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Author(s): Christine S. S. Bernardo, Paulo Rubim, Rafael S. Bueno, Rodrigo A. Begotti, Fernanda Meirelles, Camila I. Donatti, Carolina Denzin, Carla E. Steffler, Renato M. Marques, Ricardo S. Bovendorp, Sabrina K. Gobbo, and Mauro Galetti

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DENSITY ESTIMATES OF THE BLACK-FRONTED PIPING GUAN IN THE BRAZILIAN ATLANTIC RAINFOREST

CHRISTINE S. S. BERNARDO,[1,2,3] PAULO RUBIM,[1] RAFAEL S. BUENO,[1] RODRIGO A. BEGOTTI,[1] FERNANDA MEIRELLES,[1] CAMILA I. DONATTI,[1] CAROLINA DENZIN,[1] CARLA E. STEFFLER,[1] RENATO M. MARQUES,[1] RICARDO S. BOVENDORP,[1] SABRINA K. GOBBO,[1] AND MAURO GALETTI[1]

ABSTRACT.—We studied the Black-fronted Piping Guan (*Pipile jacutinga*), a medium-sized cracid (1.5 kg), endemic of Atlantic rainforest and considered endangered. We present density estimates of Black-fronted Piping Guans derived from line-transect surveys (total effort = 2,246 km) across 11 protected areas (6 continuous mainland areas, 3 non-connected mainland areas, and 2 inshore islands) in São Paulo State, southeastern Brazil. Both islands and the continuous mainland forests of Paranapiacaba massif had the highest density estimates of the species. The largest continuous mainland Atlantic Forest (Serra do Mar massif) had the lowest density estimates and the species was absent in some regions of this mountain range. All non-connected mainland forests also had low density estimates or absence of the species. Our data indicate the Black-fronted Piping Guan is not extremely sensitive to habitat disturbance and the major threat to its conservation is most likely from illegal hunting. The absence or low density estimates of the species in three survey sites is of special concern, because it is known guans are important in seed dispersal, which may have long-term consequences for forest regeneration.
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The Atlantic coastal rainforest of South America represents the world's most critically endangered biodiversity hotspot (Myers et al. 2000, Mittermeier et al. 2005) as only ~12.9% (194,524 km^2) of the original 1.1 million km^2 of forest cover remains (Tabarelli et al. 2010). Much of this habitat is highly fragmented and severely impacted by deforestation through illegal logging, expansion and consolidation of agricultural land-uses, and expansion of urban areas (Dean 1996, Oliveira-Filho and Fontes 2000). More than 80% of the remnant forest fragments are estimated to be <50 ha in size and relatively isolated (Ribeiro et al. 2009). The protected areas network throughout this hotspot covers <9% of the remaining Atlantic rainforest habitat (Ribeiro et al. 2009). There are concerns the few remnant areas of Atlantic rainforest are not sufficiently extensive or of suitable ecological integrity to maintain viable populations of endemic large-bodied vertebrate species, including large-bodied birds (Marsden et al. 2005). The plight of these species is exacerbated by illegal hunting which is widespread, particularly close to more developed areas (Dean 1996, Chiarello 2000, Cullen et al. 2000, Pinto et al. 2008).

Local extinction of large-bodied frugivorous species is of special conservation concern because they may be fundamental in promoting long-distance dispersal of seeds of many endemic plant species (Théry et al. 1992, Galetti et al. 1997, Holbrook and Loiselle 2009). Few quantitative data are available on abundance and biomass of large-bodied birds in Atlantic rainforest remnants, particularly cracids, which represent some of the most important game bird species throughout Latin America and contribute most to avian biomass harvested by hunters (e.g., Silva and Strahl 1991, Thiollay 1994). Previous studies have almost exclusively focused on Amazonian cracids (e.g., Silva and Strahl 1991, Begazo and Bodmer 1998, Haugaasen and Peres 2008), whereas published data on the population abundance or density of cracids in the Atlantic rainforest biome is only available for three species: *Penelope obscura, P. superciliaris* (Cullen et al. 2000), and *Pipile jacutinga* (Galetti et al. 1997, Guix et al. 1997, Sánchez-Alonso et al. 2002, Rubim and Bernardo 2008).

