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ORIGINAL ARTICLE

The influence of environmental variables on capybara (*Hydrochoerus hydrochaeris*: Rodentia, Hydrochoeridae) detectability in anthropogenic environments of southeastern Brazil

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Abstract Capybaras were monitored weekly from 1998 to 2006 by counting individuals in three anthropogenic environments (mixed agricultural fields, forest and open areas) of southeastern Brazil in order to examine the possible influence of environmental variables (temperature, humidity, wind speed, precipitation and global radiation) on the detectability of this species. There was consistent seasonality in the number of capybaras in the study area, with a specific seasonal pattern in each area. Log-linear models were fitted to the sample counts of adult capybaras separately for each sampled area, with an allowance for monthly effects, time trends and the effects of environmental variables. Log-linear models containing effects for the months of the year and a quartic time trend were highly significant. The effects of environmental variables on sample counts were different in each type of environment. As environmental variables affect capybara detectability, they should be considered in future species survey/monitoring programs.

Keywords Agroecosystem · Herbivore · Log-linear models · Monitoring · Observer error

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Introduction

Estimates of wildlife population size are necessary for many purposes, including conservation, exploitation and control (Caughley 1977; Begon and Mortimer 1996; Caughley and Sinclair 1994; Sinclair et al. 2006). Wildlife population size can sometimes be estimated approximately by direct sample counts, or by indirect methods such as mark–recapture (Lancia et al. 1996; Thompson et al. 1998; Williams et al. 2002; Sinclair et al. 2006; Sutherland 2006). Sample counts are used often in wildlife research and management, but often incorrectly, as pointed out by Sinclair et al. (2006). Bias due to sampling the habitat improperly, ignoring visibility error, or other problems is common in animal counting.

One of the main purposes of animal counting is to assess the temporal dynamics of animal populations via monitoring programs (Gibbs 2000; Yoccoz et al. 2001). Extensive monitoring programs are conducted using population indices by assuming that the probability of detection is constant over space and time (Pollock et al. 2002), which is clearly invalid in many field studies (Yoccoz et al. 2001; Pollock et al. 2002). Species detectability can be influenced by environmental variables, habitat features and observer bias (Bayliss 1987; Lancia et al. 1996; Karanth et al. 2003; Field et al. 2005; Wayne et al. 2005; Pinto et al. 2006). These problems are generally underestimated by wildlife biologists in vertebrate surveys (Yoccoz et al. 2001; Pollock et al. 2002). As population monitoring plays a critical role in animal ecology and wildlife conservation (Gibbs 2000), the sources of variability should be seriously considered in such studies (Mönkkönen and Aspi 1998).

The capybara (*Hydrochoerus hydrochaeris*, Linnaeus 1766, Hydrochoeridae), which is the largest living rodent and is widely distributed in South America, has received special attention from researchers due to its intrinsic ability to adapt to anthropogenic habitats and agricultural landscapes (Ferraz et al. 2009), evidenced by an apparent increase in social groups and population sizes (Verdade and Ferraz 2006; Ferraz et al. 2007). Overabundant capybara populations are generally associated with agricultural damage (Ferraz et al. 2003) and tick infestations (Labruna et al. 2001). In these circumstances, population surveys are required to guide management strategies. Wildlife control should provide an effective way to minimize these problems (Caughley and Sinclair 1994), although hunting has been forbidden in Brazil since 1967 (Federal Law No. 5.197 from January 1967).

The capybara is a selective grazer (González-Jiménez 1978), exhibiting distinct foraging patterns in relation to environmental variables (Barreto and Herrera 1998). Species population size is usually estimated by performing foraging animal counts in open areas near water during daylight hours (Ojasti 1973; Cordero and Ojasti 1981; Schaller and Crawshaw 1981; Herrera 1986; Jorgenson 1986; Alho et al. 1989; Mourão and Campos 1995).

Although animal counting has been commonly used to estimate capybara population size, variables that affect species detectability such as the distance from the observer (Verdade and Ferraz 2006) and vegetation density (Pinto et al. 2006) are rarely considered. Also, the influence of environmental variables on species detection has never been examined before. Because of its importance, we have evaluated the influence of environmental variables (ambient temperature, humidity, wind speed, precipitation and global radiation) on adult capybara detectability when it is foraging in three different habitat types. The null hypothesis examined was that environmental variables did not affect the detection of adult capybaras. This information is relevant for future capybara monitoring and management.

