24 (2026) 214–222

Contents lists available at ScienceDirect

Perspectives in Ecology and Conservation

journal homepage: www.perspectecolconserv.com

Research Letters

Landscape structure influences prey consumption and ecosystem services of Aplomado Falcons in agroecosystems of central Argentina

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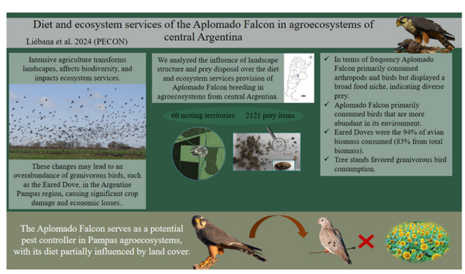
HIGHLIGHTS

- Aplomado Falcon predates Eared Doves, supporting pest control in agroecosystems.
- Tree stands increase granivorous bird prey, linking diet to landscape features.
- Falcon diet study combines pellet analysis with prey abundance field surveys.
- Raptors support sustainable agriculture by reducing reliance on chemical controls.
- The Aplomado Falcon adjusts its diet to exploit resources in modified ecosystems.

GRAPHICAL ABSTRACT



ARTICLE INFO

Keywords:
Falco femoralis
Biological control
Eared dove
Land use
Trophic dynamics
Predator-prey interactions

ABSTRACT

Agricultural expansion and land-use intensification have transformed Argentina's Pampas region, leading to biodiversity declines and ecosystem imbalance. This study examines the Aplomado Falcon (*Falco femoralis*) as a potential biological pest controller in agroecosystems of central Argentina. We evaluated how landscape structure and prey availability influenced its diet, focusing on the consumption of granivorous birds like the Eared Dove (*Zenaida auriculata*), a significant agricultural pest. Using regurgitated pellets and prey remains from 60 nesting territories, we identified 83 prey species and assessed prey abundance in the field. Results show the falcon's diet is dominated by birds, particularly Eared Doves, which constituted 94% of avian biomass consumed. Tree stands positively influenced the consumption of granivorous birds, while arthropod consumption declined in these areas. The study highlights the Aplomado Falcon's role in pest control, demonstrating its adaptability to agroecosystem modifications. These findings emphasize the ecological and economic importance of raptors in supporting sustainable agriculture.

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https://doi.org/10.1016/j.pecon.2026.02.009
Received 7 January 2025; Accepted 3 February 2026
Available online 14 February 2026

Introduction

Agricultural expansion and land-use intensification are major drivers of biodiversity loss worldwide, with severe implications for ecosystem functioning and the ecosystem services (ES) that support human well-being (Norris, 2008; Scharlemann et al., 2004; Mantyka-pringle et al., 2012; Tilman et al., 2012). In Argentina, extensive agricultural intensification over the past 50 years has transformed the original temperate grasslands of the Pampas region, leading to significant declines in native biodiversity (Aizen et al., 2009; Viglizzo et al., 2011). These changes have particularly affected grassland birds, both directly through habitat loss and indirectly by altering the ecosystem dynamics that sustain biodiversity and associated ES (Medan et al., 2011; Bilenca et al., 2012; Codesido et al., 2012).

In some cases, landscape changes associated with agroecosystems benefit certain bird species by creating new habitats, eliminating some predators, and increasing food availability (La Sorte, 2006; Balbontín et al., 2008; Costán and Sarasola, 2021). However, population booms of granivorous species, such as Columbiformes (pigeons and doves) and Psittaciformes (parrots and parakeets), can lead to significant crop damage, generating economic losses for farmers and disrupting ecosystem balance. In central Argentina, for example, the Eared Dove (*Zenaida auriculata*) has thrived in modified landscapes, with nesting densities reaching up to 5000 nests per hectare in some areas (Bernardos, 2010), resulting in crop losses estimated at $10 million during the 2011–2012 season alone (Bernardos and Farrel, 2012). Managing these overabundant populations is essential to minimize economic impacts while preserving ecological balance and enhancing ES, such as natural pest control.

Predatory species, particularly raptors, can play a vital role in regulating prey species and providing natural pest control services within agricultural landscapes. These ecosystem services may be especially valuable in reducing the populations of economically damaging granivorous birds, thus alleviating the need for costly and potentially harmful control measures. The Aplomado Falcon (*Falco femoralis*), a raptor with a strong preference for bird prey, has a wide distribution across the Americas and is commonly found in the Pampas (Ferguson-Lees and Christie, 2001). While previous studies have documented its dietary habits (Keddy-Hector et al., 2020; Macías-Duarte et al., 2004; Salvador, 2013), there is limited research connecting its prey consumption to prey abundance and habitat conditions in agroecosystems, as well as its potential to provide pest control services.

In the Pampas region, the proliferation of granivorous bird populations, such as the Eared Dove, may influence the trophic dynamics and ecosystem services provided by raptors like the Aplomado Falcon. Investigating the dietary response of these falcons to prey availability can shed light on their role in pest control and their potential contribution to ecosystem service provision in agricultural landscapes.

Thus, we hypothesize that the diet of the Aplomado Falcon is influenced by the availability of granivorous bird prey and the type of land use within its breeding territory, suggesting that variation in its dietary composition reflects the dynamics of prey populations in agricultural ecosystems of La Pampa. Our specific objectives are to assess the abundance and diversity of bird species, particularly granivorous ones, in the breeding areas of the Aplomado Falcon; analyze how different types of land use affect the frequency of prey consumption and dietary diversity; and investigate the relationship between the dietary composition of the Aplomado Falcon and the abundance of prey birds in its territory.

