

# SWS Research Brief

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## Marshes, Mosquitoes, and Malaria .....and what about Nutrients?



### Background

Most people are aware of the connection between malaria and wetlands, which provide habitats for mosquito that carry disease-causing parasites. But how do nutrients fit into this scheme? Malaria is one of the vector-borne diseases impacted by ecological changes. Its incidence has recently increased in many parts of the tropics due not only to drug resistance and failure of control measures, but also to changes in vector (mosquito) and host (human) ecology. These ecological changes often result from increased nutrient input into the environment.

Presence and abundance of mosquito larvae in aquatic habitats and consequently the number of adults capable of malaria transmission are regulated by a variety of environmental factors operating at several organizational levels and spatial/temporal scales. Presence of water, food source, and refuge are the key variables. Aquatic plants provide protection from predators, while fringing trees and shrubs contribute detritus that supports a bacterial community, which, in turn, serves as food for larvae. A change in any component in this complex structure may have a substantial impact on the mosquito population and can lead to a replacement of one species with another. Since not all mosquito species are equally efficient in transmitting malaria, replacement of a less efficient vector with a more efficient one would have serious negative consequences.

Our study site, located in northern Belize, is one of the least environmentally impacted countries in Central America, yet it is experiencing increasing deforestation, coupled with intensified production of

existing crops, specifically sugar cane. These environmental changes have a strong potential to affect malaria vector populations. Of the two malaria vectors present in the region, *Anopheles albimanus* is a less efficient vector, and is mainly associated with shallow marshes dominated by sparse spikerush (*Eleocharis*), while larvae of the more efficient *An. vestitipennis* generally occur in marshes



**Figure 1. Larval habitats of mosquito species, *Anopheles albimanus* (A) and *An. vestitipennis* (B).**

dominated by tall dense cattail (*Typha*) (Fig.1). The most conspicuous characteristic of spikerush marshes is their limitation by phosphorus (P). When P input increases, tall dense cattails usually outcompete spikerush.

Nutrient enrichment (particularly P) of wetlands from agricultural run-off poses a significant environmental impact relevant to malaria transmission in Belize.

### Study Goal

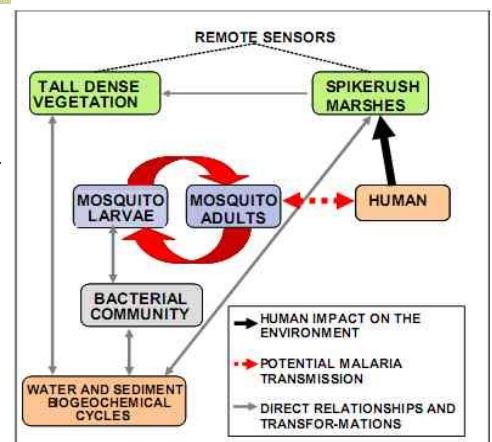
Based on the above scenario and Fig. 2 we formulated the following hypotheses:

**H1:** Phosphorus-enriched runoff from agricultural lands (pasture, sugarcane, and other crops) and human settlements causes an expansion of tall dense vegetation such as cattails.

**H2:** Marshes with tall dense vegetation provide more productive habitat for *An. vestitipennis* than for *An. albimanus*.

To test these hypotheses we addressed the following specific objectives:

- (1) Determine spatial relationships between land use and marsh type using satellite imagery.
- (2) Record the preference of each mosquito species for a particular type of habitat based on habitat nutrient dynamics.
- (3) Conduct larval growth/survival and egg-laying (oviposition) experiments to explain mosquito habitat selection.
- (4) Examine the effects of spatial distributions of larval habitats on movement of adult mosquitoes to human settlements.