Methods

We surveyed capybaras in an agricultural landscape containing artificial wetlands, mixed agricultural fields (mostly corn), exotic pastures (mostly *Panicum maximum*), implanted forest (mostly *Pinus* spp. and *Eucalyptus* spp.), and small fragments of semi-deciduous Atlantic forest (Rodrigues 1999) in Piracicaba, central-eastern São Paulo, Brazil (22°42′S–47°38′W, Fig. 1). The following study sites were considered: (a) open area—an open wetland surrounded by an exotic pasture field (*Panicum maximum*), an eucalyptus plantation with native vegetation regeneration and a small fragment of second-growth semi-deciduous Atlantic forest; (b) forest area—an artificial reservoir completely surrounded by a stand of mixed implanted forest (*Pinus* sp. and *Eucalyptus* sp.) and a small fragment of second-growth semi-deciduous Atlantic forest; and (c) mixed agricultural field—an artificial reservoir (about 1 ha) surrounded by annual corn plantations with a fragment of second-growth semi-deciduous Atlantic forest, a stand of mixed implanted forest (*Pinus* sp. and *Eucalyptus* sp.), and a small field of exotic pasture (mostly *Brachiaria decumbens*). The largest distance between study sites was about 3.5 km (Fig. 1).

Summer is warm and wet with average temperatures above 22°C, whereas winter is mild and dry with average temperatures below 18°C in these study areas. Annual average precipitation is 1200 mm (Setzer 1946).

Capybara surveys in the study sites were performed by counting the animals every week from July 1998 to January 2006 for the open area, from June 2000 to January 2006 for the mixed agricultural field, and from December 2000 to January 2006 for the forest area. The study sites were sampled on the same day by the same observer (one immediately after another) to avoid potential double counting. The observer walked around the water body and counted the animals sighted. The distance from the observer to the animals was up to 100 m at all sites during the whole study period. Animals were counted during the latest 2 h of sunlight, when capybaras usually forage in open areas near water. Three age classes were considered: adult (above 30 kg); juvenile (from 10 to 30 kg); and young (below 10 kg) (Ojasti 1973). Although somewhat arbitrary, as the animals were not weighed in this study, this classification is easy to use and does not require much observer training or skill.

The possible influences of five environmental variables [temperature (°C), humidity (%), wind speed (m/s), precipitation (mm) and global radiation (MJ/m^2 day)] on animal counts were examined for each site using log-linear models assuming Poisson counting with overdispersion using the GenStat statistical package (VSN International 2009). Because of clear seasonal trends within years and time trends, an initial model for each of the three study sites allowed for the effects of months of the year, while quartic polynomial models was used to allow for the time trends. Quartic models were chosen since they are the simplest possible models that could account for the time trends based on plots of animal counts.

For each sampling site, the five environmental variables were added to the model allowing for monthly effects and time trends. Any nonsignificant environmental variables at the 5% level were then removed to simplify the models. The juvenile and young counts were not included in the analyses because of their small body sizes, which could lead to bias due to their inherently low detection probability.

The environmental variables database was provided by the University of São Paulo Meteorological Station in

