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# PHYSICAL AND BIOLOGICAL ATTRIBUTES OF WATER CHANNELS UTILIZED BY *CULEX PIPIENS PALLENS* IMMATURES IN SAGA CITY, SOUTHWEST JAPAN

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ABSTRACT. Physical and biological attributes of water channels utilized by immatures of *Culex pipiens pallens* were studied in Saga City, Japan. Water in mosquito-productive segments generally was stagnant or slowly running (mean < 5 cm/sec), with low and fluctuating dissolved oxygen concentrations and high electric conductivity. Water flow > 20 cm/sec was considered necessary for prevention of mosquito breeding. The aquatic fauna in mosquito-productive segments was composed of taxa tolerable to polluted water. Adult Odonata were more diverse in segments with emergent vegetation irrespective of physical attributes of channel water. Fish diversity was higher in mosquito-free segments. Twenty-three fish species were confirmed in the creek networks. Temporary flooding did not flush mosquito immatures from mosquito-productive segments, indicating the high stability of those segments as mosquito immature habitats.

## INTRODUCTION

Throughout the warmer regions of the world, urban drains are the main breeding habitats of the *Culex pipiens* species complex, which transmit human and animal diseases and cause nuisance problems (Curtis and Feachem 1981). Nevertheless, larval ecology of the *Cx. pipiens* species complex in urban drains has not been studied intensively. Rajagopalan et al. (1976) and Menon and Rajagopalan (1981) estimated survival rates of *Culex quinquefasciatus* Say in urban drains in India. Mogi and Okazawa (1990) estimated survival rates of *Culex pipiens pallens* Coquillett in polluted water channels in Saga City, southwest Japan, and indicated that mortality due to predation is substantial. Mogi et al. (1995) also indicated that mosquito production is strongly suppressed with the increase in flow rates at respective channel segments and that mosquito-productive segments tend to persist over years.

Control of the *Cx. pipiens* species complex breeding in urban drains has mainly relied on chemical methods against either larvae or adults (Curtis and Feachem 1981, Subra 1981, World Health Organization [WHO] 1988). Increasing costs, development of insecticide resistance, and increasing public concerns about insecticide use require control by methods other than insecticides. Among others, environmental management measures, such as velocity alteration or cleaning of open drains, are expected to provide a permanent solution (WHO 1988). Flow speeds necessary for flushing anopheline larvae from hill streams have been investigated (Oomen et al. 1990), but those for the *C. pipiens* species complex in urban channels have not been proposed. Change in flow speed may also influence other organisms including predators and animals preferred by humans. Saga City has promoted the increase in dragonflies as a symbol of amenity of the urban environment. To minimize the impact on the faunal and floral diversity is an important factor to be considered even in urban mosquito control. This report compares some physical and biological attributes of mosquito-productive segments with those of mosquito-free segments in Saga City. A specific purpose of this comparison is to propose a flow speed necessary for control of the *C. pipiens* species complex breeding in urban channels.

## MATERIALS AND METHODS

*Study area:* The study was done in Saga City, Kyushu, southwest Japan, in 1990 and 1991. The area has a warm-temperate climate with hot summers (August mean for 1961–90 = 27.6°C) and rain through all seasons (mean annual total precipitation = 1,876 mm). Larvae of *Cx. p. pallens* occur in water channels from April through November, with a peak abundance around June (Mogi 1987[2]). The city territory is divided into the central urban area (old town) and suburbs (suburban and rural area). For more information about Saga City and its water channels, see Mogi et al. (1995).

*Mosquito census:* Four pairs of channel segments, 2 (Kouno, Kanko) in the urban area and

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[2] Mogi, M. 1987. Report of basic studies for mosquito control. Saga City, Japan. [In Japanese.]

