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Seasonal Patterns in Aquatic Bird Counts at Five Andean Lakes of Ecuador

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Abstract.—Seasonal (semestral) counts of aquatic birds at five Andean lakes in Ecuador (Colta, La Mica, Yambo, Yahuarcocha and San Pablo) were analyzed to detect trends in population size between 2004 and 2011. Trends of four abundant species (*Ardea alba*, *Anas georgica*, *Fulica ardesiaca* and *Oxyura jamaicensis*) and those of five functional groups (based upon body size and diet) were tested using generalized additive mixed modeling. In total, 19 bird species were consistently recorded over the whole period. The Andean Coot (*F. ardesiaca*) was found in highest densities (c. 3 birds per ha at Colta and Yambo). No significant trends were detected. However, the counts of functional groups exhibited a seasonal pattern (higher counts in February than in July), possibly due to lower resource availability in the dry season. Piscivorous species were relatively abundant at one lake (Yahuarcocha), which might be related to the introduction of Tilapiine cichlid fishes. *Received 29 February 2012, accepted 26 June 2012.*

Key words.—Andes, bird monitoring, functional groups, GAMM.

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The inter-Andean valleys of Ecuador encompass wetlands that sustain important populations of aquatic bird species (Ridgely and Greenfield 2001). In Ecuador, a monitoring program to provide baseline information on the distribution and abundance of aquatic birds started in 2004 (López-Lanús and Blanco 2005). Such data are essential to provide guidelines for the management and conservation of wetlands (Tamisier and Boudouresque 1994; Paillisson *et al.* 2002; Lagos *et al.* 2008; Mistry *et al.* 2008). Andean lakes have endemic fish (Ruzzante *et al.* 1998) and bird species that are threatened at the national level (e.g. *Theristicus melanopis* Williams and Olmedo 2002). Bird monitoring data for these lakes are especially important because the increasing extraction of water for drinking and irrigation (Santander *et al.* 2006) and alterations in trophic cascades due to the introduction of exotic fish, may precipitate a decline in bird populations (Ortubay *et al.* 2006). In this context, the aim of our study was to assess trends in the first eight years of seasonal (semestral) bird counts for five inter-Andean lakes of Ecuador.

METHODS

Study Area

Lake Colta is located 17 km south of the city of Riobamba (Chimborazo province, 1°44'S 78°45'W) at 3,420 m above sea level (a.s.l). Lake Colta covers 240 ha and has a maximum depth of 3.5 m (Santander *et al.* 2006). La Mica is a 360 ha glacial lake with an average depth of 22.5 m situated in the Antisana Ecological Reserve (Napo province, 00°32'S 78°12'W) at 3,900 m a.s.l. Lake Yahuarcocha is in the dry inter-Andean valley of northern Ecuador (Imbabura province, 00º22'N 78°06'W) at 2,210 m a.s.l. The lake covers 230 ha at a maximum depth of 7.9 m (Consejo Provincial de Imbabura 1997). Lake San Pablo is 20 km south of Lake Yahuarcocha (Imbabura province, 0°13' N, 78°14' W) at 2660 m a.s.l. With an area of 670 ha and a maximum depth of 35 m, it is one of the largest Andean lakes in Ecuador (Santander *et al.* 2006). Lake Yambo is situated in the inter-Andean valley of Central Ecuador (Cotopaxi province, 1°05'S 78°35'W), at 2,600 m a.s.l. The lake covers 16 ha and has a maximum depth of 25 m (Steinitz-Kannan *et al.* 1993).

Bird Census

At each lake, bird counts were performed in February and July during 2004-2011. On a typical monitoring day, experienced observers carried out their census, which started in the morning (08:00 h) and lasted for two to three hours. Observations were conducted from either a boat that toured the wetlands perimeter at a constant velocity, remaining at 60-100 m from the shore to avoid massive take-off of birds that congregate, or by hiking along the lake shores. If more than one observer counted birds simultaneously the highest value was considered.

Numerical Analysis

Because the total monitoring period was short, we included the lakes as random effects and analyze the counts of only the four most abundant species (*Ardea alba, Anas georgica, Fulica ardesiaca* and *Oxyura jamaicensis*). These four species are common in Andean lakes (Fjeldså and Krabbe 1990). Also, we tested for trends in the counts of all species grouped into five functional groups related to body size and diet (large and medium size piscivorous and medium size herbivorous, insectivorous and omnivorous; del Hoyo *et al.* 1992, 1996).