Materials and methods

Study area

The study was conducted in a 7000 km^2 agricultural area in northwestern La Pampa province, Argentina (Fig. 1). This area lies within the Pampas phytogeographical province and its transitional zone (ecotone) with the Espinal phytogeographical province (Soriano et al., 1991). The climate in this region is classified as dry sub-humid, with average annual rainfall ranging from approximately 350–850 mm, predominantly occurring in spring and summer (Lorda et al., 2008). In the late 18th century, vegetation consisted of temperate grasslands dominated by various tussock grasses, with an absence of trees (Cabrera, 1976). However, this landscape has been significantly transformed by intensive

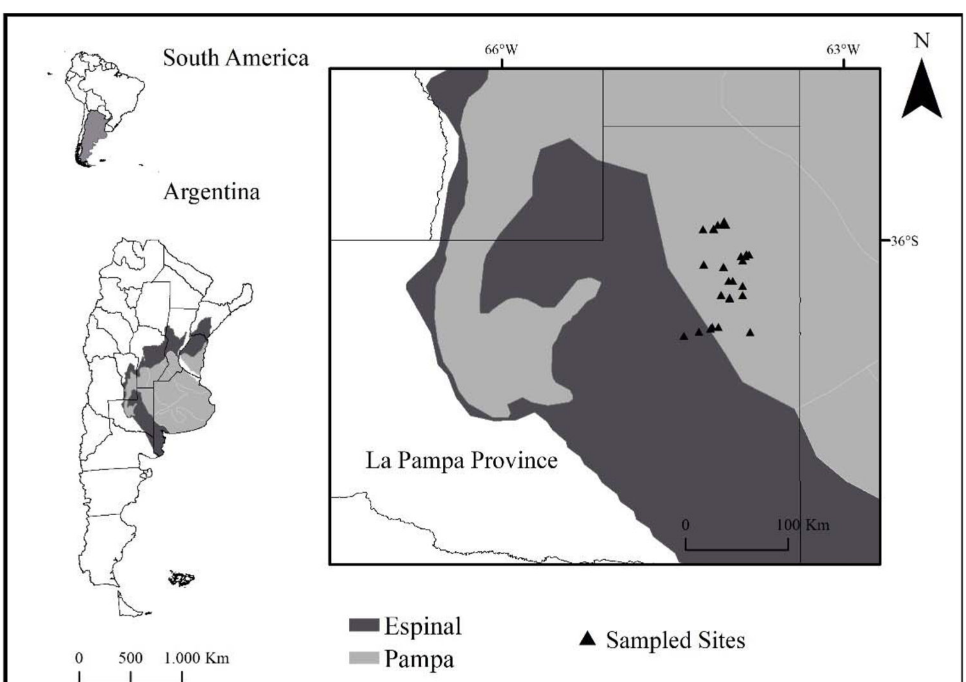

Fig. 1. Study area and geographic location of the sample sites corresponding to Aplomado Falcon breeding territories in La Pampa, Argentina, showing political and biogeographic boundaries.

mixed agricultural and livestock activities (Caviglia et al., 2010). Currently, the vegetation comprises a mosaic of crops (including cultivated pastures, alfalfa, corn, sunflower, soybean, wheat, and barley), low grasslands, and exotic tree stands primarily used for shade for cattle and as windbreaks. Some patches of native forest, mainly composed of Caldén (*Neltuma caldenia*), remain in the area, originating from the surrounding Espinal phytogeographical province (Williamson, 1967; Cano, 1980; Soriano et al., 1991; Merenson et al., 2004).

Aplomado falcon territory and nest surveys

Between September and January of 2010–2014, intensive surveys were conducted throughout the study area to locate Aplomado Falcon (Falco femoralis) individuals and breeding pairs. Field searches covered approximately 10,000 km annually. During this period, falcons were more conspicuous and easily detected through reproductive and territorial behaviors such as courtship displays, copulations, and agonistic interactions. Once nests were located, they were georeferenced using GPS and monitored every 10–15 days to minimize disturbance, from discovery until fledging or breeding failure. Territories were revisited annually to confirm occupancy, and some were re-sampled in multiple years to collect pellets and prey remains. Field procedures followed standard methodologies for raptor breeding surveys and diet studies (Liébana, 2015; Marti et al., 2007; Macías-Duarte et al., 2004).

Habitat analysis

To assess the influence of landscape cover on the trophic habits of the Aplomado Falcon and its role as an ecosystem service provider in pest control, we established a buffer zone with a radius of 1000 m around each nest (approximately 314 ha). This radius corresponds to the mean distance between the nearest nests in our study area (Liébana, 2015). For each buffer, we generated a shapefile by manually digitizing all land covers using a georeferenced Google Earth® image (≈1 m per pixel). The land covers within each polygon were verified in the field to create a Geographic Information System (GIS) for each Aplomado Falcon territory, which were classified into four types: exotic tree stands (primarily composed of *Eucalyptus* spp. and *Ulmus pumila*), native forest (dominated by Caldén), agricultural lands (including crops, pastures, grasslands and stubble), and peri-domestic areas (comprising residences, surrounding structures and associated parks or gardens; roads were not included, as they were unpaved, narrow, and represented a negligible proportion of the landscape). This analysis allows us to better understand how landscape composition affects the availability of prey species and, consequently, the falcon's foraging behavior.

