Polar Biology
https://doi.org/10.1007/s00300-021-02965-7

ORIGINAL PAPER

Habitat use by threatened sheldgeese (*Chloephaga* spp.) in Austral Patagonia at two spatial scales

Natalia A. Cossa[1,2] · Laura Fasola[2,3] · Ignacio Roesler[1,2,4] · Hernán Dieguez[5] · Juan C. Reboreda[1]

Received: 10 May 2021 / Revised: 11 October 2021 / Accepted: 28 October 2021

Abstract

Upland Goose *Chloephaga picta*, Ashy-headed Goose *Chloephaga poliocephala* and Ruddy-headed Goose *Chloephaga rubidiceps* are endemic goose-like threatened birds of southern South America. This work aimed to study how sheldgeese are distributed both temporally and spatially and characterize their habitat use in part of their breeding range in Southern Argentina, a little-explored subpolar region. We conducted nine surveys between spring 2013 and summer 2016 across a maximum of 235 km in Santa Cruz and 698 km in Tierra del Fuego per survey. We recorded the presence of non-breeding sheldgoose groups and Upland Goose pairs. We collected data at site-scale (~ 0.8 km^2) and extracted data from geographic information systems for landscape-scale (5 km^2) analyses. We recorded 2396 non-breeding groups containing one, two or the three species, 788 Upland Goose pairs and 102 solitary individuals. The Upland Goose was present in almost all groups and was the most abundant sheldgoose, followed by the Ashy-headed Goose. The Ruddy-headed Goose was observed only in 15 locations. *Poa* grasslands, meadows and *Festuca* grasslands were the habitats in which we detected most individuals. Sheldgoose density was higher in Tierra del Fuego than in Santa Cruz, and increased from spring to autumn and decreased in winter. The largest sheldgoose groups were concentrated in meadows and waterbodies. Sheldgeese selected sites with greater habitat diversity, habitat richness and number of habitats patches. Our results provide information to understand which environmental conditions favour sheldgeese and to aid in the selection of important areas for the conservation of these species.

Keywords Birds · Conservation · Endangered species · Spatial scales · Argentina

Introduction

Habitat use is the way in which an animal uses the physical and biological resources of a habitat (Krausman 1999) and distribution and activity patterns of animals are indicators of habitat quality and suitability. When habitats are used disproportionately to their availability, the use is selective. For birds, habitat selection is the result of hierarchical decisions based on different environmental cues (Block and Brennan 1993), which are usually associated with spatial and temporal variation in the quantity and quality of food resources, predation, inter and intra specific competition and the presence of suitable nesting sites (Chudzińska et al. 2015). The presence of anthropogenic elements and disturbances (i.e. buildings, settlements, roads, industrial infrastructure, hunting, amongst others) are other factors that could influence habitat use (Béchet et al. 2004; Tian et al. 2021). Determining which habitats are selected over others provides important information about the nature of a species and how it meets its requirements (Manly et al. 2004) and, therefore,

✉ Natalia A. Cossa
ncossa@ege.fcen.uba.ar

[1] Departamento de Ecología, Genética y Evolución & Instituto de Ecología, Genética y Evolución de Buenos Aires (IEGEBA-UBA-CONICET), Facultad de Ciencias Exactas y Naturales, Universidad de Buenos Aires, Pabellón II Ciudad Universitaria, Buenos Aires, Argentina

[2] Programa Patagonia, Aves Argentinas, Buenos Aires, Argentina

[3] Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET)-Dirección Regional Patagonia Norte, Administración de Parques Nacionales, O'Connor 1180, San Carlos de Bariloche, Río Negro, Argentina

[4] EDGE-ZSL Affiliate, London, England

[5] Departamento de Métodos Cuantitativos y Sistemas de Información, Facultad de Agronomía, Universidad de Buenos Aires (FAUBA), Buenos Aires, Argentina

Published online: 09 November 2021

this information has key implications for the conservation of the species and its management.

Migratory sheldgeese (continental Upland Goose *Chloephaga picta picta*, Ashy-headed Goose *Chloephaga poliocephala* and continental Ruddy-headed Goose *Chloephaga rubidiceps*) are endemic to southern South America. The Ruddy-headed and Upland Geese have also separate and genetically distinct sedentary populations in the Malvinas/Falklands Islands (Bulgarella et al. 2013; Kopuchian et al. 2016). At present, the continental, migratory populations are threatened by illegal hunting, overgrazing and invasive predators (Canevari 1996; Madsen et al. 2003; Petracci et al. 2015a). Ruddy-headed Goose is classified as critically endangered (MAyDS and AA 2017, MMA 2019), with an estimated population of fewer than 1000 individuals (Cossa et al. 2017; Petracci and Carrizo 2017; Pedrana et al. 2018a). Ashy-headed Goose and the Upland Goose are categorized as 'endangered' in Argentina (MAyDS and AA 2017). These goose-like species of the subfamily Tadorninae share anatomical and behavioural characteristics with the true geese (Anserinae) and the true ducks (Anatinae) (Livezey 1997; Johnsgard 2010). Migratory sheldgeese exhibit seasonal migrations like many waterfowl species of the northern hemisphere (Baldassarre 2014). They migrate in large mixed flocks from the breeding grounds in Southern Patagonia (Argentina and Chile) to wintering grounds in northern Patagonia and the southern part of the Pampas region (Canevari 1996, Fig. 1). On the breeding grounds, the three species frequent the steppe, however, the Ashy-headed Goose reproduces in the forested and ecotonal areas, whilst the Ruddy-headed Goose reproduces only in the Magellanic steppe (Matus et al. 2000). The Upland Goose is the most widely distributed, and it reproduces mainly in the steppe. These species are herbivorous, and at breeding grounds, they feed mostly (80%) on grasses (Antonijevic 2012).

During the breeding season (austral spring and summer), sheldgoose pairs select a territory and defend it. This territory is usually close to a wetland (Summers and McAdam 1993), which the pair with their goslings use as a quick escape route from terrestrial predators. Non-breeding individuals flock together in large groups at feeding sites during the day and roosting sites at night (Summers and McAdam 1993). In summer, some sheldgeese gather in wetlands to moult all flight feathers simultaneously and remain flightless for about a month, whilst some individuals skip the moult (Summers and Martin 1985). During austral autumn (May–June), most individuals of the three species migrate to the wintering grounds (Pedrana et al. 2018b, 2020). Some individuals do not migrate and remain on the breeding

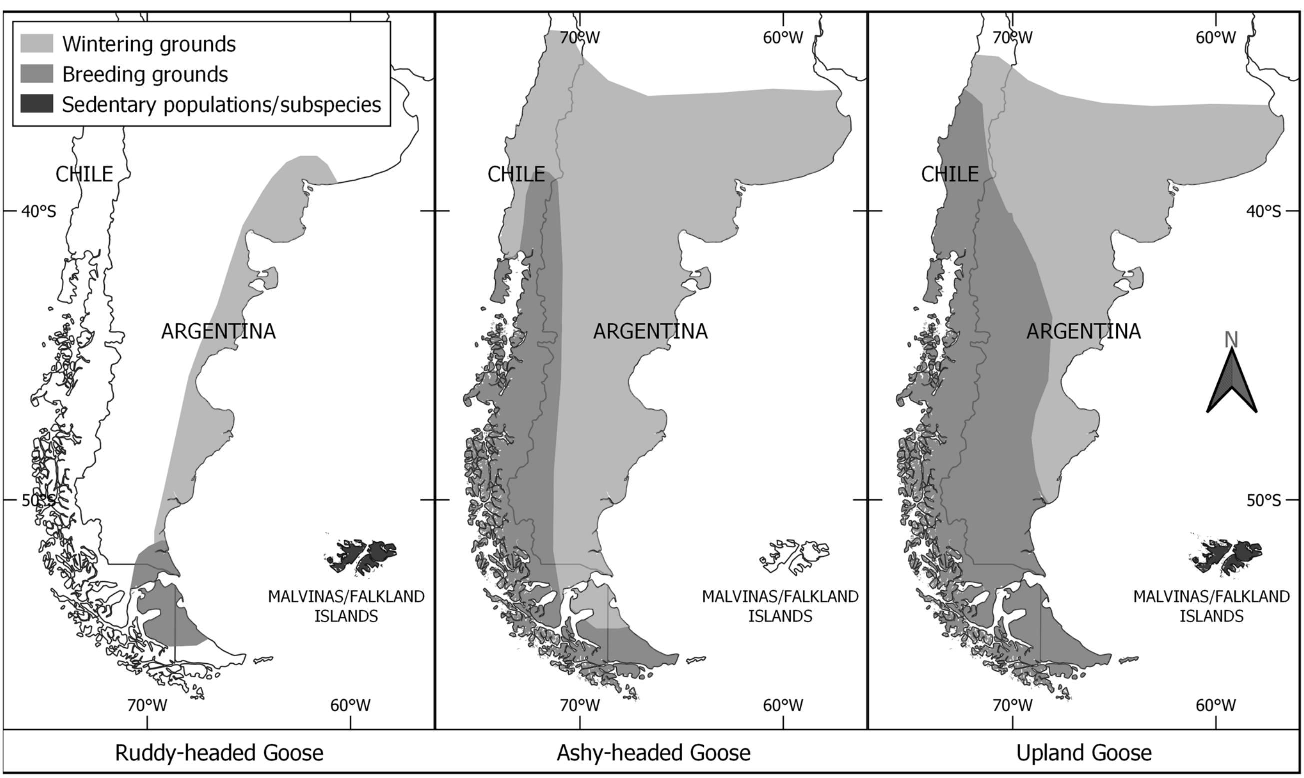

Fig. 1 Geographic ranges of migratory sheldgeese in Argentina and Chile. Sheldgoose spatial data was obtained from NatureServe and UICN (2008)

grounds all year, gathering in large feeding groups in sites where food is available during winter (Martin 1984).

There is a lack of information regarding variables that determine the distribution of migratory sheldgeese in the Magellanic steppe, an area that historically concentrated large groups and breeding pairs, mainly of Ruddy-headed Goose. Therefore, this work aimed to study how sheldgeese are distributed both temporally and spatially in part of their breeding grounds in Southern Argentina. We described sheldgoose aggregation patterns and, for the only dimorphic species (Upland Goose), the sex ratio, which is an important aspect of the population demographics of endangered species and has key implications in their conservation. We were particularly interested in characterizing sheldgoose habitat use at two spatial scales: site and landscape scales. At site-scale (~ 0.8 km^2), we analysed habitat use at the moment of observation of sheldgeese, whilst at the landscape-scale (5 km^2) we analysed habitat use in an area that is assumed to encompass the daily movements of individuals (Pedrana et al. 2015, 2018b). We hypothesized that sheldgeese are attracted to diverse areas containing habitats with high food availability and habitats that offer refuge, near wetlands and without human disturbance. At the site-scale, we predicted that sheldgeese would be attracted to meadows or *Poa* grasslands and any type of wetland. At the landscape-scale, we predicted that sheldgeese would be attracted to areas with a high diversity of habitats, with meadows and *Poa* grasslands as dominant habitats, high NDVI (as a predictor of primary productivity and, thus, a predictor of food availability), with a high length of watercourses and with a low number of oil wells, as they are a source of disturbance. We predicted that the largest groups would be present in the austral autumn, previous to migration. Based on the life cycle of the species and their migratory nature, we predicted that breeding pairs would be present predominately in the austral spring and summer, and predominantly in Tierra del Fuego because of its more humid environment. Our results will help to prioritize conservation actions by focussing on the most used habitat types and by determining the appropriate time of the year to apply conservation actions. Also, our work broadens the knowledge of a little-explored area of a subpolar region, which is particularly vulnerable to global climate change (Rabassa 2009) and in which scientific research is scarce.

