Factors Affecting the Number of Caimans Seen during Spotlight Surveys in the Mamirauá Reserve, Brazilian Amazonia

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Between 1995 and 1998 we studied the effects of water level, moon phase, and site on the number of caimans observed in spotlight surveys in the Mamirauá Sustainable Development Reserve, Brazilian Amazonia. Multiple linear regression analyses including water level of the Amazon River and the moon phase explained 91 and 73% of the variance in number of *Melanosuchus niger* seen in spotlight surveys in Lago Mamirauá and Cano Mamirauá, respectively, and 60 and 76%, respectively, of the variance in the number of *Caiman crocodilus* seen. Water level had a statistically significant and negative effect on the number of *M. niger* and *C. crocodilus* seen. Moon phase had no significant effect on the number of *C. crocodilus* seen, but more *M. niger* were detected in Lago Mamirauá on nights with more moon light. The regression equations derived for Lago Mamirauá and Cano Mamirauá did not adequately predict the variation in numbers seen in 18 other water bodies in the Mamirauá Reserve. Analysis of covariance showed an interaction between water level and site on the numbers of *M. niger* and *C. crocodilus* observed in the spotlight surveys in these water bodies, indicating that the effect of water level depends on the site. In these analyses, moon phase did not have a significant effect on either species, and there was no interaction between moon phase and site. To monitor natural tendencies, or impacts (e.g., controlled commercial hunting), on caiman populations of Mamirauá Reserve, it will be necessary to undertake regular spotlight surveys in many water bodies of all types at a narrow range of water level to have confidence in the results.

THE conservation status of crocodilian populations has been estimated by relative-abundance indices obtained during spotlight surveys (Gorzula, 1984; Magnusson, 1984). However, the number of crocodilians seen in a spotlight survey depends on water level (Montague, 1983; Jenkins and Forbes, 1985), moon phase (Woodward and Marion, 1978), and many other environmental factors and habitat characteristics, such as temperature (Murphy and Brisbin, 1974), depth (Da Silveira et al., 1997), and vegetation (Cherkiss et al., 2006). Many spotlight surveys of caimans have been carried out in the Brazilian Amazon since the 1980s (Rebelo, 1983; Magnusson, 1985; Brazaitis et al., 1996), but those authors did not account for the potential effects of habitat structure and other environmental variables on observed densities.

Most researchers who developed models relating environmental variables to the probability of sighting caimans during spotlight surveys undertook the studies in a small number of water bodies. In the absence of other information, the resulting models are generalized to other water bodies, habitats or regions. However, the value of these extrapolations is questionable, because the water bodies in extensive areas, such as Amazonia, vary greatly in their physical characteristics and models developed for one type of water body might not be valid for others.

The largest caiman populations in the Brazilian Amazon occur in várzea habitats (Da Silveira, 2002), seasonally inundated floodplains bordering rivers with high sediment load (Junk, 1997). The Mamirauá Sustainable Development Reserve is the Amazon's largest protected várzea, and includes thousands of water bodies (Mamirauá, 1996). Three crocodilian species, the Black Caiman (*Melanosuchus niger*), the Spectacled Caiman (*Caiman crocodilus*), and Cuvier's Dwarf Caiman (*Paleosuchus palpebrosus*) occur in the Mamirauá Reserve. In 2004, the government of Amazonas State began a pilot program for the sustainable harvesting of caimans in the Mamirauá Reserve. A prerequisite for this, or any other management program, is a robust system for monitoring the target populations (Stirrat et al., 2001).

Our principal objective in this paper was to evaluate whether it is necessary to rigorously standardize the conditions under which spotlight surveys are undertaken in the Mamirauá Reserve, or if it is possible to compare results from surveys made under different conditions after calibrations based on the values of environmental variables. Specifically, we examined the seasonal effects of the Amazon River water level and moon phase on the numbers of *M. niger* and *C. crocodilus* seen during spotlight surveys in Lago Mamirauá and Cano Mamirauá, and whether or not predictive models developed for these water bodies can be used to estimate the relative abundance of caiman in other water bodies in the Mamirauá Reserve.

