostly with BB guns, while slingshots and bow and arrows were used in the past. Shorebird egg gathering is an activity enjoyed by families and children. Shorebirds and their eggs are used for food; no other uses such as source of materials, regalia, or medicinal benefits were identified. Shorebirds are boiled or roasted, and their eggs are boiled or eaten raw.

Respondents indicated that shorebirds were harvested in higher numbers in the past, when they were harvested for food using bow and arrow, slingshot, and diverse creative approaches (see also Fienup-Riordan 2007, Jacobson 2012). One respondent reported past use of snares on mudflats at low tide to harvest shorebirds. On Saint Lawrence Island (Bering Strait-Norton Sound), phalaropes were harvested in the past with a rope stretched on a lake shore, which was vigorously whipped across bird flocks (L. C. Naves personal observation). Elders also harvested shorebirds, which were abundant and easy to capture.

Ethnotaxonomy. Respondents were most familiar with Yup'ik shorebird names and often did not know or use English names ("*We don't know English names of the birds, we just know them by their Yup'ik names*" and "*I never used to know the English words for our species until I started working for the U.S. Fish and Wildlife* [*Service*]."). We identified 24 shorebird Yup'ik names and 10 main ethnotaxonomic categories, most of them likely including more than one species or genus (Figure 5, Supplemental Material Figure 7 and Table S3). At least 8 names were

TABLE 2. Estimated subsistence harvest of shorebirds in Alaska (number of birds per year) ± confidence interval (as a percent of the harvest estimate) by region and season, 1990–2015.

Species or species categories (bird harvest)	North Slope	Northwest Arctic	Bering Strait-Norton Sound	Y-K Delta South Coast	Y-K Delta North Coast and Inland	Interior Alaska	Upper Copper River	Bristol Bay	Aleutian-Pribilof Islands	Kodiak Archipelago	Gulf of Alaska-Cook Inlet	Southeast Alaska	Alaska total
Black-bellied/ Golden plovers	4 ± 140%	0	35 ± 106%	13 ± 103%	2 ± 208%	0	0	0	7 ± 140%	0	0	0	61 ± 68%
Spring	4 ± 140%	0	18 ± 163%	11 ± 102%	2 ± 210%	0	0	0	0	0	0	0	35 ± 92%
Summer	0	0	9 ± 252%	0	0	0	0	0	0	0	0	0	9 ± 252%
Fall-winter	0	0	8 ± 172%	2 ± 478%	0	0	0	0	7 ± 140%	0	0	0	17 ± 112%
Black Oystercatcher	0	0	0	0	0	0	0	0	26 ± 138%	0	1 ± 288%	0	27 ± 133%
Spring	0	0	0	0	0	0	0	0	0	0	1 ± 288%	0	1 ± 288%
Summer	0	0	0	0	0	0	0	0	14 ± 142%	0	0	0	14 ± 142%
Fall–winter	0	0	0	0	0	0	0	0	12 ± 251%	0	0	0	12 ± 251%
Whimbrel/Bristle-thighed Curlew	0	0	4 ± 185%	57 ± 96%	50 ± 649%	1 ± 83%	0	103 ± 36%	0	0	0	0	215 ± 160%
Spring	0	0	0	0	7 ± 307%	0	0	5 ± 105%	0	0	0	0	12 ± 189%
Summer	0	0	0	13 ± 329%	30 ± 84%	0	0	82 ± 41%	0	0	0	0	125 ± 48%
Fall–winter	0	0	4 ± 186%	44 ± 73%	13 ± 255%	1 ± 84%	0	0	0	0	0	0	62 ± 537%
Unknown season	0	0	0	0	0	0	0	16 ± 0%	0	0	0	0	16 ± 0%
Godwits	0	0	3 ± 233%	1,096 ± 63%	7 ± 109%	9 ± 64%	0	0	0	0	0	0	1,115 ± 62%
Spring	0	0	0	10 ± 252%	6 ± 156%	2 ± 120%	0	0	0	0	0	0	18 ± 145%
Summer	0	0	1 ± 427%	509 ± 68%	1 ± 246%	7 ± 76%	0	0	0	0	0	0	518 ± 67%
Fall–winter	0	0	2 ± 258%	577 ± 62%	0	0	0	0	0	0	0	0	579 ± 61%
Small shorebirds	252 ± 60%	0	28 ± 55%	17 ± 98%	62 ± 64%	5 ± 76%	7 ± 69%	236 ± 39%	0	0	2 ± 191%	0	609 ± 30%
Spring	31 ± 62%	0	9 ± 125%	11 ± 100%	42 ± 89%	0	3 ± 69%	148 ± 53%	0	0	0	0	244 ± 37%
Summer	221 ± 60%	0	2 ± 135%	0	10 ± 76%	5 ± 76%	0	41 ± 89%	0	0	0	0	279 ± 49%
Fall–winter	0	0	17 ± 93%	6 ± 196%	10 ± 76%	0	4 ± 69%	47 ± 72%	0	0	2 ± 196%	0	86 ± 47%
Shorebirds (unidentified)	20 ± 298%	0	54 ± 182%	0	18 ± 306%	0	0	183 ± 72%	321 ± 144%	25 ± 353%	89 ± 358%	46 ± 285%	756 ± 81%
Spring	0	0	8 ± 529%	0	18 ± 317%	0	0	16 ± 137%	0	0	0	0	42 ± 176%
Summer	20 ± 298%	0	46 ± 193%	0	0	0	0	0	0	0	0	3 ± 583%	69 ± 157%
Fall–winter	0	0	0	0	0	0	0	67 ± 69%	0	25 ± 374%	31 ± 331%	43 ± 417	166 ± 139%
Unknown season	0	0	0	0	0	0	0	100 ± 104%	321 ± 144%	0	58 ± 904%	0	479 ± 147%
Total shorebirds	276 ± 38%	0	124 ± 62%	1,183 ± 58%	139 ± 240%	15 ± 45%	7 ± 26%	522 ± 28%	354 ± 131%	25 ± 346%	92 ± 348%	46 ± 285%	2,783 ± 35%
Spring	35 ± 37%	0	35 ± 122%	32 ± 91%	75 ± 90%	2 ± 115%	3 ± 26%	169 ± 39%	0	0	1 ± 281%	0	352 ± 31%
Summer	241 ± 39%	0	58 ± 152%	522 ± 67%	41 ± 65%	12 ± 50%	0	123 ± 40%	14 ± 137%	0	0	3 ± 583%	1,014 ± 37%
Fall–winter	0	0	31 ± 73%	629 ± 56%	23 ± 145%	1 ± 84%	4 ± 26%	114 ± 38%	19 ± 167%	25 ± 368%	33 ± 314%	43 ± 417%	922 ± 58%
Unknown season	0	0	0	0	0	0	0	116 ± 89%	321 ± 144%	0	58 ± 904%	0	495 ± 143%

