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SHORT NOTE

Winter bird gets the worm: consumption of earthworms (Lumbricidae) by striated caracaras (Phalcoboenus australis) in invasive Yorkshire fog (Holcus lanatus) in the Falkland Islands (Malvinas)

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Abstract
Biological invasions can drive ecosystem change and alter predator ecology by providing trophic subsidies that mitigate the effects of seasonally pulsed resources. Striated Caracaras (*Phalcoboenus australis*) are near threatened, non-migratory falconids who inhabit the southern coasts of South America and the Falkland Islands (Malvinas) and feed on seasonally migratory colonial seabirds. Here we report the first multi-day observation of caracaras foraging extensively for earthworms (Lumbricidae) and beetle larvae (Coleoptera) in introduced Yorkshire fog (*Holcus lanatus*) on New Island, Falkland Islands. Our results suggest that invertebrates may be a more important winter resource than previously thought, and that caracaras benefit indirectly from introduced grasses in the Falklands, a relationship that merits special consideration when identifying ecological restoration plans.

Keywords Falconid · Ground-foraging · Invasive species Lumbricidae · Pulsed resources · Species conservation

Introduction

Biological invasions can drive ecosystem change and alter predator ecology (Cameron and Bayne 2012). Some introduced species can negatively impact native taxa through direct predation or competition (Savidge 1987; Roemer et al. 2002), while others can positively impact predator population growth by providing trophic subsidies (Barber et al. 2008; Pearson et al. 2009). In some island systems, predators have adapted to depend directly or indirectly on non-native species (Roemer et al 2002; Bergstrom et al. 2009), a relationship that merits special consideration when identifying invasive eradication plans (Speziale and Lambertucci 2013), particularly as predators can structure ecological communities (Legagneux et al. 2012) and may already be facing conservation threats. Here we report an unintentional effect of human-altered grassland ecology that may benefit an endemic predator during the seasonal absence of migratory prey.

Striated Caracaras (*Phalcoboenus australis*; hereafter "caracaras") are near threatened falconids who inhabit the extreme southern coasts of South America and the Falkland Islands (Malvinas; Balza et al. 2017; Reeves et al. 2018; BirdLife International 2020). During summer, caracaras feed on a seasonal resource pulse (sensu Yang 2010) associated with colonial seabird populations (Strange 1996; Balza et al. 2017; Harrington et al. 2018). In winter, when most seabirds migrate offshore, caracaras' diets include native Upland Geese (*Chloephaga picta*), the feces and carrion of resident southern fur seals (*Arctocephalus australis*), southern sea lions (*Mirounga leonina*), and Gentoo Penguins (*Pygoscelis papua*), beetles (Coleoptera), and subsidies available at farms (Strange 1996; Rexer-Huber and Bildstein 2013; Harrington et al. 2018).

While Strange (1996) noted that caracaras consume invertebrate prey throughout the year, the relative importance of this dietary component throughout their range has never been assessed, and invertebrate prey are absent from most discussions about the species' winter diet (Catry et al. 2008;

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Autilio et al. 2019), despite that invertebrates form a part of the diet of all other caracara species (Thiollay 1991; Travaini et al. 2001; Donadio et al. 2007; Morrison et al. 2008; Solaro and Sarasola 2012). Here we report a multi-day observation of caracaras foraging for earthworms (Lumbricidae) and beetle larvae in introduced grasslands on a formerly farmed island.

Methods

New Island (51.72 S, 61.30 W) is a 2200-ha nature preserve in the southeast Falkland Islands (Malvinas), near the southern tip of South America (Fig. 1). The island retains stands of native tussock grass (*Poa flabellata*), but is dominated by stretches of diddle-dee (*Empetrum rubrum*) and introduced Yorkshire fog (*Holcus lanatus*) and sheep's sorrel (*Rumex acetosella*) (for a detailed description of New Island, see Quillfeldt et al. 2008). Livestock were gradually removed from the island between 1972 and 2006, during which time the breeding population of caracaras rebounded from zero pairs (Strange 1996) to 86 pairs (Reeves and Bildstein 2018). During the austral summer, New Island supports globally significant colonies of Thin-billed Prions (*Pachyptila belcheri*), Southern Rockhopper Penguins (*Eudyptes chrysocome*), and Black-browed Albatrosses (*Thalassarche melanophris*), as well as Imperial Shags (*Phalacrocorax atriceps*) and Magellanic Penguins (*Spheniscus magellanicus*), who all vacate the island during winter. The island supports resident populations of Gentoo Penguins, Upland Geese, southern fur seals, and southern sea lions year-round (Strange et al. 2007).