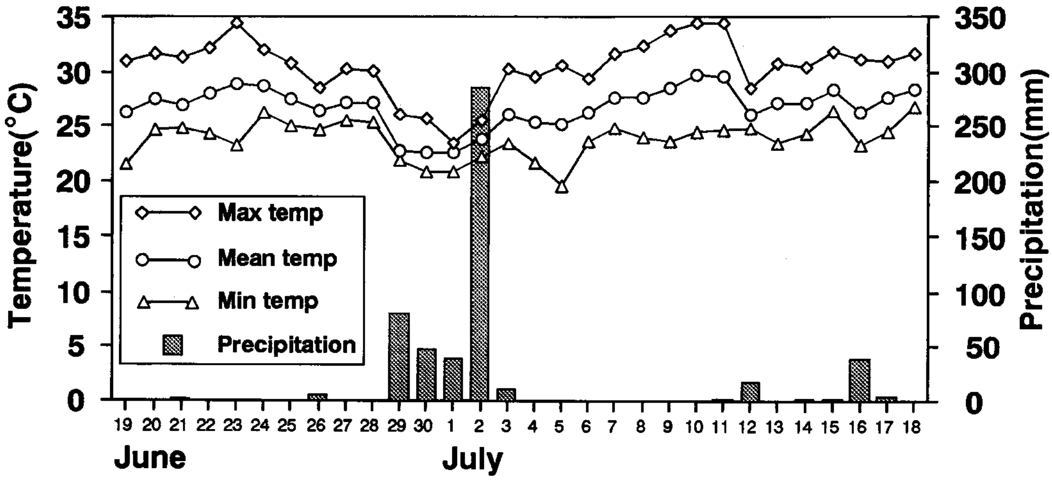


Fig. 1. Weather conditions observed at Saga Meteorological Station located within 3 km of mosquito sampling sites.

2 (Shin'ei, Nabeshima) in the suburban area were selected as study sites based on records of larval censuses in 1986–88. Two segments in each pair were located within 200–500 m of one another. One (mosquito-productive) in each pair was selected from segments where immature mosquitoes were confirmed for >50% of weekly census dates for all the 3 years, whereas the other (mosquito-free) was selected from those where immature mosquitoes were not confirmed during 3 years. Though 1 year intervened between the records and this study, the preliminary inspection revealed that the conditions of selected segments remained the same as in 1986–88. A portion of *ca.* 30 m of each segment was selected as a census site. The census was conducted during 1 month (June 19–July 18) in 1990 when the daily mean temperatures were >25°C except for a few days with heavy rains (Fig. 1). In this season *Cx. p. pallens* breeding is usually most active. Each site was visited daily from 1000 to 1200 h except for July 2 when heavy rain inundated many parts of the city territory and census sites could not be reached.

Physical conditions were measured near the midpoint of each census site. Flow speed was measured as the time required for a paper disk (5-mm diam) floated at 30 cm from the bank to move 5 m. Daily maximum and minimum temperatures were measured at 5 mm below the water surface by a thermometer attached to the underside of a tethered styrofoam float. Dissolved oxygen (DO) and electric conductivity were measured by an oxygen meter (HDO-22, DKK Co., Tokyo) and a conductivity meter (HPK-22, DKK Co.), respectively.

Mosquitoes and other aquatic organisms were collected by a dipper (capacity 500 ml) at 2-m intervals. Contents of 5 dips were pooled and preserved in 10% formalin. At each site, 3 samples (total 15 dips) were taken. On June 19 and July 18, dip samples were taken at all 8 sites. From June 20 through July 17, dip samples were taken daily at mosquito-productive segments only. Presence of fish and adult dragonflies (Odonata, Anisoptera) and damselflies (Odonata, Zygoptera) were recorded at all sites. Fish were collected by a hand net for identification. Aquatic animals other than mosquitoes and fish were identified to family or higher categories by using Ueno (1973) and Kawai (1985). Fish species were identified by Miyadi et al. (1978).

Mosquito and crustacean density was expressed by the procedure for 2-stage sampling in which secondary sampling unit (dips) are pooled (Snedecor and Cochran 1967). The daily mean ($\bar{x}$) per dip and its standard error (SEM) were estimated as:

$$\bar{x} = \Sigma\, x_i/n$$
$$\mathrm{SEM} = \sqrt{\Sigma\,(x_i - \bar{x})^2/n(n-1)},$$

where $\bar{x}_i$ is the mean per dip for each sample and $n$ is the number of samples ($n$ = 3).

*Fish census:* Because fish censuses by visual observation and hand nets cannot reveal the full fish fauna, a census by cast nets was done at 8 sites (different from the 8 mosquito census sites) in July and August 1990 and at 33 additional sites in July and August 1991. At each site, a cast net was thrown 3–8 times and all fish were identified *in situ* and released there. A highly larvivorous poeciliid, *Gambusia affinis* (Baird and Girard), had been released every spring from 1972 to 1985 at several segments in the

Table 1. Physical conditions of channel segments studied in Saga City, Japan.