Materials and methods

Study area

The study was conducted in two areas of the southern part of the migratory sheldgoose breeding range in southern Argentina (Figs. 1 and 2). One area was located in Santa Cruz Province (SC) in the southern tip of the South

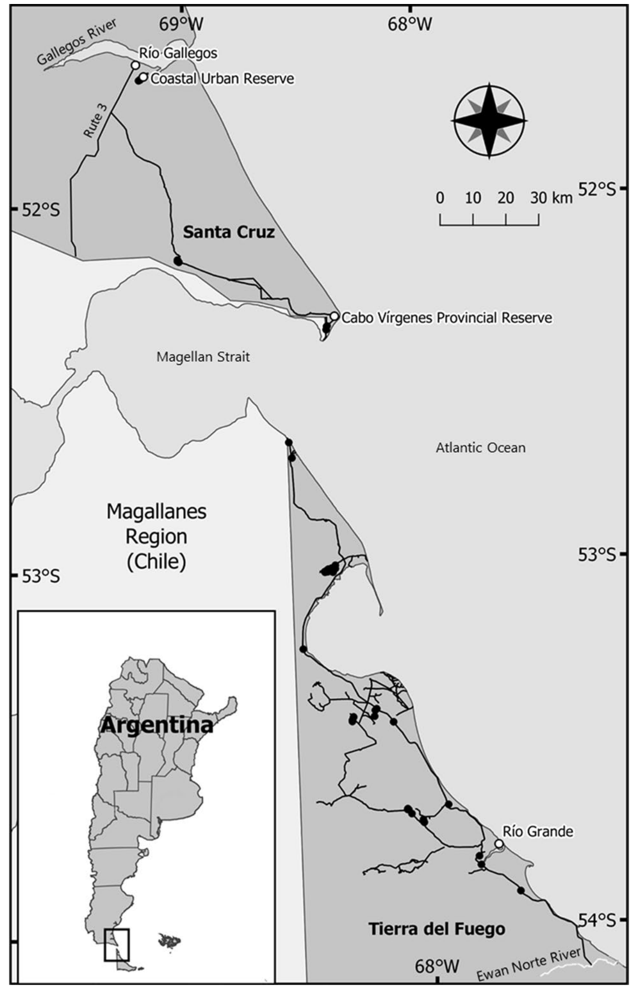

Fig. 2 Study area. Dark grey areas show Argentina and light grey areas show Chile. Black lines inside dark grey areas show the paths followed in the road surveys carried out between 2013 and 2016 in search for sheldgeese. White dots indicate the location of cities and protected areas. Black dots indicate Ruddy-headed Goose sightings

American continent. This area is delimited by the Río Gallegos River in the north (latitude 51° 38′ S), route 3 in the west, the Atlantic Ocean in the east and Chile in the south, comprising approximately 3300 km^2. The second area was in the main Island of Tierra del Fuego Archipelago located in Tierra del Fuego Province (TDF). This area is delimited by Magellan Strait in the north, Chile in the west, Atlantic Ocean in the east and Ewan Norte River in the south (latitude 54° 07′ S), comprising approximately 5900 km^2. These two areas combined are part of the Magellanic steppe and are one of the main sheldgoose reproductive areas and the historic Ruddy-headed Goose reproductive area. Breeding attempts occur in spring (September to December), so in summer (December to March), broods can be observed. In autumn (May–June), most individuals migrate to wintering areas (Pedrana et al. 2018b, 2020), so in winter (June to September), only non-migrant individuals remain in the area.

The Magellanic steppe represents a more humid and oceanic variant of the arid climate that prevails over most of Patagonia, and, within this region, Tierra del Fuego is considerably more humid than Santa Cruz (Oyarzabal et al. 2018). Mean annual precipitation is 300–400 mm, mean annual temperature is 5 °C (average temperature during the coldest month, July, is 0 °C; and during the warmest month, January, is 10 °C) and mean monthly wind speeds exceed 30 km^{-h} during summer (Koremblit and Forte Lay 1991). The whole region has been dramatically altered since the last decades of the nineteenth century when a Paleolithic culture was supplanted by large-scale sheep ranching. Early fencing resulted in conspicuous degradation patterns driven by the habits of exotic sheep and the management routines (Collantes et al. 2005). Similar to what occurs in subpolar regions of the northern hemisphere, the cold climate and the strong winds that are present most of the year cause harsh environmental conditions for plant growth, keeping the vegetation low. The region is dominated by tussock grasslands, mainly *Festuca gracillima*, associated with shrubby vegetation in varying proportions. Lowlands are associated with shallow lakes, streams or temporarily flooded areas called 'meadows' or 'mallines' where other grasses (e.g. *Poa pratensis*, *Hordeum comosum*), as well as rushes and *Carex* spp. dominate (Madsen et al. 2003; Collantes et al. 2009; Petracci et al. 2014; Anchorena et al. 2016).

Surveys

Between spring 2013 and summer 2016 we conducted nine road surveys. For each survey, we followed all available main roads (national and provincial public routes) and secondary tracks (private) in a vehicle at 40–60 km^{-h}. This speed was selected to optimize detection and coverage over the wide study area. We surveyed a maximum of 235 km in Santa Cruz and 698 km in Tierra del Fuego per survey (Online Resource 1, Tables S1, S2). We recorded the presence of sheldgeese along a strip of 500 m at both sides of the road. Previous to surveys, we trained the observers by placing several posts in the field at known distances (50, 100, 200, 300, 400 and 500 m). For each sheldgoose sighting, we recorded the observer position (latitude and longitude) on the road, the distance between sheldgeese and the observer determined visually, the angle formed between the direction of the observation and the north with a compass, the number of adults, goslings and early juveniles (which are easily distinguishable up to 50 days of life, Matus 2012) of each species and their sex (only for the Upland Goose which is sexually dimorphic). Observations were conducted using 10×42 and 8×32 binoculars and a 20–60 × spotting scope. We recorded the path of the road surveys and sightings information using a mobile device and the software CyberTracker (www.cybertracker.org). We used CyberTracker to calculate the real position of sheldgeese using the observer position on the road, the distance between sheldgeese and the observer and the angle formed between the direction of the observation and the north. All repeat surveys were conducted along the same roads (Fig. 2). However, it was not possible to keep the sampling effort constant in all seasons due to climatic conditions (snow, rain and windstorms) that affected the condition of the roads and visibility (e.g. some paths could not be surveyed in winter). Although some individuals may not have been detected in areas of high vegetation during the surveys, these areas are scarce (coverage of shrubs in the area is between 2 and 5%, Table 1) and the 500 m strip is effective for spotting sheldgeese given the open nature of the steppe environment and the size of the species (standing 60–65 cm tall; Martín 1984; Petracci et al. 2013, 2014, 2015b).

Data collection for site-scale analyses

For each sheldgoose sighting, we visually delimited a circular area of 500 m radius (centred on the position of sheldgoose group or pair, ~ 0.8 km^2) and recorded three variables. (1) Habitat: most prevalent vegetation physiognomy using Gibbons et al. (1998) and Petracci et al. (2013) classification, with minor adaptations (see description and proportion of the area occupied by each of the six types of habitat in Table 1 and Online Resource 1 Figure S1). (2) Distance to the nearest wetland (m): we considered only those at < 500 m. (3) Type of wetland: watercourses (rivers, streams and canals), waterbodies (lakes), flooded areas (low-lying lands that are naturally flooded) and sea.

Data collection for landscape-scale analyses

We delimited a circular buffer area of 5 km^2 (hereafter 'buffer cells') with the centre in the position of every recorded sheldgoose. From the available literature (Pedrana et al. 2015, 2018b), we are assuming that sheldgeese use in a day an area of approximately 5 km^2. However, we are conscious that there is an important assumption we made from Pedrana et al. (2015) reports about the migration of one migrant Upland Goose which used an area of 5 km^2 during the day in two of the sites where it was recorded. Then, Pedrana et al. (2018b) reported that an Upland Goose moved on average 0.76 ± 0.69 km^{-day} during the breeding season and 0.67 ± 0.54 km^{-day} during the wintering season, ranges that fall inside our chosen area. To assess landscape variables (see description below) availability in the study area, we randomly chose the same number of 5 km^2 buffer cells (as the number of sheldgoose observations), distributed across the study area (hereafter 'random cells').

Table 1 Description and percentage of the area occupied by the different types of habitat, the extension of wetlands and the number of oil wells in the study areas in Tierra del Fuego and Santa Cruz

Habitat	Description	Vegetation height	Tierra del Fuego	Santa Cruz
Festuca grasslands (%)	Community dominated by *Festuca gracillima* with a low proportion of *Chilliotrichum diffusum* and *Empetrum rubrum*. On some occasions, it appears as pure *Festuca* units	20–50 cm	45	82
Meadows (%)	Area of low-lying land that is flooded temporary or permanent dominated by cyperaceae, hygrophilous plants and juncaceas. We included in this category the valleys and banks of watercourses and waterbodies	5–20 cm	23	1
Poa grasslands (%)	Community dominated by *Poa* spp., small grasses and herbs, with a low proportion of *F. gracillima*	20–50 cm	12	0
Heather fields of *E. rubrum* (%)	Community dominated by *E. rubrum*. High proportion of bare soil and lichen, scarce *F. gracillima* and *C. diffusum*	5–20 cm	10	2
Scrub (%)	Community dominated by shrubs (*C. diffusum*, *Lepidophyllum cupressiforme*, *Berberis buxifolia*, etc.), with a low proportion of *F. gracillima* and *E. rubrum*	0.5–1 m	5	2
Bare soil–Human altered (%)	This category includes human infrastructure such as roads, quarries and abandoned oil wells	0–5 cm	3.5	12
Waterbodies (km$^{2\text{- km2}}$)	Lakes		0.53	0.03
Watercourses (km$^{-\text{ km2}}$)	Rivers, streams and canals		0.53	0.16
Oil wells (n$^{\circ-\text{km2}}$)			0.34	0.1

Data were obtained by randomly choosing 5 km^2 cells from vegetation physiognomy maps and thematic layers. For Tierra del Fuego, we used Anchorena et al. (2016) vegetation physiognomy map. For Santa Cruz, the map was produced using a supervised classification based on a Landsat 8 satellite image. Thematic layers were obtained from the Instituto Geográfico Nacional de la República Argentina (waterbodies and watercourses vector layers) and from the Ministerio de Energía y Minería de la República Argentina (oil wells vector layer)

We produced a vegetation physiognomy map of Santa Cruz area at the landscape-scale by using a supervised classification based on a Landsat 8 satellite image (Entity: IDLC82280962015297LGN00, Coordinates: 51° 41′ 36.49″ S, 69° 21′ 33,16″ O, Date: 10/24/2015, Path / Row: 228/96, Resolution: 30 m), 123 training points (obtained in the field and from Google Street View tool) and 94 control points (obtained in the field). We used the minimum distance algorithm for the classification. The accuracy assessment was performed through a confusion matrix. The overall accuracy of the map was 82.89%. The classes defined were as follows: water, *Festuca* grasslands, scrubs, heather fields of *Empetrum rubrum*, bare soil and meadows. The supervised classification did not identify *Poa* grasslands areas at the landscape-scale, but small areas were detected at a site-scale.

For Tierra del Fuego, we used Anchorena et al. (2016) vegetation physiognomy map. The overall accuracy of the map, calculated through a confusion matrix, was 87%. The twelve vegetation classes of the original map were as follows: water, edge, forest, *Poa* grasslands, *Festuca* grasslands, *Festuca* grasslands with shrubs, *Festuca* grasslands with *Empetrum rubrum*, scrubs, heather fields of *E. rubrum*, bare soil, urban and meadows. Edge, forest and urban classes were not present in our study area. We combined *Festuca* grasslands, *Festuca* grasslands with shrubs and *Festuca* grasslands with *E. rubrum* classes in only one class named *Festuca* grasslands. Our final 7 classes were as follows: water, *Poa* grasslands, *Festuca* grasslands, scrubs, heather fields of *E. rubrum*, bare soil and meadows.