From 4 to 10 August 2019 (austral winter), we conducted a walking transect survey of New Island during daylight hours (0900 h to 1800 h), recording caracara abundance, location, age, and foraging behavior. We randomly selected 53 caracaras raking in the soil and conducted 30 s focal sampling (Altmann 1974), in which we stood at a 3 m distance and used binoculars to count the number and, when possible, type of invertebrates consumed. Like many island endemics, caracaras are generally unwary of human approaches (Strange 1996), which created the unique opportunity to conduct the behavioral sampling described. We then surveyed ten 625 cm^2 plots of Yorkshire fog to record abundance of invertebrate prey within the top 5 cm of grass roots and soil. We only sampled one grass plot per territory and targeted areas adjacent to where we had observed caracaras digging. Except for sheep's sorrel, we only observed caracaras digging under Yorkshire fog, thus we restricted our sampling to plots of Yorkshire fog for consistency. Earthworms were later identified to the family using field markings from photographs (Reynolds 2020). To provide comparison between the caracaras' winter body condition and their summer body condition, we trapped adult caracaras (aged following

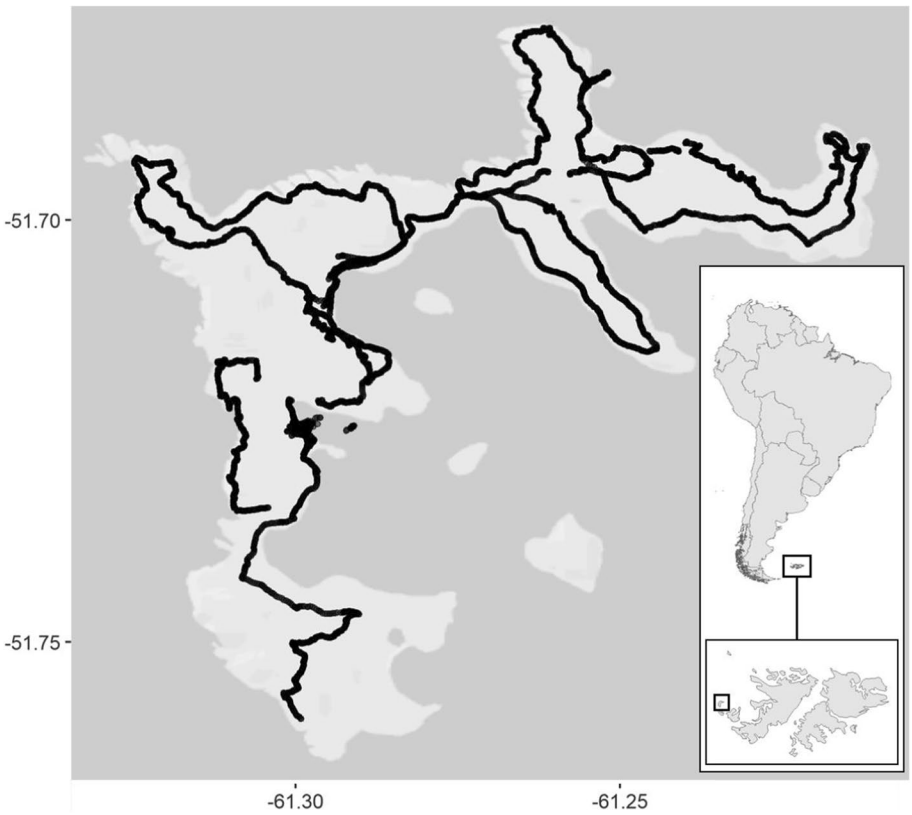

Fig. 1 Map of New Island, Falkland Islands (Malvinas), prepared using the get_googlemap function in the R package ggmap (South 2017). Insets show the location of the Falkland Islands to the northeast of Cape Horn and the position of New Island within the archipelago, both prepared using the ne_countries function in the R package rnaturalearth (Kahle and Wickham 2013). The thick black line shows the locations of the walking transect survey