| | | | | Mean (coefficient of variation [%]) conditions of water | | | | |
|---|---|---|---|---|---|---|---|---|
| Site[1] | Width (m) | Waste-water dis-charge | Flow rate[2] (%) | Depth[3] (cm) | Flow speed (cm/sec) | Temper-ature[4] (°C) | Dissolved oxygen concentration[5] (ppm) | Electric conduc-tivity (μS/cm) |
| Mosquito-productive | | | | | | | | |
| Kouno | 3 | + | 66 | 12 (11) | 3.6 (48) | 26.6 (6.7) | 2.4 (61) (0.2–6.0) | 404 (21) |
| Kanko | 2 | + | 59 | 32 (10) | 4.5 (99) | 25.8 (5.9) | 2.8 (50) (0.1–5.0) | 423 (23) |
| Shin'ei | 3 | – | 0 | 48 (17) | — | 27.1 (7.3) | 3.0 (64) (0.3–7.5) | 122 (33) |
| Nabeshima | 3 | + | 0 | 27 (28) | — | 25.7 (5.1) | 4.9 (57) (0.2–8.1) | 213 (23) |
| Mosquito-free | | | | | | | | |
| Kouno | 1 | – | 100 | 14 (39) | 28.7 (30) | 22.7 (5.1) | 7.0 (25) (3.1–8.8) | 96 (22) |
| Kanko | 1 | – | 17 | 6 (22) | 6.2 (99) | 27.2 (6.6) | 5.9 (29) (2.6–7.9) | 399 (25) |
| Shin'ei | 3 | – | 100 | 46 (34) | 16.6 (34) | 23.2 (3.9) | 4.9 (24) (1.0–6.5) | 103 (22) |
| Nabeshima | 3 | – | 83 | 48 (27) | 19.7 (35) | 25.0 (6.6) | 7.2 (15) (4.5–8.3) | 101 (50) |

[1] Explanations for mosquito-productive and mosquito-free channels are in the Materials and Methods section.
[2] No. days with water flow ÷ 30.
[3] Excluding July 2 when water depths exceeded 100 cm at all sites due to heavy rains.
[4] Mean of daily mean temperatures [(daily maximum + minimum) ÷ 2].
[5] Range in second parentheses.

urban area by the Department of Environment, Saga City. Fish census sites included 4 of the former release sites, where, in addition to cast net sampling, cyprinodonts and poeciliids were collected by hand nets.

## RESULTS

*Physical condition:* Mosquito-productive segments other than that at Shin'ei received domestic wastewater directly from houses along the banks, whereas mosquito-free segments did not have drainpipe openings, and thus there was no direct influx of wastewater (Table 1). Water depths were >10 cm except for a mosquito-free segments at Kanko. Water in mosquito-productive segments generally was running slowly or was stagnant, with low average but highly variable (CV = 50–64%) dissolved oxygen (DO) concentrations and high electric conductivity. Mosquito-free segments generally had the opposite characteristics: running fast, with higher average and less variable (CV = 15–29%) DO concentrations and lower conductivity. Exceptions were a mosquito-productive segment at Shin'ei, and a mosquito-free segment at Kanko. Mosquito-productive Shin'ei, without direct influx of wastewater, had low conductivity, whereas shallow and often stagnant water at mosquito-free Kanko had high conductivity. Among the 3 segments with the highest conductivity (*ca.* 400 μS), water of mosquito-productive segments at Kouno and Kanko was highly polluted, with low DO concentrations, whereas water of a mosquito-free segment at Kanko was generally clear, with DO concentrations comparable to other mosquito-free segments. Except for Kanko, mean flow speeds at mosquito-free segments were >16 cm/sec, indicating that a flow speed of 20 cm/sec was enough to prevent mosquito breeding.

*Biota:* Mosquito-productive segments at Kouno and of mosquito-free segments at Kouno and Nabeshima had virtually no aquatic macrophytes (Table 2). Mosquito-productive segments at Kanko and Shin'ei had both emergent and submerged macrophytes. A mosquito-free segment at Kanko was characteristically rich in the submerged plant *Hydrilla verticillata* Casp. (Hydrocharitaceae).

Culicid larvae, chironomid larvae, cladocerans, and copepods were the most abundant macroinvertebrates collected at mosquito-productive segments. Taxa collected from mosquito-free segments were essentially the same, but only copepods were abundant. Culicid larvae were collected at all of mosquito-productive segments but from mosquito-free segments only at Shin'ei. The dominant species was *Cx. p. pallens* except for both mosquito-productive and mosquito-free segments at Shin'ei. At mosquito-productive Shin'ei, with less polluted water due to the absence of direct influx of wastewater, *Culex tritaeniorhynchus* Giles was more abundant than *Cx. p. pallens*. At mosquito-free Shin'ei, a few *Cx. tritaeniorhynchus* larvae were collected

Table 2. Aquatic biota in channel segments in Saga City, Japan.