Diet composition analysis

During the reproductive seasons (September to January) from 2010 to 2013, we collected pellets and prey remains from nests and roost sites belonging to 60 reproductive territories, some of which were sampled repeatedly in different years (Fig. 1). Samples were collected during each visit to the nesting territories throughout the breeding season, following the same general schedule as nest monitoring. However, collection frequency varied among territories and years depending on accessibility and breeding activity. During each visit, potential perching and feeding sites near the nests were also inspected for additional remains. All samples were collected following standardized protocols: they were carefully removed from under nests and roosts, placed in labeled containers, and preserved by air-drying to prevent decomposition and fungal growth. In the laboratory, pellets were manually disaggregated, and prey items were sorted for identification (Marti et al., 2007). From all the samples (pellets and preys remains) birds were identified to the species level using feathers, beaks, and other remains, supported by reference collections and, when necessary, through the examination of feather microstructures (nodes and barbs) (Reyes, 1992). Mammals were identified using skulls, teeth, and hairs, employing keys (Chehébar and Martín, 1989; Pearson, 1995) and reference collections. Insects were identified to family level based on mandibles, heads, elytra, and other parts using reference materials. To determine the number of individual prey items in each sample, we counted mammal and bird skulls. For arthropods, we considered whole heads, legs, elytra, and mandibles. When only hairs, bones, or feathers were found, they were treated as a single individual. Unidentified prey items were recorded and included in total prey counts; their proportion relative to the total diet was noted but excluded from species- or taxon-specific analyses.

For each identified taxon, we calculated its relative frequency (% Ni), defined as the number of individuals of prey i over the total number of prey expressed as a percentage, and the biomass (% Bi), calculated as the proportion of the total biomass consumed represented by prey i. The mean mass of vertebrate prey was sourced from literature (Camperi and Darrieu, 2005) and our own data. For arthropods, we employed a mean weight of 1 g, following Vargas et al. (2007). We used the Shannon diversity index (H') to assess dietary diversity and Levins' niche breadth index (B), as these metrics provide critical insights into resource use patterns, feeding flexibility, and potential responses to habitat changes in managed landscapes (Colwell and Futuyma, 1971).

Prey abundance

To estimate prey availability and abundance within the reproductive territories, we conducted bird surveys in each territory during the reproductive seasons (September–January) from 2010 to 2013. Surveys were carried out using fixed-point counts with a 200 m radius and a 10-minute duration per point, conducted in the morning (7:00–10:30) under favorable weather conditions (Bibby et al., 1992). All birds seen or heard were included in the counts, including flying individuals, as falcons are capable of capturing prey in flight, making these individuals part of the available prey pool. Due to logistical constraints, only 1–2 counts were conducted per territory; when more than one count was performed, these were temporal replicates at the same point. Each count point was located as close as possible to the nest while ensuring adequate visibility of the surrounding area. This approach together with the analysis of diet composition allows us to link prey availability to the falcon's functional role in agricultural landscapes.

Because each sampling point was visited only once or two times per breeding season, detection probabilities were not estimated, and abundance values should therefore be interpreted as indices of relative abundance rather than absolute population estimates. This limitation was considered when comparing prey availability with dietary data.

Statistical analysis

For statistical analyses, prey items were grouped into three main categories representing the dominant trophic components of the Aplomado Falcon diet: Columbiformes, Other Birds, and Arthropods. The Other Birds category included primarily Passeriformes, but also a few non-passerine species of similar size and ecological role (e.g., Piciformes and Cuculiformes). To determine whether the analyzed land covers explained variation in the consumption of the main prey types, we performed Generalized Linear Models (GLM; McCullagh and Nelder, 1989) with a quasibinomial error distribution to address the observed overdispersion. The dependent variable was the relative frequency of prey (e.g., the number of arthropods out of total identified prey for a territory sample), while the explanatory variables were the land cover types of each territory. Year was included as a fixed factor in the models to account for potential interannual variation in prey availability and consumption. For modeling purposes, we only included territories where a minimum of ten prey items were identified ($n = 29$). Taxa such as Mammalia, Reptilia, and Amphibia were excluded from the analysis due to their representation being below 5% of the total biomass consumed, and we included only one nesting pair from different years to avoid pseudo-replication.

Additionally, we constructed linear models to test the effects of land cover and year on Levins' standardized food-niche breadth and Shannon diversity index values for each nest. A stepwise removal procedure was applied, excluding all variables with $p > 0.05$, resulting in a final model that included only significant effects (Hosmer and Lemeshow, 1989). We employed likelihood ratio tests (LRT) to compare models differing by the inclusion of a focal variable, with associated chi-squared values taken as a measure of support for retaining the focal variable in the model (Crawley, 2007). Residuals of each model were examined post-fitting by examining residual plots to verify assumptions of normality, homoscedasticity, and absence of influential outliers (Crawley, 2007). For binomial and quasibinomial GLMs, we calculated dispersion parameters and adjusted for mild overdispersion where needed. Finally, to verify the association between bird prey consumption and their abundances in the territories, we performed a Spearman rank correlation between the proportion of each bird prey species in the diet and their corresponding abundance in the field (n = 47 nesting territories). Due to limited prey sample sizes per year and territory, we pooled diet and survey data across years for each territory to obtain more stable estimates. While this approach reduced temporal resolution, it allowed us to retain sufficient data for a conservative, non-parametric correlation analysis. All statistical analyses were conducted using R version 3.1.2 (R Development Core Team, 2011).

Results

Landscape characterization

The percentages of mean land uses (±SE, range in brackets) around Aplomado falcon nesting sites in the study area during the 2010–2013 breeding seasons confirm that agricultural lands are the predominant surface, accounting for 90.8% (±20.7; 0–102.9) of the landscape surface. Among the other three cover types, native forest was the largest, accounting for 5.3% (±14.8; 0–56.1), followed by exotic tree stands with 2.3% (±3.5; 0–15.3) and peri-domestic areas with 1.6% (±2.5; 0–13.1). Within the category previously described as agricultural lands, the pastures and grasslands were the predominant cover type, representing 55.9% (±34.3; 0–40.5) of the surface. This was followed by stubbles with 23.6% (±32.3; 0–24.8) and crops with 20.5% (±33.4; 0–34.6).