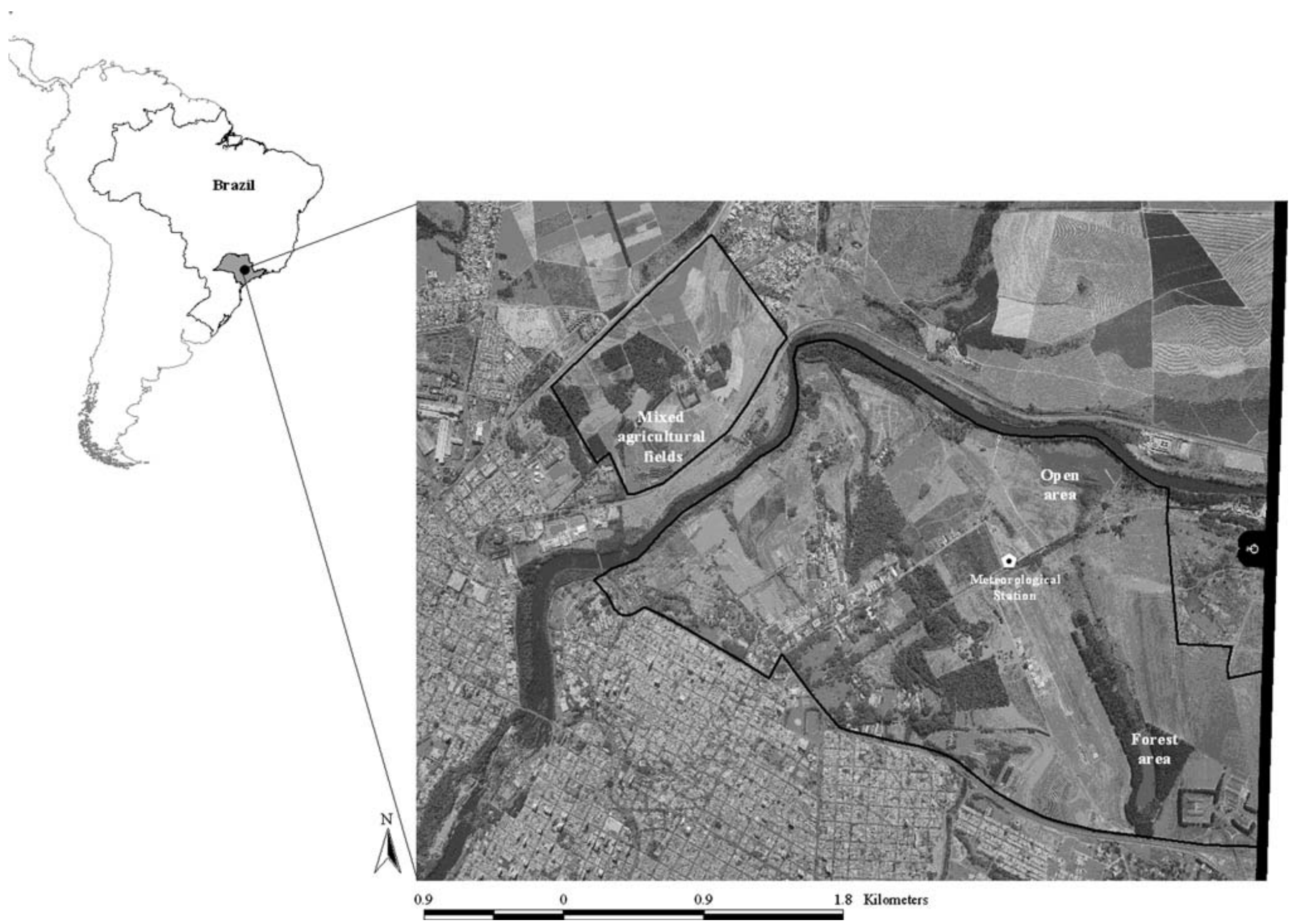

Fig. 1 Study sites (mixed agricultural fields, forest area and open area) in Piracicaba, central-eastern São Paulo, Brazil

Piracicaba, Southeastern Brazil (http://www.lce.esalq.usp.br/station.html), which is located near (0.8–2 km) to the study sites (Fig. 1). Although environmental variables can have a delayed effect on animal behavior, we only considered values on sampling days because of our interest in the influence of these variables on the detectability of animals.

Results

There was consistent seasonality in the number of capybaras in the study area, with a specific seasonal pattern in each area (Fig. 2). The highest mean of number of capybaras was found for the open area (Table 1). The species abundance at this study site began to increase in April (42.4 ± 12.2 individuals counted) and peaked in October (69.2 ± 25.7 individuals counted). The capybara abundance was lower in the forest area, but showed more variation from April (4.8 ± 8.0 individuals) to August (13.1 ± 15.6 individuals). In the mixed agricultural fields, the number of individuals usually began to increase in July (14.8 ± 12.5 individuals) and peaked in October (27.0 ± 17.2 individuals). Although reproduction occurs year-round, the number of young peaked in the rainy season in the open area as well as in the mixed agricultural fields (from 5.3 ± 6.1 individuals in September to 10.8 ± 10.5 individuals in February in the open area and from 1.1 ± 2.2 individuals in September to 7.3 ± 7.6 individuals in the mixed agricultural fields). In the forest area, peak nurturing occurred in June (from zero in April to 4.2 ± 7.2 individuals in June).