| Taxon[1] | Mosquito-productive | | | | Mosquito-free | | | |
|---|---|---|---|---|---|---|---|---|
| | Kouno | Kanko | Shin'ei | Nabe-shima | Kou-no | Kanko | Shin'ei | Nabe-shima |
| Macrophyte | | | | | | | | |
| Emergent | − | + | + | + | − | − | + | − |
| Submerged | − | + | + | − | − | + | − | − |
| Invertebrate | | | | | | | | |
| *Cx. p. pallens* (L)[2] | 20 | 1,684 | 4 | 2,656 | | | | |
| *Cx. tritaeniorhynchus* (L) | | | 164 | 12 | | | 3 | |
| Chironomidae (L) | 60 | 208 | 44 | 26 | 1 | 4 | 6 | 6 |
| Ephydridae (L) | 4 | | 4 | 12 | | | 1 | |
| Gerridae | | | | | | | 1 | |
| Zygoptera (L) | | 36 | | | | 4 | 1 | |
| Anisoptera (L) | | | | | | 3 | | |
| Ephemeroptera (L) | | 4 | | | | | | |
| Cladocera | 1,616 | 2,000 | 500 | 11,736 | 1 | 7 | 9 | 1 |
| Copepoda | 32 | 324 | 824 | | 16 | 128 | 286 | 22 |
| Ostracoda | 16 | 4 | | | | 24 | | |
| *Asellus* | | 8 | | | | | | |
| Naididae | | 8 | 16 | 292 | 16 | 16 | 2 | |
| Planorbidae | | | 108 | | | 9 | | |
| *Hydra* | | | | | | 1 | | |
| Fish[3] | | | | | | | | |
| *P. rivularis* | − | − | − | − | − | − | − | + |
| *P. herzi* | − | − | − | − | − | + | − | − |
| *P. parva* | − | − | − | − | − | + | − | + |
| *C. carpio* | − | + | − | − | − | − | − | − |
| *Carassius* spp. | − | + | + | − | + | + | + | + |
| *Rhodeus* spp. | − | − | − | − | − | + | − | + |
| *S. asotus* | − | − | − | − | − | − | − | + |
| *O. latipes* | + | + | + | + | − | + | − | + |
| *C. argus* | − | + | + | − | − | + | + | − |

[1] Invertebrate density was expressed as the total number collected on June 19 and July 18 (15 dips on each day). + = Presence was confirmed during the 1-month study period.
[2] L = Only immatures are aquatic.
[3] See Table 3 for full names.

from spaces within clumps of an emergent plant, *Phragmites communis* Trin. Gerrids, dragonfly nymphs, and hydras (Hydroida) were collected only from mosquito-free segments, where they were minor components. Dip samples collected during 1 month of daily censuses at mosquito-productive segments also included larvae of the mosquito *Anopheles sinensis* Wied. (Shin'ei), ceratopogonid larvae (Shin'ei), psychodid larvae (Kouno, Kanko, Nabeshima), tipulid larvae (Shin'ei), hydrophilids (Kanko, Shin'ei), dyticids (Kanko), larval Scirtidae (Kanko), and leeches (Hirudinidae) (Shin'ei): all of these also were minor components of the fauna.

Eight fish taxa were confirmed at mosquito-free segments. Six out of these 8 taxa were confirmed only at either Kanko or Nabeshima, and only one and 2 taxa were confirmed at Kouno and Shin'ei, respectively. The number of taxa confirmed at mosquito-productive segments was 4, of which a highly larvivorous cyprinondont, *Orizias latipes* (Temminck and Schlegel), was present at all 4 sites.

In an extensive fish fauna survey with cast nets, 21 species were collected (Table 3). Some species were benthic but most were nektonic. Except for 3 carnivorous species, these fish species were polyphagous and their juveniles at least have a potential for consuming mosquito larvae. Carnivores consume small fish, frogs, and large crustaceans such as crabs and shrimps, but their juveniles may be larvivorous. In fact, schools of *C. argus* fry (length < 4 cm) voraciously consumed mosquito immatures among emergent

Table 3. Fish species collected by cast nets from channels in Saga City, Japan.