General diet composition

During the study period, we collected and analyzed 589 regurgitated pellets and 278 prey remains, identifying a total of 2119 prey items belonging to 83 species across four classes of vertebrates (Aves, Mammalia, Reptilia, and Amphibia) and two classes of arthropods (Insecta and Arachnida) (Table 1). In terms of relative frequency, Aplomado Falcons primarily consumed arthropods (52%), followed by birds (44%). The other groups did not exceed 5% occurrence: reptiles (%Ni = 2.5), mammals (%Ni = 1.9), and amphibians (%Ni < 1) (Table 1). Birds contributed the most biomass to the diet of Aplomado Falcons (83.1%), followed by reptiles (11.9%), mammals (3.9%), arthropods (1.1%), and finally amphibians (<1%) (Table 1). Among the birds, columbiformes were the main prey species, representing 94% and 91% of the relative frequency and biomass, respectively, and constituting 66.1% of the total biomass. Eared Doves were the most common item among the total prey items (Table 1). The standardized food-niche breadth observed for the Aplomado Falcon in the study area was relatively high, with a value of 0.7. Totals for the main prey groups (Columbiformes, Other Birds, and Arthropods), used in subsequent analyses, are shown in Table 1.

Effects of land cover on diet composition

Regarding the influence of land cover on diet composition, tree stand cover was the only variable retained in the model for the occurrence of Columbiformes in the Aplomado Falcon's diet ($\chi^2 = 13.45$, $p = 0.027$). This effect was positive and significant ($\beta = 0.02 \pm 0.01$), indicating that falcons nesting in areas with larger tree stand surfaces consumed higher levels of this prey type. Model diagnostics for this GLM indicated mild overdispersion ($\hat{c} = 2.93$); thus, a quasibinomial model was applied.

For Other Birds (mostly Passeriformes), tree stand cover also had a positive effect ($\beta = 0.04 \pm 0.01$, $\chi^2 = 23.28$, $p = 0.01$), and prey consumption differed among years ($\chi^2 = 38.59$, df = 3, $p = 0.01$). In contrast, arthropod consumption was negatively associated with tree stand area ($\beta = -0.04 \pm 0.008$, $\chi^2 = 67.1$, $p = 0.008$) and with the proportion of natural forest ($\beta = -0.007 \pm 0.0029$, $\chi^2 = 18.05$, $p = 0.0029$). No strong deviations or influential outliers were observed upon inspecting residuals, and model fit was considered adequate across all GLMs.

Although the effect sizes were moderate, their direction and significance consistently support the interpretation that wooded habitats (especially tree stands) increase avian prey availability, while more open or forested areas support a higher proportion of arthropod prey. This pattern suggests a landscape-mediated shift in trophic composition.

Relation between diet and prey availability

During prey sampling (2010–2013), a total of 34,630 individuals were recorded in the study area, representing 63 species belonging to 23 avian families (Table 2). The Eared Dove was the most abundant species (79% of the total bird species recorded). A positive association was confirmed between the abundance of birds in the field and their appearance in the diet of the Aplomado Falcon (Fig. 2; n = 47 nesting territories; $\rho = 0.73$; $p < 0.001$).

Discussion

The Aplomado Falcon (*Falco femoralis*) in the study area primarily consumed arthropods and birds in that order, but exhibited a high food-niche breadth, indicating a wide diversity of prey items. However, considering the biomass contribution of each prey group, this species behaves predominantly as a bird consumer, as has also been proposed by other authors studying its diet in agricultural landscapes (Héctor, 1985; Bó, 1999; Figueroa Rojas and Corales Stappung, 2004, 2005; Salvador, 2013). The extraordinary consumption of arthropods, documented in previous studies, highlights their significance. Jiménez (1993) found a high frequency of arthropods (42.5%) in the diet of the Aplomado Falcon in Chile, though based on a small sample size (n = 3), while Héctor (1985) reported a higher percentage (65%) in Mexico based on focal observations (n = 234). In the remaining reports, the consumption of arthropods was not significant compared to other types of prey (Montoya et al., 1997; Bó, 1999; Macías-Duarte et al., 2004; Figueroa Rojas and Corales Stappung, 2004, 2005; Baladrón et al., 2012; Salvador, 2013).

Most studies on the diet of the Aplomado Falcon have focused on prey remains; few have combined this analysis with that of regurgitated pellets, or relied solely on the analysis of regurgitations (Montoya et al., 1997; Bó, 1999; Macías-Duarte et al., 2004; Figueroa Rojas and Corales Stappung, 2004, 2005; Baladrón et al., 2012; Salvador, 2013). This may explain the low frequency of arthropods in many studies based solely on prey remains, except for Héctor (1985), who combined analyses of remains with focal observations. He noted differences in the frequency of prey types depending on methodology: in focal observations, birds accounted for 35%, while arthropods comprised 65% of consumed prey; in remains, birds represented 93%.