For each sample unit (5 km^2 buffer and random cells), we extracted the following variables from the vegetation maps and other thematic layers. (1) Diversity of habitats (Shannon–Wiener index): calculated from the proportion of the area occupied by the different types of habitat included in each cell. (2) Habitat richness: calculated as the number of different habitats within each cell. (3) Number of patches of the different habitats: we defined a patch as a homogeneous area that differs from its surroundings. (4) Dominant habitat: habitat type with a cover over 50% of the cell. When this condition was not met by any of the habitat types, the cell was categorized as "mixed". (5) Spatially weighted average of the Normalized Difference Vegetation Index (NDVI): we used NDVI as a proxy of primary productivity, which can be an important driver of fauna distribution (Pettorelli et al. 2011). The analysis was based on data derived from MODIS sensor onboard Terra satellite, downloaded from https://earthdata.nasa.gov/earth-observation-data/near-real-time/rapid-response/modis-subsets. MODIS product MOD13Q1 has a 250 m spatial resolution and a 16-day temporal resolution. The 16-day composite is formed by recording the highest NDVI value of each pixel obtained during the period. See image dates in Online Resource 1 Table S3. (6) Area covered by waterbodies (m^2): data obtained as vector coverage from the Instituto Geográfico Nacional de la República Argentina (IGN), http://www.ign.gob.ar/NuestrasActividades/Informacion Geospatial/CapasSIG. (7) Length of watercourses (m): data obtained from a vector coverage produced by the IGN. (8) Number of oil wells: data obtained from a vector coverage from the Ministerio de Energía y Minería de la República Argentina, http://datos.minem.gob.ar/dataset?groups=mapas.

We used the QGIS software version 2.18.27 (QGIS Development Team 2019) to extract landscape variables and process data that involved the use of geographic information systems. Particularly, for producing the Santa Cruz vegetation map, we used the Semi-Automatic Classification Plugin package (Congedo 2016).

Data analysis

Using spring sightings from the 2013 survey, when we had the greatest effort, we analysed the variation in group size in each province (fixed factor with two levels: Tierra del Fuego and Santa Cruz) using a generalized linear model (GLM) with Negative Binomial distribution. We analysed the adult Upland Goose sex ratio using a Chi-square test. For this analysis, we used only groups sightings that were < 100 m from the observer because, on some occasions (large groups, poor observation light, etc.), it was difficult to distinguish between males and females in groups that were farther away. Using only surveys that could be conducted in both provinces (spring 2013, autumn 2014, spring 2014, summer 2015, autumn 2015 and winter 2015), we compared the number of Upland Goose pairs^{-km} and the proportion of Upland Geese present as pairs between the provinces (fixed factor with two levels: Tierra del Fuego and Santa Cruz) and including the year (2013, 2014 and 2015) as a random factor using generalized linear mixed models (GLMMs, Zuur et al. 2009; Logan 2010; Crawley 2012) with Binomial distribution.

Site-scale

We analysed the variation in sheldgoose group size and the presence of Upland Goose pairs according to the fixed factors season of the year, habitat, distance to the nearest wetland and type of wetland. For group size, we performed a with Poisson distribution (log link function). For the presence of pairs, we performed a GLMM with Binomial distribution (logit link function). In the latter, we considered as "presence of pairs (1)" sightings with only one male and one female Upland Goose (with or without goslings or early juveniles). By contrast, the sightings of sheldgoose groups of more than two individuals (or two individuals of the same sex in the case of Upland Geese) were considered as "absence of pairs (0)". Year (2013, 2014, 2015 and 2016) was included as a random factor in all models. The analyses were carried out independently for each area, one in Santa Cruz (mainland Argentina) and the other in the Tierra del Fuego Archipelago due to differences in livestock management routines and assembly of the terrestrial predators, amongst others (Cossa 2019).

Landscape-scale

We analysed the selection of areas by sheldgoose groups and Upland Goose pairs in relation to the fixed factors diversity of habitats, habitat richness, number of patches of different habitats, dominant habitat, area covered by waterbodies, length of watercourses, number of oil wells and the interaction between season and the NDVI. Some variables were highly correlated (diversity/richness/number of patches and watercourses/waterbodies) (Online Resource 1 Table S4). Therefore, we only included diversity and watercourses in the global models. For the analyses on pairs, we only used sightings recorded in the spring and summer surveys to reflect the selection of pairs at the time of reproduction. For both groups and pairs, we performed a GLMM with Binomial distribution and log link function, considering as "1" sheldgoose/pairs sightings (buffer cells) and as "0" the landscape variables availability cells (random cells). We included the year as a random factor in all models and performed the analyses independently for each province.

For all GLMs and GLMMs analyses, we calculated the overdispersion parameter and evaluated homoscedasticity, which allowed us to make the choice of the distribution to be used in each case. To evaluate the significance of the variables included in the global models, we used the hypothesis test method with a backward elimination procedure, removing one by one non-significant terms in descending order of significance (Crawley 2012). The relation between the different levels of the same factorial variable was tested using Tukey's Contrasts.

We performed all analyses using the software R version 2.15.3 (R Core Team 2016), with lme4, glmmADMB, MASS and multcomp packages (Venables and Ripley 2002; Hothorn et al. 2008; Skaug et al. 2014; Bates et al. 2015). Analyses were two-tailed, the values are expressed as mean ± standard error and $p < 0.05$ was considered significant in all cases. Tables show final models, in which we excluded non-significant fixed effects.

Results

We recorded 74,256 sheldgeese in 3286 sightings (Table 2). 102 sightings correspond to solitary individuals, 788 to Upland Goose pairs and 2396 to mixed or single-species

Table 2 Number of sheldgeese recorded on road surveys in Tierra del Fuego and Santa Cruz between 2013 and 2016

Survey	Area	Effort		Upland Goose			Ashy-headed Goose		Ruddy-headed Goose		Total adults
		Km	Days	Adults	Pairs	Goslings	Adults	Goslings	Adults	Goslings	
Spring 2013	TDF	698	11	2052	40	0	127	0	18	0	2197
	SC	235	4	754	68	0	0	0	5	0	759
	TOTAL	933	15	2806	108	0	127	0	23	0	2956
Summer 2014	TDF	645	8	9279	37	22 (4)	214	0	35	0	9528
Autumn 2014	TDF	555	7	9803	40	0	1425	0	27	0	11,255
	SC	177	2	457	14	0	4	0	9	0	470
	TOTAL	732	9	10,260	54	0	1429	0	36	0	11,725
Winter 2014	TDF	400	2	1704	53	0	0	0	0	0	1704
Spring 2014	TDF	698	6	1928	213	0	214	0	20	0	2162
	SC	177	3	661	102	0	1	0	6	0	668
	TOTAL	875	9	2589	315	0	215	0	26	0	2830
Summer 2015	TDF	698	8	12,118	38	17 (4)	332	0	37	3 (1)	12,487
	SC	177	3	953	36	89 (25)	0	0	16	0	969
	TOTAL	875	11	13,071	74	106 (29)	332	0	53	3 (1)	13,456
Autumn 2015	TDF	645	10	13,732	49	0	2484	0	49	0	16,265
	SC	177	2	585	8	0	7	0	5	0	597
	TOTAL	822	12	14,317	57	0	2491	0	54	0	16,862
Winter 2015	TDF	400	3	4075	47	0	0	0	0	0	4075
	SC	9	1	223	0	0	2	0	0	0	225
	TOTAL	409	4	4298	47	0	2	0	0	0	4300
Summer 2016	TDF	645	10	10,501	43	28 (7)	354	0	40	0	10,895

TDF: Tierra del Fuego. SC: Santa Cruz. Goslings' columns include early juveniles and numbers between brackets indicate the number of pairs with goslings or early juveniles (families)

groups. The proportion of groups with all three species was 1.3% (31 groups) whilst 16.4% had two species (364 Upland and Ashy-headed Goose mixed groups, 28 Upland and Ruddy-headed Goose mixed groups). The remaining groups (82.3%) were monospecific (1926 Upland Goose groups, 33 Ashy-headed Goose groups and 14 Ruddy-headed Goose groups). The Upland Goose was present in 98% of the groups, the Ashy-headed Goose in 18% of the groups and the Ruddy-headed Goose in only 3% of the groups. The average group size was 30.58 ± 1.2 individuals (median: 14, range: 3–1069 individuals, $n = 2396$ groups). Using data from the spring 2013 survey, the average group size in Tierra del Fuego (28.5 ± 4.9; $n = 74$) was almost twice that in Santa Cruz (13.7 ± 3.2; $n = 44$) (GLM Negative Binomial distribution, $p < 0.001$). Most individuals were sighted in *Poa* grasslands and meadows in Tierra del Fuego and *Festuca* grasslands in Santa Cruz (Fig. 3). We generally observed a higher sheldgoose density in Tierra del Fuego than in Santa Cruz (Fig. 4). On the winter 2015 survey, sheldgeese were concentrated in Río Gallegos Coastal Urban Reserve in Santa Cruz.

The Upland Goose was the most abundant species and was present in all surveys (Table 2, Figs. 2 and 4). The sex ratio was biased towards males 1.03:1 (percentage of males$^{-\text{group}}$: 51.38 ± 0.3, $n = 1{,}249$ groups, $\chi^2{}_{1248} = 1392$; $p = 0.003$). The Ashy-headed Goose was the second sheldgeese in abundance, and in Santa Cruz, we observed very few of this species. This species was absent in summer in Santa Cruz and absent in winter in Tierra del Fuego. Also, there was an increase of ~ 600% in the number of individuals in autumn in Tierra del Fuego in comparison to summer counts. We did not detect breeding of the Ashy-headed Goose.

The Ruddy-headed Goose was sighted only in 15 locations, three of them in Santa Cruz and 12 in Tierra del Fuego. In Santa Cruz, two locations were in protected areas (Río Gallegos Coastal Urban Reserve and Cabo Vírgenes Provincial Reserve) and one in private land at Estancia Cóndor. In Tierra del Fuego, 10 locations were in private lands and the remaining two on public lands (unprotected), the banks of the Chico and Grande Rivers. The maximum count was 49 individuals in Tierra del Fuego (in autumn 2015) and 16 individuals in Santa Cruz (in summer 2015). In January 2015, we recorded a pair with three young goslings in Tierra del Fuego. Ruddy-headed Goose was not detected in winter in either Tierra del Fuego or Santa Cruz.

