RESEARCH REPORT

57

Small Irrigation Tanks as a Source of Malaria Mosquito Vectors: A Study in North-Central Sri Lanka

Felix P. Amerasinghe, Flemming Konradsen, Wim van der Hoek,
Priyanie H. Amerasinghe, J. P. W. Gunawardena, K. T. Fonseka and G. Jayasinghe

International Water Management Institute

FUTURE HARVEST
IWMI is a Future Harvest Center
supported by the CGIAR

Research Reports

IWMI's mission is to improve water and land resources management for food, livelihoods and nature. In serving this mission, IWMI concentrates on the integration of policies, technologies and management systems to achieve workable solutions to real problems—practical, relevant results in the field of irrigation and water and land resources.

The publications in this series cover a wide range of subjects—from computer modeling to experience with water user associations—and vary in content from directly applicable research to more basic studies, on which applied work ultimately depends. Some research reports are narrowly focused, analytical and detailed empirical studies; others are wide-ranging and synthetic overviews of generic problems.

Although most of the reports are published by IWMI staff and their collaborators, we welcome contributions from others. Each report is reviewed internally by IWMI's own staff and Fellows, and by external reviewers. The reports are published and distributed both in hard copy and electronically (www.iwmi.org) and where possible all data and analyses will be available as separate downloadable files. Reports may be copied freely and cited with due acknowledgment.

Research Report 57

Small Irrigation Tanks as a Source of Malaria Mosquito Vectors: A Study in North-Central Sri Lanka

Felix P. Amerasinghe
Flemming Konradsen
Wim van der Hoek
Priyanie H. Amerasinghe
J. P. W. Gunawardena
K. T. Fonseka
and
G. Jayasinghe

International Water Management Institute
P O Box 2075, Colombo, Sri Lanka

IWMI receives its principal funding from 58 governments, private foundations, and international and regional organizations known as the Consultative Group on International Agricultural Research (CGIAR). Support is also given by the Governments of Ghana, Pakistan, South Africa, Sri Lanka and Thailand.

IWMI gratefully acknowledges the financial support for this work from NORAD. The authors wish to sincerely thank D. M. D. Sarath Lionel and S. P. Ranasinghe for their wholehearted assistance in the field and the laboratory.

The authors: F. P. Amerasinghe is Theme Leader, Water, Health and Environment at IWMI; F. Konradsen was Environmental Health Biologist at IWMI and is now at the Department of International Health, University of Copenhagen, Denmark; W. van der Hoek was Theme Leader, Water, Health and Environment at IWMI and is now an IWMI Consultant based in the Netherlands; P. H. Amerasinghe is Head, Department of Molecular Biology & Biotechnology and Senior Lecturer, Department of Zoology, University of Peradeniya, Peradeniya, Sri Lanka; J. P. W. Gunawardena was an IWMI Research Assistant and is now an officer in the Sri Lanka Navy; K. T. Fonseka was an IWMI Research Assistant and is now in the Sri Lanka Foreign Service; and G. Jayasinghe is a Biostatistician at IWMI.

Amerasinghe, F. P., F. Konradsen, W. van der Hoek, P. H. Amerasinghe, J. P. W. Gunawardena, K. T. Fonseka and G. Jayasinghe. 2001. *Small irrigation tanks as a source of malaria mosquito vectors: A study in north-central Sri Lanka.* Research Report 57. Colombo, Sri Lanka: International Water Management Institute.

/ watersheds / tank irrigation / rehabilitation / malaria / waterborne diseases / vectors / data analysis / siltation / Sri Lanka / Huruluwewa /

ISBN 92-9090-461-5

ISSN 1026-0862

Please direct inquiries and comments to: *iwmi-research-news@cgiar.org*

Contents

Summary

Malaria causes human mortality, morbidity and economic loss, especially in tropical rural communities. The disease is transmitted by *Anopheles* mosquitoes whose larval stages breed in watery habitats such as those found in irrigation systems. Mosquitoes that transmit other diseases, as well as nuisance mosquitoes, may also breed in such habitats. A previous study in 1994 in the Upper Yan Oya watershed in the north-central dry zone of Sri Lanka indicated the high malariogenic potential of a small irrigation reservoir that forms part of a cascade irrigation system in the dry zone of Sri Lanka. The present work followed up on this finding, and investigated mosquito breeding in nine small irrigation reservoirs (known locally as "tanks") in the same watershed during 1995–1997. The objectives were to determine a) whether important malaria-vector mosquitoes breed in the tanks, b) tank characteristics that may enhance mosquito breeding, and c) rehabilitation and management measures that help reduce mosquito breeding opportunities in the tanks.

The investigation showed that the major *Anopheles* vector of malaria in Sri Lanka occurred infrequently in the tanks. However, important secondary vectors and others that are involved in malaria transmission did occur frequently. Thus tanks certainly contribute to the malaria risk in Sri Lanka. Additionally, they also generate *Aedes* and *Culex* mosquitoes that constitute a biting nuisance. Tanks varied considerably in characteristics such as the extent of the water margin, the vegetation cover of the margin and free water area, the degree of pooling and the extent of seepage. These characteristics could be expected to have impacts on mosquito breeding depending on the preferences of individual species. Not surprisingly, tanks also varied in their attractiveness as breeding habitats for different mosquito species.

All three major tank-related habitats (tank margins, tank-bed pools and seepage pools) provided breeding opportunities for different mosquitoes. Habitat characteristics such as water and light conditions, vegetation, and potential predators of mosquito larvae were determinants of mosquito occurrence. Based on detailed analyses, we provide a simplified schematic that serves as a guide to the species likely to occur in three major habitat types, under different sets of habitat conditions.