In the dry season, the number of capybaras varied from 42.4 ± 12.2 individuals in April to 59.3 ± 25.0 individuals in September ($n = 181$) in the open area, from 14.8 ± 12.6 individuals in July to 22.6 ± 11.8 individuals in April ($n = 119$) in the mixed agricultural fields, and from 4.8 ± 8.0 individuals in April to 13.1 ± 15.6 individuals in August ($n = 119$) in the forest area. In the wet season, the number of capybaras varied from 43.0 ± 20.1 individuals in February to 69.2 ± 25.7 individuals in October ($n = 194$) in the open area, from 19.7 ± 11.8 individuals in December to 23.7 ± 13.1 individuals in February ($n = 142$) in the mixed agricultural fields, and

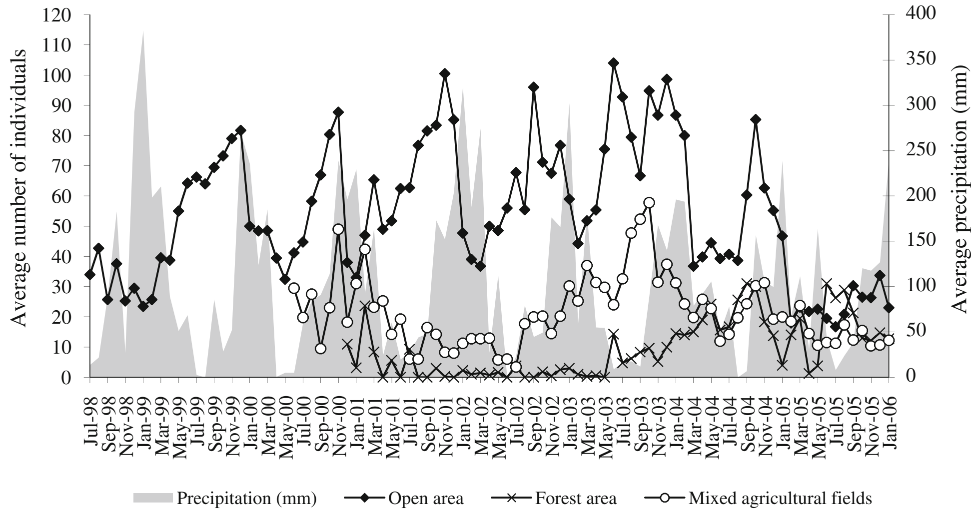

Fig. 2 Capybara population fluctuations in three anthropogenic environments (mixed agricultural fields, forest area and open area) in Piracicaba, central-eastern São Paulo, Brazil

Table 1 Average numbers of capybaras (mean ± standard deviation) at three anthropogenic habitats (mixed agricultural fields, forest and open areas) in Piracicaba, central-eastern São Paulo, Brazil

	n	Population	Adult	Juvenile	Young
Year period					
Open area	375	53.77 ± 24.88	35.25 ± 19.68	10.63 ± 8.14	7.89 ± 7.35
Forest area	252	9.11 ± 11.15	5.27 ± 6.31	2.13 ± 3.40	1.72 ± 3.64
Mixed agricultural fields	277	21.25 ± 13.81	12.98 ± 9.13	5.17 ± 4.93	3.10 ± 4.23
Dry season (April–September)					
Open area	181	51.35 ± 22.41	33.98 ± 18.43	10.67 ± 7.28	6.70 ± 5.84
Forest area	119	9.92 ± 12.55	5.83 ± 6.89	2.37 ± 3.55	1.72 ± 4.29
Mixed agricultural fields	135	18.98 ± 13.33	11.89 ± 8.76	5.28 ± 5.36	1.81 ± 3.05
Wet season (October–March)					
Open area	194	56.02 ± 26.85	36.43 ± 20.75	10.59 ± 8.88	8.99 ± 8.38
Forest area	133	8.38 ± 9.73	4.76 ± 5.72	1.91 ± 3.27	1.71 ± 2.95
Mixed agricultural fields	142	23.42 ± 13.96	14.02 ± 9.37	5.06 ± 4.51	4.34 ± 4.80