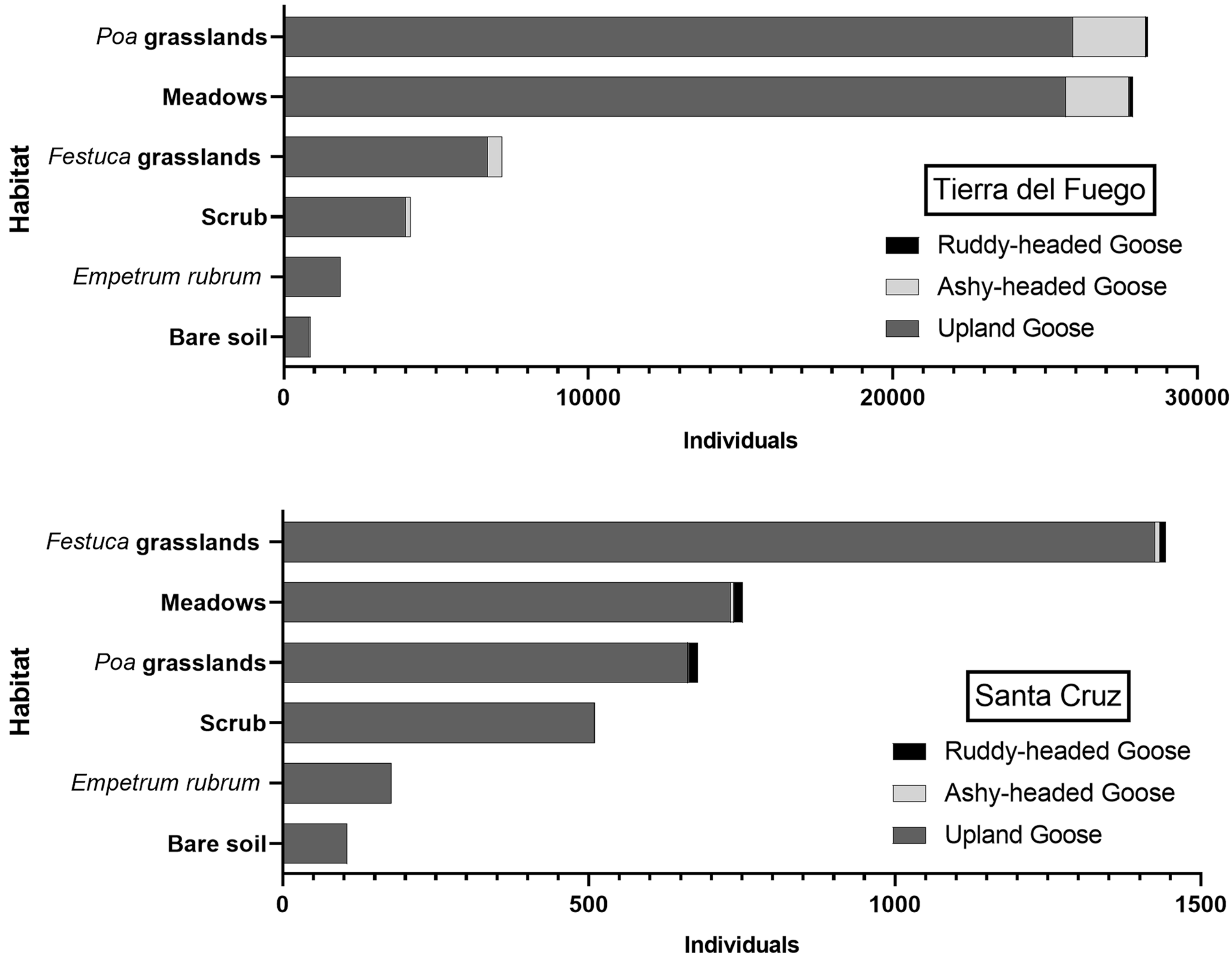

Fig. 3 Number of sheldgeese recorded in each habitat type in Tierra del Fuego and Santa Cruz. Data were obtained from road surveys carried out between 2013 and 2016

Upland Goose pairs

The largest number of Upland Goose pairs was observed in spring 2014. The number of pairs^{-km} surveyed was similar in the two provinces (TDF: 0.16 ± 0.06 pairs^{-km}, S: 0.26 ± 0.13 pairs^{-km}, $p = 0.26$, $n = 12$ surveys, GLMM binomial distribution). However, the number of pairs^{-total} Upland Geese individuals was greater in Santa Cruz (SC: 0.12 ± 0.05 pairs$^{-individuals}$, TDF: 0.08 ± 0.03 pairs$^{-individuals}$, $p = 0.04$; $n = 12$ surveys; GLMM binomial distribution). For another study (Cossa 2019) in Tierra del Fuego, we searched nests exhaustively by focussing on solitary male activity and inspecting potential nesting sites from the beginning of the 2013 breeding season. We only found 3 active nests in that reproductive season. Successful breeding events (pairs with goslings or early juveniles) were recorded only in summer and were very scarce, especially in Tierra del Fuego (TDF: 4^{-661} km, SC: 25^{-150} km).

Habitat use at site-scale

Sheldgoose group size

In Tierra del Fuego, group size varied according to habitat, type of wetland and season (Table 3). Groups were largest in meadows, waterbodies and in both summer and autumn (Online Resource 1 Table S5, Fig. 5). In Santa Cruz, group size varied only with the season, with largest group sizes in both winter and summer (Table 3, Online Resource 1 Table S5, Fig. 5).

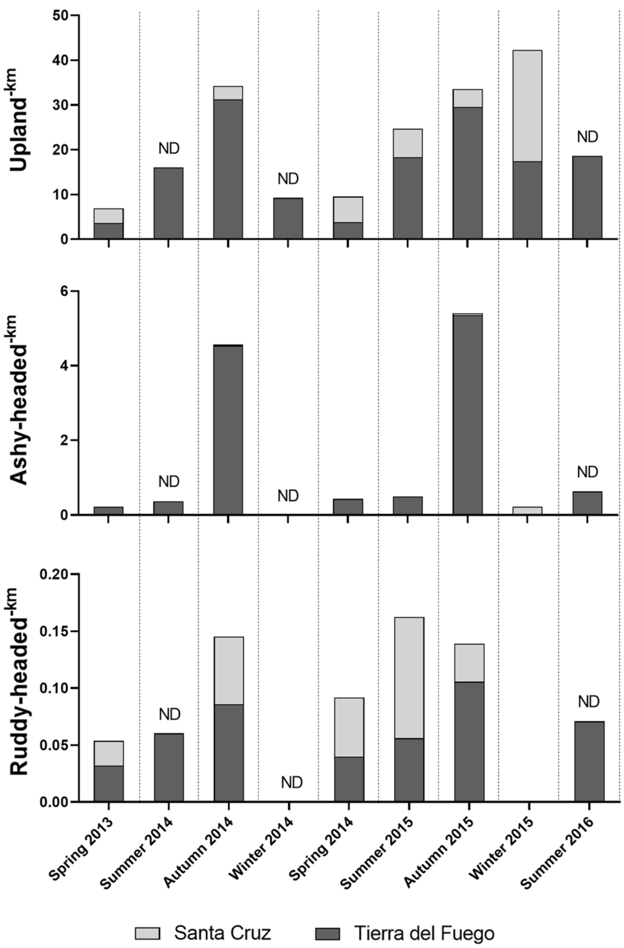

Fig. 4 Number of sheldgeese^{-km} recorded in each road survey in Tierra del Fuego and Santa Cruz between 2013 and 2016. ND: No data available because we were unable to conduct the survey in Santa Cruz in that season

Table 3 Results of the generalized linear mixed models analyses (Poisson distribution and log link function) including the standard error (SE), *t*-statistic (*t*) and significance (*p*)

	Estimate ± SE	*t*	*p*
Tierra del Fuego			
Intercept	3.17 ± 0.21	15.47	**< 0.001***
Habitat (*Festuca* grasslands)	− 0.29 ± 0.2	− 1.41	0.16
Habitat (Scrub)	− 0.56 ± 0.22	− 2.51	**0.01***
Habitat (*Empetrum rubrum*)	0.2 ± 0.36	0.55	0.59
Habitat (Bare soil)	− 0.33 ± 0.44	− 0.73	0.46
Habitat (Meadow)	0.37 ± 0.1	3.54	**< 0.001***
Wetland (Watercourses)	− 0.37 ± 0.11	− 3.35	**< 0.001***
Wetland (Flooded areas)	− 0.34 ± 0.12	− 2.69	**0.01***
Wetland (Sea)	− 0.65 ± 0.4	− 1.61	0.11
Season (Autumn)	0.6 ± 0.16	3.63	**< 0.001***
Season (Spring)	− 0.04 ± 0.29	− 0.15	0.88
Season (Summer)	0.85 ± 0.17	4.95	**< 0.001***
Santa Cruz			
Intercept	3.34 ± 0.32	10.35	**< 0.001***
Season (Autumn)	− 0.78 ± 0.36	− 2.18	**0.03***
Season (Spring)	− 0.78 ± 0.36	− 2.18	**0.03***
Season (Summer)	− 0.27 ± 0.36	− 0.74	0.46

The results show the effect of habitat, wetland and season on sheldgoose group size at site-scale in Tierra del Fuego and Santa Cruz study areas. Year was included as a random factor. Data were obtained from road surveys between 2013 and 2016

* and bold indicate significant differences ($p < 0.05$)

Upland Goose pairs

The proportion of pairs in Tierra del Fuego varied according to season, distance to wetland and type of wetland (Table 4). There was a greater proportion of pairs in spring and near waterbodies (Online Resource 1 Table S6, Fig. 6). In Santa Cruz, the proportion of pairs varied according to habitat and season (Table 4). There was a greater proportion of pairs in both spring and summer and, though the variable habitat was included in the selected model, no clear trend was observed regarding the proportion of pairs in each type of habitat (Online Resource 1 Table S6, Fig. 6).

Habitat use at landscape-scale

Sheldgoose groups

In Tierra del Fuego, the use of sites by sheldgoose groups was related to dominant habitat, diversity of habitats and the interaction between season and the NDVI (Table 5, Online Resource 1 Table S7). Sheldgeese used sites mainly with low vegetation (meadows and bare soil, Fig. 7) and greater diversity of habitats. In winter, they preferred sites with higher NDVI. In contrast, during the other seasons, particularly in spring, they preferred sites of lower NDVI (Online Resource 1 Table S8).

In Santa Cruz, the use of sites by sheldgoose groups was affected by the dominant habitat, the diversity of habitats, watercourses, number of oil wells and the interaction between season and NDVI (Table 5). They used sites with greater diversity and number of oil wells and fewer watercourses. Although the dominant habitat was included in the final model, no clear trend was observed amongst types of habitat (Online Resource 1 Table S7, Fig. 7). In winter, no relationship was found with the NDVI. In contrast, in autumn, spring and summer, the use of sites increased as the NDVI decreased (Online Resource 1 Table S8).

Upland Goose pairs

The use of sites by Upland Goose pairs in Tierra del Fuego was positively associated with the diversity of habitats and the number of oil wells (Table 6). Although dominant habitat

