

The influence of the area of the *Serra da Mesa* Hydroelectric Plant, State of Goiás, on the frequency and diversity of anophelines (Diptera: Culicidae): a study on the effect of a reservoir

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ABSTRACT

Introduction: Bioecological aspects of anophelines (Diptera: Culicidae) near areas under the direct influence of the hydroelectric plant reservoir of *Serra da Mesa* in Goiás, Brazil, were analyzed. **Methods:** Samples were collected at the surrounding dam area during the phases before and after reservoir impoundment. The influence of climatic and environmental factors on the occurrence of *Anopheles darlingi*, *Anopheles albitarsis*, *Anopheles triannulatus*, *Anopheles oswaldoi* and *Anopheles evansae* was assessed using Pearson's correlations with indicators for richness and diversity as well as the index of species abundance (ISA) and the standardized index of species abundance (SISA). **Results:** The highest anopheline density occurred during the phase after filling the tank; however, no direct correlation with the climatic factors was observed during this stage. The reservoir formation determined the incidence of the anopheline species. *An. darlingi* was the predominant species (SISA = 1.00). **Conclusions:** The significant difference ($p < 0.05$) observed between the species incidence during the different reservoir phases demonstrates the environmental effect of the reservoir on anophelines.

Keywords: Anophelines. Hydroelectric plants. Environmental impact.

INTRODUCTION

With its especially diverse geographical setting of extensive forest regions and favorable rainfall patterns, Brazil is among the countries with the greatest renewable energy potential in the world. Currently, approximately 80% of all of the energy produced in Brazil is based on an electrical system fueled primarily by hydroelectric plants.

Despite generating energy from a naturally renewable source and being considered *clean energy* given that it does not contaminate or release toxic substances into nature, hydroelectric power plants have significant effects on the environment. These plants have been associated with the emergence and increase of various pathogens that are transmitted by mosquito vectors that infect humans and wild animals.

Essentially, the power generated by hydroelectric plants originates from the damming of rivers and the formation of large water reservoirs. These constructions cause environmental and

social effects related to the removal of riverine populations and the changes in the flow of the dammed river. These alterations interfere with the biological and social systems of the affected regions and, in some cases, can lead to the emergence or increase of disease⁽¹⁾.

The Serra da Mesa hydroelectric Power Plant [*Usina Hidrelétrica de Serra da Mesa* (UHSM)] and its associated reservoir is the largest in Brazil in terms of water volume, with 54.4 billion cubic meters; it is associated with a flooded area of 1,784km². The importance and extent of its construction resulted in a large influx of humans to the region, the emergence of new urban centers and significant wood and gold extraction. These actions resulted in the deforestation of large areas, not including to those already affected by the reservoir impoundment. In its entirety, the UHSM powers five major cities in Goiás: Minaçu, Campinorte, Uruaçu, Barro Alto and Niquelândia. Furthermore, this power plant has caused profound changes in the local natural habitat.

Studies of similar developments^{(1) (2) (3) (4) (5) (6)} have demonstrated a strong association between environmental changes (e.g., the formation of hydroelectric reservoirs) and the emergence of malaria (via the increased incidence of anopheline mosquitoes). Guimarães⁽⁷⁾ observed that environmental changes lead to changes in the degree of the incidence of malaria in regions endemic for this disease.

Thus, the present study evaluated the changes in the diversity and density of anopheline populations in the localities directly affected by the reservoir formation of the UHSM.

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METHODS

As described in detail by Guimarães⁽⁷⁾, anophelines were captured in the five municipalities under the direct influence of the UHSM reservoir, namely Minaçu, Campinorte, Uruaçu, Barro Alto and Niquelândia. The samples were collected every two months for five consecutive days at each sampling point over the three-year study period, which was composed of three impoundment phases. Phase I corresponded to the period prior to the start of the reservoir filling; these samples were considered as the control and standard for the incidence of anophelines in the region. Phase II corresponded to the period between the beginning of the filling of the reservoir until the beginning of plant operation. Finally, Phase III corresponded to the period after the start of plant operation.

Study area

To assess the effect of the reservoir in each municipality, five sampling points with different environmental settings were established. These settings ranged from the UHSM construction site to zones of new human population, mining camps and areas of mineral exploitation.