The Black-fronted Piping Guan (*P. jacutinga*) is a medium-sized cracid (1.5 kg), endemic to the Atlantic rainforest hotspot of southeastern and southern Brazil (Bahia to Rio Grande do Sul), Paraguay, and northern Argentina (Collar et al. 1992). The species is currently listed as

[1] Laboratório de Biologia da Conservação, Departamento de Ecologia, Universidade Estadual Paulista, CP 199, CEP 13506-900, Rio Claro, SP, Brazil.

[2] Current address: Laboratório de Ecologia, Departamento de Ciências Biológicas, Universidade Estadual do Sudoeste da Bahia, campus Jequié, Aveida José Moreira Sobrinho s/n, CEP 45206-510, Jequié, BA, Brazil.

[3] Corresponding author; e-mail: christinesteiner@yahoo.com

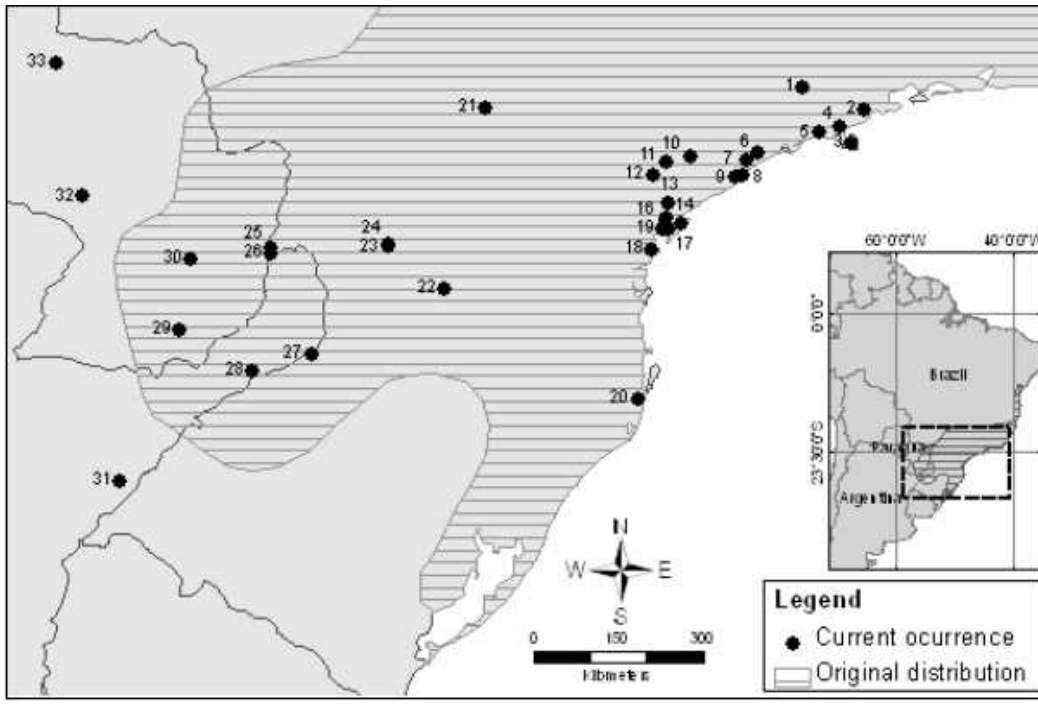

FIG. 1. Known populations of Black-fronted Piping Guans: (1) Mandala, (2) Serra do Mar-Núcleo Cunha/Santa Virgínia, (3) Ilhabela, (4) Serra do Mar-Núcleo Caraguatatuba, (5) Boracéia, (6) Curucutu, (7) Peruíbe, (8) Itanhaém, (9) Juréia-Itatins, (10) Carlos Botelho, (11) Intervales, (12) PETAR, (13) Jacupiranga, (14) Ilha do Cardoso, (15) Lauráceas, (16) Salto Morato, (17) Cachoeira, (18) Guaraqueçaba, (19) Itaqui, (20) Serra do Tabuleiro, (21) Londrina, (22) Foz do Areia, (23) Charqueada, (24) Corredor do Iguaçu, (25) Iguaçu (Brazil), (26) Iguazu (Argentina), (27) Turvo, (28) Missiones, (29) San Rafael, (30) Amambay, (31) Corrientes, (32) Golondrina, and (33) Mbaracayu (Sources: Galetti et al. 1997, Clay 2001, Marques et al. 2002, Tomim-Borges et al. 2002, Giraudo and Povedano 2003, Straube et al. 2004, ICMBio 2008; Bruno Lima, pers. comm.; Fabio Schunck, pers. comm.). The hatched area corresponds to the original range of Black-fronted Piping Guans (IUCN 2010), which excluded original range areas 31 to 33.