Most count-time relationships were distinctly nonlinear and the variances in the counts differed substantially between species or functional groups (Fig. 1a, 1b). Therefore, we applied a generalized additive mixed model of counts against time, applying one model for the counts of the selected species, and another model for the counts of the functional groups (Fewster *et al.* 2000; Zuur *et al.* 2009). The starting models were as follows:

```
model <- gamm(sqrt(counts) ~ ID + cos(time*pi) + s(time, by = ID)), method = "ML", random = list(IDlake=~1), weights = varIdent(form = ~ 1 | ID))
```

In this, ID refers to the selected species or functional groups as factor; cos(time*pi) a cosinus function to implement a fixed seasonality effect in the model; s(time, by = ID) a thin plate regression spline smoother, one for each level of ID; random=list(IDlake=~1) the name of each lake as random effect; method = "ML" the Maximum Likelihood method of model fitting; and weights = varIdent(form = ~ 1 | ID)) to the implementation of different variances for each level of ID in the model. We applied the square root transformation of the counts because the weights argument in the nlme function (which forms part of the gamm function) may only be used in case of a gaussian identity link. The value of Akaike's Information Criterion (AIC) of the above model was similar (selected species) to or lower (functional groups) than models from which the seasonality effect was removed. The standardized residuals of both models (selected species and functional groups) showed clear patterns of short-term autocorrelation. Therefore, we adjusted the models by including the following term for the correlation structure: correlation = corARMA (p = 3, q = 3). As a result, both models showed substantial lower AIC values, and the autocorrelation of residuals was eliminated (functional groups) or highly reduced (selected species). Further model validation (residuals against fitted values or against time) did not produce anymore pattern. The residuals did not deviate strongly from normality (visual inspection of quantile-quantile plots per lake). Analyses were done using R 2.14.1 (R Development Core Team 2011), applying the mgcv (Wood 2006), nlme (Pinheiro *et al.* 2011) and lattice (Sarkar 2008) packages.

Results

A total of 19 bird species were recorded and classified into five functional groups (Table 1). Mean (± one SD) seasonal bird counts were 963 ± 388.1 at La Mica, 919 ± 229.6 at San Pablo, 831 ± 327.4 at Colta, 797 ± 277.2 at Yahuarcocha and 310 ± 141.7 at Yambo. Mean (± SD) seasonal counts per ha were 19.4 ± 8.9 at Yambo, 3.5 ± 1.2 at Yahuarcocha, 3.5 ± 1.4 at Colta, 2.7 ± 1.1 at La Mica and 1.5 ± 0.4 at San Pablo. *F. ardesiaca* exhibited high densities, especially at Yambo and Colta (approximately 3 birds per hectare at both lakes).

Between 2004 and 2011, no significant trends were detected in the counts of the selected species or functional groups (Table 2). The seasonality effect (cosinus function) was highly significant for functional groups ($P < 0.001$) reflecting consistently higher counts in February than in July (Table 2). By including lakes as random effects, the trends in selected species or functional groups in individual lakes were not tested. Yet, the counts of *F. ardesiaca* at the lakes San Pablo, La Mica and Colta, and those of the large size piscivorous group at Lake Yahuarcocha and the medium size omnivorous group at lakes San Pablo and La Mica showed a distinct upward tendency, whereas those of *A. georgica* at Lake La Mica, *O. jamaicensis* in Lake San Pablo and the herbivorous group at Lake Yambo seemed decreasing in time.

Discussion

The high densities of *F. ardesiaca* are consistent with other studies that report species of the *Fulica* genus as most abundant in wetlands (Hamdi *et al.* 2008). The tendency for large piscivorous birds to increase at Yahuarcocha is noteworthy, also piscivorous species seem more abundant at this lake compared to the other lakes (c. one bird per ha at Yahuarcocha versus 0.0 to 0.04 birds per ha at the other lakes). Possibly, these results may relate to the recent introduction of Tilapiine cichlid fish (*Oreochromis niloticus* and *Tilapia mossambica*) at Yahuarcocha. The introduction of these fish has been postulated to explain the presence and growth of