n, total number of counts taken for all years sampled

from 6.35 ± 6.5 individuals in January to 10.0 ± 11.3 individuals in February ($n = 133$) in the forest area. Table 1 shows the average number of capybaras for the whole year and for the dry and wet seasons.

The log-linear models for an expected count take the form: $E(\text{count}) = \exp(\beta_0 + \text{month effect} + \text{time trend effect} + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_5 X_5)$, when all five environmental variables (X_1–X_5) are included. The β values are then regression parameters that can be estimated with the statistical package GenStat using standard quasi-maximum likelihood methods, assuming a Poisson distribution for counts with overdispersion. Table 2 shows the estimated β values with standard errors and significance levels after the removal of insignificant environmental effects from the equations, while Fig. 3 shows how the observed counts compare with the expected counts from the fitted models.

Monthly effects and quartic time trends are highly significant, and there is evidence that average temperature, average humidity, precipitation and global radiation influenced capybara detectability. However, the effects of environmental variables on the sample counts were different for each type of environment (Table 2). In the open area, the estimated effect of increased humidity ($P = 0.004$) and increased global radiation ($P = 0.025$) was a reduction in the number of adults seen. In the mixed agricultural area, the estimated effect of increased temperature ($P = 0.001$), increased humidity ($P = 0.007$) and increased global radiation ($P = 0.036$) was also a reduction in the number of adults seen. In the forested area, the estimated effect of increased precipitation ($P = 0.011$) was an increase in the number of adults seen.

Discussion

The seasonality observed in the capybara numbers revealed specific patterns for each study site. The open area, characterized by an open wetland with abundant forage even

Table 2 Estimated β values with standard errors (SE) and significance levels after the removal of insignificant environmental effects from the equations for the study sites

Effect	Estimated β values	SE	t	P
Open area				
Constant	3.277800	0.318191		
February	−0.215459	0.100634	−2.14	0.033
March	−0.247881	0.097880	−2.53	0.012
April	−0.236779	0.097943	−2.42	0.016
May	−0.094271	0.097077	−0.97	0.332
June	0.020205	0.102309	0.20	0.844
July	0.083315	0.097423	0.86	0.393
August	0.135071	0.100489	1.34	0.180
September	0.294782	0.098673	2.99	0.003
October	0.460391	0.086053	5.35	<0.001
November	0.430003	0.085299	5.04	<0.001
December	0.358911	0.085033	4.22	<0.001
Linear	0.078792	0.016607	4.74	<0.001
Quadratic	−0.002779	0.000717	−3.88	<0.001
Cubic	0.000050	0.000012	4.26	<0.001
Quartic	0.000000	0.000000	−5.10	<0.001
Humidity	−0.006911	0.002413	−2.86	0.004
Global radiation	−0.011114	0.004920	−2.26	0.025
Forest area				
Constant	72.125500	12.408100		
February	0.359279	0.320806	1.12	0.264
March	0.465269	0.315131	1.48	0.141
April	0.291172	0.315054	0.92	0.356
May	0.437287	0.317013	1.38	0.169
June	0.808567	0.313286	2.58	0.010
July	0.905946	0.293227	3.09	0.002
August	0.969515	0.289286	3.35	0.001
September	1.142070	0.296801	3.85	<0.001
October	0.908407	0.287951	3.15	0.002
November	0.482174	0.298919	1.61	0.108
December	0.383985	0.287826	1.33	0.183
Linear	−4.963040	0.908580	−5.46	<0.001
Quadratic	0.119303	0.023583	5.06	<0.001
Cubic	−0.001201	0.000261	−4.60	<0.001
Quartic	0.000004	0.000001	4.14	<0.001
Precipitation	0.020395	0.007988	2.55	0.011
Mixed agricultural fields				
Constant	22.998200	2.770810		
February	−0.068559	0.157861	−0.43	0.664
March	−0.039421	0.150933	−0.26	0.794
April	−0.121450	0.150633	−0.81	0.421
May	−0.559985	0.184345	−3.04	0.003
June	−0.802538	0.194919	−4.12	<0.001
July	−0.938263	0.204585	−4.59	<0.001
August	−0.511463	0.195033	−2.62	0.009
September	−0.266830	0.181962	−1.47	0.144
October	0.132691	0.146440	0.91	0.366
November	−0.007235	0.146521	−0.05	0.961
December	−0.057232	0.147055	−0.39	0.697
Linear	−1.434080	0.234069	−6.13	<0.001
Quadratic	0.039592	0.006692	5.92	<0.001
Cubic	−0.000449	0.000081	−5.55	<0.001
Quartic	0.000002	0.000000	5.09	<0.001
Temperature	−0.047549	0.014699	−3.23	0.001
Humidity	−0.013606	0.005012	−2.71	0.007
Global radiation	−0.019484	0.009240	−2.11	0.036