Combining analyses of regurgitated pellets and prey remains can provide additional insights into the habits of raptors concerning frequency and diversity of prey items (Simmons et al., 1991; Oro and Tella, 1995). The combined method used here confirms that arthropod consumption by the Aplomado Falcon is significant, despite their low

Table 1
Diet composition of Aplomado Falcon during the reproductive season (2010–2014) in agroecosystems of La Pampa, Argentina. Values for pellets, prey remains, and total prey are presented. **n** = number of individuals; **%Ni** = relative frequency of each prey category over the total number of prey; **%Bi** = biomass contribution of each prey category. Prey mass is expressed between parentheses, "–" indicates no data available. Totals for the main prey groups (**Columbiformes**, **Other Birds**, and **Arthropods**) were calculated by summing all species within each group and are shown in bold in their corresponding rows. The *Other Birds* category includes primarily Passeriformes and a few non-passerine species.

	Pellets			Prey Remains			Total (Pellets + Prey Remains)		
	n	$\%N_i$	$\%B_i$	*n*	$\%N_i$	$\%B_i$	*n*	$\%N_i$	$\%B_i$
Birds									
Unidentified Birds	46	2.50	–	8	2.88	–	54	2.55	–
Unidentified Passeriform	19	1.03	–	4	1.44	–	23	1.08	–
Tinamidae									
Nothura spp. (400)		–	–	4	1.44	5.08	4	0.19	1.74
Anatidae	1	0.05	–		–	–	1	0.05	–
Spatula cyanoptera (400)		–	–	2	0.72	2.54	2	0.09	0.87
Charadriidae									
Vanellus chilensis (320)		–	–	2	0.72	2.03	2	0.09	0.70
Columbidae									
Unidentified Columbidae		–	–	1	0.36	–	1	0.05	–
Zenaida auriculata (128)	326	17.82	69.10	148	53.24	60.11	474	22.35	66.12
Columbina picuí (47)	76	3.91	5.91	17	6.12	2.54	93	4.38	4.76
Columba livia (400)		–	–	1	0.36	1.27	1	0.05	0.44
Patagioenas spp. (350)	6	0.33	3.48	8	2.88	8.88	14	0.66	5.34
Columbiformes (total)								**27.49**	**76.66**
Psittacidae									
Myopsitta monachus (98)	2	0.11	0.32	2	0.72	0.62	4	0.19	0.43
Cuculidae									
Guira guira (190)	13	0.71	3.19	13	4.68	6.10	26	1.23	4.19
Picidae									
Colaptes campestris (190)	1	0.05	0.31		–	–	1	0.05	0.21
Furnaridae									
Unidentified Furnaridae	2	0.11	–		–	–	2	0.09	0.10
Cinclodes fuscus (31)		–	–	1	0.36	0.10	1	0.05	0.03
Furnarius rufus (64)	4	0.22	0.42	4	1.44	0.81	8	0.38	0.56
Pseudoseisura lophotes (82.44)	1	0.05	0.14		–	–	1	0.05	0.09
Anumbius annumbi (18)	5	0.27	0.15	1	0.36	0.06	6	0.28	0.12
Tyrannidae									
Unidentified Tyrannidae	3	0.16	–		–	–	3	0.14	–
Pyrrocephalus rubinus (13)	7	0.38	0.15	2	0.72	0.08	9	0.42	0.13
Xolmis irupero (28.3)	1	0.05	0.05		–	–	1	0.05	0.03
Pitangus sulphuratus (70.5)	2	0.11	0.23		–	–	2	0.09	0.15
Tyrannus savana (29)	1	0.05	0.05	1	0.36	0.09	2	0.09	0.06
Troglodytidae									
Troglodytes musculus (11)		–	–	1	0.36	0.03	1	0.05	0.01
Motacillidae									
Anthus spp. (19.28)	7	0.38	0.22		–	–	7	0.33	0.15
Anthus correndera (20.6)	3	0.16	0.10	1	0.36	0.07	4	0.19	0.09
Mimidae									
Mimus saturninus (66)		–	–	2	0.72	0.42	2	0.09	0.14
Thraupidae									
Raunis bonariensis (31.3)	1	0.05	0.05		–	–	1	0.05	0.05
Sicalis spp. (16)	36	1.96	0.95	2	0.72	0.10	38	1.79	0.66
Sicalis luteola (16)	2	0.11	0.05	1	0.36	0.05	3	0.14	0.05
Sporophila caerulescens (10)	3	0.16	0.05		–	–	3	0.14	0.03
Diuca diuca (26)	2	0.11	0.09	9	3.24	0.51	11	0.52	0.31
Passerellidae									
Zonotrichia capensis (18.96)	24	1.30	0.75	1	0.36	0.06	25	1.18	0.52
Ammodramus humeralis (18)	3	0.16	0.09		–	–	3	0.14	0.06
Fringilidae									
Spinus magellanicus (15)	1	0.05	0.02		–	–	1	0.05	0.02
Icteridae									
Molothrus badius (44)	3	0.16	0.22	1	0.36	0.14	4	0.19	0.19
Molothrus rufoaxillaris (41)		–	–	2	0.72	0.26	2	0.09	0.09
Molothrus bonariensis (45)		–	–	3	1.08	0.43	3	0.14	0.15
Leistes spp. (101)	4	0.22	0.67		–	–	4	0.19	0.44
Leistes superciliaris (53)	5	0.27	0.44	4	1.44	0.67	9	0.42	0.52
Molothrus spp. (41)	4	0.22	0.32	3	1.08	0.47	7	0.33	0.37
Ploceidae						–	1	0.05	–
Passer domesticus (31)	66	3.59	3.39	3	1.44	0.30	69	3.30	2.33
Other Birds (total)								**11.02**	**7.45**
Arthropods									
Unidentified Arthropods	10	0.54	0.02	3	1.08	–	13	0.61	–
Aranae	7	0.38	0.01		–	–	7	0.33	–
Insecta									
Unidentified Insecta	10	0.54	0.02		–	–	10	0.47	0.01
Hemíptera	1	0.05	0.00		–	–	1	0.05	0.00