| Taxon | Life form[1] | Food habit[2] | No. collected (no. sites) | | | |
|---|---|---|---|---|---|---|
| | | | Urban | | Suburbs | |
| | | | Flow + (6) | Flow − (6) | Flow + (22) | Flow − (7) |
| Cyprinidae | | | | | | |
| *Zacco temmincki* (Temminck and Schlegel) | N | P | 5 (1) | 2 (1) | 22 (6) | 2 (1) |
| *Zacco platypus* (Temminck and Schlegel) | N | P | 5 (2) | 14 (1) | 30 (8) | |
| *Aphyocypris rasborella* (Fowler) | N | P | | 3 (1) | 8 (1) | |
| *Pseudogobio esocinus* (Temminck and Schlegel) | B | P | 5 (3) | | 6 (3) | |
| *Pseudogobio rivularis* (Basilewsky) | B | P | | 12 (1) | 9 (3) | |
| *Pseudogobio zezera* Ishikawa | B | P | 1 (1) | | | 2 (2) |
| *Sarcocheilichthys variegatus* (Temminck and Schlegel) | N | P | 1 (1) | | | |
| *Pungtungia herzi* Herzentein | N | P | 1 (1) | | 1 (1) | |
| *Pseudorasbora parva* (Temminck and Schlegel) | N | P | | 5 (1) | 9 (3) | 1 (1) |
| *Cyprinus carpio* Linnaeus | N | P | 9 (3) | 4 (2) | 2 (2) | 2 (2) |
| *Carassius* spp.[3] | N | P | 4 (2) | 150 (6) | 232 (15) | 550 (7) |
| *Rhodeus ocellatus* (Kner) | N | P | | 2 (2) | 17 (3) | 2 (1) |
| *Rhodeus sinesis atremius* (Jordan and Thompson) | N | P | | 3 (2) | 3 (2) | 1 (1) |
| *Rhodeus lanceolatus* (Temminck and Schlegel) | N | P | 5 (3) | 9 (1) | 18 (5) | 9 (3) |
| *Rhodeus limbatus* (Temminck and Schlegel) | N | P | | | 4 (1) | |
| *Rhodeus rhombeus* (Temminck and Schlegel) | N | P | 1 (1) | 51 (2) | 34 (5) | 1 (1) |
| Siluridae | | | | | | |
| *Silurus asotus* Linnaeus | B | C | | | 1 (1) | |
| Channidae | | | | | | |
| *Channa argus* Cantor | N | C | | 4 (1) | | |
| Gobiidae | | | | | | |
| *Odontobutis obsura* (Temminck and Schlegel | B | C | 1 (1) | 3 (1) | 1 (1) | |
| *Rhinogobius brunneus* (Temminck and Schlegel) | B | P | | | 1 (1) | |

[1] N = Nektonic, B = benthic.
[2] P = Polyphagous, C = carnivorous.
[3] *Carrasius* included at least 2 species but specific identification for each individual was not possible.

weeds at mosquito-productive segments of Shin'ei, as evidenced by chitinous fragments of mosquito larvae in their stomachs. This feeding habit also was confirmed by laboratory observation.

All segments had at least one fish species (Fig. 2). The maximum number of species per site was 12 at a 1–2-m wide segment with running water. One side of this segment had rice fields, and the other side was a road along houses; thus, it was a typical suburban segment without any special conditions. Differences in frequency distributions of fish species were not significant (Kolmogorov–Smirnov 2-sample test, $P > 0.05$) between flowing and stagnant segments (maximum unsigned difference $D = 0.333$ for urban, 0.208 for suburbs) and between urban and suburbs segments ($D = 0.086$). *Gambusia affinis* was confirmed at 2 out of 4 former release sites, where the ratio of *G. affinis* and native *O. latipes* was 1:4. Thus, 23 fish species were confirmed in channel networks in Saga City.

Fifteen species of Odonata adults were identified, of which 4 were observed only at mosquito-productive segments, whereas one was

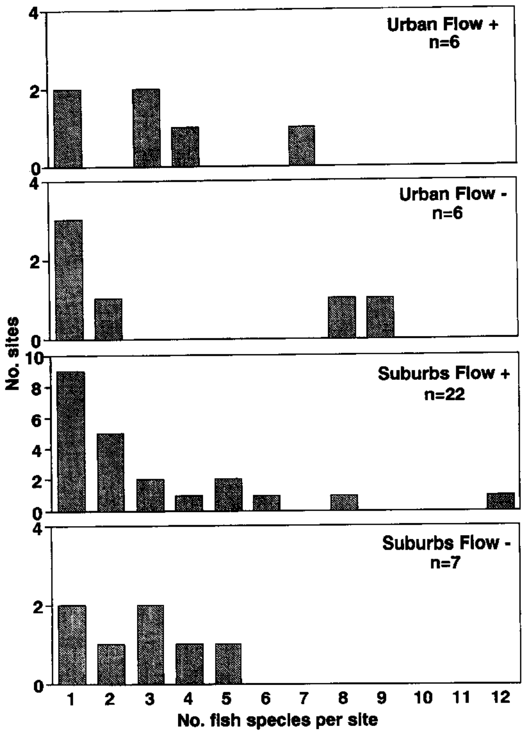


Fig. 2. Frequency distribution of number of fish species per channel segment.

found only at mosquito-free segments (Table 4). The total species and the maximum number of species per site were 14 and 11, respectively, for mosquito-productive segments, whereas those for mosquito-free segments were 11 and 9, respectively. Four out of 5 segments with ≥7 species of Odonata adults (mosquito-productive segments of Shin'ei and Nabeshima, mosquito-free segments of Kanko and Shin'ei) had emergent vegetation; the other one (mosquito-free Nabeshima) had no emergent vegetation but one bank connected to crop fields had rich weeds.