MATERIALS AND METHODS

Study area.—The Mamirauá Sustainable Development Reserve contains 1,124,000 ha of várzea in the western

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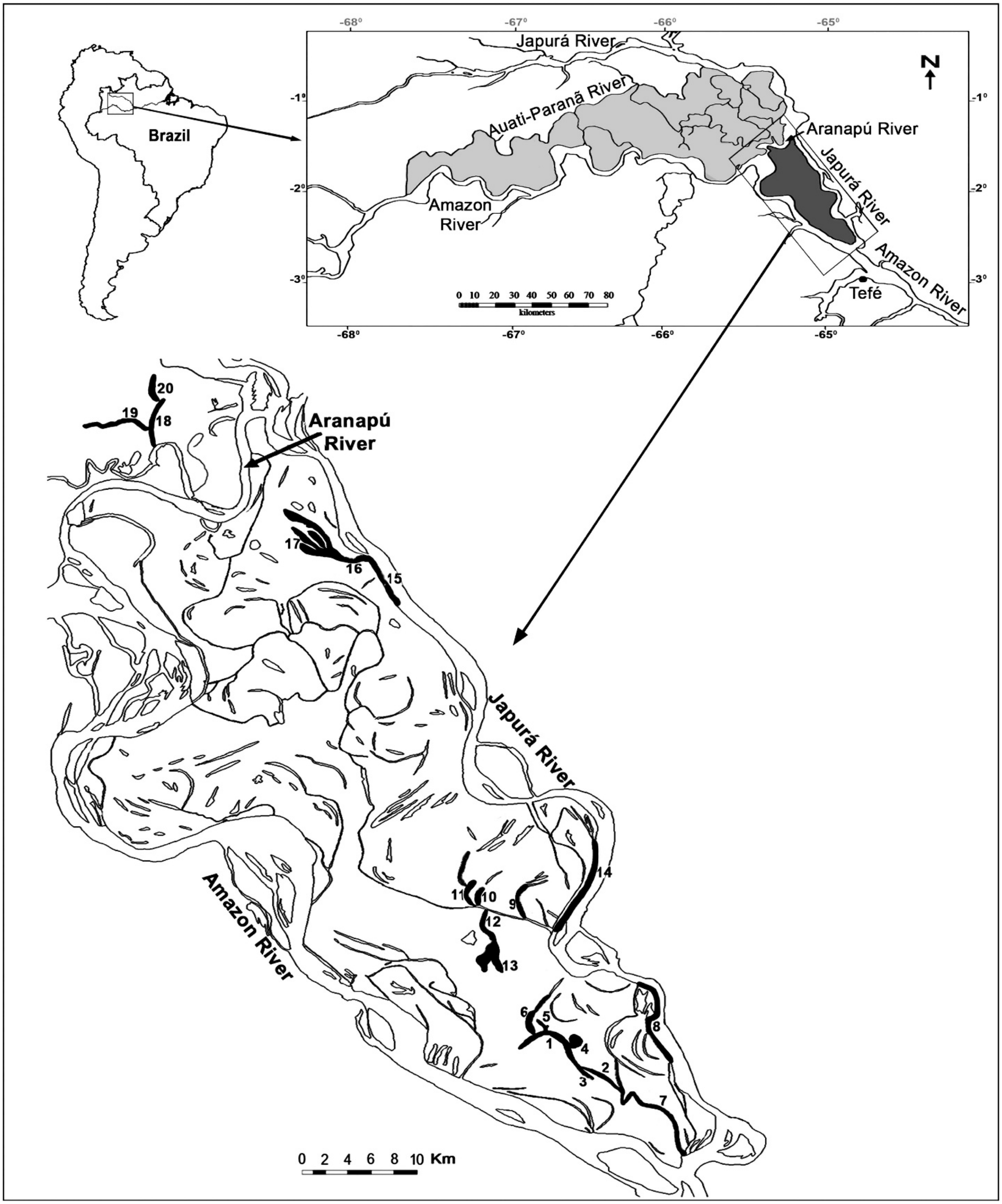

Fig. 1. Map of the Mamirauá reserve and location of the 20 lakes and canals where 147 spotlight surveys were undertaken between 1995 and 1998. The numbers on inserts represent the survey sites. Survey routes around water bodies are in bold.