Area 1: the Municipality of Minaçu. This sampling point was located at the UHSM construction site between S 13° 49' 26.9" and W 48° 18' 56.5" on the east bank of the Tocantins River near the secondary dam (i.e., *Dyke II*), 5km from the major reservoir dam. The forest in this area is dense, with strong characteristics of cerrado or dense woodlands, trees of approximately 6m in height and canopies that occlude light penetration to the lower strata. These canopies enable the occurrence of a thicker layer of organic matter. The forest reaches the banks of the reservoir, forming shaded backwaters.

Area 2: the Municipality of Campinorte. This sampling point was located at S 14° 05' 38.5" and W 48° 59' 51.3" on the west bank of the Tocantins River in the areas of *Planeta Água* Farm, 18km from the secondary access in Jerusalem on highway BR-153. These samples were performed at the edge of a spring of a creek that flowed into the reservoir, where we observed fertile soils and vegetation typical of gallery forests that formed dense, predominantly arboreal vegetation. The humidity and water availability maintained the vegetation throughout the year, thereby providing an ecotope that did not suffer because of the drought period.

Area 3: the Municipality of Uruaçu. This sampling point was located at S 14° 32' 04.4" and W 49° 01' 07.8" on the east bank under the bridge of the Tocantins River, 14km from the entry point of the Uruaçu municipality near highway GO-237. The influx of people to this region was large, and many commercial fishing and leisure activities are associated with this reservoir. The vegetation includes shrubbery with a few trees above 3m in height. The understory consists of small shrubs and a soil covered by sparse patches of leaf litter. Because the vegetation does not directly reach the banks of the reservoir, extensive areas with clear signs of deforestation can be observed. During the dry season, the few shaded backwaters are exposed to sunlight, and the banks of the reservoir become arid.

Area 4: the Municipality of Barro Alto. This sampling point was located at S 14° 39' 47.9" and W 48° 57' 35.2" on the west bank of the Tocantins River amid areas of gold mining, 27km from the secondary access of the district of Placa and highway BR-080. This entire area has been severely altered because of gold mining activity. The humans in this region reside in poor living conditions such as huts without basic personal sanitation, the disposal of appliances and food, or both. The active transit of trucks needed to transport people, equipment and mining material heavily altered this geographic setting throughout the anopheline sampling. It remains possible to find woods near the mining areas with typical cerrado characteristics such as spaced trees and dominant shrubbery. The soil is low in organic matter, often sandy and exposed to sunlight. The Tocantins River forms at the site of the tranquil backwaters where the sparse vegetation maintains shaded banks.

Area 5: the Municipality of Niquelândia. This sampling point was located at S 14° 26' 51.0" and W 48° 57' 34.6" on the east bank of the Tocantins River in the area of *Córrego Dantas* Farm, 9km away from the secondary access of Vendinha on highway GO-237. Despite being the region most heavily affected by the UHSM reservoir, it remains possible to find patches of land with characteristics of the original cerrado, although without the cerrado formations present in the other localities. The entire region is located between the county centers of Uruaçu and Niquelândia, and it is formed by the large soybean farms as well as livestock breeding and settlement areas of small subsistence farming colonies. The human presence in this area is striking: Humans live in simple houses near the reservoir, with an everyday life closely linked to fishing. The vegetation is altered because of the deforestation due to agriculture and livestock. Nevertheless, it is possible to find more dense shrubs clusters and soil covered by grass next to the reservoir.

Data analysis

The index of species abundance (ISA) and the standardized index of species abundance (SISA) were used to analyze the data obtained from the collections based on the definitions of Robert and Hsi⁽⁸⁾. The ISA was calculated using the following formula:

$$ISA = \frac{(a \pm Rj)}{k}$$

Where k is the number of collections, a is the number of species not present in k multiplied by c , c is the highest position of the species in k plus 1, and Rj is the sum of the classifications of each species.

To standardize this index, it was converted to a scale between 0 and 1 using the SISA calculation: $SISA = \frac{(c - ISA)}{(c - 1)}$

A species was considered as the most abundant when the SISA was closest to its maximum of 1. The results provide information regarding the relative abundance of the species and the spatial distribution of the collected individual samples.

