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MACROCONDITIONS OF CHANNEL SEGMENTS UTILIZED BY *CULEX PIPIENS PALLENS* IMMATURES IN SAGA CITY, SOUTHWEST JAPAN

M. MOGI,[1] T. SOTA[1,2] AND M. MOTOMURA[3]

ABSTRACT. The relation between macroconditions of water channels and the breeding of *Culex pipiens pallens* in Saga City were examined, based on weekly census data over 3 years for *ca.* 2,000 channel segments. Mosquito breeding activity was greatest in channel segments between building lots and field lots in the suburban area. The segments involved ranged from narrow roadside ditches (width < 1 m) to wide irrigation canals (width > 10 m), all of which were utilized by mosquitoes. There was a weak tendency for more mosquito breeding in narrower segments. Water flow indices ranged from 0% (always stagnant) to 100% (always flowing). Mosquito breeding tended to be suppressed with an increase in flow indices. Mosquito breeding was confirmed in *ca.* 35% of segments yearly, and such mosquito-productive segments tended to persist during 3 study years.

INTRODUCTION

One feature characterizing Saga City in western Japan is the presence of channel networks. The origin of the channels dates back to those constructed on reclaimed land in the 7th century. Since then, channels have been developed as sources of water for irrigation and domestic use as well as drains for rainwater and waste (Saga City 1977). The channels supply water for agricultural fields in rural and suburban areas of the city and, in the rainy season, protect the urban area lying at sea level from flooding. Excess sewage from an increasing human population since the middle 20th century has polluted the water. Consequently, numerous segments along the channel networks have turned into favorable habitats for larvae of the mosquito *Culex pipiens pallens* Coquillett. Adult females of this species actively bite humans, and thus pose nuisance problems for Saga citizens (Motomura et al. 1995). This species also readily bites dogs (Suenaga and Itoh 1976, Karoji et al. 1980) and is a main vector of canine filariasis in western Japan (Suenaga and Itoh 1973). Since 1986, larviciding with insect growth regulators has routinely been implemented by the Department of Environment in Saga City. However, increasing public concerns about the environment have necessitated mosquito control by nonchemical management measures.

Larval habitats of species of the *Culex pipiens* complex are variable depending on local conditions (Subra 1981). However, polluted open drains are the common habitat for *Culex quinquefasciatus* Say at various localities in Southeast Asia. Following the widespread development of insecticide resistance in this mosquito (World Health Organization 1986), environmental management measures, such as improvement of water flow and quality by cleaning and design modification, have been recommended for permanent control of the mosquitoes (World Health Organization 1988). However, the feasibility of environmental management for *Cx. quinquefasciatus* control in large areas has not been reported.

Channel networks in Saga City collectively have been called "creeks" by the citizens. In reality, they are extremely variable in their location and size, ranging from rural irrigation canals >10 m wide to urban roadside ditches <1 m wide. In some channels, water constantly flows, whereas in others, water is stagnant, making narrow ponds. Defining the gross features of channel segments most responsible for mosquito production is the first requirement when assessing the feasibility of mosquito control by environmental management measures. We report here the macroconditions of mosquito-productive channel segments in Saga City, determined through the analysis of collection records of immature *Cx. p. pallens.*

MATERIALS AND METHODS

Study area: Saga City is located on the central part of the Tsukushi alluvial plain, northern Kyushu. This alluvial plain supports a rice production area, and the central urban area (*ca.* 13% of the whole city) is surrounded by suburban and rural areas where buildings and farms are interspersed, forming intricate patterns. Rice is planted from late June through late October, then it is replaced with a winter crop, barley. Vegetables also are cultivated at some lots. Three-quar-

[1] Division of Parasitology, Department of Microbiology, Saga Medical School, Nabeshima, Saga 849, Japan.
[2] Present address: Department of Biology, Faculty of Science, Shinshu University, Matsumoto 390, Japan.
[3] Department of Environment, Saga City, Saga 849, Japan.

ters of the human population lives in suburban and rural areas.

The annual mean temperature is 16.1°C (for 1961–90) with the monthly minimum of 5.0°C in January and the maximum of 27.6°C in August. The mean annual precipitation is 1,836 mm with a monthly minimum of 62 mm in January and a maximum of 341 mm in July.

In Saga City, *Cx. p. pallens* overwinters as adult females in diapause. Biting activity starts in March and continues until November with the predominant biting season being from May though September (Mogi 1987[4]). Larvae sometimes are found in artificial containers around human houses, but, quantitatively, the role of such habitats in the reproduction of *Cx. p. pallens* is negligible compared to the omnipresent water channels.