**Figure 2. The conceptual scheme of the connection between human-induced environmental change (increased P input), mosquito larval habitats, and malaria transmission.**

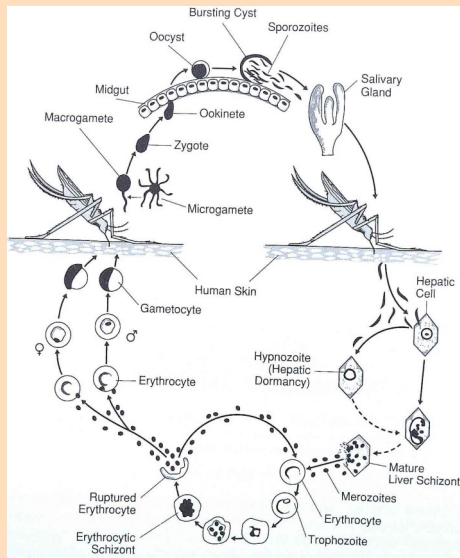
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# “CAN CHANGES IN WETLAND PLANT COMMUNITY LEAD TO CHANGES IN MALARIA TRANSMISSION?”

## Malaria Cycle

*Malaria in humans is caused by four species of protozoan parasite of the genus Plasmodium and is transmitted by female mosquitoes from the genus Anopheles. Of the approximately 430 known species of Anopheles, only 30-50 transmit malaria in nature.*

*Both the parasite and the vector have complex life cycles. The parasite requires both human and a mosquito to complete its development.*



The life cycle of the malaria parasite (adapted from Oaks et al. 1991)

*A female mosquito takes a blood meal to carry out egg production. This feeding process is the link between the human and the mosquito host in the parasite life cycle. The female then lays eggs in the aquatic environment. The mosquito goes through four stages: egg, larva, pupa and adult. After hatching, anopheline larvae lie and feed along the water-air interface, molt four times, pupate and emerge as adults.*

*When studying ecology of malaria transmission we have to consider the ecology of a parasite as well as the ecology of the vector and human host.*

## Study Area

Belize is a malaria endemic Central American country populated with approximately 230,000 people in a geographic area of 22,963 km<sup>2</sup>. Slightly less than half of the country is low-lying coastal plain; the rest is hilly and mountainous. The lowlands consist of a variety of relatively undisturbed wetlands including extensive herba-ceous marshes.



Until the mid-19<sup>th</sup> century, agriculture in Belize was insignificant. Sugar cane cultivation was established in the 1850's but most of its development, preceded by extensive deforestation, has occurred during the last 30 years. Sugar cane has become the most important cash crop in northern Belize with some 30,000 hectares cultivated in 1987. Areas under sugar cane cultivation are spreading into more and more marginal soils, which in turn requires increased doses of fertilizers. The often inefficient application of fertilizers results in substantial losses through runoff after heavy rains.

## Methods

To document the plant and subsequent mosquito community change we employed multiple approaches. Using detailed maps of the study area based on satellite imagery and incorporated in a Geographic Information System (GIS) database, we determined the spatial relationships between marsh type and land use. We then executed a

sampling program analyzing sediment and plant tissue to determine spatial patterns of phosphorus loading in and around marshes (Fig 3). The larval sampling was conducted to correspond with the early wet (August-September), late wet (October-November), early dry (February-March) and late dry (May-June) seasons. At each sampling location we collected anopheline larvae and recorded the preference of each mosquito species for a particular type of habitat. A long term field manipulative experiment following changes in ecosystem processes and community structure upon nutrient additions is still in progress, but it has already shown a strong response of vegetation to P enrichment. In order to explain mosquito habitat selection, we conducted field larval growth and survival experiments, as well as laboratory egg-laying (oviposition) experiments (Fig. 3). The effects of spatial distributions of larval habitats on movement of adult malaria vectors to human settlements was assessed in a series of mark recapture experiments.