The relationship between the phases of the reservoir filling and the presence of anophelines was determined using the paired

t-test analysis (SYSTAT 8.0) between the species abundance of each phase. To establish an average, the values of each phase were converted to the Williams mean (X_w) as defined by Haddow⁽⁹⁾. To define the association between the collected anophelines and the climate data, Pearson's correlation analysis was used. The number of samples collected during each phase of the reservoir was used to establish the critical value of r . The climate data were obtained from the National Weather Service [Instituto Nacional de Meteorologia (INMET)].

The species diversity analysis for the study area was assessed using the Shannon-Wiener Diversity Index (H) and the Evenness Index (EH), which describe the parameters characteristic of the region. The H' evaluates diversity to compare communities with regard to biodiversity conservation and management to assess the effects of human disturbance and make environmental policy decisions. The EH' assesses how the species are distributed in a homogeneous manner based on the number of specimens collected during each period. The diversity indices were established during each reservoir stage using Past⁽¹⁰⁾.

RESULTS

A total of 5,395 anophelines were captured in the samples collected from the five municipalities near the UHSM reservoir.

These anophelines belonged to the species *Anopheles darlingi*, *Anopheles albitarsis*, *Anopheles triannulatus*, *Anopheles oswaldoi* and *Anopheles evansae*.

The abundance index analysis revealed that *An. darlingi* was the predominant species (SISA = 1.00) for all of the reservoir phases. The remaining species listed in **Table 1** maintained the same order of dominance, regardless of the filling period. The incidence calculations according to X_w showed that the most frequent species was *An. darlingi*, which presented the highest X_w frequency values during Phase I (50.3%), Phase II (56.3%) and Phase III (59.9%), followed by *An. albitarsis*, *An. triannulatus*, *An. oswaldoi* and *An. evansae* (**Table 2**).

However, the anopheline incidence analyses for each of the three studied reservoir phases revealed that Phase II (which began when the reservoir was filled to capacity) had the highest incidence of anophelines, with an X_w value of 518.7. This value represented an increase of nearly 15 times the total incidence of anophelines during Phase I ($X_w = 35$). This value corresponds to the control phase of the study because it does not reflect the influence of the reservoir. A decrease in the incidence of anophelines was observed during Phase III ($X_w = 37.2$), which approached the value of the control phase (**Table 2**). The comparative analysis of the abundance index indicated a significant difference ($p < 0.05$) among the phases of the reservoir, confirming its effect on anophelines (**Table 3**).

TABLE 1 - The abundance index converted to the SISA for anophelines captured at the UHSM in Goiás.

	ISA			SISA		
	Phase I	Phase II	Phase III	Phase I	Phase II	Phase III
<i>Anopheles darlingi</i>	1	1	1	1.00	1.00	1.00
<i>Anopheles albitarsis</i>	2	2	2.3	0.50	0.50	0.33
<i>Anopheles triannulatus</i>	3	3	3.8	0.33	0.33	0.07
<i>Anopheles oswaldoi</i>	-	5.4	4.9	-	0.12	0.03
<i>Anopheles evansae</i>	-	6	-	-	0.00	-

UHSM :Usina Hidrelétrica de Serra da Mesa; ISA: index of species abundance; SISA: standardized index of species abundance.

TABLE 2 - The number and X_w values for the anophelines captured over the three reservoir phases of the UHSM in Goiás.

Species	Phase I			Phase II			Phase III		
	N	X_w	$X_w\%$	N	X_w	$X_w\%$	N	X_w	$X_w\%$
<i>An. darlingi</i>	58	17.60	50.3	2,696	292.00	56.3	552	22.30	59.9
<i>An. albitarsis</i>	52	15.43	44.0	1,516	212.37	40.9	346	13.45	36.1
<i>An. triannulatus</i>	6	2.00	5.7	100	10.88	2.1	34	1.23	3.3
<i>An. oswaldoi</i>	0	0.00	0.0	20	2.14	0.4	4	0.26	0.7
<i>An. evansae</i>	0	0.00	0.0	11	1.31	0.3	0	0.00	0.0
Total	116	35.03	100.0	4,343	518.70	100.0	936	37.24	100.0

UHSM :Usina Hidrelétrica de Serra da Mesa; N: number; X_w : values of *Anopheles*. **Phase I**: before the reservoir formation; **Phase II**: during the reservoir formation; **Phase III**: plant operation. *An.*: *Anopheles*.