(*continued on next page*)

Table 1 (*continued*)

	Pellets			Prey Remains			Total (Pellets + Prey Remains)		
	n	$\%N_i$	$\%B_i$	*n*	$\%N_i$	$\%B_i$	*n*	$\%N_i$	$\%B_i$
Himenóptera									
Formicidae	142	7.71	0.24		–	–	142	6.69	0.15
Homoptera									
Cicadidae	59	3.20	0.10		–	–	59	2.78	0.06
Diptera	1	0.05	0.00	3	1.08	0.01	4	0.19	0.00
Coleoptera									
Unidentified Coleoptera	186	10.10	0.31		–	–	186	8.77	0.20
Scarabidae	74	4.02	0.12	4	1.44	0.01	78	3.68	0.09
Carabidae	17	0.92	0.03	4	1.44	0.01	21	0.99	0.02
Curculionidae	127	6.90	0.21		–	–	127	5.99	0.14
Elateridae	3	0.16	0.00	2	0.72	0.01	5	0.24	0.01
Ortoptera									
Unidentified Ortoptera	53	2.88	0.09		–	–	53	2.50	0.06
Acrididae	244	13.2	0.40		–	–	244	11.50	0.27
Tetigonidae	43	2.34	0.07	1	0.36	0.00	44	2.07	0.05
Gryllidae	42	2.28	0.07		–	–	42	1.98	0.05
Grillotalpidae	14	0.76	0.02		–	–	14	0.66	0.02
Psychidae	1	0.05	0.00		–	–	1	0.05	0.00
Mantodea									
Mantidae	3	0.16	0.00		–	–	3	0.14	0.00
Odonata	38	2.06	0.06		–	–	38	1.79	0.04
Dermaptera	1	0.05	0.00		–	–	1	0.05	0.00
Arthropods (total)								**51.53**	**1.17**
Mammalia									
Unidentified Mammalia	1	0.05	–		–	–	1	0.05	–
Rodentia									
Unidentified Rodentia	4	0.22	–		–	–	4	0.19	–
Cricetidae									
Unidentified Cricetidae	2	0.11	–		–	–	2	0.09	–
Akodon spp. (30)	6	0.33	0.30		–	–	6	0.28	0.20
Reithrodon auritus (71)	1	0.05	0.12	1	0.36	0.23	2	0.09	0.15
Eligmodontia sp. (17)	11	0.60	0.31		–	–	11	0.52	0.20
Calomys spp. (16)	7	0.38	0.19		–	–	7	0.33	0.12
Graomys griseoflavus (61)	1	0.05	0.10		–	–	1	0.05	0.07
Cavidae									
Unidentified Cavidae		–	–	1	0.36	0.63	1	0.05	–
Galea musteloides (225.7)	1	0.05	0.37		–	–	1	0.05	0.25
Lagomorpha									
Leporidae									
Lepus europeus (300)	3	0.16	1.49	1	0.36	0.95	4	0.19	1.31
Reptilia									
Unidentified Reptilia	8	0.43	–		–	–	8	0.38	–
Teius oculatus (29)	8	0.43	0.38		–	–	8	0.38	0.25
Liolaemidae NI (15)	10	0.54	0.25		–	–	10	0.47	0.16
Liolaemus spp. (14.9)	19	1.03	0.47	2	0.72	0.09	21	0.99	0.34
Unidentified Colubridae (500)	4	0.22	3.31	1	0.36	1.59	5	0.24	2.72
Philodryas patagoniensis (800)		–	–	1	0.36	2.54	1	0.05	0.87
Anfibia									
Rhinella spp. (31)		–	–	1	0.36	0.10	1	–	0.03
Total	**1841**			**278**			**2119**		

biomass incidence. Furthermore, this approach facilitated the identification of rare prey items, including certain reptiles (snakes, *Philodryas patagoniensis*, or lizards, *Teius oculatus*, *Liolaemus* spp.) and amphibians (*Rhinella* sp.), which are either infrequently encountered or not previously recorded for this species (Bó, 1999; Keddy-Hector et al., 2020; Figueroa Rojas and Corales Stappung, 2005; Di Giácomo, 2005; Granzinolli and Motta-Junior, 2006; Baladrón et al., 2012; Salvador, 2013; Liébana, 2015).

Land cover types within reproductive territories exhibited a significant relationship with the consumption of different prey groups (Columbiformes, Other Birds, and Arthropods), though not with diversity estimates of diet contents. The models had low explanatory power, so interpretations should be approached cautiously. Columbiformes, particularly Eared Doves, are strongly associated with tree plantations and forests (Bucher, 1998; Bucher and Ranvaud, 2006; Codesido et al., 2015). Our study observed a weak but significant positive effect of the percentage of land occupied by tree stands on the proportion of Columbiformes and Small Birds in the diet, while this type of cover negatively impacted arthropod consumption. The coefficients highlight that wooded habitats promote bird prey availability, whereas arthropods become more relevant in open, less-wooded landscapes. Nonetheless, the absence of field data on arthropod abundance across different landscapes limits further interpretations.

Our findings indicate that land-use composition strongly mediates the trophic role of Aplomado Falcons in agroecosystems. Although agricultural lands dominate the landscape (>90% of the area), prey availability and consumption were significantly influenced by habitats that occupied only a small fraction of the landscape. For example, tree stands covered at most 6% of the territory (mean: 2.2%) but were associated with increased consumption of granivorous birds, particularly Eared Doves. Although the estimated effect sizes for land cover variables were modest (e.g., $\beta = 0.02–0.04$), their statistical significance suggests that even limited wooded areas can alter prey composition and foraging behavior. By contrast, the stronger effect of year observed for Passeriformes likely reflects interannual variability in prey abundance, breeding productivity, or climate. These findings emphasize the importance of interpreting model outcomes considering both ecological scale and temporal variability to shape trophic interactions and

Table 2
Bird species recorded during census in the study area on the sampled seasons. Values are expressed as frequencies.

