Journal of the American Mosquito Control Association, 16(1):19–21, 2000

CONTROL OF ACIDIC DRAIN-WATER–BREEDING MOSQUITOES IN NEW SOUTH WALES, AUSTRALIA, BY INSTALLING CONTROLLED LEAKAGE HOLES IN TIDAL FLAP GATES

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ABSTRACT. Effects on mosquito breeding, acidity, and fish presence were assessed after installation of a small tidal leakage port into an acidic drain's tidal exclusion flap gate. Before gate modification the drain water had pH values as low as 2.7. These water conditions were toxic to fish and continually held mosquito larvae. At 4 wk after gate modification, water pH had risen to 6.0, at least 3 fish species inhabited the drain, and mosquito larval numbers had been reduced by 99.98%.

KEY WORDS Acid sulphate, mosquito control, environmental management

INTRODUCTION

Millions of hectares of Holocene-age wetlands, lowlands, and swamps throughout the world are underlain by sulfidic sediments that contain iron sulfide minerals (Dent 1986). During the development of these sediments, under anaerobic conditions in organically rich waterlogged soils, sulfate in seawater was reduced by bacteria to iron sulfide (Pons et al. 1982).

Water bodies carrying high levels of sulfuric acid, released by iron sulfide oxidation, may mobilize aluminum, iron, and other ions from soil minerals that are highly toxic to fish (Sammut et al. 1995). These acidic waters may also provide highly productive mosquito breeding areas devoid of fish and other predators (Soukop and Portnoy 1986).

Large areas of eastern Australia's coastal lowlands are underlain by sulfidic sediments, which when drained for agriculture, aquaculture, or urban uses, often oxidize to form acid sulfate soils, producing highly acidic discharges. These discharges have significant impacts on estuarine ecosystems (Willett et al. 1993, Sammut et al. 1995, White et al. 1997). The New South Wales (NSW) Soil Conservation Service has mapped a probable 660,000 ha of coastal sulfidic sediments in this state alone (Naylor et al. 1995).

Extensive flooding after 500 mm of rain occurred in March 1987 throughout the Tweed Valley in northern NSW, Australia. This flood was preceded by a long period of below-average rainfall associated with an El Niño weather pattern. After the flood, a large discharge of acidic water flowed into the Tweed River from drained lowlands and sugar cane farms, causing a massive kill of fish, crabs, worms, and shellfish over a 23-km stretch of the river. The only visibly unaffected aquatic fauna were large numbers of mosquito larvae flushed into the river from the extensive lowlands and associated drains (Easton 1989).

Since the 1987 fish kill, Tweed Shire Council staff have monitored acidity levels (pH) throughout Tweed River tributaries and drainage systems. During these surveys, large numbers of drains, which were separated from the river by flap gates to exclude floodwaters and high tides, had high acidity levels (pH < 4). Many of these acidic drains were also found to be year-round immature mosquito habitats for large numbers of the nuisance brackish water mosquito *Culex sitiens* Weidemann. After heavy rain, the drains also contained the salt marsh mosquito *Aedes vigilax* (Skuse). Without fish predators, both mosquito species thrived in the acidic conditions. By contrast, drains that had poor-sealing flap gates, which allowed moderate leakage of river water into these drains had much higher water pH, supported fish populations, and had less mosquito breeding.

Consequently, the following study investigated the effects of a controlled leak in a tidal-water exclusion flap gate as a potential means for reducing drain water acidity and controlling mosquito numbers by making the water quality suitable for larvivorous fish.