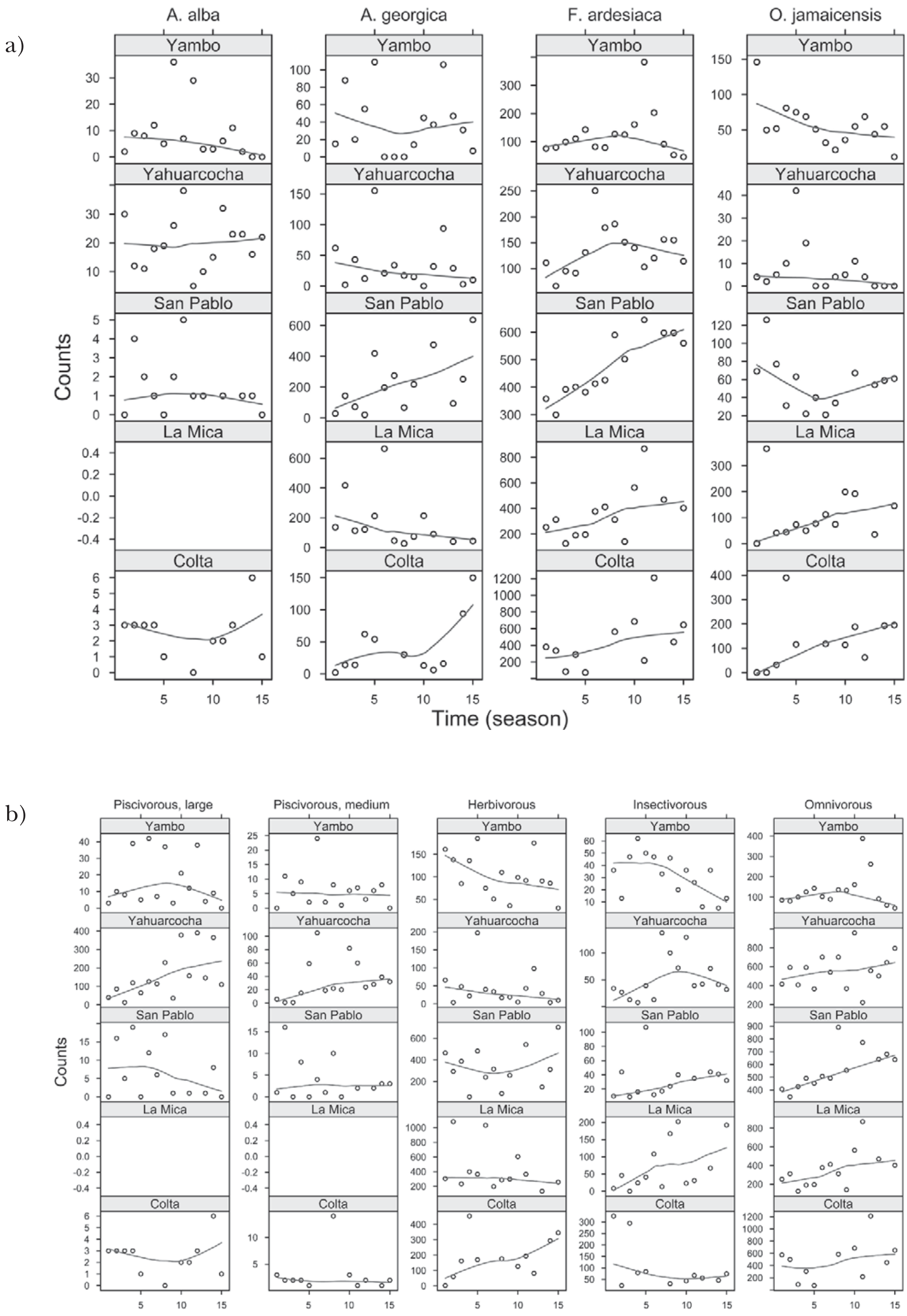

Figure 1. Seasonal (semestral) bird counts in five Andean lakes in Ecuador between 2004 and 2011, for each of the selected species (Fig. 1a) and functional groups (Fig. 1b). The lines give the loess smoother (applying a span of 0.9).

Table 1. Seasonal (semestral) bird counts at five Andean lakes in Ecuador from 2004 to 2011. Functional groups are according to diet and body size (del Hoyo et al. 1992, 1996) as follows: LP = Large size Piscivorous, MP = Medium size Piscivorous, MH = Medium size Herbivorous, MH = Medium size Insectivorous, MO = Medium size Omnivorous.