Species	Seasons 2010 (n = 3834)	2011 (n = 4940)	2012 (n = 21,815)	2013 (n = 4041)
Tinamidae				
Nothura maculosa	0.83	0.18	0.09	0.37
Eudromia elegans	0.08	–	–	–
Nothoprocta cinerascens	–	–	0.00	0.05
Rhynchotus rufescens	0.10	0.10	0.04	0.07
Ardeidae				
Ardea ibis	0.73	–	–	–
Threskiornithidae				
Plegadis chihi	5.24	–	0.36	0.22
Anatidae				
Dendrocygna viduata	4.04	–	–	–
Anas georgica	–	–	0.01	0.07
Anas spp.	–	–	0.01	–
Recurvirostridae				
Himantopus mexicanus	0.18	–	0.00	–
Chararidriidae				
Vanellus chilensis	2.45	0.83	0.22	1.51
Scolopacidae				
Tringa melanoleuca	0.29	–	–	–
Tringa flavipes	0.29	–	–	–
Bartramia longicauda	0.16	0.02	–	–
Columbidae				
Patagioenas maculosa	1.62	0.20	0.25	0.89
Zenaida auriculata	49.61	91.26	94.38	80.20
Columbina picuí	1.36	0.20	0.07	0.02
Patagioenas picazuro	0.42	0.06	0.02	0.32
Columba livia	0.68	–	0.03	–
Psittacidae				
Myopsitta monachus	1.12	0.73	0.28	0.89
Thectocercus acuticaudatus	0.52	0.08	0.22	1.19
Cuculidae				
Guira guira	0.63	0.22	0.27	0.84
Trochilidae				
Chlorostilbon lucidus	0.03	–	–	–
Picidae				
Colaptes melanolaimus	0.21	–	0.04	0.05
Colaptes campestris	0.26	0.10	0.03	0.12
Dendrocolaptidae				
Lepidocolaptes angustirostris	0.03	–	–	–
Furnaridae				
Furnarius rufus	0.86	0.14	0.10	0.40
Tarphonomus certhioides	0.03	–	0.00	–
Anumbius annumbi	0.78	0.28	0.16	0.27
Synallaxis albescens	0.47	0.02	0.07	0.20
Pseudoseisura lophotes	0.03	0.04	0.00	–
Leptasthenura platensis	–	–	0.01	–
Tyrannidae				
Pyrrocephalus rubinus	0.47	0.18	0.12	0.45
Xolmis irupero	0.10	0.10	0.04	0.12
Lessonia rufa	0.03	–	–	–
Machetornis rixosa	0.13	–	0.01	0.05
Tyrannus melancholicus	0.16	0.18	0.02	0.12
Pitangus sulphuratus	0.39	–	0.03	0.05
Tyrannus savana	3.31	0.85	0.22	1.51
Pseudocolopteryx flaviventris	0.08	0.06	0.01	0.10
Serpophaga subcristata	0.13	–	0.01	0.02
Stigmatura budytoides	–	0.04	–	–
Hirundinidae				
Tachycineta leucorrhoa	0.08	–	–	–
Troglodytidae				
Troglodytes musculus	0.63	0.18	0.16	0.42
Motacillidae				
Anthus spp.	0.44	–	–	–
Anthus correndera	0.10	0.10	–	0.05
Mimidae				
Mimus saturninus	0.76	0.26	0.07	0.40
Mimus triurus	–	–	0.01	0.05
Emberizidae				
Sporophila caerulescens	1.28	0.12	0.01	0.05
Sicalis luteola	8.09	1.05	0.99	2.60
Sicalis flaveola	0.10	–	0.00	0.35
Zonotrichia capensis	1.17	0.34	0.44	1.71
Ammodramus humeralis	0.91	0.43	–	0.45
Embernagra platensis	0.03	0.02	0.13	0.02
Diuca diuca	–	–	0.05	–
Fringilidae				
Spinus magellanicus	0.05	–	–	–
Icteridae				
Molothrus badius	0.60	0.49	0.14	0.82
Molothrus bonariensis	1.88	0.57	0.30	0.92
Leistes superciliaris	3.34	0.32	0.03	0.20
Molothrus rufoaxillaris	–	0.04	0.04	0.49
Leistes loica	–	0.04	0.11	0.10
Ploceidae				
Passer domesticus	2.71	0.14	0.38	1.26

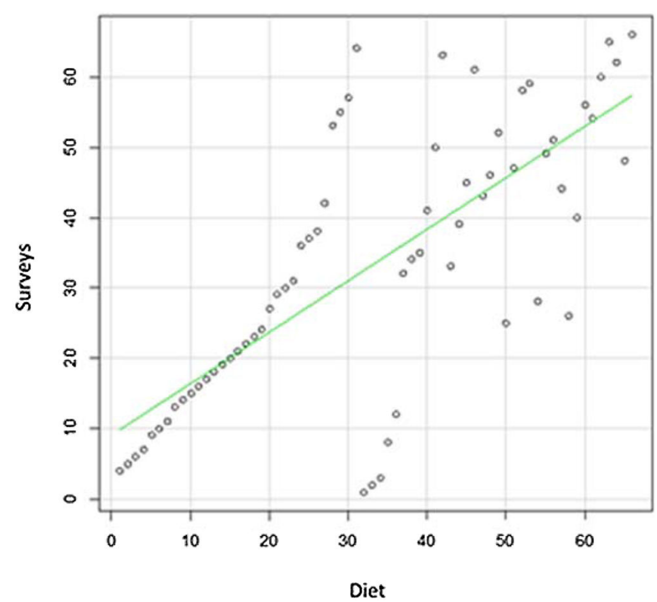

Fig. 2. Relationship between the relative abundance of bird species in the study area (based on point count surveys) and their frequency in the Aplomado Falcon's diet in La Pampa, Argentina. Each point represents a bird species detected both in diet samples and in surveys. The green line represents the Spearman rank correlation between prey abundance and dietary frequency across pooled data from all territories (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

ecosystem service delivery by raptors.