Census: Water channels form intricate networks. A census unit consisted of one segment along the network. One segment typically was a part of a network between 2 junctions, where the channel width was constant. When the width changed within a part between 2 junctions (often at turns), each subpart with a constant width was regarded as a separate segment. The census was conducted from 1986 through 1988. Before the 1986 mosquito breeding season, 2,135 segments were listed and numbered as potential larval habitats. Excluded from this list were cement-lined segments with constantly flowing clear water. Segments located >100 m from the nearest houses in the rural area also were excluded due to labor limitations. In succeeding years, some of initially registered segments were deleted from the list because census results in the preceding year(s) indicated little possibility of those segments being utilized by mosquitoes. Thus, 1,737 and 1,698 segments were inspected in 1987 and 1988, respectively. The mean length of registered segments was *ca.* 150 m.

Registered segments were surveyed weekly from May through September. Presence or absence of water flow, irrespective of flow speed, was recorded by visual inspection, if necessary

[4] Mogi, M. 1987. Report of basic studies for mosquito control, Saga City.

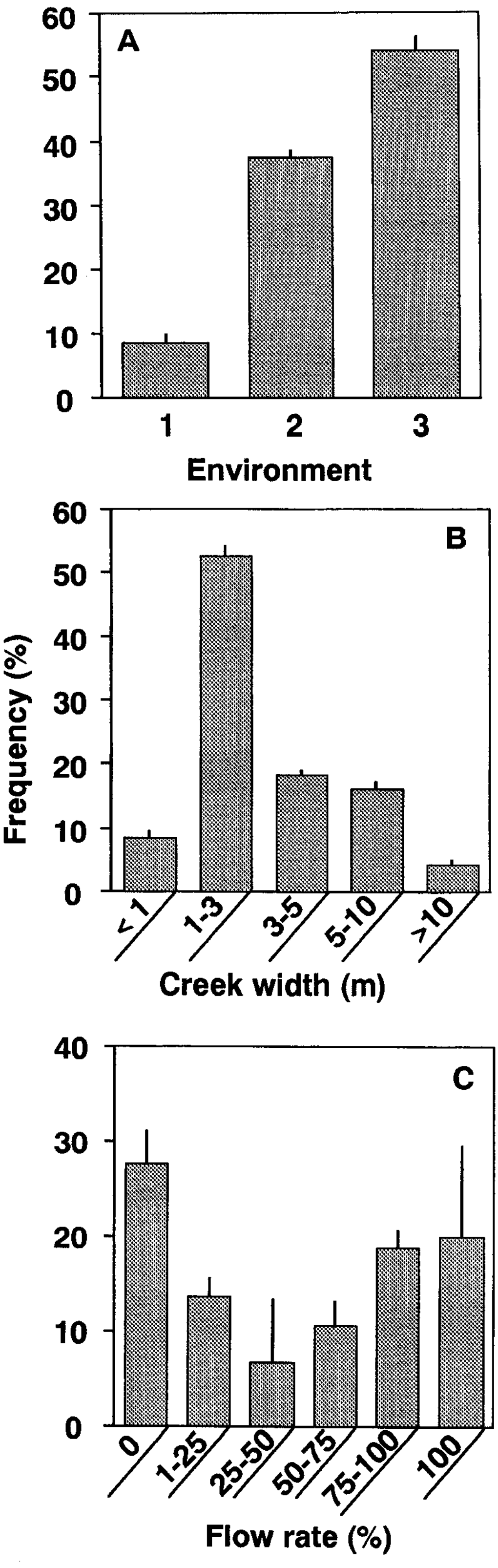

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Fig. 1. Macroconditions or channel segments classified by environments (A; 1 = between field lots, 2 = between a field lot and a building lot, 3 = between building lots), widths (B), and flow indices (C; no. censuses with flow/total no. censuses per year). Class values indicated by ranges include the lower limit but exclude the upper limits. Vertical lines on the bar indicate 1 SD for 3 years.

Table 1. ANCOVA summary table.