Common names	Scientific names	Functional Group	Colta	La Mica	San Pablo	Yahuarcocha	Yambo
			Range (min-max)				
Yellow-billed Pintail	*Anas georgica* (Gmelin 1789)	MH	2-150	27-665	21-637	2-155	7-109
Andean Teal	*Anas andium* (Sclater and Salvin 1873)	MH	2-116	59-317	4-366	0-1	1-78
Ruddy Duck	*Oxyura jamaicensis* (Gmalin 1789)	MH	32-390	35-366	21-126	2-42	12-146
Pied-billed Grebe	*Podilymbus podiceps* (Linnaeus 1758)	MI	1-6	0	8-44	8-137	2-55
Neotropic Cormorant	*Phalacrocorax brasilianus* (Gmelin 1789)	LP	0	0	2-15	1-322	1-26
Black-crowned Night-Heron	*Nycticorax nycticorax* (Linnaeus 1758)	LP	0	0	0-2	2-103	0-1
Striated Heron	*Butorides striata* (Linnaeus 1758)	MP	0-2	0	1-2	1-49	1-6
Cattle Egret	*Bubulcus ibis* (Linnaeus 1758)	MO	6-23	0	100-269	100-800	1-59
Cocoi Heron	*Ardea cocoi* (Linnaeus 1766)	LP	0	0	0	0-1	0
Great Egret	*Ardea alba* (Linnaeus 1758)	LP	1-6	0	1-5	5-38	2-36
Snowy Egret	*Egretta thula* (Molina 1782)	MP	1-14	0	1-14	1-80	2-24
Little Blue Heron	*Egretta caerulea* (Linnaeus 1758)	LP	0	0	1-7	0	1
Common Gallinule	*Gallinula galeata* (Lichtenstein 1818)	MO	1-184	0	3-74	5-24	1-4
Slate-colored Coot	*Fulica ardesiaca* (Tschudi 1843)	MO	72-1211	125-869	300-645	66-250	46-383
Southern Lapwing	*Vanellus chilensis* (Molina 1782)	MI	0-3	0	0-5	0	0
Andean Lapwing	*Vanellus resplendens* (Tschudi 1843)	MI	2-320	4-200	1-6	0-2	0
Andean Gull	*Chroicocephalus serranus* (Tschudi 1844)	MI	2-50	1-129	1-87	2-23	1-15
Laughing Gull	*Leucophaeus atricilla* (Linnaeus 1758)	MI	0	0	0-3	0	0
Large-billed Tern	*Phaetusa simplex* (Gmelin 1789)	MP	1	0	0	0	0

Table 2. Results of Generalized Additive Mixed Modeling analysis for selected species and functional groups.

Selected species			
Parametric Terms:			
	df	F	p-value
cos(time * pi)	1	3.24	0.073
ID (selected species)	3	25.6	1.5E-14
Approximate significance of smooth terms			
	Estimated df	F	p-value
s(time): A. alba	0.9978	0.33	0.57
s(time): A. georgica	0.9990	0.022	0.88
s(time): F. ardesiaca	0.9999	0.23	0.63
s(time): O. jamaicensis	0.9999	0.017	0.90
Functional groups			
Parametric Terms:			
	df	F	p-value
cos(time * pi)	1	17.8	3.1E-05
ID (functional group)	4	33.7	<2e-16
Approximate significance of smooth terms			
	Estimated df	F	p-value
s(time): Piscivorous, large	1	0.96	0.33
s(time): Piscivorous, medium	1	0.68	0.41
s(time): Herbivorous	1	0.029	0.87
s(time): Insectivorous	1	0.017	0.90
s(time): Omnivorous	1	0.053	0.82

Phalacrocorax brasilianus and other piscivorous birds from coastal origin at Lake Yahuarcocha (Jahn *et al.* 2010; Guevara *et al.* 2011; Santander *et al.* 2011). Recent observations of aquatic bird species outside their formerly known range have been suggested as an indication of the ongoing colonization of Andean wetlands (Henry 2012). Given the distinct upward or downward tendencies in the counts of several species or functional groups at a number of lakes, continued monitoring should enable researchers to provide firmer evidence for changing waterbird population sizes.

Seasonality patterns in neotropical bird counts have mostly been reported for terrestrial bird communities (e.g. Karr 1976; Loiselle and Blake 1992; see also Alves and Pereira 1998). Seasonal variations in rainfall and temperature have been identified as primary factors driving food resource availability in tropical systems (e.g. seeds, fruits, insects; Karr 1976; Faaborg *et al.* 1984), which ultimately influence bird abundances. Interpolated climate surfaces developed for the period between 1950 and 2000 (Hijmans *et al.* 2005) indicate that the precipitation in July and August at the five lakes analyzed in this study is relatively low. Therefore, a hypothetical decline in resource abundance during the dry season might explain the seasonality pattern of the species clustered in functional groups.

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