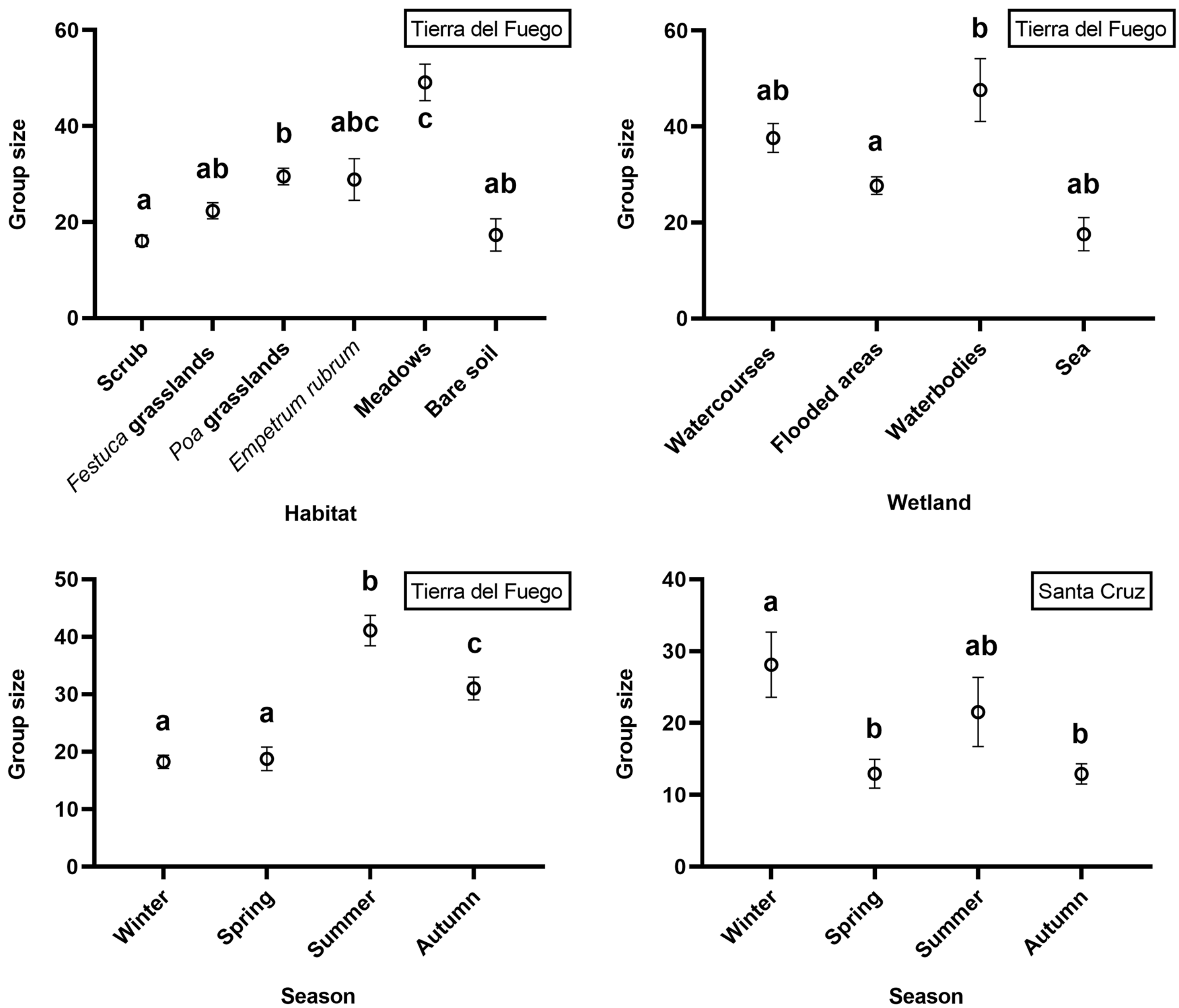

Fig. 5 Sheldgoose group size according to habitat, wetland and season in Tierra del Fuego and according to season in Santa Cruz. Circles indicate means, bars indicate the standard error. Different letters indicate significant differences ($p < 0.05$) after performing Tukey's Contrasts and Generalized Linear Mixed Models analyses at site-scale. Data were obtained from road surveys carried out between 2013 and 2016 in Tierra del Fuego and Santa Cruz

was a variable included in the final model, no clear trend was observed (Online Resource 1 Table S9, Fig. 7).

In Santa Cruz, the use of sites by Upland Goose pairs was positively associated with the diversity of habitats, NDVI and the number of oil wells and negatively associated with watercourses (Table 6). Although dominant habitat was a variable included in the final model, no clear trend was observed (Online Resource 1 Table S9, Fig. 7).

Discussion

Sheldgoose surveys on the breeding grounds of Tierra del Fuego and Santa Cruz at all seasons of the year over multiple years allowed us to determine how sheldgeese are distributed temporally and spatially, their aggregation patterns and their habitat use at two spatial scales. Upland Geese were present

Table 4 Results of the generalized linear mixed models analyses (Binomial distribution and log link function) including the standard error (SE), *z*-statistic (*z*) and significance (*p*)

	Estimate ± SE	*z*	*p*
Tierra del Fuego			
Intercept	− 0.79 ± 0.29	− 2.69	**0.007***
Season (Autumn)	− 1.28 ± 0.22	− 5.74	**< 0.001***
Season (Spring)	1.2 ± 0.23	5.13	**< 0.001***
Season (Summer)	− 0.88 ± 0.24	− 3.73	**< 0.001***
Distance to wetland	− 0.001 ± 0.001	− 1.98	**0.05***
Wetland (Watercourses)	− 0.67 ± 0.17	− 3.83	**< 0.001***
Wetland (Flooded areas)	− 0.5 ± 0.19	− 2.6	**0.009***
Wetland (Sea)	0.11 ± 0.44	0.25	0.8
Santa Cruz			
Intercept	− 2.32 ± 0.39	− 5.99	**< 0.001***
Habitat (*Festuca* grasslands)	1.11 ± 0.31	3.64	**< 0.001***
Habitat (Scrub)	0.9 ± 0.37	2.39	**0.02***
Habitat (*Empetrum rubrum*)	0.74 ± 0.59	1.27	0.2
Habitat (Bare soil)	0.65 ± 0.52	1.26	0.2
Habitat (Meadow)	0.63 ± 0.4	1.6	0.1
Season (Winter)	− 19.27 ± 117.46	− 0.16	0.87
Season (Spring)	1.92 ± 0.3	6.4	**< 0.001***
Season (Summer)	1.18 ± 0.38	3.1	**0.002***

The results show the effect of habitat, wetland, distance to wetland and season on the presence of Upland Goose (*Chloephaga picta*) pairs at site-scale in Tierra del Fuego and Santa Cruz study areas. Year was included as a random factor. Data were obtained from road surveys between 2013 and 2016

* and bold indicate significant differences ($p < 0.05$)

in almost all groups and was the most abundant species in all the surveys. We recorded a higher sheldgoose density in Tierra del Fuego than in Santa Cruz. In addition, in Tierra del Fuego, sheldgoose density increased from spring to autumn and decreased in winter, which is consistent with the migratory nature of the birds since they depart the southernmost part of the surveyed area for northern wintering areas. The increase towards early autumn is consistent with sheldgoose group gathering before migration. The surveyed area may have been a place where sheldgeese concentrated as a result of the arrival of individuals from other breeding areas. This result is similar to what was found for the Greylag Goose (*Anser anser*) in Europe (Paludan 1973; Nilsson and Persson 1992), which present a tendency towards flocking in autumn. *Poa* grasslands, meadows and *Festuca* grasslands were the habitats in which we detected most individuals, which is similar to the result of previous surveys in the same area (Petracci et al. 2013, 2014, 2015b).

The Upland Goose was recorded in high numbers throughout the surveyed area, as part of groups and in pairs. This species was the only sheldgeese recorded in Tierra del Fuego during winter. This could be due to the greater abundance, distribution range and ecological plasticity of this species. These Upland Geese observed in winter may be individuals that migrated from the south or west, or they may be non-migratory individuals. It is thought that the number of individuals wintering in the area is increasing due to a greater food availability during this season (Martin 1984) and local residents affirm that it is due to less harsh winters. Upland Goose dimorphism, which is a characteristic it shares with some true ducks rather than true geese, allowed us to study the sex ratio of this goose-like species. We found that the adult Upland Goose sex ratio was slightly biased towards males. This same pattern was also found for adult Upland Geese in previous surveys (Siegfried et al. 1988; Petracci et al. 2013), in juveniles Upland Geese in Malvinas/Falklands Islands (Quillfeldt et al. 2005) and in other Anseriformes (Gowaty 1993; Wood et al. 2021). Despite Upland Goose abundance, we observed few pairs with goslings or early juveniles, particularly in Tierra del Fuego. The low reproductive success of this species in the area has already been noticed (Petracci et al. 2013, 2014; Cossa 2019). This could be due to the high predation rate by the invasive grey fox (Cossa 2019), disturbances with livestock (Cossa et al. 2018, 2020) and/or a lack of suitable habitat due to overgrazing.

In Tierra del Fuego, the number of Ashy-headed Geese increased notably in autumn compared to other seasons. As this species nests in forested areas and the ecotone (forest-steppe transition), this increase in early autumn may also indicate pre-migration concentration, with pairs with their juveniles arriving at the steppe from the areas where they have bred. Accordingly, we did not record reproductive events in the surveyed area.

The Ruddy-headed Goose was observed only in 15 locations, three of them in Santa Cruz and 12 in Tierra del Fuego, and only 2 of these locations were in protected areas. The reproductive event that we observed in Tierra del Fuego was the first successful record there for the species since 1993 (Benegas 1997 in Petracci et al. 2014; Cossa et al. 2017). The nesting of this species in all its reproductive area, particularly in Tierra del Fuego, has been decreasing dramatically over the last 80 years (Cossa et al. 2017). In Santa Cruz, only a few pairs have been recorded nesting in recent years in the area of Estancia Cóndor and Cabo Vírgenes Provincial Reserve (Petracci et al. 2014, park ranger pers. comm.). In the Chilean territory, recent population counts in the continental area (San Juan and San Gregorio) and the insular area (Porvenir) indicate that there would be no more than 300 adults and 10 breeding pairs (Ricardo Matus, pers. comm.), half of the numbers recorded in the 1999–2000 breeding season (Matus et al. 2000). Particularly for San Gregorio area, 25 pairs were counted in 1999, only 4 in 2017 and no individuals in 2018 (Matus et al. 2000, Ricardo Matus pers. comm.).

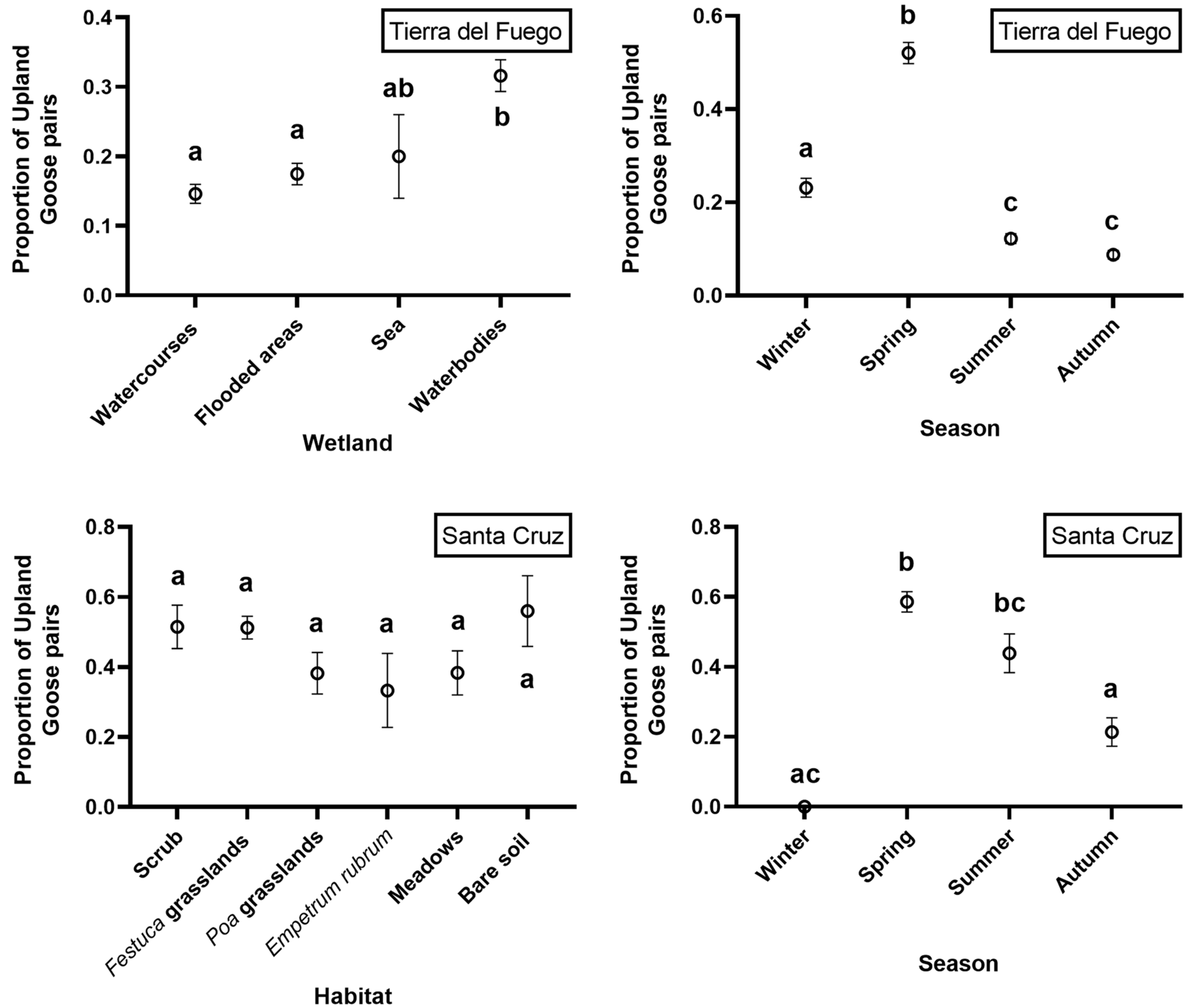

Fig. 6 Proportion of Upland Goose (*Chloephaga picta*) pairs according to wetland and season in Tierra del Fuego, and according to habitat and season in Santa Cruz. Circles indicate means, bars indicate the standard error. Different letters indicate significant differences ($p < 0.05$) after performing Tukey's Contrasts and Generalized Linear Mixed Models analyses at site-scale. Data were obtained from road surveys carried out between 2013 and 2016 in Tierra del Fuego and Santa Cruz

In Tierra del Fuego, the largest sheldgoose groups were concentrated in meadows, waterbodies and during summer and autumn seasons. Large groups in meadows could be due to the high food availability in this type of habitat. Similarly, wetlands dominated by Cyperaceae species, principally *Carex* spp, were the principal habitats used by the Greater Snow Geese (*Anser caerulescens atlanrticus*) in the Arctic (Giroux et al. 1984) and different variations of meadows are the principal habitats of true geese (Owen 1980). Open waterbodies (i.e. lakes) are essential to escape from predators or other disturbances during moulting (flightless period) which mainly occurs in groups. In addition, vegetation surrounding the waterbodies is usually consumed by sheldgeese (personal observation). Another study also found that wetlands had a positive influence on the abundance of several goose species (Webb et al. 2010). In spring, breeding pairs defend their territories and, therefore, are not associated with non-breeding groups. In summer, breeding pairs leave the territories where they attempted to nest and group with other sheldgeese. In addition, individuals begin to group before migration, which continues during autumn. On the other hand, in autumn in Santa Cruz, we did not see large groups as in Tierra del Fuego, probably because Santa Cruz surveys were conducted when migration had already begun. This result is consistent with the decrease in sheldgoose numbers in Santa Cruz in autumn compared to summer.