Brazilian Amazon, near the city of Tefé. The reserve is located at the confluence of the Amazon, Japurá, and Auatí–Paraná rivers (Fig. 1), and these rivers seasonally flood the reserve with ten to 15 meters of water during the wet season (April to July). Rainfall varies from 2,200 to 2,400 mm per year, and is most intense between January and April. The mean monthly maximum temperature ranges from 30 to 33°C, and the minimum oscillates between 21 and 23°C.

The reserve has an enormous variety of wetlands and more than 620 lakes and canals (Mamirauá, 1996).

Spotlight surveys.—We conducted nocturnal surveys from an aluminum boat with a 15 HP motor moving between ten and 15 km/h. Caimans were located by their eyeshine when illuminated with a spotlight (Da Silveira et al., 1997). Spotlight surveys ($n = 147$) were undertaken between January 1995 and November 1998 along routes in 20 water bodies which were clustered in four parts of the Mamirauá Reserve (Fig. 1). Before undertaking multiple regression analyses we tested if spotlight surveys undertaken in the same cluster were independent. Analysis of covariance (ANCOVA) indicated no relationship between the total number of caiman found in each survey (dependent variable) and the cluster ($P = 0.720$) when this variable was included with the continuous variables. Therefore, water bodies from all clusters were used in analyses as independent samples.

Fifteen spotlight surveys were undertaken in Lago Mamirauá and Cano Mamirauá. In ten other lakes, the numbers of spotlight surveys varied between five and 15 (mean = 7.6 ± 3.1), and in eight canals the number of surveys varied between four and six (mean = 5.1 ± 0.6). Because of the extremely large number of caimans, it was possible to determine the species of all individuals seen in only four spotlight surveys. In 110 surveys, every second or fifth caiman was approached to a distance of ≤5 m to determine the species, and in five surveys densities were so high we identified the species of every tenth caiman. In 28 surveys undertaken during the peak of the dry season (September to October), it was not necessary to stop to identify caiman species because they were aggregated in dense groups along the shorelines.

The percentage of caimans identified to species varied from 7–100% (mean = 45 ± 19) of the individuals observed in a given survey. On surveys where 100% of the caiman were not identified to species, we estimated the numbers of each species from the relative proportion of the species observed on that survey multiplied by the total number of caiman counted. Only three *Paleosuchus palpebrosus* were located during the surveys, and we excluded those occurrences from the following analyses. Hatchlings (snout–vent length < 22 cm) of all species were excluded due the high mortality expected for this size class.

Environmental variables.—The Amazon River water level in meters above mean sea level was measured in Tefé, about 30 km from the reserve by the Capitânia dos Portos/Brazilian Navy. Values for the water level on the afternoon before the spotlight surveys were used in analyses. Water levels varied more than 12 m across all spotlight surveys, and each of the 20 water bodies was sampled at a range of available water levels. During this study, the mean water level of the Amazon River reached its lowest level in September (3.8 m) and October (2.0 m ± 1.6 for both months), dropping from peak levels of 14.2 m in June. Moon phase was estimated as the percentage illumination by the moon on the day of each survey using the program "Almanac" (developed by Ross Alford, James Cook University, Townsville, Australia). In 47% of the 147 surveys, the moon had not risen or had already set and, in those cases, a value of zero was attributed to moon phase. Surveys were undertaken during nights with no rain and little cloud cover, but cloud cover was not recorded.