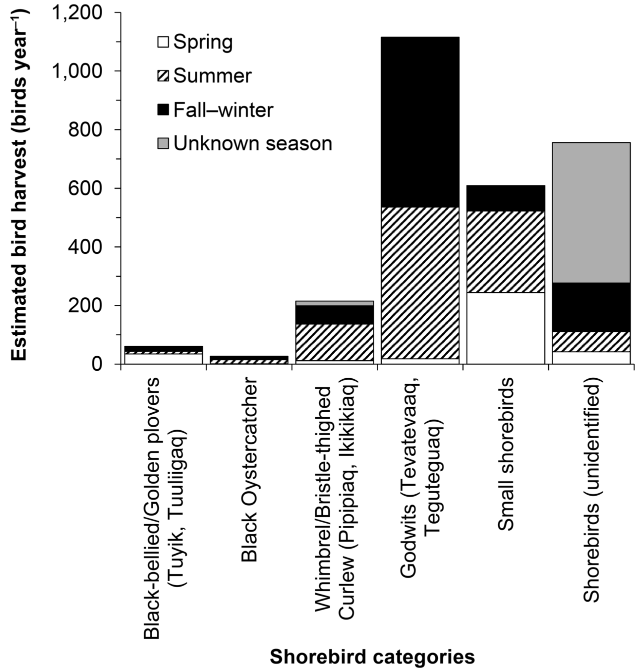

FIGURE 4. Seasonality of subsistence harvest of shorebirds in Alaska, 1990–2015.

onomatopoeic, and some categories were primarily identified by sound, that is, respondents often could name a sound (*tuyik/tuuliigaq, temtemtaq, levlevleraq, kukukuaq, tevatevaaq/teguteguaq, pipipiaq*) but could not name a photograph ("*I never connected bird songs with the actual bird, only the song*"). Names describing behaviors often included a verb (*ikigcaqaq, elagayuli, mayurayuli*: Supplemental Material Table S3). Some names described conspicuous anatomy and plumage (*sugg'erpak, kanagarpak, uyarr'uyaq, augtuar, qayaruartalek*).

Respondents were often unfamiliar with shorebirds and their names, and were surprised in learning about their large species diversity. When respondents were asked to name shorebird photographs and sounds, on average, 61% of responses was "*I don't know* [*this bird or a name for it*]" (range: 25–98%, SD = 0.20). Some respondents considered sparrows and other songbirds (e.g., *tekciuk, uipinipaaq*) in the same category as small sandpipers (*iisuraar/iiyuraar*) and the Semipalmated Plover (*Charadrius semipalmatus*) (*uyarr'uyaq/tapruar*) (Figure 5A, Supplemental Material Figure 7). Names for lower taxonomic categories were poorly known (e.g., *temtemtaq, levlevleraq, qayaruartalek*; Supplemental Material Figure 8). The English word "snipe" was used for all kinds of shorebirds and "curlew" was used for all shorebirds with long bills (Figures 5A and 5C).

During the free-listing activity, respondents on average mentioned 4.04 names related to shorebirds (range: 1–11, SD = 2.63). The Smith's index identified the 3 most

TABLE 3. Estimated subsistence harvest of shorebird eggs in Alaska (number of eggs per year) ± confidence interval (as a percent of the harvest estimate) by region, 1990–2015.

