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POSSIBILE *CULEX PIPIENS PALLENS* CONTROL BY IMPROVEMENT OF FLOW RATES IN WATER CHANNELS OF SAGA CITY, SOUTHWEST JAPAN

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ABSTRACT. Water levels and flow rates (no. censuses with flow/no. censuses per year) were analyzed for 208 mosquito-productive and 422 mosquito-free channel segments during 1986–88 in Saga City, southwest Japan. Mean water levels tended to be higher at mosquito-free segments than at mosquito-productive segments, but the differences were <5 cm and usually not significant. Flow rates exceeded 80% at 60–67% of mosquito-free segments. In contrast, flow rates were <20% at 49–62% of mosquito-productive segments. Expected flow speeds at cement-lined segments exceeded 20 cm/sec (a flow speed required for mosquito control) for water levels of >15 cm. Most mosquito-productive segments had mean water levels of >15 cm, indicating that water stagnancy at those segments was due not to low water levels but to their structure. Engineering is necessary to yield flow speeds high enough to prevent mosquito breeding at mosquito-productive segments. Alternatively, engineering to prevent wastewater discharge into open channels may improve water quality, leading to mosquito suppression through colonization of larvivorous predators.

INTRODUCTION

Two preceding reports on *Culex pipiens pallens* Coquillett in the water channel network in Saga City, southwest Japan, revealed that mosquito breeding is suppressed in channel segments with water flow and that a flow speed of 20 cm/sec can be a criterion for mosquito control as well as for preventing accumulation of sediment (Mogi et al. 1995, Mogi and Sota 1996). However, it was observed that mosquito larvae in some highly mosquito-productive segments were not flushed out at temporary floods caused by heavy rains (Mogi and Sota 1996). Mosquito-productive segments tend to persist over years (Mogi et al. 1995) and successful suppression of mosquito breeding at such sites is of vital importance for mosquito control success in Saga City.

Because species of the *Culex pipiens* complex are a dominant mosquito in urban drains worldwide, their control is an important subject under the continuing urban expansion, especially in tropical areas. For control of urban drain mosquitoes, environmental management measures, such as velocity alteration or cleaning of open drains, are expected to provide a more permanent solution than repeated treatment with expensive insecticides (World Health Organization 1988). Development of insecticide resistance and increasing public concern about insecticides as environment pollutants further require mosquito control by methods other than the use of insecticides. However, the possibility of solving urban mosquito problems by water management has not been explored extensively. Feasibility of water management as a countermeasure against urban mosquitoes partly depends on whether specific engineering is required for effective control. This report examines whether the critical flow speed of 20 cm/sec can be attained without additional engineering in channel segments in Saga City, southwest Japan.

MATERIALS AND METHODS

Study area: Saga City is located on the central part of a rice production area developed on an alluvial plain in north Kyushu, Japan. It has a warm climate with hot summers and rain throughout the year. One of the features of this city is the water channel network distributed over the city. Further descriptions of the area and its channel network are in Mogi et al. (1995), with additional information about physical and biological attributes of channel segments in Mogi and Sota (1996).

Census: Weekly immature mosquito censuses in Saga City from 1986 through 1988 were described in Mogi et al. (1995). Channel segments selected for the present analysis are those where mosquito immatures were confirmed throughout 3 years (mosquito-productive) and those where mosquito immatures were never confirmed (mosquito-free). Only segments of 1–3-m widths were considered, because channel segments of this size comprised >50% of all the segments and were utilized by mosquito immatures most extensively (Mogi et al. 1995). The number of mosquito-productive segments selected was 208 and that of mosquito-free ones was 422. Of 208 mosquito-productive segments, 70 (33.7%) were of 1 m width, 95 (45.7%) were of >1–2 m width, and 43 (20.7%) were of >2–3 m width. Weekly records of water levels at all of those segments were the bases for the analysis.

Calculation of flow speed: Expected mean flow

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speeds, V (m/sec), were calculated by using Manning's formula,

$$V = (R^{2/3} \times S^{1/2})/n,$$

where R = hydraulic radius (= cross-sectional area of water prism divided by length of wetted perimeter in m), S = hydraulic gradient, and n = coefficient of roughness, which depends on the lining conditions (World Health Organization 1982). Because crosssections of channel segments in Saga City are rectangular, R values could be calculated from channel widths and water levels. For the mean hydraulic gradient of the Saga City territory, 0.0002 was adopted (Koga et al. 1990). Most segments are lined with cement but some were unlined with emergent and/or submerged plants. Thus, the coefficient of roughness for average finished cement linings (0.015) and that for earth channels with considerable aquatic weed growth (0.030–0.035) were used. Given S and n values, V at segments with the same width depends on water levels: the higher the water level, the higher the flow speed.