Strange 1996; $n = 12$ females, 5 males) using a mutton-baited snare carpet and recorded their mass to the nearest 25 g using a hand-held scale (Harrington et al. 2018). We visually assessed individual's crop size, which we categorized as not distended, partially distended, or distended, allowing us to restrict our mass analysis to birds that did not have distended crops. We combined these mass data with data collected following the same protocol in March 2019 ($n = 4$ females, 7 males) and June 2014 ($n = 13$ females, 7 males; KH unpubl. data). Molecular sexing was performed as described in Griffiths et al. (1998). Caracaras are size dimorphic, with females being larger than males (Strange 1996), thus we grouped individuals by sex a priori. Austral winter comprised June and August data, and austral summer comprised March data. We tested the effect of season on mass by using a Welch Two Sample *t* test for our normally distributed female dataset and a Kruskal–Wallis test for our non-normal male dataset. Statistical analyses were performed using R version 3.5.2.

Results and discussion

During the island-wide survey, 70% of observed caracaras ($n = 284$) were foraging. Of the foraging birds, 81% were raking with their talons in dense mats of invasive Yorkshire fog and sheep's sorrel and feeding on invertebrates, often in adult pairs or small groups of up to 15 individuals of all age classes (Fig. 2). Of caracaras not foraging on invertebrates, 10% were scavenging (i.e., walking and pecking at objects along the shore), 7% were feeding on carcasses of Upland Geese, and 3% were feeding on pinniped feces. During focal sampling of caracaras raking in the soil, we recorded a feeding rate of 4 ± 2 invertebrates per 30 s. Within Yorkshire fog survey plots ($n = 10$), we recorded 24 ± 29 readily visible invertebrates, with a maximum of 102 in a single plot (earthworms: 19 ± 25, range: 3–86; beetle larvae: 5 ± 6, range: 0–16; Fig. 2C). Winter masses were lower by 1.2% for adult females and 4.8% for adult males when compared with summer masses. However, we found no significant difference in seasonal mass for females (winter 1685 ± 86 g [$n = 25$], summer 1706 ± 75 g [$n = 4$]; Welch Two Sample *t* test, $t_4 = 0.52$, $p = 0.63$), nor for males (winter 1445 ± 81 g [$n = 12$], summer 1518 ± 150 g [$n = 7$]; Kruskal–Wallis test, $H_1 = 0.80$, $p = 0.37$).

In the Falkland Islands (Malvinas), the direct and indirect effects of sheep farming, including intense direct persecution (Woods and Woods 1997), have reduced caracaras' historical distribution (Darwin 1845) to the outer islands of the archipelago (Cawkell and Hamilton 1961; Strange 1996; Woods 2017). While the species is now protected and appears to be recovering (Reeves and Bildstein 2018), they are not recolonizing across their entire historical range, and the ecological mechanisms that facilitate their recolonization of islands remain unknown. A study of caracaras roosting near a settlement on a farmed island posited that winter food stress may limit the species' recovery (Rexer-Huber and Bildstein 2013). However, caracaras throughout the Falklands inhabit a wide range of landscapes, including formerly farmed (i.e., all stock has been removed) and "vegetationally pristine" islands (Reeves and Bildstein 2018), which have differing resource availability through winter. Though mass measurements are not always a reliable indicator of body condition or stress (King and Murphy 1985; Brown 1996), our results suggest that invertebrates may be a more important winter resource for caracaras than previously thought, and that it is possible that winter may not be a time of food stress for all caracaras in the Falklands. However, more work is needed to establish baselines for body condition within the species.

In this study, we observed caracaras foraging for invertebrates almost exclusively within patches of introduced Yorkshire fog and sheep's sorrel and not in the island's native vegetation (e.g., feldmark and stands of tussac grass). We hypothesize that the grasses introduced as pasturage and