Species or species categories (egg harvest)	North Slope	Northwest Arctic	Bering Strait-Norton Sound	Y-K Delta South Coast	Y-K Delta North Coast and Inland	Interior Alaska	Upper Copper River	Bristol Bay	Aleutian-Pribilof Islands	Kodiak Archipelago	Gulf of Alaska-Cook Inlet	Southeast Alaska	Alaska total
Black-bellied/ Golden plovers	0	0	106 ± 76%	156 ± 33%	112 ± 35%	0	0	0	16 ± 84%	0	27 ± 147%	0	417 ± 27%
Black Oystercatcher	0	0	0	0	0	0	0	0	259 ± 81%	186 ± 116%	1 ± 273%	0	446 ± 67%
Whimbrel/Bristle-thighed Curlew	0	0	30 ± 207%	11 ± 85%	43 ± 72%	0	0	28 ± 66%	0	0	0	0	112 ± 65%
Godwits	0	0	23 ± 441%	50 ± 52%	77 ± 48%	0	0	98 ± 159%	0	0	0	0	248 ± 77%
Small shorebirds	12 ± 112%	0	731 ± 40%	440 ± 35%	750 ± 24%	12 ± 77%	0	17 ± 60%	0	0	0	0	1,962 ± 19%
Shorebirds (unidentified)	0	3 ± 280%	600 ± 106%	0	787 ± 110%	0	0	42 ± 96%	61 ± 77%	0	0	0	1,493 ± 72%
Total shorebirds	12 ± 103%	3 ± 280%	1,490 ± 29%	657 ± 29%	1,769 ± 36%	12 ± 54%	0	185 ± 84%	336 ± 58%	186 ± 44%	28 ± 123%	0	4,678 eggs per year