endangered due to ongoing and unsustainable hunting pressure, and severe habitat loss (Sick 1997, IUCN 2010). This species was formerly abundant (Sick 1997) and now has been extirpated from most of its original distribution, particularly in the Brazilian states of Bahia, Espírito Santo, Minas Gerais, and Rio de Janeiro (Collar et al. 1992, Galetti et al. 1997, Bernardo and Clay 2006). Currently, 33 different populations are estimated to be extant in the wild (Fig. 1) with 26 in Brazil (ICMBio 2008), four in Paraguay (Clay 2001), and three in Argentina (Benstead and Hearn 1994). A recent study in Misiones (Argentina) provided new records for the species in at least 13 localities of this region (Cockle and Bodrati 2011). The species has been successfully reintroduced in three protected areas in the Brazilian states of Minas Gerais (Ipatinga), Rio de Janeiro (Guapiaçu), and São Paulo (Paraibuna) using captive-bred individuals from the Crax Brasil breeding center in Minas Gerais and from CESP in São Paulo (ICMBio 2008).

Our objective is to present density estimates derived from data collected during a series of intensive population surveys across 11 protected areas in São Paulo State, southeastern Brazil, between 2001 and 2007. We expected to find higher density estimates of Black-fronted Piping Guans among continuous mainland forests than within the non-connected mainland and inshore islands' remnant Atlantic rainforests because continuous mainland forests generally present higher immigration rates and, consequently, higher re-colonization rates than non-connected forests or islands (Hanski 1999).

TABLE 1. Characteristics of study sites in Atlantic rainforest remnants of São Paulo State, Brazil.

Study area	Size[a] (ha)	Park creation[a] (year)	Connectivity	Altitudinal range (m)[a]	Study period	Number of park rangers[a]
Islands						
Parque Estadual Ilha do Cardoso (PEIC)	11,100	1962	Island	0–784	2001–2004	5
Parque Estadual Ilhabela (PEI)	27,025	1977	Island	0–1,375	2004–2005	11
Serra de Paranapiacaba Massif						
Parque Estadual Carlos Botelho (PECB)	37,644	1982	Continuous	50–975	2004–2006	12
Parque Estadual Turístico Alto Ribeira (PETAR)	35,712	1958	Continuous	600–1,200	2006–2007	19
Parque Estadual Jacupiranga (PEJa)	150,000	1969	Isolated	10–1,310	2005–2006	13
Parque Estadual Jurupará (PEJu)	26,250	1988	Isolated	400–900	2004	7
Serra do Mar Massif						
Estação Ecológica de Juréia-Itatins (EEJI)	79,270	1986	Isolated	0–1,369	2001–2002/ 2005–2006	8
Parque Estadual Serra do Mar – Caraguatatuba (Car)	13,770	1977	Continuous	500–1,298	2004–2006	8
Parque Estadual Serra do Mar – Santa Virgínia (SV)	13,000	1989	Continuous	860–1,500	2002–2003	5
Parque Estadual Serra do Mar – Picinguaba (Pic)	47,500	1979	Continuous	0–1,670	2002–2003	4
Parque Estadual Serra do Mar – Cunha (Cun)	11,660	1974	Continuous	1,100–1,820	2002–2003	5

[a] According to IF (2011) and park managers.

METHODS

Study Areas.—We surveyed nine large areas ranging from 111 to 1,500 km^2 of mainland remnant Atlantic rainforest (6 continuous and 3 non-connected forests), and two forested inshore islands in São Paulo State, Brazil (Table 1). These legally protected areas comprise some of the few largest Atlantic rainforest remnants, including the Serra do Mar and Serra de Paranapiacaba mountain ranges (Table 1). The inshore island of Ilha do Cardoso is a land-bridge island and its closest point to the continent is 300 m. The oceanic inshore island of Ilhabela is 1.7 km from the nearest point of the continent. All areas were dominated by three different types of forest habitat, which vary according to the latitude and altitude: lowland rainforest, and submontane and lower montane rainforest (Oliveira-Filho and Fontes 2000). Mean annual temperatures of these areas vary between 17 and 25° C (IF 2011).