during the dry season, presented the highest number of individuals over the entire year. It also presented a significant increase in numbers at the beginning of the early dry season (from April), peaking in the transition between dry and rainy seasons, which was always followed by a sudden decrease in population numbers. This observed fluctuation in capybara numbers is probably related to seasonal aggregation (Ojasti 1973; Herrera and Macdonald 1987, 1989). The pattern of seasonal aggregation in the dry season and the spreading out observed at the beginning of the raining season is commonly observed in capybaras that inhabit seasonally flooded grasslands such as the Brazilian Pantanal and the Venezuelan Llanos (Ojasti 1973; Schaller 1983; Herrera 1986; Herrera and Macdonald 1987, 1989). In the seasonally flooded savannas, the main factor favoring capybaras aggregation is water resource fluctuations (Ojasti 1973), while it is probably the shortage of grass in the anthropogenic environments studied. The open area monitored in this study is the only one that sustained high-quality forage even in the dry season, explaining the increased capybara abundance, especially during this period.

The different population fluctuation patterns that occurred from May/June 2003 onwards started when the area was drained, which could not be avoided or even controlled by us. One of the possible effects of this could have been a reduction in the carrying capacity of this area for capybaras.

The forest area and mixed agricultural fields—different habitats from the seasonally flooded grasslands commonly described as the typical habitat of capybaras (Ojasti 1973; Herrera and Macdonald 1989)—sustained a lower number of capybaras in comparison with the open area. This may have been due to a shortage in food resources. Neither of these populations showed a cyclical seasonal fluctuation such as that seen in the open area. Habitat use, availability and selectivity of resources and dispersion patterns should be investigated to clarify this.