Table 5 Results of the generalized linear mixed models analyses (Binomial distribution and log link function) including the standard error (SE), *z*-statistic (*z*) and significance (*p*)

	Estimate ± SE	*z*	*p*
Tierra del Fuego			
Intercept	− 2.97 ± 0.3	− 9.79	**< 0.001***
Habitat (Water)	− 0.31 ± 0.69	− 0.45	0.65
Habitat (*Poa* grasslands)	− 0.07 ± 0.28	− 0.24	0.81
Habitat (*Festuca* grasslands)	0.73 ± 0.21	3.47	**< 0.001***
Habitat (Mixed)	0.84 ± 0.22	3.89	**< 0.001***
Habitat (Bare soil)	1.99 ± 0.28	7.07	**< 0.001***
Habitat (Meadow)	2.31 ± 0.22	10.44	**< 0.001***
Season (Autumn)	1.11 ± 0.21	5.22	**< 0.001***
Season (Spring)	4.1 ± 0.38	10.86	**< 0.001***
Season (Summer)	0.91 ± 0.21	4.28	**< 0.001***
Diversity	1.48 ± 0.16	9.39	**< 0.001***
NDVI	0.86 ± 0.39	2.18	**0.03***
Season (Autumn): NDVI	− 2.82 ± 0.48	− 5.9	**< 0.001***
Season (Spring): NDVI	− 13.62 ± 1.17	− 11.67	**< 0.001***
Season (Summer): NDVI	− 2.06 ± 0.47	− 4.35	**< 0.001***
Santa Cruz			
Intercept	11.5 ± 8.05	1.43	0.15
Habitat (Mixed)	− 0.35 ± 0.66	− 0.53	0.59
Habitat (*Empetrum rubrum*)	10 ± 888	0.01	0.99
Habitat (Bare soil)	− 2.64 ± 1.1	− 2.39	**0.02***
Habitat (Meadow)	− 27.3 ± 49,300	0	0.99
Season (Autumn)	− 18.3 ± 8.19	− 2.23	**0.03***
Season (Spring)	− 17.9 ± 8.14	− 2.20	**0.03***
Season (Summer)	− 23.3 ± 8.4	− 2.78	**0.006***
Diversity	5.37 ± 0.55	9.68	**< 0.001***
Watercourses	− 0.0002 ± 0.0001	− 2.11	**0.03***
NDVI	− 36.1 ± 20.1	− 1.8	0.07
Oil wells	0.36 ± 0.08	4.49	**< 0.001***
Season (Autumn): NDVI	44.8 ± 20.4	2.2	**0.03***
Season (Spring): NDVI	44.3 ± 20.3	2.19	**0.03***
Season (Summer): NDVI	57.6 ± 20.8	2.77	**0.006***

The results show the effect of habitat, season, diversity, watercourses, Normalized Difference Vegetation Index (NDVI), oils wells and the interaction between season and NDVI on the presence of sheldgoose groups at landscape-scale in Tierra del Fuego and Santa Cruz study areas. Year was included as a random factor. Data were obtained from road surveys between 2013 and 2016

* and bold indicate significant differences ($p < 0.05$)

At landscape-scale, sheldgeese selected sites with greater diversity, richness and number of patches of different habitats, both in Tierra del Fuego and Santa Cruz. This is consistent with studies in the wintering grounds where sheldgeese also prefer heterogeneous sites (Pedrana et al. 2014) as a probable way of securing access to a variety of food provided by the combination of habitats. Similarly, another study found that the most suitable habitats for the Lesser White-fronted Goose (*Anser erythropus*) had higher habitat diversity (Tian et al. 2021). The individuals that remained in Austral Patagonia during winter selected sites with higher primary productivity, different to autumn, spring and summer, when the presence of sheldgoose groups was associated with areas of lower productivity. In winter, the day length is less than half compared to summer (7:52 h in July vs. 16:33 h in January, Servicio de Hidrografía Naval Argentino). Sheldgeese have less time to forage and, therefore, require a more efficient intake of food. This may be the reason why the groups that remain in Patagonia would concentrate on highly productive sites during winter months, i.e. places where the rate of energy intake can be high. This result contradicts a previous study in Santa Cruz, in which primary productivity was the main predictor of Upland Goose distribution (Pedrana et al. 2011) in summer. However, that study covered the entire Santa Cruz territory, which includes not only the Magellanic steppe but also large areas of the Patagonian steppe. The Magellanic steppe is considerably more humid and therefore more productive than the steppe of the centre and north of Santa Cruz. This could be the reason for the positive relationship with primary productivity found by Pedrana et al. (2011). That is, on a scale that covers the entire province, sheldgeese prefer highly productive sites such as the Magellanic steppe, but on a finer scale, in which only the Magellanic steppe is analysed, sheldgeese prefer areas of lower productivity (except for the winter months). Probably the range of productivity offered by the Magellanic steppe is high enough to cover the energy requirements of these species and lower productivity areas may be offering additional requirements as refuge for their nest or during moulting.

In Tierra del Fuego and also at landscape-scale, sheldgeese selected sites with a predominance of meadows, probably due to the high food availability offered by this type of habitat, and areas with a predominance of bare soil, which correspond mainly to the edges of large lakes. In Santa Cruz, they selected sites with a greater number of oil wells. Oil wells could be a proxy for something that might be attractive to sheldgeese, such as early successional vegetation due to the alteration of the site by human activity. Nevertheless, this result could be a methodological bias as most surveys in the internal private lands were carried out on roads that lead to oil wells. Pedrana et al. (2011) found that urban areas and probably also oil fields would have a negative impact on Upland Goose distribution (although the variable was not included in the final models). However, in the present study and contrary to what we expected, we did not observe that sheldgeese perceive the oil structures as a disturbance, since they used the areas near them, whether they were active or inactive. Again, the scale of the study could be partially explaining differences in results amongst works, as our

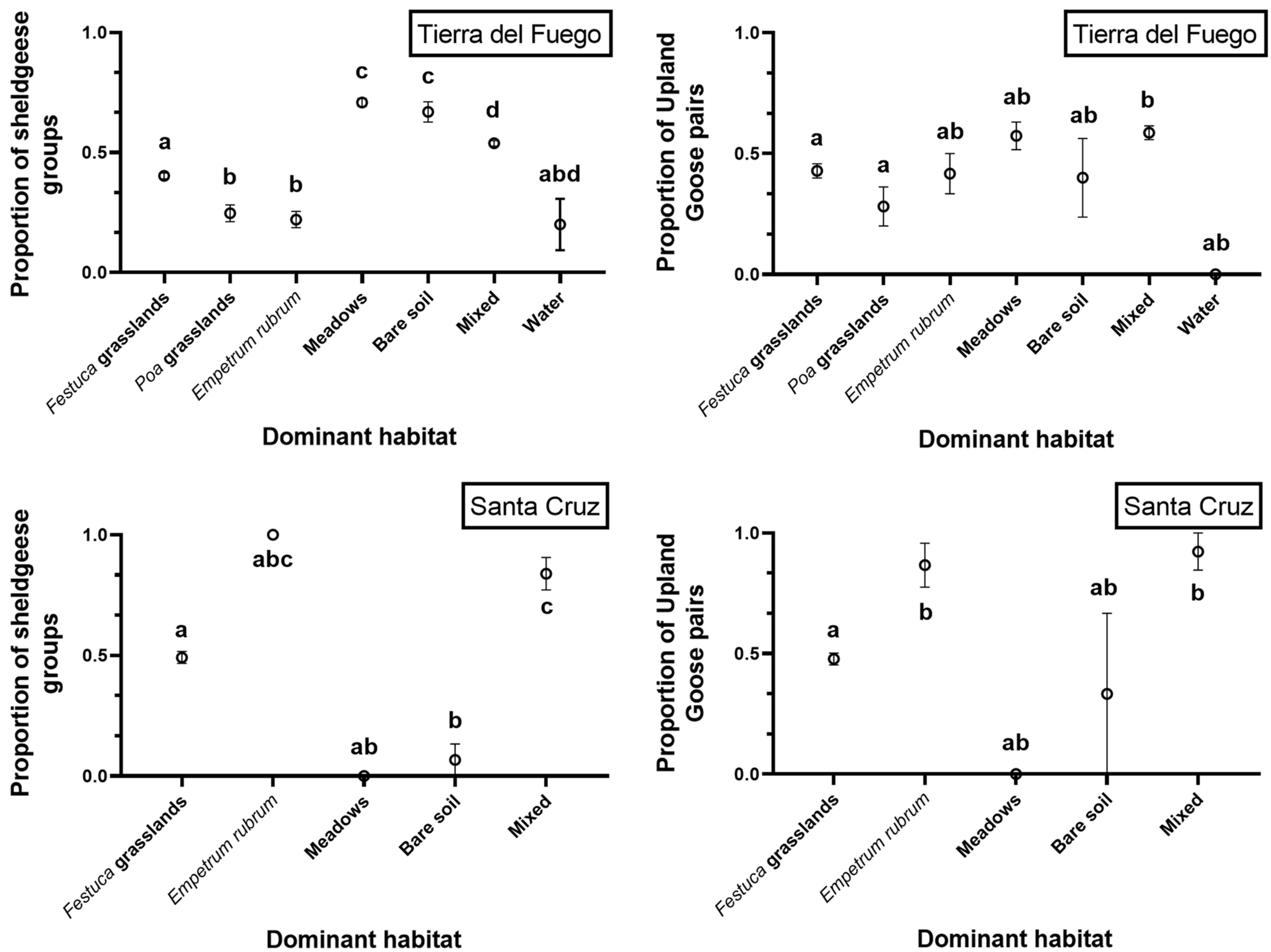

Fig. 7 Proportion of sheldgoose groups (left) and Upland Goose (*Chloephaga picta*) pairs (right) according to dominant habitat in Tierra del Fuego (up) and Santa Cruz (down). Circles indicate means, bars indicate the standard error. Different letters indicate significant differences ($p < 0.05$) after performing Tukey's Contrasts and Generalized Linear Mixed Models analyses at landscape-scale. Data were obtained from road surveys carried out between 2013 and 2016 in Tierra del Fuego and Santa Cruz

whole study area is under oil companies influence whilst Pedrana et al. study included areas beyond oil extraction main sectors.