Year	Source of variation	df	Sum of squares	Mean square	F
1986	Environment	2	0.95	0.47	9.95*[1]
	Width	1	1.42	1.42	29.81*
	Flow index	1	11.58	11.58	243.44*
	Error	2,126	101.09	0.05	
1987	Environment	2	1.35	0.68	15.63*
	Width	1	0.64	0.64	14.85*
	Flow index	1	8.20	8.20	189.46*
	Error	1,527	66.12	0.04	
1988	Environment	2	1.27	0.63	15.96*
	Width	1	1.53	1.53	38.52*
	Flow index	1	5.54	5.54	139.56*
	Error	1,567	62.24	0.04	

[1] * indicates $P < 0.0001$.

with the aid of paper pieces placed on the water surface. Presence or absence of culicine mosquito immatures, including egg rafts, larvae, and pupae, was inspected by dipping. Stagnant or slowly running areas along each segment where mosquitoes might occur were sampled by a dipper (capacity 500 ml). When emergent plants, such as *Phragmites communis* (Gramineae) and *Oenanthe javanica* (Umbelliferae), were present, areas among plants also were sampled by dipping. Sampling was discontinued when the presence of mosquitoes was confirmed, irrespective of their density. Due to time constraints, a maximum of 20 dips per site was established. Specimens were not preserved. Previous surveys indicated that *Cx. p. pallens* was the dominant culicine species breeding in urban and suburban segments (>95%), although *Culex tritaeniorhynchus* Giles may also be abundant in some rural segments near rice fields in midsummer (Mogi 1987[4]).

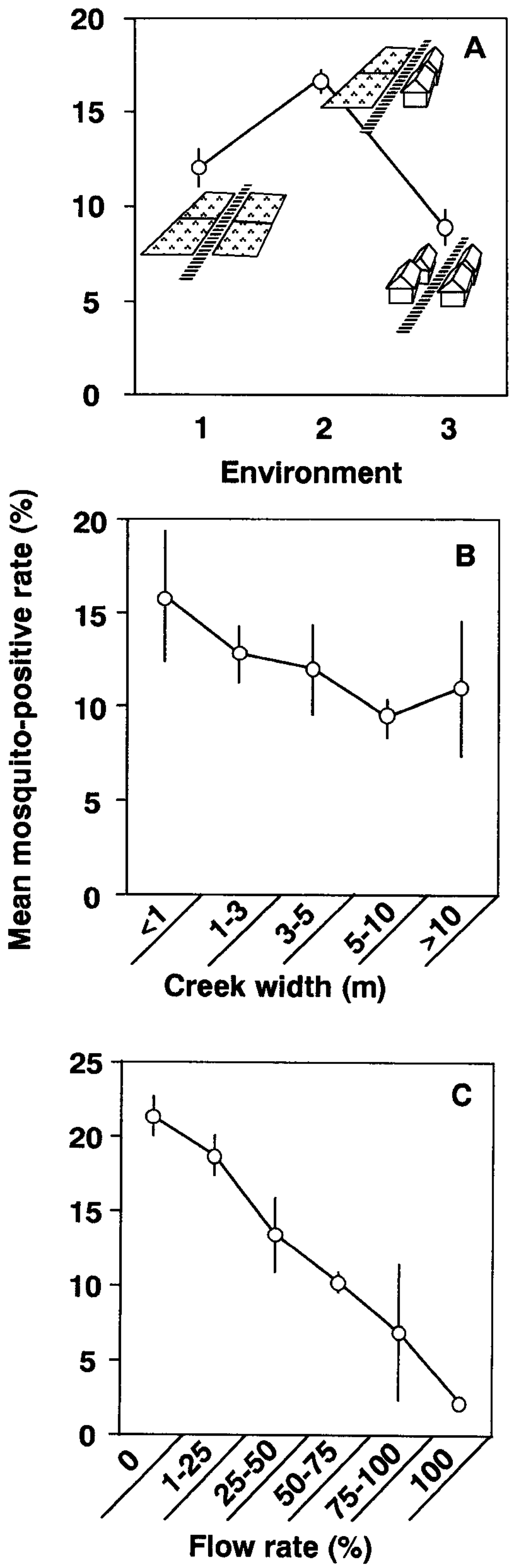
Among macroconditions that may influence mosquito breeding, general environments around segments, segment widths, and flow indices were selected for analyses. These conditions varied widely among segments but could easily be quantified. All segments were more or less exposed to direct sunlight and none were completely covered by trees. Most segments were lined with cement with only a few being unlined. Though vegetation varied among segments, quantification of the vegetation cover was difficult due to seasonal changes and movement of floating vegetation by winds and water flow. The environment of each segment was classified into one of 3 categories: 1 = between field lots, 2 = between a field lot and a building lot, and 3 = between building lots. Field lots were pieces of land used for rice, barley, and vegetable cultivation. Building lots consisted of houses, shops, schools, temples, factories, car parks, and office buildings. The flow index at each segment was calculated as no. of flow-positive censuses/total no. censuses per year.