RESULTS

Water levels approximately doubled during a short period in early June and were kept high throughout the mosquito breeding season. The high water level period (June–September) coincided with the period of rice field irrigation. Water levels at mosquito-free segments tended to be higher than those at mosquito-productive segments irrespective of season and year. However, the difference was <5 cm, usually with 95% confidence intervals overlapping. Mean water levels at mosquito-productive segments are shown in Fig. 2 by year and channel width.

Despite the similar water levels, flow rates (number of weeks when water flow was observed divided by the yearly total number of census weeks) markedly differed between mosquito-productive and mosquito-free segments. Flow rates exceeded 80% at 60 (1986), 63 (1987), and 67% (1988) of mosquito-free segments (Fig. 1). Water flow was confirmed throughout the year (flow rate = 100%) for 25 (1986), 39 (1987), and 59% (1988) of mosquito-free segments. In contrast, flow rates were <20% at 55 (1986), 62 (1987), and 49% (1988) of mosquito-productive segments. Water flow was not observed throughout the year (flow rate = 0%) for 39 (1986), 41 (1987), and 32% (1988) of mosquito-productive segments.

Mosquito-productive segments with greater widths included proportionally more segments with higher water levels (Fig. 2). For segments of >2 m, 51 (1986, 1988) and 63% (1987) had yearly mean water levels of >26 cm and almost none had water levels of ≤10 cm. For segments of 1 m, only 10 (1986, 1988) and 11% (1987) had mean water levels of >26 cm, whereas 39 (1986), 27 (1987), and 36% (1988) had water levels of ≤10 cm. Thus, the overall mean water level for segments of >2 m width was approximately twice that for segments of 1 m width (27–29 vs. 14–15 cm).

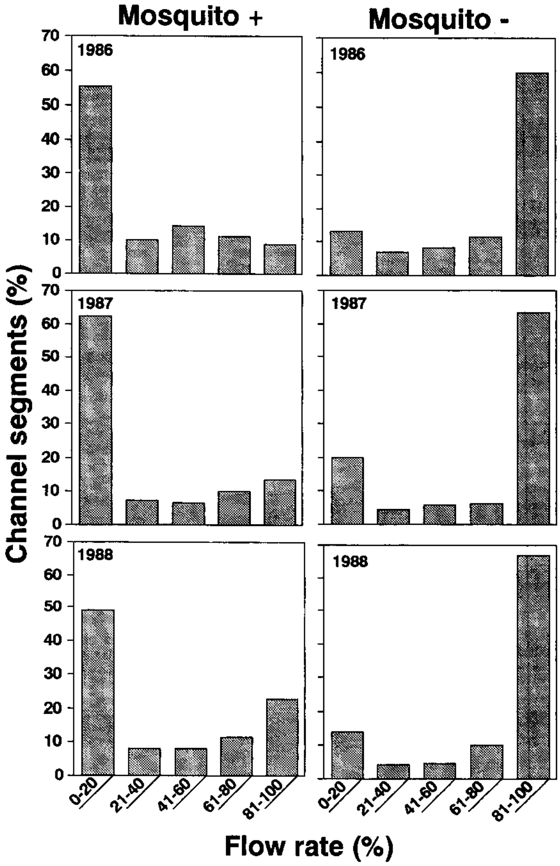

Fig. 1. Mosquito-productive and mosquito-free channel segments classified by flow rates (no. censuses with flow/no. censuses per year) in Saga City, southwest Japan, 1986–88.

Expected flow speeds calculated with Manning's formula increase with water levels. Expected flow speeds at cement-lined segments exceeded 20 cm/sec for water levels of >15 cm. Proportions of segments with water levels of >15 cm were 60–73% for a width of 1 m, 82–92% for a width of >1–2 m, and 98–100% for a width of >2–3 m. Flow speeds expected at unlined segments with considerable weed growth were approximately halved and of <20 cm/sec at nearly all segments of ≤2 m width. Even at segments of >2 m width, flow speeds of >20 cm/sec were expected only with water levels of ≥40 cm (19–30% of segments of this width).

DISCUSSION

The present analysis clearly indicates that water stagnancy at mosquito-productive segments could not be attributed to insufficient water discharge into those segments. Water levels were high enough to