TABLE 3 - The species frequency, compared using paired *t*-tests, before and after the reservoir of the UHSM in Goiás.

Species	Phase I		Phase II		p-value
	X	95% CIs	X	95% CIs	
<i>An. darlingi</i>	3.87	1.45 to 6.29	88.52	60.06 to 116.97	0.0001
<i>An. albitarsis</i>	3.47	0.42 to 6.51	49.77	31.05 to 68.50	0.0006
<i>An. triannulatus</i>	0.40	-0.05 to 0.86	3.23	1.66 to 5.57	0.0075
<i>An. oswaldoi</i>	0	-	0.65	0.25 to 1.04	0.0132
<i>An. evansae</i>	0	-	0.35	0.08 to 0.63	0.0386

UHSM: Usina Hidrelétrica de Serra da Mesa; X: absolute average; *An.*: *Anopheles*.

The fluctuation in the abundance of anophelines was directly related to the climatic factors of the absent reservoir during Phase I. During this phase, increases in air humidity, temperature and, principally, the pluviometric indices were associated with the increased number of specimens collected. During the formation of the reservoir (Phase II), a weak correlation with abundance was observed, especially with regard to the pluviometric indices that presented a nearly non-existent correlation. However, the rain returned to influence Phase III, showing a strong correlation with anopheline abundance (Table 4).

The H' analysis did not reveal significant differences between the anopheline collections performed over the three reservoir phases (H' = 0.86, H' = 0.79 and H' = 0.82). Thus, despite the increase in the incidence of anophelines from Xw = 35 to Xw = 518.7, which was directly related to the reservoir filling, the diversity index of this genus remained unchanged in the presence of the reservoir. However, the equitability index showed a small decrease during the second phase (E'H = 0.44) compared with the control phase (E'H = 0.79). Although Phase II showed the greatest species richness (5 species) and incidence (Xw = 518.7), it also showed a lower homogeneity in the distribution of the individuals among the species (Table 5). This result reflects the strong dominance of *An. darlingi*, which represented over 50% of all specimens captured, thereby influencing the homogeneity of the distribution.

DISCUSSION

Invariably, the natural habitat near hydroelectric project areas is seriously altered with the formation of the water reservoir that is responsible for power generation. Studies of the population densities of anophelines throughout the process of filling reservoirs have established the variables involved in the interaction of these mosquitoes and their new environmental structure. The adaptive dynamic of anophelines has been observed since the first changes caused by the deforestation in this area and the initiation of the reservoir formation.

We found that the abundance index was determined by the quantity of the specimens and the manner in which they were distributed throughout the samples. The effect of the reservoir did not influence the species dominance (i.e., all species were proportionally affected). Paula⁽¹¹⁾ reported similar results regarding the dominance of mosquitoes in hydroelectric project areas.

In the samples collected before the start of the reservoir formation during Phase I, the population of *An. darlingi* showed a low frequency of approximately 1.8% of the total species collected throughout the study (n=3,306), in contrast to the 81.5% observed during Phase II when the reservoir was filled

TABLE 4 - The linear correlation coefficient (r) between the abundance of anophelines collected over the three filling phases of the UHSM in Goiás by temperature (°C), relative humidity (%) and precipitation (mm).

Reservoir phase	Phase I			Phase II			Phase III		
	$r_{0,05(2)15} = 0.52$			$r_{0,05(2)30} = 0.38$			$r_{0,05(2)45} = 0.29$		
Species	mm	°C	%	mm	°C	%	mm	°C	%
<i>An. darlingi</i>	0.92	0.65	0.27	0.04	0.57	0.29	0.74	0.05	0.45
<i>An. albitarsis</i>	0.97	0.66	0.59	0.04	0.39	0.35	0.67	0.02	0.42
<i>An. triannulatus</i>	0.87	0.68	0.60	0.17	0.66	0.33	0.66	0.13	0.36
<i>An. oswaldoi</i>	-	-	-	0.32	0.68	0.34	0.79	0.14	0.28
<i>An. evansae</i>	-	-	-	0.04	0.73	0.52	-	-	-
Total	0.94	0.53	0.59	0.04	0.51	0.31	0.72	0.04	0.44

UHSM: Usina Hidrelétrica de Serra da Mesa; *An.*: *Anophales*.