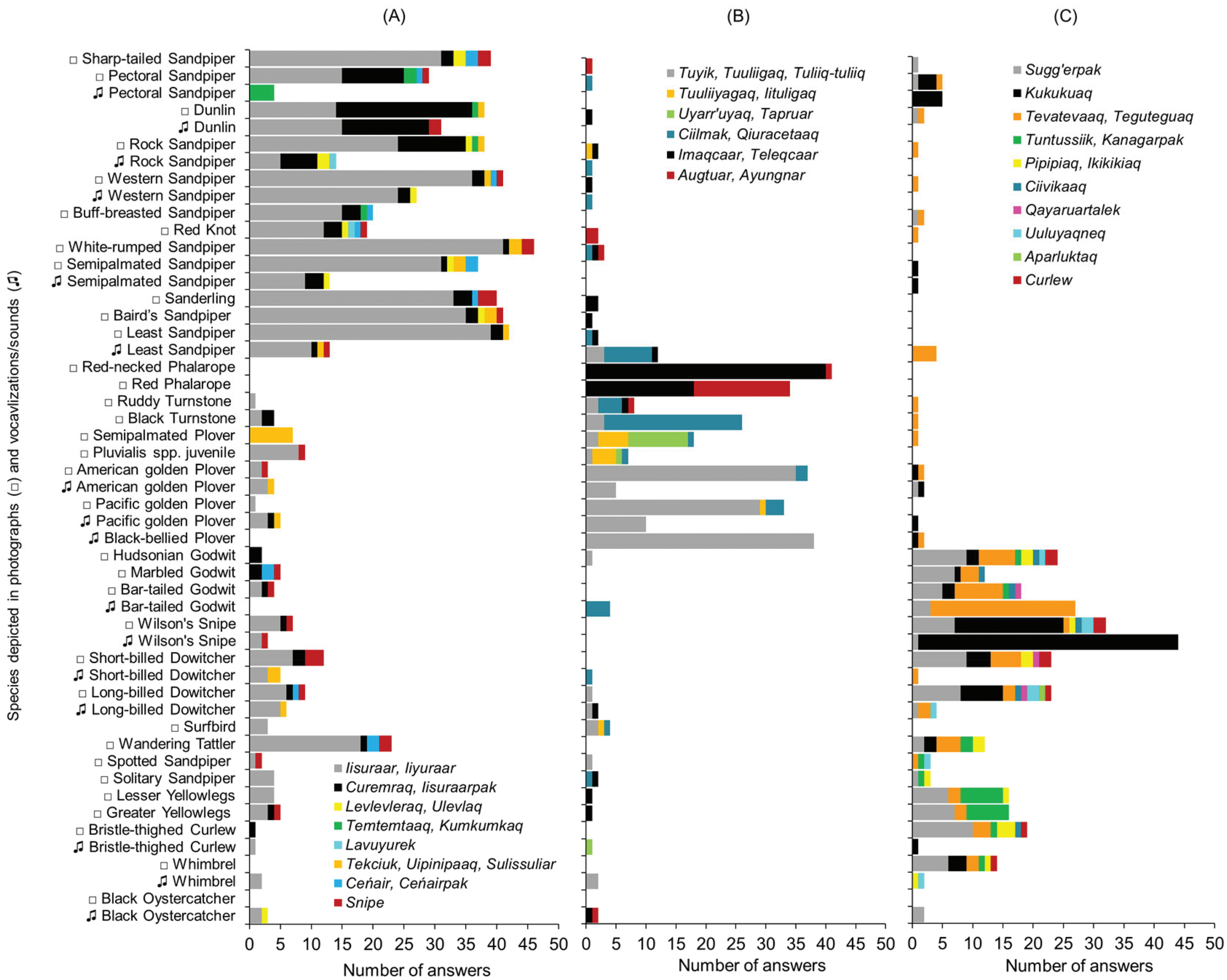

FIGURE 5. Words used by respondents to name shorebird photographs and sounds. Species represented in photographs and sounds were listed on the *y*-axis to approximately depict main categories in Yup'ik ethnotaxonomy. To facilitate representation of many names, results were divided in 3 panels: (**A**) small sandpipers and "snipe" (shorebirds in general); (**B**) Black-bellied/Golden plovers, Semipalmated Plover, turnstones, and phalaropes; and (**C**) shorebirds with a long bill.

salient names: *iisuraar/iiyuraar* (small sandpipers), *tuyik/tuuliigaq* (*Pluvialis* spp.), and *imaqcaar/teleqcaar* (phalaropes). The frequency of occurrence of names in all ethnotaxonomy activities together identified 4 other salient names: *kukukuaq* (Wilson's Snipe [*Gallinago delicata*]), *ciilmak/qiuracetaaq* (turnstones), *tevatevaaq/teguteguaq* (godwits), and *curemraq/iisuraarpak* (Dunlin [*Calidris alpina*]) (Supplemental Material Figure 8).

Variation in local ethnotaxonomies likely reflect species abundance. For instance, all respondents in Platinum were familiar with *pipipiaq* (Whimbrel and likely other shorebirds with a long bill), while few respondents in other communities were familiar with this name (frequency of occurrence [$\text{FO}_{pipipiaq}$] = 0–18%). Conversely, fewer respondents in Platinum were familiar with other names for shorebirds with long bills ($\text{FO}_{sugg'erpak}$ = 11%, $\text{FO}_{tevatevaaq/teguteguaq}$ = 22%) as compared to the other communities ($\text{FO}_{sugg'erpak}$ = 24–72%, $\text{FO}_{tevatevaaq/teguteguaq}$ = 50–92%). *Pipipiaq* stops in fall in Platinum to feed on highly productive berry fields. Hooper Bay respondents were more familiar with *tuuliiyagaq/iituligaq* (young *Pluvialis* spp., $\text{FO}_{tuuliiyagaq/iituligaq}$ = 56%) and *augtuar/ayungnaar* (Red Phalarope, $\text{FO}_{augtuar/ayungnaar}$ = 67%) than respondents in other communities ($\text{FO}_{tuuliiyagaq/iituligaq}$ = 0–9%, $\text{FO}_{augtuar/ayungnaar}$ = 0–17%), who more often used *imaqcaar/teleqcaar* for both phalarope species.

Pluvialis spp. (*tuyik/tuuliigaq*) and especially the Black-bellied Plover (*P. squatarola*) were recognized by their vocalization and black and white plumage (Figure 5B). *Tuyk/tuuliigaq* eggs are highly prized because they are difficult to find and are relatively large (see also Brandt 1943). Juveniles are occasionally harvested in fall when they are fat, although this activity seemed to be more frequent in the past.

Most respondents readily named *kukukuaq*'s (Wilson's Snipe) sound and described its aerial displays, but a smaller proportion of respondents named a photograph (Figure 5C). Several traditional beliefs referred to *kukukuaq* including weather forecasting, harvesting of their eggs, and human vision loss. However, respondents' recalling of these beliefs were often unclear, suggesting they are being forgotten.

The Black Turnstone (*Arenaria melanocephala*) (*ciilmak/qiuracetaaq*) is recognized by its black and white plumage. Turnstones are seen feeding at dumpsites and on maggots in fish carcasses at fishing camps. Occasionally, at least in the past, turnstone chicks were captured to be raised as house pets, then released in fall to join the southbound migration.

Shorebirds as Yup'ik cultural resources. A Yup'ik wooden mask collected in the early 1900s representing a godwit (accession number NMAI 9/3415) suggests cultural ties to shorebirds. Masks from this period usually had a story connecting their icons to the traditional way of life and featured in winter festivals that culturally dealt with the abundance of hunted animals (Fienup-Riordan 1996). Unfortunately, little is known about this mask's meanings. Intangible cultural resources relating to shorebirds included stories, a song, place names, and worldviews. Three Yup'ik place names referred to locations where shorebirds likely are or were abundant: *Tevatevaaq* Bay (Tvativak Bay in Orth [1971]; 58°50′18.57″N, 159°32′55.54″W), *Tapruarmiut* Beach (60°32′32.77″N, 165°1′36.99″W), and *Tuyiigtalek* Valley (60°31′51.39″N, 165°9′16.69″W). Further ethnographic details were documented in Naves and Keating (2019b).