*Mosquito and crustacean dynamics:* Densities of dominant mosquito species in mosquito-productive segments fluctuated widely, but were not reduced by the temporary high water level at the flooding (Fig. 3). Thus, the flooding did not wash out larval mosquito populations in mosquito-productive segments. Rather, densities of *Cx. p. pallens* at mosquito-productive Kouno and *Cx. tritaeniorhynchus* at mosquito-productive Shin'ei increased after flooding. Crustacean densities also did not drop due to the flooding, except for Ostracoda at mosquito-productive Kouno, and population peaks frequently were observed after flooding (Fig. 4).

## DISCUSSION

In the mosquito-productive channel segments, water was stagnant or slowly running (mean < 5 cm/sec). One of these channels (mosquito-productive Shin'ei) did not receive domestic waste directly; thus, water was relatively clean (conductivity was comparable to that of mosquito-free segments) and *Cx. tritaeniorhynchus,* which prefers clearer water than *Cx. p. pallens,* was dominant. All the mosquito-productive segments, however, had a common feature in that DO concentrations were highly variable; they often dropped to levels of <0.5 ppm, which may be lethal to aquatic animals other than those capable of taking oxygen from the air, such as mosquito larvae. On other occasions, the DO concentrations were high enough to allow the survival of various aquatic animals.

Three of the mosquito-free segments had features contrasting with those of the mosquito-productive segments: always or usually running with flow speeds > 16 cm/sec, higher and less variable DO concentrations and low electric conductivity. The other mosquito-free segment at Kanko was unique in its shallow, usually stagnant but clear water with high conductivity, indicating the high concentration of dissolved substances. This segment also was characterized by a dense mat of submerged plants and the richest fish fauna, including larvivorous *O. latipes.* Both damselfly and dragonfly nymphs also occurred there. Predation by these animals probably suppressed the mosquito breeding at this segment despite stagnant water.

The fauna in mosquito-productive segments was similar to that observed for 4 segments with active breeding of *Cx. p. pallens* in 1984 (Mogi and Okazawa 1990) and was composed mostly of taxa that can tolerate polluted water with large variations of pH and DO concentrations. The fauna in mosquito-free segments was essentially similar to that in mosquito-productive segments but included taxa intolerant of polluted water, represented by several fish species absent from mosquito-productive segments. Cast net censuses of the fish fauna also gave evidence for the presence in channel networks, including those in the urban area, of species susceptible to water pollution. Thus, the aquatic fauna in urban channels in Saga City is characterized by the wide variation of component species with regard to water quality preference.

Occurrence of animals indicative of different water qualities would have resulted from channel networks connecting segments with different water qualities and also from wide fluctuations of conditions in each segment. Animals inhabiting less polluted segments can invade polluted

Table 4. Adult dragonflies confirmed at channel segments in Saga City, Japan.

| Taxon | Mosquito-productive | | | | Mosquito-free | | | |
|---|---|---|---|---|---|---|---|---|
| | Kou-no | Kan-ko | Shin'ei | Nabe-shima | Kou-no | Kan-ko | Shin'ei | Nabe-shima |
| Zygoptera | | | | | | | | |
| Agrionidae | | | | | | | | |
| *Ceriagrion melanurum* Selys | − | − | − | − | + | − | − | − |
| *Ceriagrion nipponicum* Asahina | − | + | + | + | − | − | + | − |
| *Ischnura senegalensis* Rambur | + | + | + | + | − | + | + | + |
| *Cercion calamorum* Ris | − | − | + | − | − | − | + | + |
| *Cercion hieroglyphicum* (Brauer) | − | − | − | + | − | − | + | + |
| Platycnemididae | | | | | | | | |
| *Copera annulata* (Selys) | − | − | − | + | − | − | − | − |
| Anisoptera | | | | | | | | |
| Aeschnidae | | | | | | | | |
| *Anax parthenope julius* Brauer | − | + | + | + | − | − | − | + |
| *Aeschnophlebia anisoptera* Selys | − | − | − | + | − | − | − | − |
| Libellulidae | | | | | | | | |
| *Orthetrum albistyrum speciosum* (Uhler) | + | + | + | + | − | + | + | + |
| *Orthetrum triangulare melania* (Selys) | − | + | − | − | − | − | − | − |
| *Deielia phaon* (Selys) | − | + | + | + | − | + | + | + |
| *Crocothemis servilia* (Drury) | − | − | + | − | − | − | + | − |
| *Pseudothemis zonata* Brumeister | + | − | + | + | − | − | + | + |
| *Rhyothemis fuliginosa* Selys | − | − | − | + | − | − | − | − |
| *Pantala flavescens* Fabricius | + | + | + | + | + | + | + | + |
| Total species | 4 | 7 | 9 | 11 | 2 | 4 | 9 | 8 |