TABLE 5 - The diversity index over the reservoir phases of the UHSM in Goiás.

	Phase I	Phase II	Phase III
Number of species (<i>S</i>)	3	5	4
Number of specimens (<i>N</i>)	116	4,343	936
Shannon (<i>H'</i>)	0.86	0.79	0.84
Evenness ($E=e^{H'/S}$)	0.79	0.44	0.58
Total X_w	35.03	518.70	37.24

UHSM: Usina Hidrelétrica de Serra da Mesa; X_w : values of *Anopheles*.

to its maximum capacity. These figures clearly demonstrate the great capacity for adaption within this species and how the effects of waterlogging favorably influenced the occurrence of *An. darlingi* in an area where a large hydroelectric project was installed. Because *An. darlingi* is the primary malaria vector in Brazil⁽¹²⁾, its direct relationship with reservoir formation requires continuous monitoring; moreover, the risk of disease occurrence in these areas should be constantly reassessed⁽⁷⁾.

Studies conducted near the Itaipu Hydroelectric Plant⁽¹⁾ demonstrated that reservoir formation was responsible for the favorable breeding conditions of *An. darlingi* and *An. albitarsis*. These authors have reported the occurrence of thousands of new cases of malaria in locations where this disease was thought to be eradicated approximately 30 years ago due to the reintroduction of anophelines and the migration of workers from other areas of Brazil with high rates of malaria. Importantly, however, the present study (unlike Guimarães⁽¹⁾) did not find that these anophelines had a constant population density throughout the year. In the case of the UHSM during Phase III (i.e., immediately after the start of the plant operation), we found a significant reduction in the incidence of anophelines. This finding might be related to two concurrent events: the low rainfall across almost all of Brazil caused by El Niño and the resulting need for the UHSM to function at full power generation capacity to compensate for the energy deficiencies at other hydroelectric plants most affected by the prolonged drought. The combination of these events led to a significant decrease in the volume of water in the tank, reaching the maximum negative index of 12 meters and exposing the banks of the reservoir to direct sunlight. This event prevented the posture and development of immature forms of anophelines and drastically reduced the incidence of these species. This reduction in the anopheline population consequently reduced the incidence of malaria in a manner proportional to the abundance of anophelines⁽⁷⁾.

During the first stage of the studies that occurred before filling the reservoir in Phase I, we observed a significant relationship between the occurrence of anophelines and particular regional climate characteristics. Similar studies⁽¹³⁾⁽¹⁴⁾ have reported that rainfall primarily controls the availability of breeding sites and the abundance of mosquitoes. However, the early formation of the reservoir during Phase II resulted in the flooding of vast areas of forest and the presence of decaying vegetation around the reservoir, which significantly favored *An. darlingi* because this

species preferentially uses these environments for egg laying and the breeding of its larvae. This result demonstrates that climatic factors had a secondary influence on the result of this study⁽⁶⁾⁽⁷⁾⁽¹⁵⁾⁽¹⁶⁾. *An. darlingi* was the most frequent anopheline, and its high incidence, the reservoir stability and the arrival of miners were responsible for the malaria cases diagnosed in the region⁽⁷⁾.

The Shannon-Wiener Diversity Index did not show significant differences between the collections performed across the three reservoir phases, which indicates that the diversity index remained constant, regardless of the level of the reservoir, despite the significant increase in the incidence of anophelines directly related to the reservoir filling. A similar phenomenon was observed for *An. darlingi* in other areas influenced by the hydroelectric projects on the border of São Paulo and Mato Grosso do Sul during the periods before and after the reservoir formation⁽⁶⁾.

The equitability index showed a small decrease during Phase II compared with Phase I. Thus, although species richness and species incidence were highest during Phase II, it was also the least homogeneous with regard to the distribution of individuals. This reduction was because of the high percentage of *An. darlingi* and *An. albitarsis* specimens collected (97%). The other three species composed the remaining 3%, causing the equitability index to be lower during this period.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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