Respondents highlighted that shorebirds and other birds are an integral and joyful part of the landscape. In spring, arriving birds, their breeding displays, and sounds indicate the end of the long winter. By relating with birds as sentient beings, some respondents demonstrated close connection with nature ("*When the birds leave in fall I say to them: goodbye and come back again. My grandmother said the same thing. We don't say goodbye in Yup'ik; we say come back again.*").

Respondents associated shorebird harvesting with memories of their grandparents ("*I grew up with Yup'ik and nowadays we speak mostly English to our grandchildren. It's hard for us to remember those long-time-ago words that we hardly use nowadays. Those birds that we hardly see, we hardly remember. My grandma has been gone for about 30 years; she was the one who taught me. Maybe we are the last ones that know how to speak the true Yup'ik and we're forgetting so much. That is too bad.*"). Older generations associated shorebirds with a past when people were in closer contact with nature and their cultural roots, and voiced concerns about loss of their traditional language and culture, which is also reflected in changes in harvesting practices ("*The people that knew more about these birds are gone. We're sort of* [*cultural*] *zombies: we don't really know much because all that good knowledge that our parents used to have is pretty much gone. I wish I had recorded all my dad's stories because he used to tell interesting stories about birds. I don't think anybody knows that kind of story anymore.*"). There was a tendency for respondents of older generations to be more familiar with shorebird names, but some bird experts belonged to younger generations (Figure 6).

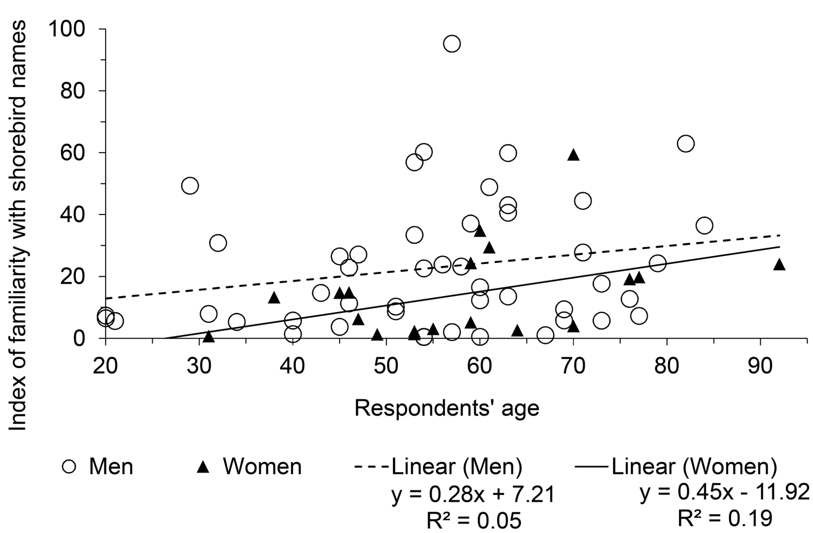

FIGURE 6. Relationship between respondents' age and their index of familiarity with shorebird names.

Changes in shorebird abundance and perceived causes. Many respondents reported that shorebird numbers are noticeably lower than in the past. Some hunters no longer harvest shorebirds because they are scarce ("*I haven't hunted* [*shorebirds*] *in a while. I hardly see them around. Their numbers are going down and I don't want them to go extinct, so I wait* [*to hunt*] *until there are more.*"). Reduced numbers of shorebirds and songbirds were of concern because birds reflect the quality of the environment ("*With any of the species we have, they don't need to be food sources, they contribute to the natural diversity we have here.*"). A few respondents were not concerned because shorebirds are not primary subsistence resources.

Respondents were often unsure why shorebird numbers are reduced. Local factors were most commonly cited, especially traffic of all-terrain vehicles, bird harvest by children, and egg harvest. Focusing on the environment around their communities, respondents often assumed that birds from their area moved elsewhere and that shorebird abundance remains high in other places. Some respondents referred to pollution and increased human activity at a large geographic scale including the 2011 Fukushima radioactive accident in Japan, oil spills, and noise from airplane traffic. Respondents were largely unaware of shorebird wintering grounds, migratory routes and ecology, and threats outside breeding grounds.

DISCUSSION

Shorebirds and Their Eggs as Subsistence Food Resources in Alaska

Shorebirds are not currently main subsistence resources in Alaska, but likely they were more important as food in the past. Archeological records document shorebird harvest in Alaska thousands of years ago (Casperson 2012, Corbett 2016). The current total subsistence harvest of birds in Alaska is ~400,000 birds per year including ducks (49%), geese (29%), crane (2%), swans (2%), grouse and ptarmigan (12%), seabirds (6%), and shorebirds (~1%) (Paige and Wolfe 1998, L. C. Naves personal observation). Shorebird eggs (4,678 eggs per year, this study) also are a small part of the total subsistence egg harvest in Alaska (~180,000 eggs per year; Paige and Wolfe 1997). Besides being harvested in relatively low numbers, shorebirds and their eggs make a small contribution to food production due to their small size: the edible mass of the largest shorebird is comparable to that of the smallest duck (Naves and Fall 2017).