All study areas have experienced palm-heart (*Euterpe edulis*) harvesting and illegal hunting (Galetti and Fernandez 1998, Aguiar et al. 2003, Olmos et al. 2004, Galetti et al. 2009). All areas are part of two Endemic Bird Areas (BirdLife International 2003): Atlantic Forest lowlands and Atlantic Forest mountains. They are also considered Important Bird Areas (IBA), except Ilha do Cardoso and Jurupará (Stattersfield et al. 1998).

Bird Surveys.—We used a variable-distance line-transect method (e.g., Buckland et al. 1993) to survey populations of Black-fronted Piping Guans following standardized methodology derived by Peres (1999) and used by Galetti et al. (2009). Between three and 14 transects were systematically positioned at each site to be representative of the surrounding habitat (Peres 1999). Transect locations were selected mainly by vegetation type, elevation and distance from rivers and roads, and the variation in these habitat features were well represented in our study areas. Transect length varied from 0.7 to 8.4 km, depending upon local topography and forest patch size (Galetti et al. 2009) (Table 2). Ten observers, who were fully trained in distance sampling techniques and cracid identification, were responsible for conducting the bird surveys at all sites during 2001 to 2007. Transects were surveyed systematically during 0615 and 1730 hrs by one or two observers, once a month at each site, with direction of travel along each transect rotated between subsequent surveys to minimize the effect of time of day. We recorded the date, time, global positioning system (GPS) co-ordinates, number of individuals seen and perpendicular distance to the line transect (accurately obtained with a measuring tape) for each piping guan detected. Survey effort at each site ranged from 103.1 to 273 km (Table 2), which is greater than the sampling effort required for reliable abundance estimates of large birds (Thoisy et al. 2008).

TABLE 2. Total effort (km), number of encounters, relative abundance (encounters/10 km) and mean density as individuals/km^2 and groups/km^2 (95% confidence interval) of Black-fronted Piping Guans in 11 Atlantic rainforest remnants in São Paulo State, Brazil (study areas correspond to Table 1).

Study area	Total number of transects	Length of transects (m)	Total km walked	Number of encounters	Relative abundance (encounters/10 km)	Density (Range) (individual/km^2)	Density (Range) (groups/km^2)
Islands							
PEIC	14	700–4,000	273	10	0.4	3 (2.4–3.5)	2 (1.6–2.3)
PEI	11	900–5,500	188	29	1.5	13.3 (11–16.2)	8 (6.7–9.8)
Paranapiacaba Massif							
PECB	9	1,200–5,400	237	17	0.7	4.4 (3.6–5.3)	3.7 (3.1–4.5)
PETAR	7	1,400–8,000	256	10	0.4	3 (2.5–3.7)	2 (1.7–2.5)
PEJa	5	700–4,500	103	1	0.1	0.5 (0.4–0.6)	0.5 (0.4–0.6)
PEJu	6	1,500–4,500	222	0	Not found	Not found	Not found
Serra do Mar Massif							
EEJI	5	700–3,350	190	1	0.1	0.27 (0.23–0.33)	0.27 (0.23–0.33)
Car	5	700–3,000	138	1	0.1	0.4 (0.3–0.5)	0.4 (0.3–0.5)
Cun	8	1,050–8,450	218	1	0.05	0.5 (0.4–0.6)	0.24 (0.20–0.29)
SV	3	700–5,300	210	0	Not found	Not found	Not found
Pic	3	1,250–8,000	210	0	Not found	Not found	Not found

Data Analyses.—Distance data were analyzed using Program DISTANCE Version 5.1 (Thomas et al. 2006). Key function selection was evaluated using Akaike's Information Criteria (AIC) and a Chi-square statistic was used to assess the 'goodness of fit' of each function (Buckland et al. 1993, 2001). Repeated line transects increased sample sizes at each site, providing more precise estimates of variance and increasing the reliability of the detection function (Buckland et al. 2001, Lee and Marsden 2008). We had small sample sizes (between 1 and 29 encounters in each area, Table 2), and used a generalized effective strip width (ESW = 9.6 m, 95% confidence interval = 7.9–11.7 m) obtained by pooling all observation data of Black-fronted Piping Guans. Pooling all records generated a more precise modeling of piping guan detection because the combined AIC values of the separate forest site detection functions were greater than the AIC value for the pooled detection function (Buckland et al. 2001). This procedure allowed us to calculate a single detection curve (half-normal key distribution with cosine adjustments) and provided a more reliable estimate of species density (individuals/km^2) (Buckland et al. 1993). Encounter rates (number of encounters/10-km transect) were calculated for all sites as an estimate of relative abundance.