Statistical analysis.—Multiple regression was used to evaluate the effects of water level and moon phase on the number of *M. niger* and *C. crocodilus* seen during spotlight surveys in the Lago Mamirauá and Cano Mamirauá. Water level was $\log_e$ transformed to linearize the relationship. Water and air temperatures and the velocity of the current during the surveys (Da Silveira et al., 1997) were included in the initial models. However, low tolerance values indicated high correlations between these variables and the others already included in the model. As the river level and moon phase were more readily available, and therefore more useful for management, we retained those variables.

To compare the results of the predictive model developed for Lago Mamirauá and Cano Mamirauá with the other water bodies in the reserve, we based our analyses on an index of the number of caiman seen on one survey expressed as a proportion of the maximum number seen on any previous or subsequent survey along the same route. This population index (PI), which ranged between zero and 100, was calculated for each species separately. For instance, if we saw 50 *M. niger* along survey on route X, where the maximum number seen on another survey of route X was 100, the index for that survey was 50.

Other water bodies.—Multiple linear regression equations derived for Lago Mamirauá and Cano Mamirauá were used to estimate the PIs at other sites to predict count variability in relation to local environmental factors (water level and moon) during those spotlight survey. The accuracy of the models at predicting the proportion of the maximum for each species of caiman seen in other water bodies is a test of their generality. Relationship between predicted and observed PIs was compared by simple linear regression analysis for each species and water-body type.

Categorical (site) and continuous variables (water level, moon phase) were analyzed together in an ANCOVA, which was used to estimate the effects of water level and moon phase, in sites other than Lago Mamirauá and Cano Mamirauá, on the number of *M. niger* and of *C. crocodilus* detected. Site was included as a categorical variable (one to 18) to account for the different overall abundances among sites. All statistical analyses were done with the program Systat (Systat 8.0, SPSS Inc., Chicago).

RESULTS

We counted a total of 31,213 caimans during 147 spotlight surveys in 20 sites throughout the Mamirauá Reserve. Significantly more *Melanosuchus niger* than *Caiman crocodilus* were detected in surveys (Paired t-test: $t = 2.082$, df = 19, $P = 0.05$).

The number of *M. niger* detected in Lago Mamirauá varied from 22 to 1,928, and *C. crocodilus* from 24 to 777. The water level of the Amazon River and moon phase together explained about 90% of the variance in the number of *M. niger* seen during spotlight surveys in Lago Mamirauá ($R^2 = 0.91$, $F_{2,12} = 59.8$, $P < 0.001$). Both factors had significant partial regressions: water level ($P < 0.001$) had a negative effect (Fig. 2A), and the moon phase ($P = 0.005$) had a positive effect (Fig. 2B). For *C. crocodilus* ($R^2 = 0.60$, $F_{2,12} = 9.2$, $P = 0.004$), the water level had a significant ($P = 0.004$) and negative effect (Fig. 2C), but the moon phase (Fig. 2D) did not have a significant effect ($P = 0.725$) on the number of individuals seen during spotlight surveys in Lago Mamirauá.