In another multi-scale habitat selection study, the Greater White-fronted Goose (*Anser albifrons*) and the Tundra Bean Goose (*Anser serrirostris*) preferred areas with a larger percentage of wetland and waterbodies at a landscape-scale (Zhang et al. 2018). Contrarily, in our study, the area covered by waterbodies did not determine the use of sites by sheldgoose groups at our landscape-scale, which is narrower. In addition, sheldgeese selected sites with fewer wetlands in Santa Cruz, where waterbodies are of small dimensions and would not offer a suitable refuge to moult. Future studies are needed to evaluate the effect of wetlands on sheldgoose distribution on a wider scale. As expected, in Tierra del Fuego, there was a greater presence of Upland Goose pairs in spring and near waterbodies due to at the beginning of the breeding season, sheldgeese form pairs and defend the nesting territory, which is usually associated with wetlands (Summers and McAdam 1993). Giroux et al. (1984) found that ponds constitute an important feature of the Greater Snow Goose (*Anser caerulescens atlanticus*) habitat during the brood-rearing period. In addition, there was a greater presence of Upland Goose pairs in winter compared to summer and autumn, which could indicate an early process of pair consolidation. In Santa Cruz, there was also a greater presence of pairs at the beginning of the breeding season (spring) and in summer. Unlike Tierra del Fuego, pairs that managed to breed in spring continued in their territories raising goslings. On the other hand, in Tierra del Fuego, the reproductive failure would cause them to leave their territories and possibly join the feeding groups sooner.

At the landscape-scale, the selection of sites by Upland Goose pairs was positively associated with diversity, habitat richness, number of patches and oil wells both in Tierra del Fuego and Santa Cruz. Similar to groups, pairs would select

Table 6 Results of the Generalized Linear Mixed Models analyses (Binomial distribution and log link function) including the standard error (SE), *z*-statistic (*z*) and significance (*p*)

	Estimate ± SE	*z*	*p*
Tierra del Fuego			
Intercept	− 1.04 ± 0.39	− 2.66	**0.007***
Habitat (Water)	− 16.33 ± 2815.6	− 0.01	0.99
Habitat (*Poa* grasslands)	− 1.29 ± 0.47	− 2.72	**0.007***
Habitat (*Festuca* grasslands)	− 0.78 ± 0.28	− 2.77	0.006
Habitat (Mixed)	− 0.51 ± 0.33	− 1.54	0.12
Habitat (*Empetrum rubrum*)	− 0.79 ± 0.43	− 1.82	0.07
Habitat (Bare soil)	− 0.82 ± 0.7	− 1.18	0.24
Diversity	1.33 ± 0.39	3.46	**< 0.001***
Oil wells	0.13 ± 0.03	4.72	**< 0.001***
Santa Cruz			
Intercept	− 7.3 ± 0.87	− 8.35	**< 0.001***
Habitat (Mixed)	2.4 ± 1.18	2.02	**0.04***
Habitat (*Empetrum rubrum*)	− 1.43 ± 0.99	− 1.45	0.15
Habitat (Bare soil)	− 2.04 ± 1.78	− 1.15	0.25
Habitat (Meadow)	− 15.33 ± 1475	− 0.01	0.99
Diversity	4.02 ± 0.49	8.27	**< 0.001***
Watercourses	− 0.0003 ± 0.0001	− 2.34	**0.02***
NDVI	12.06 ± 1.73	6.98	**< 0.001***
Oil wells	0.32 ± 0.06	4.78	**< 0.001***

The results show the effect of habitat, diversity, watercourses, Normalized Difference Vegetation Index (NDVI) and oil wells on the presence of Upland Goose (*Chloephaga picta*) pairs at landscape-scale in Tierra del Fuego and Santa Cruz study areas. Year was included as a random factor. Data were obtained from road surveys between 2013 and 2016

* and bold indicate significant differences ($p < 0.05$)

heterogeneous environments, which could be explained as a variety of food availability and refuge. In addition, in Santa Cruz, the selection of sites by Upland Goose pairs was positively associated with primary productivity (unlike what was observed for groups at this same scale) and, contrary to what was expected, negatively to wetlands. As waterbodies were generally distant from each other (personal observation), a high percentage of the area covered by waterbodies indicates the presence of large waterbodies rather than small ones. Therefore, this negative association could be reflecting that pairs were probably associated with small waterbodies. Accordingly, in Santa Cruz, we recorded pairs using small ponds to breed. There was not a clear trend in terms of the habitat type most pairs use at both scales. Probably, wetlands at a fine scale and the vegetation of their surroundings are more important features than the habitat type in the nearby area.

Our results highlight the importance of prioritizing the conservation of locations with Ruddy-headed Goose presence due to the extreme rarity of the species and its critical conservation status. We recommend performing surveys in autumn if the survey aims to record as many sheldgeese as possible. However, those numbers may include post-breeding individuals that breed in other areas (south or west). On the other hand, if the aim is to count the sheldgoose numbers that effectively breed within the Magellanic steppe, we recommend surveying in summer. In addition, in mid or late summer it is possible to record the number of successful reproductive events for Upland and Ruddy-headed Goose. We also recommend future studies to explore in greater detail those results that were not conclusive, as well as extend this study to other sites of the breeding range. In particular, we recommend continuing to investigate how productive activities as oil extraction affect sheldgeese. Finally, the large number of individuals present in Tierra del Fuego area in autumn months makes this time of the year highly sensitive for the conservation of these species, not only for the individuals who spent most of the breeding season in the area, but also for individuals that arrived from other areas. Therefore, it is highly desirable to plan conservation actions together with rural land managers and oil companies to achieve effective sheldgoose conservation.

This work describes the aggregation of migratory sheldgeese and elucidates several important site and landscape factors influencing habitat use by sheldgoose groups and Upland Goose pairs in part of their breeding range. The two-scale analysis approach allowed us to understand in which regions of the surveyed area there is a greater need for sheldgoose conservation and, within those preferred regions, which environmental conditions favour higher concentrations. When interpreting these results, it should be taken into account that, despite studying the three species of sheldgeese, groups were composed mainly of Upland Goose individuals, so, to a greater extent, these results reflect the behaviour of this species. Whilst most goose studies have been conducted in north polar regions, this work contributes to the understanding of environmental conditions and factors affecting the avifauna of the south subpolar region.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s00300-021-02965-7.

Acknowledgements Fieldwork was supported by Grants of Neotropical Grassland Conservancy, CREOi, Tasso Leventis Foundation, Toyota Argentina, Servicios Públicos (Santa Cruz), Secretaría de Ambiente (Santa Cruz), Fundación Flora y Fauna Argentina, Pan American Energy and Idea Wild. We thank the owners of ranches Sara, Cullen, Los Flamencos, María Behety, La Vizcaína, El Rincón, El Unco, Telken, Casa de Piedra, El Milagro, La Paloma and Laurak Bat for allowing us to conduct the surveys in their properties. We thank G. Montero, S. Imberti, P. Irazoqui and E. Tiberi from Asociación Ambiente Sur; M. L. Carranza, M. L. Flotron, E. Curto and D. Valenzuela from Dirección General de Áreas Protegidas y Biodiversidad of Tierra del Fuego; Consejo Agrario Provincial of Santa Cruz; T. Barreto and A. Ramos from Museo Municipal de Río Grande Virginia Choquintel; S. Alvarado from Agencia Ambiental Municipal de Río Gallegos; J. L Hormaechea, G. Connon and L. Barbero from Estación Astronómica Río Grande; A. Gorosabel; M. L. Marcías; Pietrek family; and Proyecto Macá Tobiano volunteers, NC was supported by a doctoral studentship from the Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET). We thank Dieter Piepenburg, Erica Nol, Julieta Pedrana, Peter M. Kotanen and an anonymous reviewer for their comments and suggestions on the manuscript. This is publication #22 of the Hooded Grebe Project and Patagonia Program of Aves Argentinas.

Author contributions All authors contributed to the study conception and design. NAC and LF performed material preparation, data collection and analysis. NAC wrote the first draft of the manuscript. All authors read and approved the final manuscript.

Funding This study was funded by Grants of Neotropical Grassland Conservancy, CREOi, Tasso Leventis Foundation, Toyota Argentina, Servicios Públicos (Santa Cruz), Secretaría de Ambiente (Santa Cruz), Pan American Energy and Idea Wild.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

References

Anchorena J, Dieguez H, Collantes M, Cingolani A (2016) A vegetation map for the land use planning of the southernmost rangelands of the world: the steppes of Tierra del Fuego. Poster session presentation at the meeting of the International Rangeland Congress, Saskatoon, Canada

Antonijevic V (2012) Estudio de la dieta del cauquén común (*Cloephaga picta*) y del cauquén cabeza gris (*Cloephaga poliocephala*). Dissertation, Universidad de Flores, Buenos Aires, Argentina

Baldassarre GA (2014) Ducks, geese, and swans of North America. Johns Hopkins University Press, Baltimore

Bates D, Maechler M, Bolker B, Walker S (2015) Fitting linear mixed-effects models using lme4. J Stat Softw 67:1–48. https://doi.org/10.18637/jss.v067.i01

Béchet A, Giroux JF, Gauthier G (2004) The effects of disturbance on behaviour, habitat use and energy of spring staging snow geese. J Appl Ecol 41:689–700. https://doi.org/10.1111/j.0021-8901.2004.00928.x

Block WM, Brennan LA (1993) The habitat concept in ornithology: theory and applications. In: Power DM (ed) Current ornithology. Plenum Press, New York, pp 35–91

Bulgarella M, Kopuchian C, Di Giacomo AS, Matus R, Blank O, Wilson RE, McCracken KG (2013) Molecular phylogeny of the South American sheldgeese with implications for conservation of Falkland Islands (Malvinas) and continental populations of the Ruddy-headed Goose *Chloephaga rubidiceps* and Upland Goose *C. picta*. Bird Conserv Int 24:59–71. https://doi.org/10.1017/S0959270913000178

Canevari P (1996) The Austral geese (*Chloephaga* spp.) of southern Argentina and Chile: a review of its current status. Gibier Faune Sauvag 13:355–366

Chudzińska ME, van Beest FM, Madsen J, Nabe-Nielsen J (2015) Using habitat selection theories to predict the spatiotemporal distribution of migratory birds during stopover—a case study of pink-footed *geese Anser brachyrhynchus*. Oikos 124:851–860. https://doi.org/10.1111/oik.01881

Collantes MB, Braun K, Escartín C, Cingolani AM, Anchorena J (2005) Patrones de cambio de la vegetación de la estepa fueguina en relación al pastoreo. In: Oesterheld M, Aguiar M, Ghersa C, Paruelo J (eds) La heterogeneidad de la vegetación de los agroecosistemas. Facultad de Agronomía, Universidad de Buenos Aires, Buenos Aires

Collantes MB, Anchorena JA, Stoffella S, Escartín C, Rauber R (2009) Wetlands of the Magellanic Steppe (Tierra del Fuego, Argentina). Folia Geobot 44:227. https://doi.org/10.1007/s12224-009-9044-y

Congedo L (2016) Semi-automatic classification plugin documentation. https://doi.org/10.13140/RG.2.2.29474.02242/1. Accessed 7 Apr 2021

Cossa NA (2019) Biología de la conservación de tres especies de cauquén (*Chloephaga* spp.). Dissertation, University of Buenos Aires

Cossa NA, Fasola L, Roesler I, Reboreda JC (2017) Ruddy-headed Goose *Chloephaga rubidiceps*: former plague and present protected species on the edge of extinction. Bird Conserv Int 27:269–281. https://doi.org/10.1017/S0959270916000101

Cossa NA, Fasola L, Roesler I, Reboreda JC (2018) Incubating Upland Goose (*Chloephaga picta*) differential response to livestock, human, and predator nest disturbance. Wilson J Ornithol 130:739–745. https://doi.org/10.1676/17-105.1