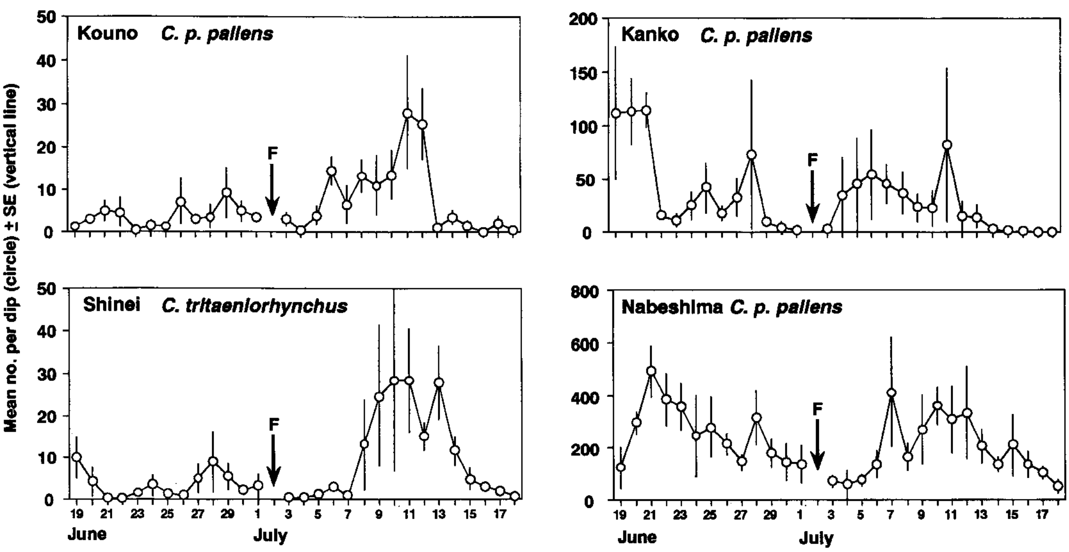


Fig. 3. Fluctuation of mosquito density at 4 mosquito-productive channel segments: Kouno, Kanko, Shin'ei, and Nabeshima. F with arrow indicates the day of flooding.