In western Alaska, historically, indigenous peoples sometimes experienced hunger and starvation in winter. A rainy summer (during which not enough fish could be dried and stocked) combined with a subsequent prolonged winter produced hardship until at least the 1990s (Fienup-Riordan 1994). In spring, arriving migratory birds relieved hunger. Although shorebirds are small, they were hunted in spring along with other birds. Thus, migratory birds hold a special place in Yup'ik culture (see below). Modern socio-economic conditions prevent famines in remote communities in Alaska, but food security still is a concern, and people sometimes need emergency meals. The cultural and emotional value of resources that traditionally alleviated hunger still is present in subsistence communities, especially among the older generations. Reliance on diverse resources is a food security strategy in remote communities.

Godwit Harvest

Most of the Alaska-wide harvest of godwits occurred in the Yukon-Kuskokwim Delta South Coast (1,096 birds per year; this study). Previous godwit harvest estimates for individual years in the 2004–2017 period for the whole Yukon-Kuskokwim Delta ranged 26–4,639 birds per year (Naves and Keating 2019a). The high end of estimates in this range likely overestimates harvest due to annual data from high-harvest communities being extrapolated to non-surveyed low-harvest communities. Conversely, the low end of estimates in this range likely underestimates harvest, due to data from low-harvest communities being extrapolated to non-surveyed high-harvest communities. Harvest estimates were improved in our study because all communities were represented, and our analytical approaches accounted for spatially variable harvest patterns.

Harvest preference for individual species of large shorebirds is unlikely because these birds are often not identified at the species level. But harvest selectivity often occurs via indirect processes. Most harvested birds reported as godwits in the Yukon-Kuskokwim Delta South Coast are likely Bar-tailed Godwits because this region hosts their main fall staging sites where birds congregate for weeks in large flocks at coastal bays and estuaries that are relatively accessible to harvesters (Gill and McCaffery 1999). Marbled Godwits (*Limosa fedoa*) do not occur in this region and Hudsonian Godwits (*L. haemastica*) occur at remote inland sites where they are unlikely to be harvested (Gibson and Kessel 1989, McCaffery et al. 2005, Gibson and Withrow 2015). Whimbrels and Bristle-thighed Curlews could be confounded with godwits but migrate through the Yukon-Kuskokwim Delta South Coast in small flocks dispersed at upland areas (Handel and Dau 1988), and thus are unlikely to be harvested in significant numbers.

Annual harvest in Alaska represented only 1.2% of the *baueri* Bar-tailed Godwit population but approached the estimated sustainable human-related mortality (population biological removal, PBR) in the East Asia–Australasia Flyway (1,184 birds per year, Table 1; Turrin and Watts 2016). Outputs of PBR models are bound to uncertainty in estimates of population size, adult survival, and age of first reproduction, and tend to be conservative because adult survival estimates already include human-related mortality (Watts et al. 2015, Turrin and Watts 2016). Nevertheless, PBR outputs indicate a low harvest potential for the *baueri* population. Adult birds have higher survival and reproductive value for populations, thus harvest of hatch-year birds has lower impact on populations (Sandercock 2003, Lyver et al. 2015). More than half of the godwit harvest in Alaska happens in fall, but the proportion of hatch-year birds varies by year (McCaffery et al. 2006).

Even low harvest levels may be unsustainable for species that naturally occur in small numbers, are sensitive to changes in mortality, or have decreasing populations (Watts et al. 2015). Whether harvest in Alaska currently is a threat to Bar-tailed Godwits and other shorebirds depends on population status and threats at other sites along their migration routes (Woodley 2009, Turrin and Watts 2016, Reed et al. 2018). Wintering habitat loss is the main threat for shorebirds in the East Asia–Australasia Flyway, but harvest and other sources of mortality can also play a role in population declines and recovery capacity (Hua et al. 2015, Piersma et al. 2016, Studds et al. 2017). In China, annual mortality by harvest with nets, traps, poison, and incidental bycatch in fishing gear may amount to tens of thousands of shorebirds per year (Melville et al. 2016). Refining estimates for Bar-tailed Godwit population parameters and quantifying sources of mortality at key sites are top priorities, but this information is challenging to gather (Woodley 2009). Meanwhile, timely conservation efforts will require outreach and communication to engage stakeholders across the flyway and implement actions that are socio-culturally sensible.

Harvest Assessment

Shorebird harvest data have been regularly collected in Alaska over many years covering a large geographic area. Lessons compiled in this study can inform improvements to harvest assessment and management in other hunting traditions and places. Harvest estimates for shorebirds are prone to having wide confidence intervals. First, the composition and magnitude of harvests often vary widely between years because of socio-economic and ecological factors (Wolfe et al. 1990, Fall et al. 2013). Second, in broad-coverage surveys, harvest estimates for resources taken infrequently or in small numbers (such as shorebirds) are less accurate than estimates for commonly taken resources (Copp and Roy 1986, George et al. 2015). A large dataset (as used in this study) helps to detect and smooth irregularities in harvest numbers, but wide confidence intervals around estimates are still expected.