RESULTS

We recorded 70 observations of Black-fronted Piping Guans across the 11 study sites from 2001 to 2007 during 2,246 km of line transects. All individuals were recorded in trees at heights between 5 to 10 m and, as rare events, some birds were observed 20 m above the ground, frequently on isolated heart-of-palm trees (*Euterpe edulis*). The birds were recorded close to each transect (95% confidence limits = 7.9–11.7 m), as shown by the effective strip width value (mean = 9.6 m, CV = 10%). Detection probability decreased with increasing distance (Fig. 2), mainly because the dense understory and abundant vines made observations of the species difficult at longer distances.

Most birds observed were either solitary (60% of all records) or in pairs (33% of all records) and were only observed in larger groups (range = 3–5 individuals) in 7% of the occasions. Pairs were seen <5 m from each other over all years. The majority of visual records (51%) occurred during the morning (28% of the records between 1000 and 1200 hrs and 23% between 0800 and 1000 hrs).

The number of observations recorded and density estimates varied among sites (Table 2). The low overall mean density estimate (1.6 individuals/km^2, range = 1.2–2.2 individuals/km^2) demonstrated how difficult it was to record the species in the largest Brazilian Atlantic Forest remnants. At least four populations were found in São Paulo State: two in the inshore islands, a small population in Serra do Mar massif, and a larger one in Serra de Paranapiacaba massif

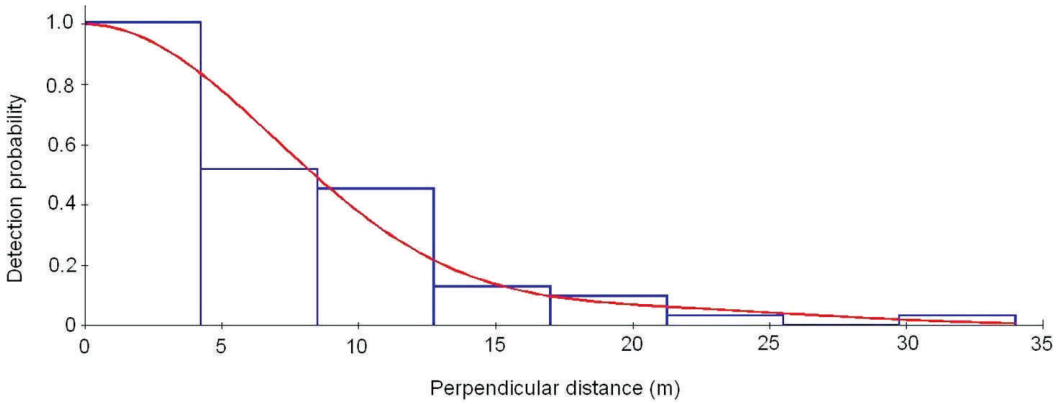

FIG. 2. Detection probability of Black- fronted Piping Guans as a function of the distance to the observer. The columns represent the number of detections in different distance classes, and the line represents the fit detection function (Software DISTANCE 5.1).

(Fig. 3). We considered a population as a set of individuals living in the same region which had no interaction with other individuals living in other regions.

The inshore islands and the contiguous protected areas of Paranapiacaba massif had the highest density estimates (DE) of this species (>10 observations and >2 groups/km^2, Table 2). The highest number of observations and DE were recorded from Ilhabela Island (29 encounters or 41% of the records, DE = 8 groups/km^2, Table 2).