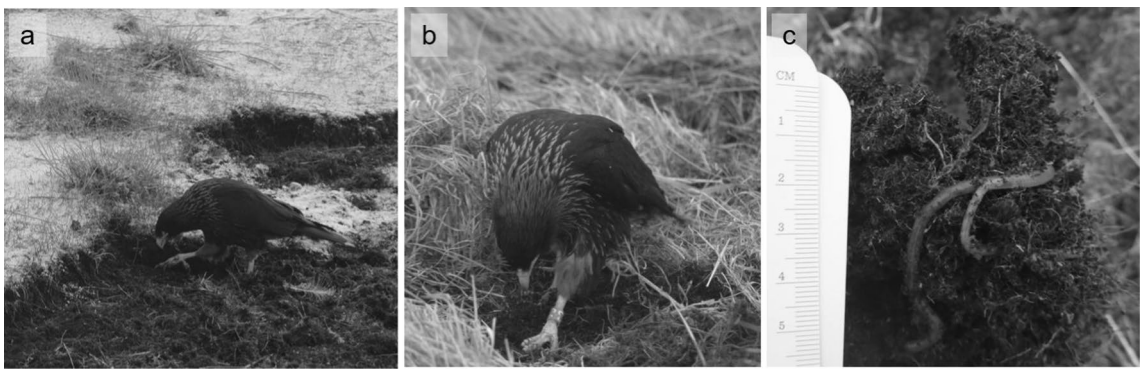

Fig. 2 Adult Striated Caracaras (*Phalcoboenus australis*) raking in Yorkshire fog (*Holcus lanatus*; **a** and **b**) and earthworms (Lumbricidae) dug from a study plot of Yorkshire fog (**c**). The darker soil patches in **a** and **b** indicate areas of grass that have already been dug out by caracaras

the removal of sheep may have facilitated caracaras' rapid recolonization of New Island by mitigating the seasonal food limitation imposed by migratory seabird prey and restoring soil composition. While the Falkland Islands have several native earthworms, introduced species are also common throughout the islands (Reynolds and Jones 2006). Similar winter foraging behavior by caracaras in introduced sheep's sorrel was observed on another formerly farmed island, Steeple Jason (51.04 S, 61.21 W), where all stock has been removed and a survey indicated a stable year-round population, despite the seasonal absence of the island's large colonies of albatrosses, penguins, and burrowing petrels (Woods et al. 2012).

These observations are in sharp contrast to observations from Saunders Island, an active sheep farm (see Harrington et al. 2018 for description) that supports non-breeding caracaras in winter (Harrington et al. 2018) though, following the 1964 government ban on direct persecution (Falkland Islands Government 1999), has not been recolonized to the extent of New Island (i.e., as of February 2019, there were 4 known nests on Saunders [KH unpubl. data] in comparison to 86 on New Island [Reeves and Bildstein 2018]). In another winter diet study, Rexer-Huber and Bildstein (2013) found beetle remains in caracara pellets at a communal roost adjacent to the farm settlement on Saunders but did not report earthworms. This may be due to the methodological limitations of pellet analyses (Marti et al. 2007), although it may also reflect lower invertebrate abundance due to soil compaction from continued sheep farming (Langmaack et al. 1999; Schon et al. 2017). Furthermore, during previous field seasons on Saunders, we have observed raking for dipteran larvae in accumulated kelp wrack, though we have observed little raking for soil invertebrates across four winters from 2016 to 2019 (KH unpubl. data). It is possible that the regular availability of subsidies at the island's farm settlement (see Harrington et al. 2018) is a more attractive winter food source than terrestrially raked invertebrates; however, this does not explain the limited recolonization of Saunders Island.

We suggest further research into caracara winter resource use on islands that have never been farmed, to better understand how caracaras seasonally cope in the absence of migratory prey and human food subsidies. Additionally, as caracaras in the Falklands are an island-restricted species of conservation concern, we suggest that the relationship between caracaras and introduced species merits special consideration when developing eradication and ecological restoration plans.

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Author contributions KJH conceptualized the study, administered the project, and obtained project funding. KJH and JM conducted fieldwork. JLH analyzed genetic data. KJH analyzed behavioral data. KJH wrote and prepared the original manuscript. KJH, JM, and JLH reviewed and edited the manuscript. All authors approved the submitted manuscript.

Data availability Data are available upon request.

Declarations

Conflict of interest The authors declare no competing or financial interests.

Ethical approval All capture, handling, and instrumentation procedures were approved by the San Jose State University Institutional Animal Care and Use Committee protocol (#1054) and conducted under the Conservation of Wildlife and Nature Ordinance of 1999, Sect. 9, License to carry out Scientific Research permit (#R22/2015, Falkland Islands Government). Informed consent was not applicable. We caught a total of 28 caracaras for this study and complemented our dataset with existing data from an additional 20 birds. We observed no adverse effects of trapping and handling. During our subsequent breeding success surveys, we observed no long-term effects of the birds having been previously trapped.

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