Previous shorebird harvest estimates were lower than those in this study: 741 birds and 2,741 eggs per year in the early 1990s; 1,411 birds per year in the mid-1990s (Paige and Wolfe 1997, 1998). Rather than an increase in harvest, the current estimates appear to depict improved harvest assessment, especially the representation of meaningful categories in harvest surveys. For instance, earlier surveys did not depict godwits (which accounted for 40% of the current harvest estimates), considered shorebirds and seabirds together as "other birds," or did not detail categories within shorebirds (Wolfe et al. 1990, Paige and Wolfe 1997, 1998).

Our harvest estimates portray cultural importance and food productivity in subsistence economies, but they may not fully represent shorebird hunting mortality. Shorebirds are harvested by children and sometimes fed to dogs. Such take may not be considered as home use and reported in harvest surveys. Also, we did not account for crippling. Future harvest surveys could specifically ask about shorebird harvest by children. Studies addressing true adult mortality in shorebird populations can explicitly account for harvest, which may be a more direct approach to assess harvest impacts on populations (Watts et al. 2015, Turrin and Watts 2016, Weiser et al. 2017).

This study increased awareness about the importance of shorebird eggs as subsistence resources in Alaska. However, about one-third of the egg harvest was documented as "shorebirds (unidentified)," indicating the need to identify categories within shorebird egg harvest. Impacts of egg harvest depend on timing and frequency of harvest (Zador et al. 2006). Shorebird nests are dispersed and difficult to find. In contrast to colony-breeding birds, shorebird egg harvest may have fewer indirect impacts such as colony disturbance and facilitation of predation.

English names can be confusing in harvest surveys. The AMBCC-HAP survey has not included Wilson's Snipe. Common Snipe (which refers to the Old World *Gallinago gallinago*) is used in other surveys conducted in Alaska, but for subsistence users, "snipe" often refers to all shorebirds. Also, the word "common" is often understood in ethnotaxonomies as the most common species locally available (Naves and Zeller 2017). Respondents tended to combine shorebirds with long bills (including godwits, Whimbrel, and Bristle-thighed Curlew) in the category *sugg'erpak*, for which they also used the English word "curlew." Thus, the words "snipe" and "curlew" should be avoided in subsistence harvest surveys. Yellowlegs (*Tringa* spp.), dowitchers (*Limnodromus* spp)., and the Semipalmated Plover have not been represented in harvest surveys conducted in Alaska. This study determined that these birds were not widely known, but they may be opportunistically harvested.

This study clarified issues related to shorebird representation and species identification in harvest surveys. Knowledge about ethnography and ethnotaxonomies helps to refine harvest assessments (Baraloto et al. 2007, Previero et al. 2013, Naves and Zeller 2017). But the representation of shorebird species in harvest surveys in a manner that is compatible with local ethnotaxonomies remains challenging. Species-, age-, and sex-specific composition information for shorebird harvests may ultimately rely on a species identification system based on biological sampling, such as bird parts or photographs provided by hunters (Carney 1992, Solokha and Gorokhovsky 2017, Reed et al. 2018).

Harvest Management

Legally authorized take of shorebirds in Alaska include spring–summer subsistence harvest of birds and eggs of 18 species (April 2–August 31; U.S. National Archives and Records Administration 2019a) and fall sport hunting of Wilson's Snipe (starting September 1; U.S. National Archives and Records Administration 2019b; Table 1). In contrast, subsistence harvests in Alaska have traditionally occurred year-round following the seasonal availability of animals and plants (Wolfe et al. 1990). Subsistence harvest of migratory birds in fall tends to follow traditional practices rather than the more restrictive sport hunting regulations, which do not authorize take of most shorebirds. Nevertheless, 40% of the shorebird harvest (mostly godwits) occurs in fall–winter. Indigenous partners of the Alaska Migratory Bird Co-Management Council have petitioned for harvest regulations that are more compatible with their seasonal harvest practices, but this issue remains unresolved (Alaska Migratory Bird Co-Management Council 2019b).

Because shorebird species are difficult to identify, harvests are likely to include incidental take of species not legally authorized. Incidental take of other shorebird species in the fall Wilson's Snipe hunt (14,567 birds per year in the Pacific Flyway; Olson 2017) is likely but has not been evaluated (Case and McCool 2009). In western and indigenous cultures, a small proportion of people learn the details of morphology, plumage, and behaviors that together allow correct identification of shorebird species (Irving 1958). Also, full compliance with harvest regulations is difficult to achieve because bird harvest in Alaska occurs in vast and remote areas, within a particular socio-cultural context. Restrictive species-specific harvest regulations are impractical and unlikely to, alone, ensure adequate harvest management. Considering lingering uncertainties on shorebird harvest sustainability, outreach and education to increase awareness about species identification, ecology, and population trends are critical to engage western and indigenous harvesters in conservation based on the principle that sustainable harvests are in their best long-term interest.