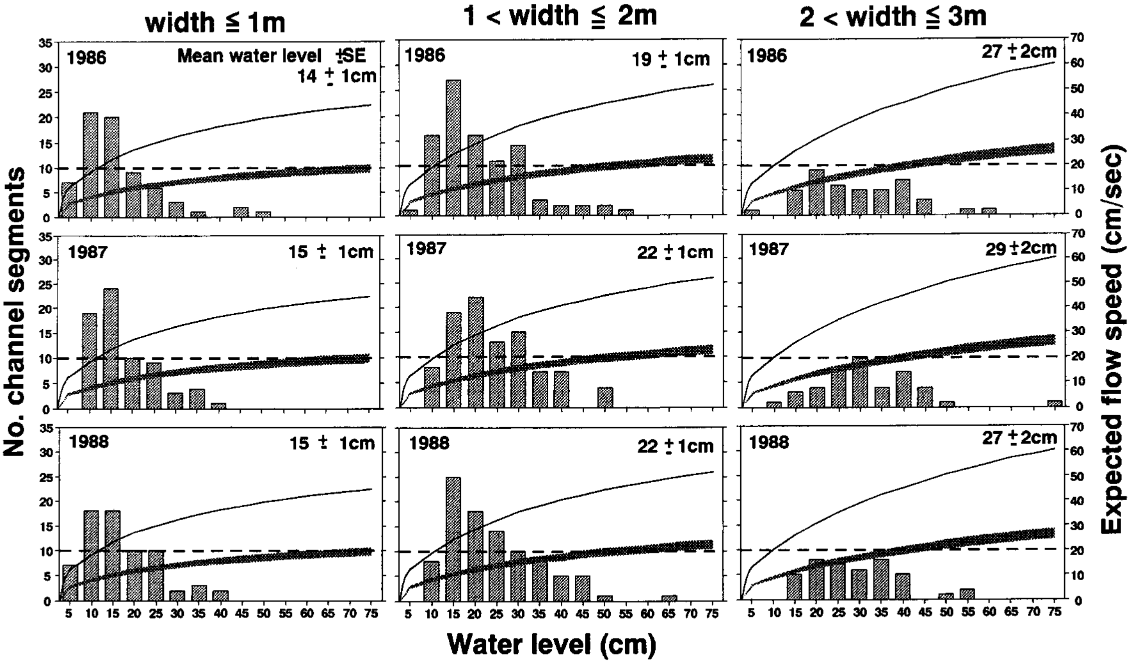

Fig. 2. Mosquito-productive channel segments classified by water levels in Saga City, southwest Japan, 1986–88 (bar; left scale), and expected flow speeds (right scale) at cement-lined segments (solid line) and at earth segments with weed growth (shaded). Horizontal broken line indicates a flow speed required for suppression of mosquito breeding. The overall mean was inserted at the top-right corner.

attain flow speeds necessary for prevention of mosquito breeding (20 cm/sec) at most segments lined with cement. Actually, flow rates at mosquito-free segments were very high despite water levels similar to those at mosquito-productive segments. Differences in mean water levels between mosquito-productive and mosquito-free segments was at most 5 cm, which can yield only slight differences in flow speeds (Fig. 2). Nevertheless, mosquito breeding was not confirmed at mosquito-free segments throughout the 3 years, indicating that the flow speed required for mosquito prevention was attained there. Flow speeds measured at some mosquito-free segments were actually >20 cm/sec (Mogi and Sota 1996).

Growth of aquatic weeds may be responsible for water stagnancy at some mosquito-productive segments. Removal of aquatic vegetation at those segments could improve water flow. However, vegetation destruction also destroys microhabitats for aquatic animals including larvivorous predators (see below). Water flow in some other mosquito-productive segments may be improved by removal of garbage and sediment that obstruct water flow. Saga citizens clean channels every spring and autumn to remove garbage and sediment, and this has contributed to improvement of water quality and flow. However, water was stagnant at many mosquito-productive segments despite the absence of garbage that obstructs water flow.

Historically, part of the channel network in Saga City has been developed as reservoirs for irrigation water and safeguards against floods. Those segments are structured not to run water but to collect water. To induce water flow at those segments, reorganization of channel systems by extensive engineering is essential. Under existing circumstances, it is difficult to control *Cx. p. pallens* breeding in water channels in Saga City by increasing the water intake at upstream main watergates. To fill up those segments with earth is impractical, because they still function as temporary water reservoirs to protect the urban area from floods at heavy rains.

Urban channels are connected to rural channels. Various larvivorous animals, including fish and predacious insects, invade urban channels if water quality is tolerable to them (Mogi and Sota 1996). Mortality due to predation is substantial for *Cx. p. pallens* larvae in urban channels (Mogi and Okazawa 1990) and, given microhabitats favoring predators, mosquito production could totally be suppressed (Mogi and Sota 1996). Saga City also has promoted the increase in dragonflies and damselflies (Odonata) as a symbol of amenity of the urban environment. Odonata nymphs are potential predators against mosquito larvae (Collins and Washino 1985). The immature stages of many Odonata species prefer lentic habitats (Ishida and Ishida 1985). The best method for resolving urban mosquito problems in Saga City would be the development of a drainage system to prevent wastewater from discharging into open channels. The improvement of water quality would then allow colonization of larvivorous insects and fish throughout the channel network.

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