Cossa NA, Fasola L, Roesler I, Reboreda JC (2020) Impacts of traditional livestock farming on threatened sheldgeese (*Chloephaga* spp.) in Patagonia. Avian Conserv. https://doi.org/10.5751/ACE-01630-150201

Crawley MJ (2012) The R book, 2nd edn. Wiley, New Jersey

Development Team (2019) QGIS geographic information system. Open Source Geospatial Foundation Project. http://qgis.osgeo.org. Accessed 7 Apr 2021

Gibbons JE, Matus R, Vilina YA, Blanco DE, Zalba S, Belenguer C (1998) Desarrollo de un plan de conservación para el Cauquén Cabeza Colorada (*Chloephaga rubidiceps*), en la región austral de Argentina y Chile. Wetlands International, Buenos Aires, Argentina and CONAF, Santiago de Chile, Chile. Technical report

Giroux JF, Bédard Y, Bédard J (1984) Habitat use by Greater Snow Geese during the brood-rearing period. Arctic 37:155–160

Gowaty PA (1993) Differential dispersal, local resource competition, and sex ratio variation in birds. Am Nat 141:263–280. https://doi.org/10.1086/285472

Hothorn T, Bretz F, Westfall P (2008) Simultaneous inference in general parametric models. Biom J 50:346–363. https://doi.org/10.1002/bimj.200810425

Johnsgard PA (2010) Ducks, geese, and swans of the world, revised edition. https://digitalcommons.unl.edu/biosciducksgeeseswans/1. Accessed 7 Apr 2021

Kopuchian C, Campagna L, Di Giacomo AS, Wilson RE, Bulgarella M, Petracci P, Mazar Barnett J, Matus R, Blank O, McCracken KG (2016) Demographic history inferred from genome-wide data reveals two lineages of sheldgeese endemic to a glacial refugium in the southern Atlantic. J Biogeogr 43:1979–1989. https://doi.org/10.1111/jbi.12767

Koremblit G, Forte Lay JA (1991) Contribución al estudio agroclimático del norte de Tierra del Fuego (Argentina). An Inst Patagon 20:125–134

Krausman PR (1999) Some basic principles of habitat use. In: Launchbaugh KL, Sanders KD, Mosley JC (eds) Grazing behavior of livestock and wildlife. University of Idaho, Moscow, pp 85–90

Livezey BC (1997) A phylogenetic analysis of modern sheldgeese and shelducks (Anatidae, Tadornini). Ibis 139(1):51–66. https://doi.org/10.1111/j.1474-919X.1997.tb04504.x

Logan M (2010) Biostatistical design and analysis using R: a practical guide. Wiley, West Sussex

Madsen J, Matus R, Blank O, Benegas L, Mateazzi G, Blanco DE (2003) Population status of the Ruddy-headed Goose (*Chloephaga rubidiceps*) in Tierra del Fuego and mainland Patagonia (Chile and Argentina). Ornitol Neotrop 14:15–28

Manly BF, McDonald L, Thomas DL, McDonald TL, Erickson WP (2004) Resource selection by animals: statistical design and analysis for field studies, 2nd edn. Kluwer Academic Publishers, Dordrescht

Martín S (1984) La avutarda magallánica (*Chloephaga picta*) en la Patagonia: su ecología, alimentación, densidad y control. IDIA 429–432:6–24

Matus R (2012) Clave para la identificación de plumajes y mudas en el genero *Chloephaga* en Patagonia. La Chiricoca 15:3–11

Matus R, Blank O, Blanco DE, Madsen J, Benegas L, Mateazzi G (2000) El Canquén Colorado (*Chloephaga rubidiceps*): antecedentes sobre sitios de reproducción y concentración en la XII Región de Magallanes, Chile. Boletín Chileno De Ornitología 7:13–18

MAyDS, AA (Ministerio de Ambiente y Desarrollo Sustentable, Aves Argentinas) (2017) Categorización de las Aves de la Argentina (2015). Ministerio de Ambiente y Desarrollo Sustentable de la Nación & Aves Argentinas report, electronic edition. Ciudad Autónoma de Buenos Aires, Argentina

Ministerio del Medio Ambiente (2019) Inventario Nacional de las Especies de Chile. Ministerio del Medio Ambiente, Gobierno de Chile. http://especies.mma.gob.cl. Accessed 7 Apr 2021

NatureServe, IUCN (International Union for Conservation of Nature) 2008. *Chloephaga picta*, *Chloephaga poliocephala*, *Chloephaga rubidiceps*. The IUCN red list of threatened species. Version 2020.3 http://www.iucnredlist.org. Accessed 10 Feb 2021

Nilsson L, Persson H (1992) Feeding areas and local movement patterns of post-breeding greylag geese *Anser anser* in south Sweden. Ornis Svecica 2:77–90. https://doi.org/10.34080/os.v2.23060

Owen M (1980) Wild geese of the world. Batsford, London

Oyarzabal M, Clavijo J, Oakley L, Biganzoli F, Tognetti P, Barberis I, Oesterheld M (2018) Unidades de vegetación de la Argentina. Ecol Austral 28:40–63. https://doi.org/10.25260/EA.18.28.1.0.399

Paludan K (1973) Migration and survival of *Anser anser* ringed in Denmark. Vidensk Medd Dan Naturhist Foren 138:217–232

Pedrana J, Bustamante J, Rodríguez A, Travaini A (2011) Primary productivity and anthropogenic disturbance as determinants of Upland Goose *Chloephaga picta* distribution in southern Patagonia. Ibis 153:517–530. https://doi.org/10.1111/j.1474-919X.2011.01127.x

Pedrana J, Bernad L, Maceira NO, Isacch JP (2014) Human-sheldgeese conflict in agricultural landscapes: effects of environmental and anthropogenic predictors on sheldgeese distribution in the southern Pampa, Argentina. Agric Ecosyst Environ 183:31–39. https://doi.org/10.1016/j.agee.2013.09.029

Pedrana J, Seco Pon JP, Isacch JP, Leiss A, Rojas PO, Castresana G, Calvo J et al (2015) First insights into the migration pattern of an Upland Goose (*Chloephaga picta*) based on satellite tracking. Ornitol Neotrop 26:245–253

Pedrana J, Bernad L, Bernardos JN, Seco Pon JP, Isacch JP, Muñóz SD, Maceira NO (2018a) Winter population size estimations of three migratory sheldgeese in the southern pampas, Argentina. Waterbirds 41:16–21. https://doi.org/10.1675/063.041.0103

Pedrana J, Pütz K, Bernad L, Seco Pon JP, Gorosabel A, Muñoz SD, Isacch JP, Matus R, Blank O, Lüthi B, Lunardelli M, Rojas P (2018b) Migration routes and stopover sites of Upland Geese *Chloephaga picta* in South America. Avian Biol Res 11:89–99. https://doi.org/10.3184/175815618X15179180488510

Pedrana J, Pütz K, Bernad L, Muñoz S, Gorosábel A, Castresana G, Leiss A, Seco Pon JP (2020) Spatial and temporal variation in the migration of Ruddy-headed Goose in southern South America using satellite tagging. Bird Conserv Int 30:634–648. https://doi.org/10.1017/S0959270920000143

Petracci P, Carrizo M (2017) Cauquén Colorado (*Chloephaga rubidiceps*), nuevo hallazgo en la provincia de Buenos Aires. Argent Nót Fauníst 2(222):1–9

Petracci P, Sarria R, Gaitán F, Fasola L (2013) Estatus poblacional de los cauquenes (*Chloephaga* sp.) en las áreas reproductivas del extremo sur de la Patagonia Argentina. Estrategia Nacional para la Conservación y el Manejo del Cauquén Colorado, Cabeza Gris y Común en la Argentina. Buenos Aires, Argentina. Technical Report

Petracci P, Bravo ME, Lizarralde CS, Flotron ML, Fasola L, Cossa N, Amorós CD et al (2014) Situación poblacional de los cauquenes (*Chloephaga picta, C. poliocephala y C. rubidiceps*) en las áreas reproductivas del extremo sur de la Patagonia Argentina, Temporada 2013–2014. Estrategia Nacional para la Conservación y el Manejo del Cauquén Colorado. Buenos Aires, Argentina. Technical Report

Petracci P, Ibáñez H, Baigún R, Meriggi J, Aguirre J, Bravo ME, León M et al (2015a) Monitoreo poblacional de cauquenes (*Chloephaga* sp.) en las provincias de Buenos Aires, La Pampa, Río Negro, Chubut y Santa Cruz. Reporte técnico, Temporada Julio 2014–2015. Estrategia Nacional para la Conservación y el Manejo del Cauquén Colorado, Cabeza Gris y Común en la Argentina. Buenos Aires, Argentina. Technical Report

Petracci P, Flotron ML, Valenzuela DF, Cossa N, Amorós CD, Cadierno SA (2015b) Abundancia y distribución del Cauquén Común (*Chloephaga picta*), Cauquén Cabeza Gris (*C. poliocephala*) y Cauquén Colorado (*C. rubidiceps*) en el extremo sur de la Patagonia Argentina. Estrategia Nacional para la Conservación y el Manejo del Cauquén Colorado, Cabeza Gris y Común en la Argentina. Buenos Aires, Argentina. Technical Report

Pettorelli N, Ryan S, Mueller T, Bunnefeld N (2011) The normalized difference vegetation index (NDVI): unforeseen successes in animal ecology. Clim Res 46:15–27. https://doi.org/10.3354/cr00936QGIS

Quillfeldt P, Strange IJ, Masello JF (2005) Escape decisions of incubating females and sex ratio of juveniles in the Upland Goose *Chloephaga picta*. Ardea 93:171–178

Rabassa J (2009) Impact of global climate change on glaciers and permafrost of South America, with emphasis on Patagonia, Tierra del Fuego, and the Antarctic Peninsula. Dev Earth Surf Process 13:415–438. https://doi.org/10.1016/S0928-2025(08)10019-0

R Core Team (2016) R: a language and environment for statistical computing. Vienna, Austria

Siegfried WR, Hockey PAR, Ryan PG, Bosman AL (1988) Sex and plumage-type ratios of the Lesser Magellan Goose in southern Chile. Wildfowl 39:15–21

Skaug H, Fournier D, Bolker B, Magnusson A, Nielsen A (2014) Generalized linear mixed models using AD model builder. R package version 0.8.0. http://glmmadmb.r-forge.r-project.org/. Accessed 7 Apr 2021

Summers RW, Martin SI (1985) Moult-skipping by the Lesser Magellan Goose in Argentina. Wildfowl 36:42–44

Summers RW, McAdam JH (1993) The Upland Goose. Bluntisham Books, Huntingdon

Tian H, Solovyeva D, Danilov G, Vartanyan S, Wen L, Lei J, Lu C, Bridgewater P, Lei G, Zeng Q (2021) Combining modern

tracking data and historical records improves understanding of the summer habitats of the Eastern Lesser White-fronted Goose *Anser erythropus*. Ecol Evol. https://doi.org/10.1002/ece3.7310
Venables WN, Ripley BD (2002) Modern applied statistics with S. Springer, New York
Webb EB, Smith LM, Vrtiska MP, Lagrange TG (2010) Effects of local and landscape variables on wetland bird habitat use during migration through the Rainwater Basin. J Wildl Manage 74:109–119. https://doi.org/10.2193/2008-577
Wood KA, Brides K, Durham ME, Hearn RD (2021) Adults have more male-biased sex ratios than first-winter juveniles in wintering duck populations. Avian Res 12:51. https://doi.org/10.1186/s40657-021-00286-1
Zhang W, Li X, Yu L, Si Y (2018) Multi-scale habitat selection by two declining East Asian waterfowl species at their core spring stopover area. Ecol Indic 87:127–135. https://doi.org/10.1016/j.ecolind.2017.12.035
Zuur A, Ieno E, Walker N, Saveliev A, Smith G (2009) Mixed effects models and extensions in ecology with R. Springer, New York