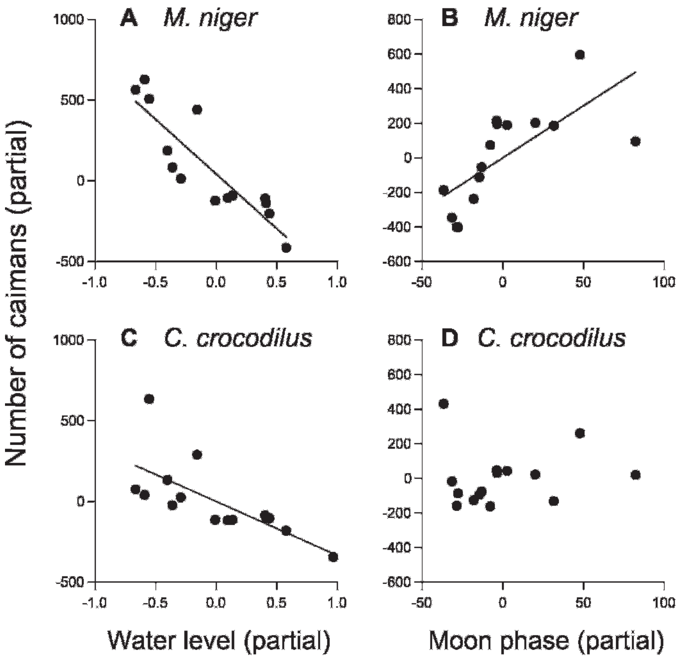

Fig. 2. Partial regressions between water level of the Amazon River ($\log_e$ transformed) and the number of (A) *M. niger* and (C) *C. crocodilus* during spotlight surveys in Lago Mamirauá. Partial regressions between moon phase and number of (B) *M. niger* and (D) *C. crocodilus* during spotlight surveys in the Lago Mamirauá.

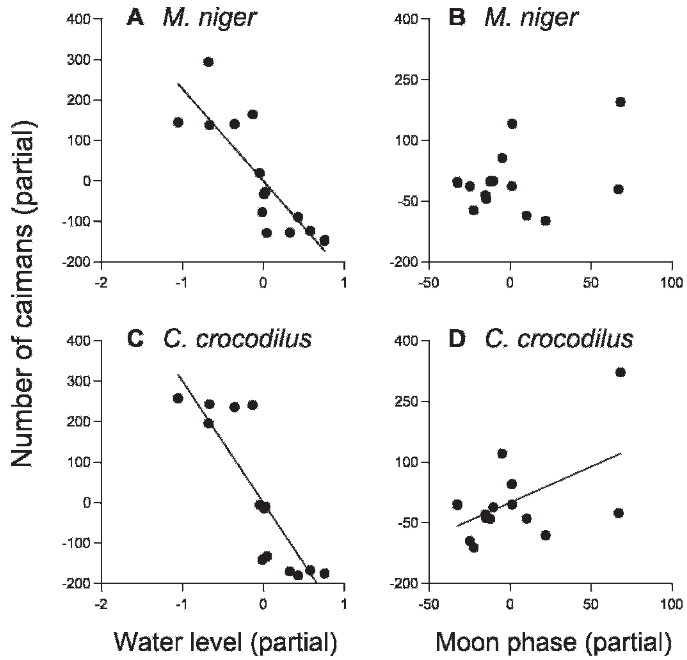

Fig. 3. Partial regressions between water level of the Amazon River ($\log_e$ transformed) and the number of (A) *M. niger* and (C) *C. crocodilus* during spotlight surveys in Cano Mamirauá. Partial regressions between moon phase and the number of (B) *M. niger* and (D) *C. crocodilus* during spotlight surveys in the Cano Mamirauá.

The number of *M. niger* seen in Cano Mamirauá varied from zero to 452 and of *C. crocodilus* from 21 to 458. The water level and moon phase together explained 73% of the variance in the number of *M. niger* ($R^2 = 0.73$, $F_{2,12} = 16.5$, $P < 0.001$) and 76% of the variance in the number of *C. crocodilus* counted during the spotlight surveys in Cano Mamirauá ($R^2 = 0.76$, $F_{2,12} = 19.1$, $P < 0.001$). Water level had a significant ($P < 0.001$) and negative effect (Fig. 3A) on the number of *M. niger* observed, but moon phase (Fig. 3B) had no significant effect ($P = 0.218$). For *C. crocodilus*, water level had a stastically significant ($P < 0.001$) and negative effect (Fig. 3C) on the number of individuals in Cano Mamirauá, and the null hypothesis associated with moon phase had a low probability ($P = 0.052$), indicating a possible positive effect (Fig. 3D). However, the fifth survey was an outlier (Fig. 3D). When this survey was excluded from the analysis, the effect of the moon phase no longer approached statistical significance ($P = 0.993$), and the probability for water level was unaffected.

Substituting in the models the number of caimans observed in each spotlight survey (dependent variable) for the respective population index (PI), regressions were essentially the same, in terms of R^2, F, total and partial probabilities, as when we analyze with the absolute value.