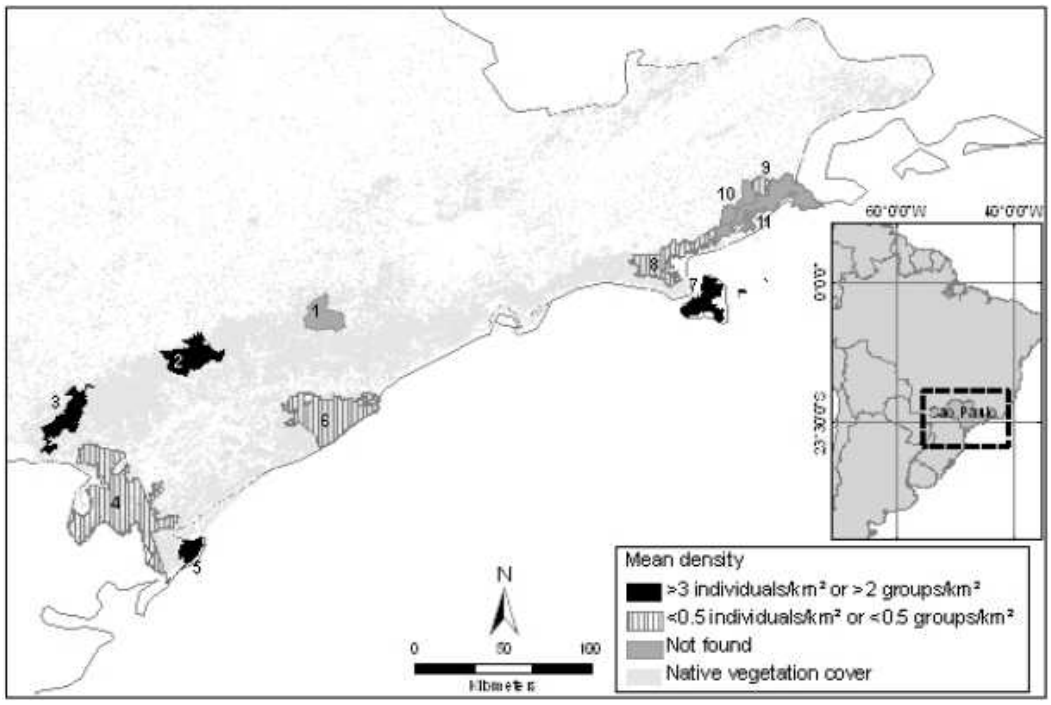

FIG. 3. Density estimates of Black-fronted Piping Guans in protected areas of São Paulo State (1 = Jurupará, 2 = Carlos Botelho, 3 = PETAR, 4 = Jacupiranga, 5 = Ilha do Cardoso, 6 = Juréia-Itatins, 7 = Ilhabela, 8 = Caraguatatuba, 9 = Santa Virgínia/Cunha, 10 = Picinguaba, 11 = Pilões).

The largest continuous mainland Atlantic Forest (Serra do Mar massif) had a low density; a similar pattern was found for the non-connected mainland forests (DE <0.5 groups/km^2) with no observations in two continuous forests and one non-connected area (Table 2).

DISCUSSION

We added to the knowledge of the global population status of Black-fronted Piping Guans, as we studied ~36% of the currently known world occurrence sites of this species. Line-transect methodology was adequate for our surveys, and we highly recommend use of this method for other areas where the species is present, mainly in southern Brazil and Paraguay. However, this methodology requires great effort considering the total number of km walked (2,241 km walked) and low number of observations (70). Pooling all observations in areas with few observations per study area was needed to obtain an effective strip width estimate. This allowed more precise density estimates based on >40 sightings, as recommended by Buckland et al. (2001).

The probability detection from the transect line up to 4.6 m was 100% (Fig. 2) indicating observers detected all birds on the transect line which met an important assumption of the method. Probability of detection decreased with increasing distance, as expected, because the dense understory and canopy made bird detection difficult. The probability of detection was ~50% and was between 4.7 and 13 m. Black-fronted Piping Guans have discrete movements and calls, and it is likely that some individuals were not detected at distances >4.7 m. Thus, our estimates should be considered conservative.

The differences in density values among areas are suggestive and not conclusive because we had insufficient sample sizes for statistical analysis. We had high density estimates in continuous forests of the Paranapiacaba massif and inshore islands. These densities were higher than in the continuous forests of the Serra do Mar massif, which is the largest remnant Atlantic rainforest.