Shorebirds as Yup'ik Cultural Resources

This study documented main aspects of the importance of shorebirds to Yup'ik people and provided context to harvest estimates. Nevertheless, despite efforts to engage relevant communities and knowledgeable respondents, this study may not have completely portrayed knowledge and perspectives about shorebirds in Yup'ik culture. Harvest and limited ethnographic information suggest that communities in the Yukon-Kuskokwim Delta South Coast represent a large part of the shorebird harvest (see also Stickney 1984). These communities have occasionally participated in harvest surveys but declined to participate in interviews in this study. The Yup'ik bird ethnotaxonomy at large remains to be documented and would clarify relationships of shorebirds with other bird categories. Also, there have not been assessments of indigenous knowledge of shorebirds in other Alaska cultures.

Traditional Yup'ik culture included complex beliefs and ceremonies intertwined in daily life that defined permeable boundaries among human, animal, and spirit worlds. Birds held a special place in Yup'ik cosmology (Fienup-Riordan 1994). Young boys learning to hunt focused on small birds including shorebirds, and their skins were dried and ceremonially disposed of to release the birds' souls for future lives (Brandt 1943, Irving 1958, Fienup-Riordan 1994, 2007). Hunting small birds remains an intrinsic part of becoming a subsistence hunter in Alaska. As children learn to hunt and process their catch, they move on to larger animals and more powerful hunting tools. Despite growing influence of western culture, harvesting, sharing, and consuming wild foods are linked to tradition, identity, social structure, recreation, and self-worth (Fienup-Riordan 1990, 2000; Blanchard 1994).

Dozens of species-specific bird names, including shorebirds, were documented in northern and interior Alaska in the mid-1900s, and the study and knowledge of birds was characterized as an intellectual activity and social amenity beyond their uses as food and materials (Irving 1958). The distribution of such knowledge across populations remains unknown. It is possible that intellectual foci differ among cultural groups, only a small proportion of populations study birds, and socio-cultural changes have resulted in loss of traditional knowledge. In our study, limited familiarity with shorebirds seems related to their status as non-primary resources ("*The ones we don't harvest we don't know.*"). Handling shorebirds provides opportunities to associate details of form and color with clues observed in live birds. Subsistence users usually identify birds based on main morphology, color, sound, and behavior observable by bare eyes, which in shorebirds often do not allow identification at the species level. Although shorebird vocalizations can allow species-specific identification, our results indicated that respondents sometimes did not connect bird sounds with images.

It is possible that material and intangible cultural resources related to shorebirds are lost or particularly difficult to uncover because of cultural changes and reduced shorebird use (Godoy et al. 2005, Alessa et al. 2010). However, vestiges of old traditions help understanding modern Yup'ik perspectives on harvest management and resource conservation (Fienup-Riordan 1990, 2000). Infrequently used bird names offer opportunities to reconnect people with their traditional knowledge, language, and culture. Also, shorebirds and other birds connect Yup'ik people with their environment and are integral to the spring soundscape (Moscoso et al. 2018).

Opportunities in Shorebird Conservation

It is well known that connections with the local environment and traditional ways of life are key for community well-being and community-based conservation (Blanchard 1994, Ruiz-Mallén and Corbera 2013). In this study we identified shorebird connections with Yup'ik traditions, language, and environment. Respondents were eager to learn about shorebird migratory routes, ecology, and threats as well as their Yup'ik names and connections with Yup'ik and other indigenous cultures (e.g., Hayward and Diamond 1978, Kuaka Project Team 2018).

Increased awareness of shorebird ecology and conservation status among subsistence users including children can inform their behaviors, attitudes, and the emergence of culturally sensible conservation practices. While external pressure to curtail shorebird hunting may be a sensitive topic (Fienup-Riordan 1990, 2000), community-based initiatives may provide alternatives for learning hunting skills and minimize non-consumptive mortality. Increased interaction of indigenous stakeholders with biologists, managers, and conservationists can facilitate sharing of Yup'ik ecological knowledge that can greatly benefit western cultures and research. For instance, some respondents clearly articulated their understanding of connectedness among ecosystem elements including people, and a unique way to relate with birds and other animals as sentient beings.

Shorebird conservation efforts that are socio-culturally sensible for subsistence communities include approaches such as (1) conduct outreach and education for increased awareness about shorebird ecology and conservation, highlighting that harvest sustainability is in the best interest of subsistence communities; (2) support transmission of traditional knowledge and languages and interactions between elders and youth; (3) support local efforts that benefit shorebirds and their environments; (4) include traditional knowledge and facilitate participation of indigenous stakeholders in research, management, and conservation; (5) support local economic initiatives based on sustainable uses of shorebirds (e.g., ecotourism and birding); and (6) collaboratively develop conservation approaches that are inclusive of traditional uses and the cultural importance of shorebirds (Blanchard 1994, Lyver et al. 2015, Naves and Keating 2019b). Harvest, ethnographic, and ethnotaxonomy information generated in this study as well as partnerships developed with local communities established a basis for such approaches.

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Ethics statements and guidelines: Participation of communities and respondents in indigenous knowledge interviews was voluntary and followed ethical principles for social science research (Alaska Federation of Natives 1993, Arctic Research Consortium of the U.S. 1999). Community consent to conduct interviews was granted as tribal council resolutions. Consent was also obtained from all interview respondents. Preliminary study results were provided for input by the studied communities and other stakeholders. Summary results in English and Yup'ik were distributed to the communities.

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