Regression equations derived for Lago Mamirauá and used for predicting the population index (PI), based on water level (WL) and moon phase (MP), of *M. niger* in other lakes was (1) PI_MN = 107.6–44.4 * WL + 0.31 * MP; and for *C. crocodilus* in the same lakes was (2) PI_CC = 114.5–43.0 * WL + 0.07 * MP. Regression equations derived for Cano Mamirauá and used for predicting the population index of *M. niger* in other canals was (3) PI_MN = 130.2–50.5 * WL + 0.20 * MP; and for *C. crocodilus* in the same canals was (4) PI_CC = 167.7–65.6 * WL + 0.39 * MP.

Spotlight surveys in other water bodies.—In 76 spotlight surveys undertaken in ten other lakes, the number of *M. niger* varied from zero to 1,153 individuals (mean = 116 ± 198.3) and *C. crocodilus* ranged from two to 310 (mean = 51 ± 50.8). In the eight canals, numbers of *M. niger* varied from zero to 246 (mean = 30 ± 52.6) and *C. crocodilus* from zero to 326 (mean = 52 ± 77.8).

Using the multiple regression equations derived for Lago Mamirauá, we calculated the predicted population indices (PIs) for *M. niger* and *C. crocodilus* in the ten other lakes. The same procedure was used for the eight other canals using the equations derived for Cano Mamirauá. Predicted PIs for *M. niger* explained 38% of the variance in observed PIs in lakes ($R^2 = 0.38$, $F_{1,74} = 43.4$, $P < 0.001$) and 25% in canals ($R^2 = 0.25$, $F_{1,39} = 13.0$, $P = 0.001$). Predicted PIs for *C. crocodilus* explained 37% of the variance in observed PIs in lakes ($R^2 = 0.37$, $F_{1,74} = 43.4$, $P < 0.001$). The relationship between observed and predicted was not statistically significant for *C. crocodilus* in canals ($P = 0.062$), and had an r^2 of only 0.087.

In general, the PIs predicted by the models underestimated the actual PIs found in the surveys sites (Fig. 4). However, when predicted PIs of either species in lakes and canals were ≤20%, generally the actual PIs of the most sites were ≤20% (Fig. 4). The inadequacy of the extrapolated values is shown by the negative values of predicted PIs of *M. niger* in lakes (Fig. 4A), and values >100% for *C. crocodilus* in canals (Fig. 4D).

In spotlight surveys undertaken at sites other than Lago Mamirauá and Cano Mamirauá, analysis of covariance (ANCOVA) indicated observed PIs were affected by water level ($P < 0.001$) and survey site ($P < 0.001$) for both species. However, the analysis also detected interactions between water level and site and observed PIs of *M. niger* ($P < 0.001$) and *C. crocodilus* ($P < 0.001$) in these spotlight surveys.