MATERIALS AND METHODS

Study area: This study was performed adjacent to a tributary of the Tweed River at Tumbulgum (28°21′S, 153°23′E), approximately 20 km upstream of the Tweed River mouth, near the NSW border with Queensland. The Tweed Valley experiences a humid, subtropical climate with an average annual rainfall of 1,700 mm, with parts of the upper catchment receiving more than 3,000 mm, most of which falls during the summer to autumn period (December to April). Daily temperatures are warm to hot (25–35°C) in summer and warm to mild (25–20°C) in winter. Cyclonic disturbances in the area often produce intense rainfalls, with 24-h recordings above 250 mm not uncommon. The valley is situated in a large volcanic caldera and after heavy rainfall is prone to short-duration river rises and lowland flooding. Most of the valley floodplain and lowlands have been previously drained for agriculture. An extensive system of flap gates, which open at low tide and close during incoming tides, keeps brackish river water off these lands and facilitates floodplain drainage. Mosquito breeding in the study area usually peaks in March and may extend through winter in suitable seasons.

Study site: The study site was a man-made drain flowing from a small, 3-hole private golf course that had been developed on lowlands. The golf course was bordered by a mangrove-lined tributary of the Tweed River, sugarcane fields, and riparian rainforest. The property was impounded in 1988 with a clay levee bank to keep tidal water and floodwater off the property. Rainwater runoff from the property drains into a 200-m-long × 3-m-wide drain, which averages ca. 1.2 m in depth. The drain holds ca. 600,000 liters of water at low tide, and empties into the river through a 700-mm pipe. The outlet pipe has a fibrous cement tidal flap gate, hinged on the pipe outlet to exclude tidal river water from the property. The river has a tidal range of approximately 1 m at the study site. Salinity in the adjacent river varies widely, ranging from <1 g/liter after rain to that of the adjacent ocean (33 g/liter) during dry periods. The acid-neutralizing capacity of these waters varies from negligible to approximately 2 mole/m^3, that of seawater. After flooding, acid water flows directly into the drain from oxidized drain spoil. The spoil has been used to form levees, and heavy rain causes the water table to rise through these acid sulfate soils.

In May 1991, a 60-mm-diameter hole was cut through the flap gate slightly above the average low tide mark. This hole was estimated to supply an attenuated flow of river water back into the drain, without flooding the property during spring tide periods or rain-induced rises in river level. Throughout 1991 and 1992 routine monitoring of larval mosquito numbers and pH was conducted before and after gate modification.

Mosquitoes: Three sites along the length of the drain were selected for monthly counts of larval mosquito numbers. Sampling after gate modification was carried out during the last week of each month and within 2 h of low tide. The 1st site was located next to the exclusion gate, the 2nd was midway along the length of the drain, and the 3rd was at the distal end of the drain. A 250-ml dipper was used to take 10 samples from each site. To assess seasonal mosquito activity, 3 adjacent ponds were also sampled monthly for mosquito larvae. These ponds were excavated to provide levee material around the property at the same time the above drain was created.

Fish: Monthly qualitative observations on the presence or absence of fish were made at the same time as mosquitoes were sampled.

pH: Acidity readings of the drain's surface water (0–200 mm) were taken twice at site 1 and site 3 during the 1st month after introduction of the drainage port. Monthly readings were then collected at 50 m from the drain's exit point using a pH meter (Kane-May 7000, London, United Kingdom).

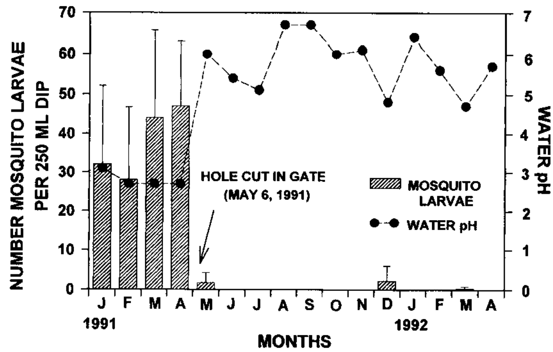

Fig. 1. Pre– and post–gate-modification mean (±SD) mosquito larval numbers and drain water pH.

Statistical methods: In order to homogenize variances, a log10 transformation was completed on all raw mosquito sampling data. A Kruskal–Wallis 1-way analysis of variance on ranks method was then used to determine if summer (January–April) pre– and post–gate-modification mosquito larval numbers were significantly different. A paired *t*-test was then used to determine if pre– and post–gate-modification water pH levels were also significantly different.