Analyses: An analysis of covariance (ANCOVA) was performed for each year with the general linear models procedure of SAS (SAS Institute 1985), with mosquito-positive index (no. mosquito-positive censuses/total no. censuses per year) as a dependent variable. The independent variables were the environments (1, 2, 3), with segment widths and flow indices as covariates.

RESULTS

Channel macrocondition: More than 50% of channel segments occurred between building lots (Fig. 1A). Combining these segments with segments between a building lot and a field lot, more than 90% of registered segments were located between or by the side of building lots. Segment widths ranged from <1 to >10 m, but 50% of segments fell into the class of 1–3 m wide (Fig. 1B). Flow indices showed a bimodal pattern with frequency peaks in both the classes of constantly stagnant segments and of constantly flowing ones (Fig. 1C). At *ca.* 40% of the segments, water was always or usually stagnant (flow indices < 25%), whereas at another 40%, water was always or usually flowing (flow indices > 75%). Thus, in Saga City, stagnant or usually stagnant segments of narrow or medium widths exist very close to human residential or working places.

Mosquito breeding: All 3 macroconditions affected mosquito breeding significantly through 3 study years (Table 1). The mean mosquito-pos-



itive index for segments between building lots and field lots was 17%, which was higher than that for segments between field lots and also that for segments between building lots (Fig. 2A). Thus, a doughnut pattern was evident, that is, mosquito breeding activity was greatest in the circular zone surrounding the central urban area. Mosquito-positive indices tended to decrease with an increase in segment widths but segments of all width classes were utilized by mosquitoes (Fig. 2B). Mosquito-positive indices decreased rapidly with an increase in flow indices from the mean >20% for stagnant segments to *ca.* 2% for segments that were always flowing (Fig. 2C). Thus, mosquito breeding activity was greatest in narrow, stagnant channel segments in the suburban area. Within each year, mosquito breeding was confirmed for *ca.* 35% of segments (Fig. 3). Segments with higher mosquito-positive indices were fewer, but *ca.* 10% of segments exceeded a mosquito-positive index of 50%. Mosquito breeding was not confirmed for 42% of segments throughout the study years, whereas 20% of segments were utilized by mosquitoes every year (Fig. 4). Frequencies (P_r) of mosquito-positive years (r) expected when mosquito-positive and -negative segments alternate randomly by year can be calculated from the binomial distribution as:

$$P_r = {}_3C_r \cdot 0.35^r \cdot 0.65^{3-r},$$

where 0.35 = mosquito-positive index per year. The actual frequency was higher than expected values for segments where mosquito breeding was either not confirmed or was confirmed in all the 3 study years (*G*-test, $G_{adj} = 51.576$, df = 2, $P < 0.001$). Thus, mosquito-negative or -positive segments tended to persist through the study years.

DISCUSSION

Mosquito-productive channel segments typically were stagnant and narrow, located between building lots and field lots. Approximately 35% of segments were responsible for mosquito production each year, and such mosquito-productive segments tend to persist at least during 3 study

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Fig. 2. Relationship between mean mosquito-positive indices (no. censuses when mosquito immatures were confirmed/total no. censuses per year) and environments (A), widths (B), or flow indices (C). For definition of environment classes and flow indices, see explanations of Fig. 1. Class values indicated by ranges include the lower limit but exclude the upper limit. Vertical lines on the bar indicate 1 SD for 3 years (not shown if smaller than the circle radius).

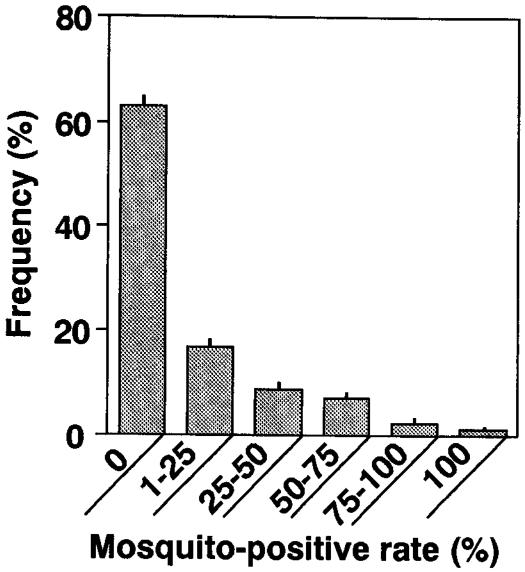

Fig. 3. Channel segments classified by mosquito-positive indices. For definition of mosquito-positive indices, see explanation for Fig. 2. Class values include the lower limit but exclude the upper limit. Vertical lines on the bar indicate 1 SD for 3 years.