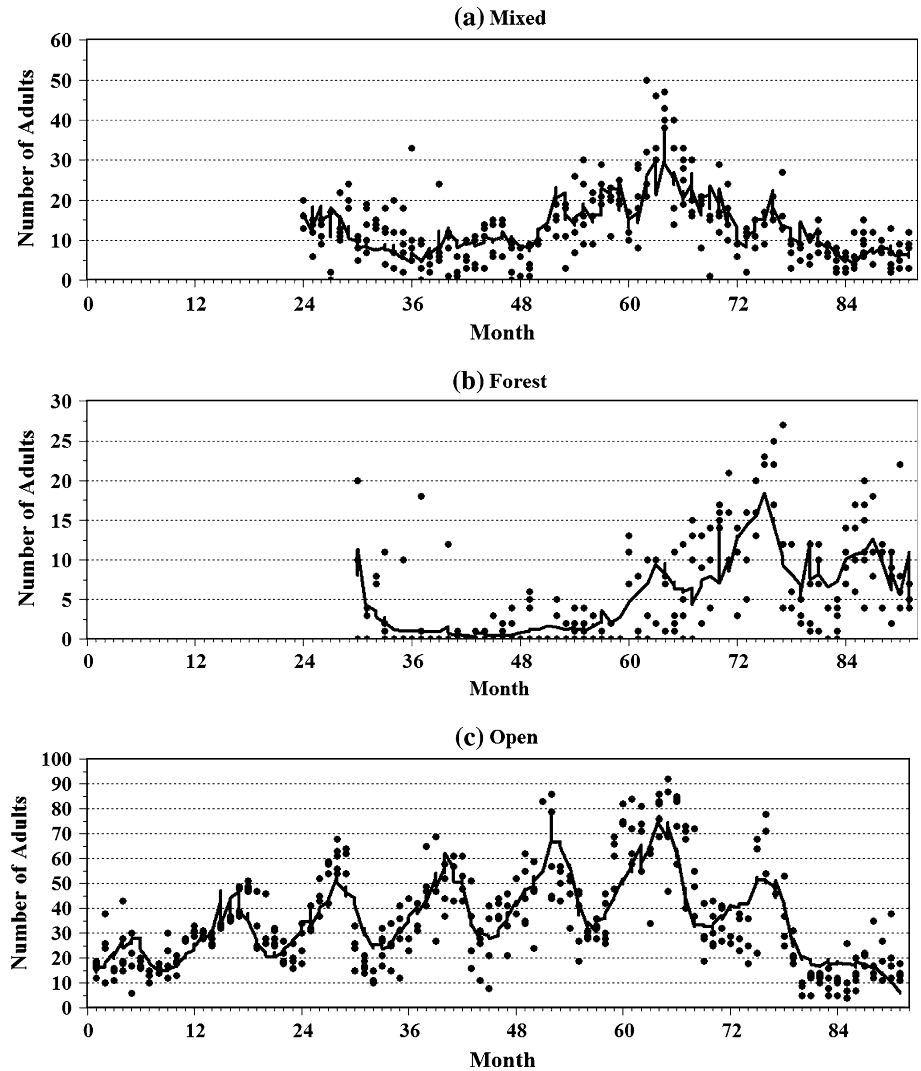

Fig. 3 Log-linear models for the sample counts of adult capybaras in three anthropogenic environments: **a** mixed agricultural fields; **b** forest area, and; **c** open area in Piracicaba, central-eastern São Paulo, Brazil. The graphics show the observed counts (*dots*) compared with the expected counts (*line*) from the fitted models

While environmental variables influenced species detection, they seemed to do so in different ways according to the characteristics of the habitats in each area. Humidity and global radiation may affect the animals' ecophysiology and behavior, as they tend to avoid extreme levels of both variables (McNab 2001). In open areas, capybaras usually forage early in the morning and at dusk when the temperature and radiation are milder, thereby avoiding exposure to sunlight during the hottest hours of the day (Ojasti 1973; Macdonald 1981). This ecophysiological adaptation apparently affects the animals' detectability by the observer. This aspect should be considered for survey planning, and not only for capybaras but possibly also for other vertebrates.

On the other hand, precipitation in forested areas can result in an increase in food resources, that are possibly used by neighboring animals (e.g., beta males). In all these cases, environmental variables may influence species movement patterns both seasonally and daily (Krebs and Davies 1993; Bilenca and Kravetz 1999; Tomas et al. 2001; Bispo et al. 2004; Gimona and Brewer 2006; Nevoux et al. 2007). The present results seem to capture those effects. This should be tested as a hypothesis in future studies. In addition, as these environmental variables affect the animals' detectability, they should be considered by future survey/monitoring programs of capybaras.

Although capybara population estimation by animal counting is relative common (Ojasti 1973; Cordero and Ojasti 1981; Schaller and Crawshaw 1981; Herrera 1986; Jorgenson 1986; Alho et al. 1989; Quintana and Rabinovich 1993; Mourão and Campos 1995), detection errors made by the observer (Yoccoz et al. 2001) and the influence of external variables on the estimation have not been considered. In order to increase survey precision and accuracy, environmental variables that can possibly affect animal detectability—and therefore counting results and population size estimates—such as those evaluated in the present study should be considered by wildlife biologists.

Also, estimations of animal abundance should incorporate both spatial variation and detectability (Yoccoz et al. 2001; Pollock et al. 2002).

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