In the study area, the Aplomado Falcon primarily consumes birds that are also the most abundant in its environment, suggesting an opportunistic foraging strategy rather than active prey selection. The main prey, Eared Doves, are considered pests that inflict significant economic damage in the region. These doves are linked to crops, tree plantations, and forests (Bucher, 1998; Bucher and Ranvaud, 2006; Calamari et al., 2018). In this study, tree stands were associated with the consumption of Eared Doves, which were the most frequent and abundant species in the reproductive territories, consistent with other studies emphasizing their significant abundance (Bernardos and Farrel, 2012) and strong association with exotic and native woodlots (Calamari et al., 2018). While Columbiformes have been identified as primary prey throughout the Aplomado Falcon's range (Bó, 1999; Keddy-Hector et al., 2020; Macías-Duarte et al., 2004; Salvador, 2013), this is the first time this pattern has been linked to the field abundance of this prey. Prior research in Chile and Argentina did not emphasize Eared Doves as a crucial prey item (Jiménez, 1993; Bó, 1999; Figueroa Rojas and Corales Stappung, 2004, 2005; Baladrón et al., 2012), although a study in the Espinal region noted their significant frequency in falcons' diets (Salvador, 2013). Conversely, in North America, other species in the same genus, such as the Mourning Dove (*Zenaida macroura*) and the White-Winged Dove (*Zenaida asiatica*), have also been identified as key prey for the Aplomado Falcon (Héctor, 1985; Macías-Duarte et al., 2004). The opportunistic nature of prey intake for the northern subspecies has been documented (Montoya et al., 1997), with positive relationships observed between abundant birds (*Leistes* spp.) and their occurrence in the diet in desert environments. Similarly, Figueroa Rojas and Corales Stappung (2005) identified a positive correlation between observed abundant birds and those found in the Aplomado Falcon's diet in agricultural areas of Chile. Our results show that Eared Doves accounted for significant proportions of both availability (79%) and consumption (61%) among birds. It is important to note that prey abundance estimates were not corrected for imperfect detection. While this limitation precludes the estimation of absolute prey densities, the resulting data still offer reliable indices of relative abundance suitable for comparative analyses. Additionally, pooling data across years may have masked interannual variation in prey use. Future studies with more extensive and balanced datasets could apply beta regression models and group prey into foraging guilds to better evaluate temporal dynamics and prey selection patterns.

In conclusion, the Aplomado Falcon in our study area demonstrates opportunistic foraging behavior, adjusting its prey consumption to the availability of prey species in the territories. This opportunism may be mediated by ecosystem modifications. In the Pampean region, tree stands, an element originally absent from the pampas, appear to modify bird communities (Daguerre, 1936; Bucher and Aramburu, 2014; Codesido et al., 2015), in ways comparable to the effects of crops and livestock. The ecology and habitat use of the Aplomado Falcon in the original system would have been markedly different from the current landscape. It is possible that the falcon now finds new and/or improved resources to exploit, such as nesting sites and food sources.

Similar patterns have been reported for other New World falcons in agricultural environments. For example, the American Kestrel (*Falco sparverius*) in the Argentine Pampas also shows flexible diet composition, reinforcing the interpretation of generalist and opportunistic trophic behavior in modified landscapes (Orozco-Valor and Grande, 2021). Grouping prey into functional foraging guilds, as done in studies of kestrels, may further improve assessments of prey selection patterns in future research.

Importantly, the Aplomado Falcon's role as a natural predator of pest species is mediated by landscape composition: tree stands increase the consumption of Columbiformes and Other Birds, while open areas maintain arthropods as alternative prey. This dietary flexibility enhances the falcon's capacity to provide ecosystem services, particularly biological pest control, which improves agricultural sustainability by potentially reducing the need for pest management. Nevertheless, the effects of intensification and changes in agroecosystems on the ecology and behavior of raptor communities require more research to foster a comprehensive understanding of these dynamics within the broader ecosystem context.

Declaration of competing interest

The authors declare that there is no conflict of interest.

Acknowledgements

We are grateful to all the property owners who allowed us to carry out our work on their land. Andrea Costán contributed to the analysis of the pellets, while Ana P. Mansilla and Marcos M. Reyes assisted with the fieldwork. We thank both reviewers and editor for their constructive and thoughtful feedback. This study was partially funded by FCEyN-UNLPam (Res.173/13), the François Vuilleumier Fund for Research on Neotropical Birds, and the Mike Madders Field Research Award. We would like to express our deep concern regarding the unprecedented scientific crisis currently affecting Argentina. Severe budget cuts and institutional dismantling are jeopardizing the continuity of basic ecological research and long-term conservation programs. These measures threaten not only the quality of science but also the preservation of biodiversity in one of the world's most ecologically valuable regions. We stand in solidarity with the scientific and conservation communities working under increasingly precarious conditions.

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