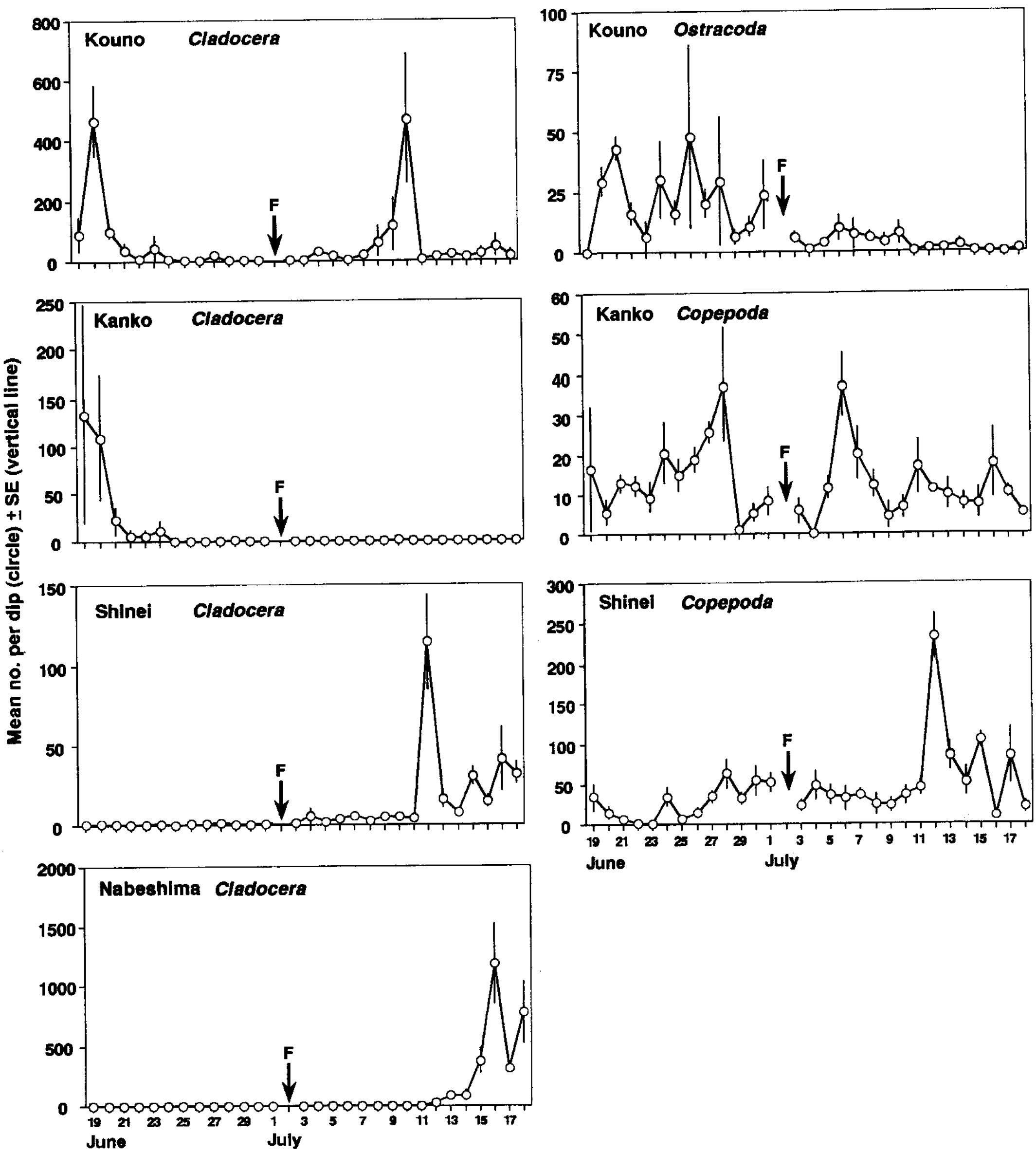


Fig. 4. Fluctuation of crustacean density at 4 mosquito-productive channel segments: Kouno, Kanko, Shin'ei, and Nabeshima. F with arrow indicates the day of flooding.

segments when the water quality there is improved temporarily, thus those invaders are exposed to the risk of death when DO concentrations drop later. This was exemplified by many dead fish observed at some mosquito-productive segments on hot sunny days when DO concentrations dropped to nearly zero. Polluted segments not only produce mosquitoes and other annoying Diptera such as chironomids and psychodids but also odor and visual problems. The present result indicates that polluted segments also act as death traps for animals that prefer clearer water and could reduce the diversity of the aquatic fauna in the whole channel network. If water quality improvement is stable, species that prefer clear water may extend their distribution into the urban area rather easily. Thus, urban segments could function either negatively or positively for the preservation of the aquatic fauna, depending upon their water quality.

Diversity of Odonata adults was not different between mosquito-productive and mosquito-free segments and appeared to be related to the presence of emergent vegetation. Odonata adults, especially Anisoptera with strong flight ability, would select habitats suitable for temporary adult resting. For management of distribution and abundance of insects with aquatic immatures and terrestrial adults, habitat for adults also is an important factor to be considered.

The flow speed necessary for suppressing the breeding of *Cx. p. pallens* was >20 cm/sec. Hydraulic studies in Saga revealed that flow speeds of 20–30 cm/sec are necessary to prevent the accumulation of sediments (Koga et al. 1990). Thus, it may be reasonable to adopt 20 cm/sec as a criterion and target for both improvement of water quality and prevention of mosquito breeding. This critical flow speed is distinctly slower than 40–50 cm/sec required for flushing of anopheline larvae in hill streams (Oomen et al. 1990). *Culex pipiens pallens* larvae may be more susceptible to water flow than riverine anophelines, but this needs confirmation. Water flow suppresses mosquito breeding by not only flushing out existing immatures but also preventing oviposition by adult (Schober 1966). The latter aspect has not been well studied but probably is important for *Cx. p. pallens* breeding in urban drains. When a small section (30 × 30 cm) of the polluted but running water segment was closed by floating frames, oviposition was concentrated into the calm surface inside the frame (Mogi and Okazawa, unpublished data).

Unexpectedly, flooding was not detrimental to mosquito immatures in the mosquito-productive segments studied, indicating the high stability of those segments as habitats for immature mosquitoes. Actual situations of mosquito immatures could not be observed at the flooding, but the high water level at the flooding probably did not change the rate of water flow, which if fast enough, can effectively flush out mosquito immatures. Practically, it implies that mosquito control at those segments could not be attained simply by increasing the water discharge into channel networks at upstream main watergates but requires reconstruction of the channel network to induce effective rates of water flow at mosquito-productive segments. One of the alternatives is to prevent wastewater discharge into those segments, thus improving the water quality up to a level that allows colonization by aquatic predators. Such a situation was exemplified by a mosquito-free segment at Kanko where the water did not flow or flowed slowly, but had a rich predator fauna. Mosquito-productive segments tend to persist over years (Mogi et al. 1995), thus environmental measures with lasting effects would eventually be more economical than continual chemical control.

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