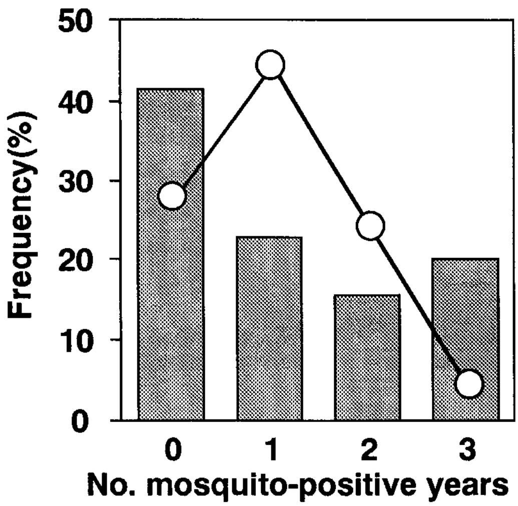

Fig. 4. Channel segments classified by the number of years when mosquito breeding was confirmed. The line graph indicates frequencies expected when mosquito-positive and -negative segments alternate randomly by year.

years. Some of these features may be characteristic to Saga City but some (e.g., stagnancy) are certainly common to other localities where open drains are the most important breeding habitat for the *Culex pipiens* complex. In view of the importance of this species complex as urban filariasis vectors worldwide (White 1989), and also as nuisance pests, the scarcity of comparative data may warrant further study. Characterization of local conditions through comparison with other localities would facilitate the establishment of control strategies appropriate to each locality.

Extensive mosquito breeding in the transition zone between urban and rural areas does not necessarily indicate the presence of intrinsic conditions facilitating mosquito breeding in this zone. Waste discharge, which tends to slow water flow and promote eutrophic conditions, is more extensive in the densely populated urban area. Dogs and humans are the most important blood meal hosts in Saga City, and their densities are higher toward the central urban area. Adult resting habitats also are abundant in the urban area. Among others, covered roadside ditches offer the best resting place for *Cx. p. pallens*. Though 90% of the houses are equipped with window screens (Motomura et al. 1995), under-floor spaces and storerooms can also easily be utilized as resting places by this endophilic species. Potential risks of intensive mosquito breeding in the urban area have been suppressed by a higher prevalence of modernized sewerage and increased channel cleaning by individual homeowners compared to the suburban area. People living in new houses in the suburban area are mostly young-generation newcomers. Consequently, community-wide activities, such as channel cleaning by community participation, are more difficult to organize and implement. Without such suppression, mosquito breeding in the urban area would have been as high as or even higher than that in the suburban area. This means that mosquito production in the suburban area also can be suppressed by an improvement of sewerage and increased community-wide activities.

Wider channel segments are usually deeper and less polluted. Furthermore, wider segments are inhabited by various kinds of larvivorous fish (Mogi et al., unpublished data). If there is rich emergent vegetation, areas among plants may be suitable habitats for *Cx. tritaeniorhynchus* immatures, but usually such habitats are less utilized by *Cx. p. pallens*. Wider segments supply fish to narrow connecting segments. In fact, native predators, including fish and predacious insects, cause a substantial mortality in *Cx. p. pallens* larvae in polluted urban channels in Saga (Mogi and Okazawa 1990). Although it is impractical to widen channel segments for mosquito control, it is a reasonable strategy to maintain channel widths and to avoid destroying wider segments so as to preserve fish diversity and abundance.

Conspicuous effects of water flow on mosquito breeding indicate the possibility of suppression of mosquito breeding in channel segments by increasing water flow. Improvement in always or usually stagnant segments (flow indices < 25%) would especially be effective. However, there are still problems to be examined. First, more information about aquatic ecosystems in channels is required. As mentioned above, these channels are habitats of various aquatic animals, some of which may be seriously affected by an increase in water flow. Second, it is necessary to establish flow speeds required for mosquito control in urban channels. Water discharge or flow speed required for riverine anopheline control in hilly areas has been studied (Kruse and Reynaldo 1955, Oomen et al. 1990), but no such information is available for culicine mosquitoes breeding in water channels in flat alluvial plains. Because water is a valuable resource, the most cost-effective manner of water use for mosquito control should be investigated.

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