Density estimates of Black-fronted Piping Guans in the Serra do Mar massif were the lowest obtained in our study (<0.5 individuals/km^2 or <0.4 groups/km^2, Table 2), and far below the average density estimates for other cracids in the Amazon and Andes regions (e.g., Silva and Strahl 1991, Thiollay 1994, Rios et al. 2005, Londono et al. 2007, Hill et al. 2008, Setina 2009). Densities in the Serra do Mar were higher than those obtained for other cracids in only two areas of the Amazon forest: Razor-billed Curassow (*Mitu tuberosum*) in an area of high hunting pressure (0.02 individuals/km^2) and Spix's Guan (*Penelope jacquacu*) in an area of low hunting pressure (0.19 individuals/km^2) (Begazo and Bodmer 1998, Haugaasen and Peres 2008). The conservation status of Black-fronted Piping Guans in the Serra do Mar region is of concern because local extinction can occur when population densities are low. This is a priority area for conducting more research and conservation action, e.g., population supplementation, if threats are eliminated.

Sánchez-Alonso et al. (2002) surveyed the Paranapiacaba area in 1998 (Intervales, Carlos Botelho, and Alto Ribeira parks), using the line-transect method, and estimated a mean density of 2.67 birds/km^2. Our mean density estimates in Paranapiacaba massif are between 3.0 and 4.4 individuals/km^2 (Table 2) and suggest Carlos Botelho is an important area for Black-fronted Piping Guan conservation. Immigration of the species from Paranapiacaba to surrounding patches may occur, e.g., Parque do Zizo (adjacent to Carlos Botelho), that apparently also have populations (C. O. Gussoni, pers. comm.).

Galetti et al. (1997) presented density estimates of Black-fronted Piping Guans in several areas of Atlantic rainforest, but our data are not comparable due to differences in methodologies. We recorded more observations in Ilhabela and Ilha do Cardoso, but lower numbers per group. The Black-fronted Piping Guan only flies short distances and the closest distance from Ilhabela to the mainland is >1 km; thus, we believe this population is isolated although the species can cross the narrow (~300 m) channel between Ilha do Cardoso and the mainland. Galetti et al. (1997) indicated the population of Black-fronted Piping Guans on Ilha do Cardoso had been extirpated based on no records between 1994 and 1995. Our study demonstrated the species is present in Ilha do Cardoso and the population density is higher than in some larger mainland regions. The absence of the Black-fronted Piping Guan records in Jurupará Park suggests movements among forests of Paranapiacaba and Serra do Mar may no longer occur (Fig. 3).

CONSERVATION IMPLICATIONS

Some observations occurred near highways with heavy traffic (Jacupiranga and Santa Virginia parks), altered forest (bamboo forest in Ilhabela Park) and areas dominated by *Cecropia* spp. (Ilha do Cardoso Park). Galetti et al. (1997) also reported Black-fronted Piping Guans in young forests dominated by *Cecropia* spp. (Juréia Park), and in monoculture of *Pinus* (Carlos Botelho Park). These observations occurred in areas surrounded by mature forest, but our data indicate Black-fronted Piping Guans are not extremely sensitive to habitat disturbance and the major threat to its conservation is most likely from illegal hunting. Cracids can be used as indicators of hunting pressure (Strahl and Grajal 1991, Strahl and Silva 1997) and studies demonstrating hunting pressure in all areas with Black-fronted Piping Guans can be done similarly to those of Silva and Strahl (1991), Begazo and Bodmer (1998), and Peres (2000).

All protected areas of São Paulo State studied have human occupation and are understaffed (according to park managers, a single park ranger is usually responsible for patrolling >1,700 ha). These areas have illegal activities including hunting, palm-heart extraction, and logging (Galetti and Fernandez 1998, Galetti 2001, Galetti et al. 2009). An obvious recommendation is to increase the number of park rangers in all areas, as well as effective law enforcement. Easy access to protected areas also increases hunting pressure (Peres and Terborgh 1995, Galetti et al. 2009). In addition to evidence of hunting, we also observed domestic dogs (*Canis lupus familiaris*) in all areas surveyed and it is well known they can impact bird biodiversity (Galetti and Sazima 2006, Bernardo 2010).

The absence or low density estimates of the species in three survey sites is of special concern, because it is known that guans are important in seed dispersal (Galetti et al. 1997, Sedaghatkshi et al. 1999). This species eat fruits ranging from tiny drupes (0.4 mm diam) to large (25 mm diam) arilate seeds (Galetti et al. 1997). Thus, the absence of Black-fronted Piping Guans may have consequences for long-term forest regeneration.

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