**Figure 3. Collecting mosquito larvae in a marsh (A); The reciprocal transplant experiment – larvae of each species were placed in individual containers in each other's habitat, and growth and mortality checked daily (B). Sampling adult mosquitoes in an experimental hut (C).**

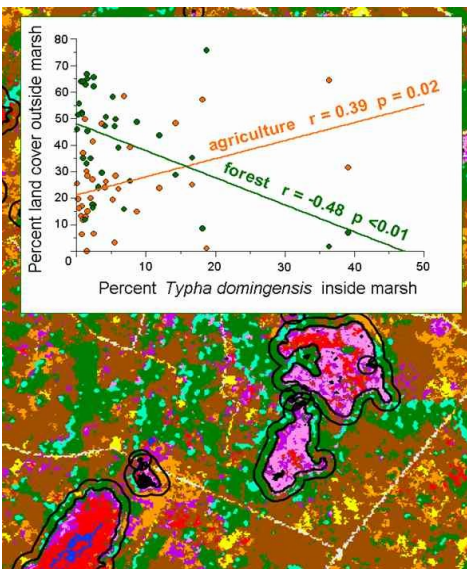
# “Two processes lead to changes in abundance of malaria vectors :

- 1) Nutrient-mediated change in wetland plant communities and
- 2) Habitat selection by female mosquitoes.”



## Findings

Analysis of the land cover using Geographic Information System demonstrated that the amount of cattail (red) in a marsh is positively correlated with the amount of agricultural land (brown) in the upland area, and negatively correlated with the amount of adjacent forest (green) (Fig. 4, inset).



**Fig. 4.** Land cover map of marshes (pink, purple, red), forest (green), and agricultural areas (orange, yellow, brown) created from remote sensing images. Buffer zones (indicated in black) were created around the marshes using the GIS.

Habitat analysis indicated that total soil P was higher in impacted marshes than in non impacted marshes. Phosphorus was positively correlated with the density of cattail.

Analysis of larval data showed that *An. albimanus* was negatively correlated with cattail density, but positively correlated with sparse spikerush interspersed with cyanobacterial mats (CBM). *Anopheles vestitipennis* was found to be positively associated with percent cover of cattail.

These results suggest that impacted marshes exhibit higher P levels and that these high P levels are conducive for the growth of cattails, resulting in more favored habitat of a more efficient malaria vector *An. vestitipennis*.

Egg-laying experiments showed that, given the choice, mosquito females preferentially laid their eggs in materials extracted from the larval habitats of their own species.

Field larval survival studies confirmed that larvae of individual species performed best in their “home” habitats. Only 10% of *An. vestitipennis* survived in the habitat of *An. albimanus*, compared to 83.5% survival in its own habitat (Table 1). The difference

was smaller for *An. albimanus* whose larvae survived well in both habitats although the survival was higher in cyanobacterial mats.

## Significance

Our study showed that changes in vegetation caused by increases in nutrients from agricultural practices, lead to replacement of one mosquito species by another. The human-induced changes in wetland habitats, combined with habitat selection by mosquito females, can lead to the replacement of a less efficient vector of malaria by a more efficient one.

With mounting evidence of increased vector potential of *An. vestitipennis*, efforts must be placed on quantifying the relative changes in malaria risk with nutrient-induced shifts in malaria vectors. If malaria risk increases with these changes, then control efforts should be focused on minimizing nutrient input in spikerush marshes. Reducing favorable larval habitats could greatly reduce the mosquito population and result in decreased disease risk.

**Table 1** Survivorship of *Anopheles* mosquito larvae in cyanobacterial mats (CBM) – a home habitat of *An. albimanus*, and tall dense cattails (TDC) – a home habitat of *An. vestitipennis*; n = number of replicates.

| HABITAT TYPE             | n   | SURVIVING % |
|--------------------------|-----|-------------|
| <b>CBM</b>               |     |             |
| <i>An. albimanus</i>     | 600 | 81.5        |
| <i>An. vestitipennis</i> | 600 | 10.0        |
| <b>TDC</b>               |     |             |
| <i>An. albimanus</i>     | 480 | 78.1        |
| <i>An. vestitipennis</i> | 480 | 83.5        |



## Additional Information

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