RESULTS

As a consequence of the gate modification, partial tidal action flushed the study site, twice per day. This flushing action was apparent within the 1st month of floodgate modification. During normal tides it was estimated that ca. 28,000 liters of river water was flushed into the drain. During spring tide periods, ca. 42,000 liters of water was exchanged.

Mosquitoes

A significant (H = 19.6, df = 5, $P < 0.0015$) reduction in larval mosquito numbers occurred within 1 month of the floodgate modification. For the period January to April 1991, before gate modification, an average of 38 (±19) mosquito larvae were collected per 250-ml dip. After gate modification, an average of 1 (±3) mosquito larvae were collected for the same period in 1992 (Fig. 1). Although it was towards the end of the mosquito season, temperatures (average maximum >23°C) remained warm enough through the 1st 2 months after drain modification to support mosquito breeding in adjacent excavated acidic ponds where levee building material had been excavated. During this time, mosquito breeding in the adjacent ponds exceeded an average of 10 larvae per 250-ml dip. Mosquito breeding in the adjacent ponds abated to <3 per dip during July and August, rising again to average >10 per dip in September 1991 and continued at >10 per dip through to the end of the study period in April 1992. Low larval numbers were found on several occasions over the next year in the upper part of the drain. In this upper section, larval *Ae. vigilax* had been washed into the drain from adjacent areas after heavy rain.

Fish

No fish were observed in the drain before modification. Acidity and extremely high dissolved aluminum levels (30 mg/liter) in the drain would have been lethal to fish (Driscoll et al. 1980). Within 18 days of modification, fish were present in 65% of the drain. The exotic mosquito fish (*Gambusia affinis* (Baird and Girard)) and an unidentified species of gudgeon (*Hypseleotris* sp.) were found throughout the drain, in water with a pH > 4.5. The Pacific blue-eye (*Pseudomugil signifer* Kner) was found where pH > 5.4. These 3 species were observed actively feeding on mosquito larvae. By 1 month after gate modification, schools of fish were observed throughout the drain.

pH

The controlled leakage hole significantly ($t = -7.60$, df $= 6$, $P < 0.0003$) increased drain water pH. By 18 days after gate modification, the drain water pH near the exit gate had risen from 2.7 to 6.0. Water pH in the upper reach of the drain had risen from 2.7 to 3.7. By 4 wk, 70% of the drain water pH was >6.0. The monthly pH readings taken 50 m from the drain's exit point remained well above the premodified state (Fig. 1). Temporary depressions in drain water pH followed heavy rainfall on October 10, 1991 (188 mm), December 12, 1991 (280 mm), and March 17, 1992 (200 mm). Acidification also occurred in the main river at these times but did not cause observable fish kills (Easton, unpublished data).

DISCUSSION

The introduction of a small drainage port to allow limited tidal flushing into an acidic drain seemed to be sufficient to control drain water acidity and mosquito breeding and create a habitable area for larvivorous fish within 4 wk. Although heavy rain during the study caused acidic runoff and temporary depressions in drain water pH, buffering and dilution from the adjacent river quickly reduced acute acidity. Since this study, many other acidic drains in the area have been manipulated to provide limited tidal flushing to control mosquitoes, reduce drain water acidity, and increase fish habitat. Some of these drains are several kilometers long. The same rapid environmental benefits shown in this study have been apparent at these other sites. Nevertheless, it is important to ensure that in carrying out such flap gate modifications, sufficient tidal attenuation is maintained so that reflooding of the flood plain surface does not occur. Otherwise much larger quantities of acidity will be accessed on each high tide, and the acid-neutralizing capacity of the drain system will be exceeded.

ACKNOWLEDGMENTS

We wish to thank K. Saito for allowing this study to be carried out on his property and the Condong Sugar Mill for meteorologic data. Michael Brown (Queensland Institute of Medical Research) reviewed this manuscript.

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