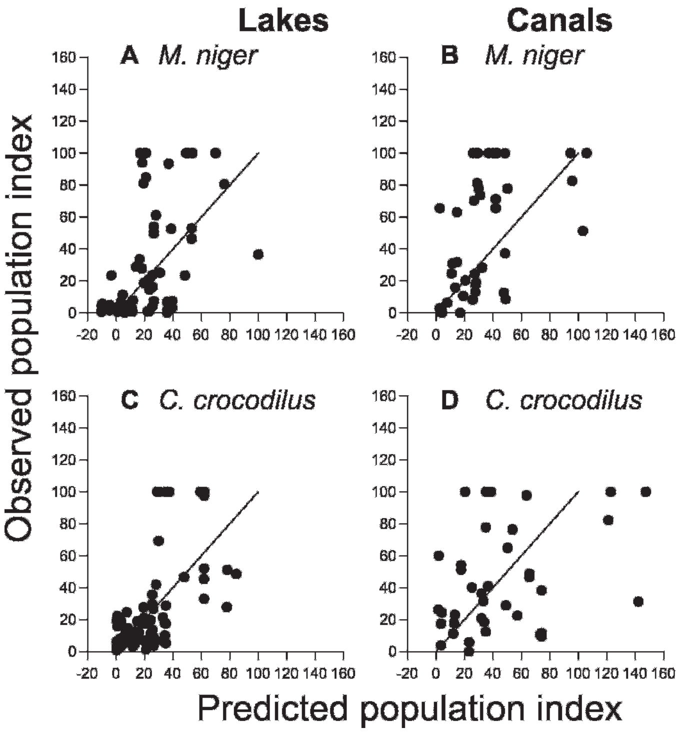

Fig. 4. Relationship between predicted population indices (PI) for *M. niger* in (A) lakes and in (B) canals, based on equations derived from Lago Mamirauá (Equations 1 and 2 in Results), and the observed PIs in spotlight surveys. Relationship between predicted PIs of *C. crocodilus* in (C) lakes and in (D) canals, based on equations derived from Cano Mamirauá (Equations 3 and 4 in Results), and the observed PIs in spotlight surveys. Lines represent the expected relationship for perfect prediction of observed PIs.

Therefore, the effect of water level on the observed number of both species varied depending on survey site. Moon phase had no significative effect on *M. niger* ($P = 0.883$) or *C. crocodilus* ($P = 0.842$), and there was no interaction between moon phase and site for *M. niger* ($P \approx 1.000$) or *C. crocodilus* ($P = 0.090$) in these other areas.

DISCUSSION

The strong negative effect of water level on the numbers of Black Caiman (*Melanosuchus niger*) and Spectacled Caiman (*Caiman crocodilus*) seen during spotlight surveys in the Mamirauá Sustainable Development Reserve, confirms the results of studies with other species of crocodilians (Gorzula, 1978; Montague, 1983; Jenkins and Forbes, 1985), and for the two species in Ecuador (Vallejo and Ron, 1994) and the Anavilhanas Archipelago in Central Amazonia (Da Silveira et al., 1997). However, in the Mamirauá Reserve, we also found a significant interaction between site and water level, indicating that, depending on local topography and the amount of habitat available to caiman in the wet and dry seasons, the effect of changes in water level has a different effect in the proportion of caimans seen in spotlight surveys.

The influence of illumination by the moon on counts of crocodilians has been much debated. Moon phase affected the number of *A. mississippiensis* seen in spotlight survey, with a greater number of alligators seen on nights with more moon light (Woodward and Marion, 1978). However, there was no relationship between moon phase and the number of *C. crocodilus* seen in spotlight surveys in Central Amazonia (Da Silveira et al., 1997), and there was little evidence for an effect of moon phase on the numbers of *C. crocodilus* seen in Mamirauá Reserve.

The number of *M. niger* detected in Lago Mamirauá was affected by moonlight. Lago Mamirauá is an extensive water body, and illumination from moonlight may increase social interactions of *M. niger*, inducing individuals to use more open water, making them more visible during spotlight surveys. Nevertheless, in other lakes, including some almost as large as Lago Mamirauá, there was no effect of moon phase on this species. These results indicate that the effect of the moon on the numbers of crocodilians seen during spotlight surveys is inconsistent and may be site specific.

Analyses of the factors that affect the number of crocodilians seen during spotlight surveys are usually made in a few water bodies, and the results are presented as though they can be extrapolated to other areas. Nevertheless, our regression models developed for Lago Mamirauá and Cano Mamirauá, which were based on much larger sample sizes than any previous study, were inadequate to estimate the number of caimans in 18 other water bodies. Therefore, generalizations about the effects of environmental variables on caiman surveys need to be made with caution.

The only variable consistently associated with the proportion of caimans seen is water level, and even this had poor predictive power if repeat surveys are not done at the same river level. Monitoring of caimans in Mamirauá Reserve and in other várzea habitats of the Brazilian Amazon could be undertaken by repeated monitoring of a fixed number of water bodies, or by random sampling of water bodies. In either case, it will be necessary to monitor a large number of water bodies of all types at a narrow range of water levels to have confidence in the results.

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