Tanks provide opportunities for mosquito breeding as a result of uneven spatial siltation (which creates shallow water pools), the presence of marginal, emergent and floating vegetation (which provides refuges), and seepage across the bund (which creates new breeding habitats). Selective desiltation to remove depressions, seepage proofing of tanks and the management of vegetation would reduce these opportunities. A further issue is the use of the tank bed for activities such as brick building and livestock wallowing during drier periods: these result in the creation of new tank-bed habitats that are exploited by mosquitoes. Thus, both rehabilitation and continuing management are necessary to maintain tanks in a condition in which they pose the minimum risk of generating disease-causing or nuisance mosquitoes that affect the lives and livelihoods of poor rural communities.

Small Irrigation Tanks as a Source of Malaria Mosquito Vectors: A Study in North-Central Sri Lanka

Felix P. Amerasinghe, Flemming Konradsen, Wim van der Hoek, Priyanie H. Amerasinghe, J. P. W. Gunawardena, K.T. Fonseka and G. Jayasinghe

Introduction

Malaria

Malaria is a disease that affects 300–500 million people every year in tropical countries (WHO 1999), killing 1–3 million and resulting in debility and lost economic productivity among survivors. The disease is caused by a single-celled parasite of the genus *Plasmodium* and transmitted from human to human by female mosquitoes of the genus *Anopheles*. Larval stages of mosquitoes occur in freshwater and, in some instances, in brackish water. In Sri Lanka, the major vector of malaria, *Anopheles culicifacies*, breeds mainly in pools formed in streams and riverbeds (see review by Konradsen et al. 2000). Other *Anopheles* species involved in malaria transmission breed in a variety of standing- and flowing-water habitats. In addition to *Anopheles*, other mosquitoes, such as those of the genera *Aedes* and *Culex,* also occur in such habitats and the females may transmit other diseases (e.g., filariasis, and arboviral infections such as Japanese encephalitis). At high abundance, the biting and buzzing activity of all these mosquitoes can constitute a nuisance hazard to humans and livestock, resulting in loss of blood and disturbed sleep.

The high-risk areas for malaria in Sri Lanka are located in the low-country dry zone. This is also the area where most of the irrigated rice is grown in the country, and malaria is a constant health hazard that farmers face. Because of its debilitating effects, the disease has a significant economic impact (Konradsen et al., *Household responses*, 1997; Konradsen et al., *Measuring the economic cost,* 1997) and contributes to the poverty of farmers.

Tank-Irrigation Systems

Since the fifth century B.C., the low-country dry zone of Sri Lanka has been populated by rice-based agricultural communities. As a result, the area is characterized by a network of irrigation systems called "cascades" consisting of reservoirs (known locally as "tanks") constructed to impound seasonal rainfall for the irrigation of rice and other crops. Tanks with an irrigation command area of 80 hectares or less are classified as "small tanks" (Panabokke 1999). Despite the construction of modern irrigation systems in the twentieth century, ancient small tank cascade systems (some partially renovated) still contribute significantly to rice production in the country. Roughly 8,000 of some 15,500 small tanks are estimated to be presently operational (Panabokke 2000), most of them located in the malarious low-country dry zone of Sri Lanka. The

Anuradhapura district in the highly malarious north-central province is estimated to contain approximately 1,870 functional small tanks (each with a command area<80 ha) and 1,170 abandoned tanks (Panabokke 1999). These tanks are located within village areas (close to human habitation) and, in addition to their primary function as a source of agricultural water, often serve as the main source of domestic and livestock water supplies to the villages. Whether functional or abandoned, tanks accumulate water during the rainy season and are a potential breeding source for disease-transmitting and nuisance mosquitoes.

Theme of the Study

A recent IWMI case study on malaria at a village within the Upper Yan Oya watershed that feeds the Huruluwewa reservoir in the dry zone of Sri Lanka showed the potential for breeding of malaria vectors in the village irrigation tank, which formed part of the tank cascade system in the watershed (Amerasinghe et al. 1997). As expected, a large proportion (37.6%) of the larvae of the main malaria vector, *Anopheles culicifacies*, occurred in a nearby stream, but unexpectedly, 52.1 percent of larvae occurred in pools formed on the tank bed. There was a temporal progression of breeding from the stream to the tank bed, thereby increasing the population size of the vector and extending the transmission season. A very recent study on malaria risk mapping in the Walawe basin of Sri Lanka also pointed to abandoned irrigation tanks as a potential source of malariogenic mosquitoes (Klinkenberg 2001).

Important questions arise from these outcomes: Are irrigation tanks likely to play a major role in initiating or sustaining malaria outbreaks? What features of tanks create the largest potential for vector breeding? What is the scope for interventions? There was a need to obtain more information on the importance of tanks for mosquito breeding in general and malaria vector breeding in particular. More generally, there is a paucity of published studies relating to mosquito breeding in irrigation tanks in south Asia, although other irrigation-associated habitats such as rice fields have received extensive coverage in south Asia (e.g., Reuben 1971; Amerasinghe 1993) and internationally (reviewed by Lacey and Lacey 1990). A few studies in Sri Lanka have touched on irrigation tanks (e.g., Amerasinghe and Ariyasena 1990; Amerasinghe and Indrajith 1994; Amerasinghe et al. 1997) in the course of more general mosquito breeding surveys in irrigation systems, but no intensive investigations have been done on the role of irrigation tanks in generating disease vectors. Thus, the objectives of the present study were to determine a) whether important malaria-vector mosquitoes breed in the tanks, b) tank characteristics that may enhance mosquito breeding, and c) rehabilitation and management measures that may help reduce opportunities for mosquito breeding in the tanks. The present report attempts to explore these issues, examining irrigation tanks holistically, to include the tank proper as well as tank-bed pools and surface-water accumulations resulting from seepage across the tank bund.

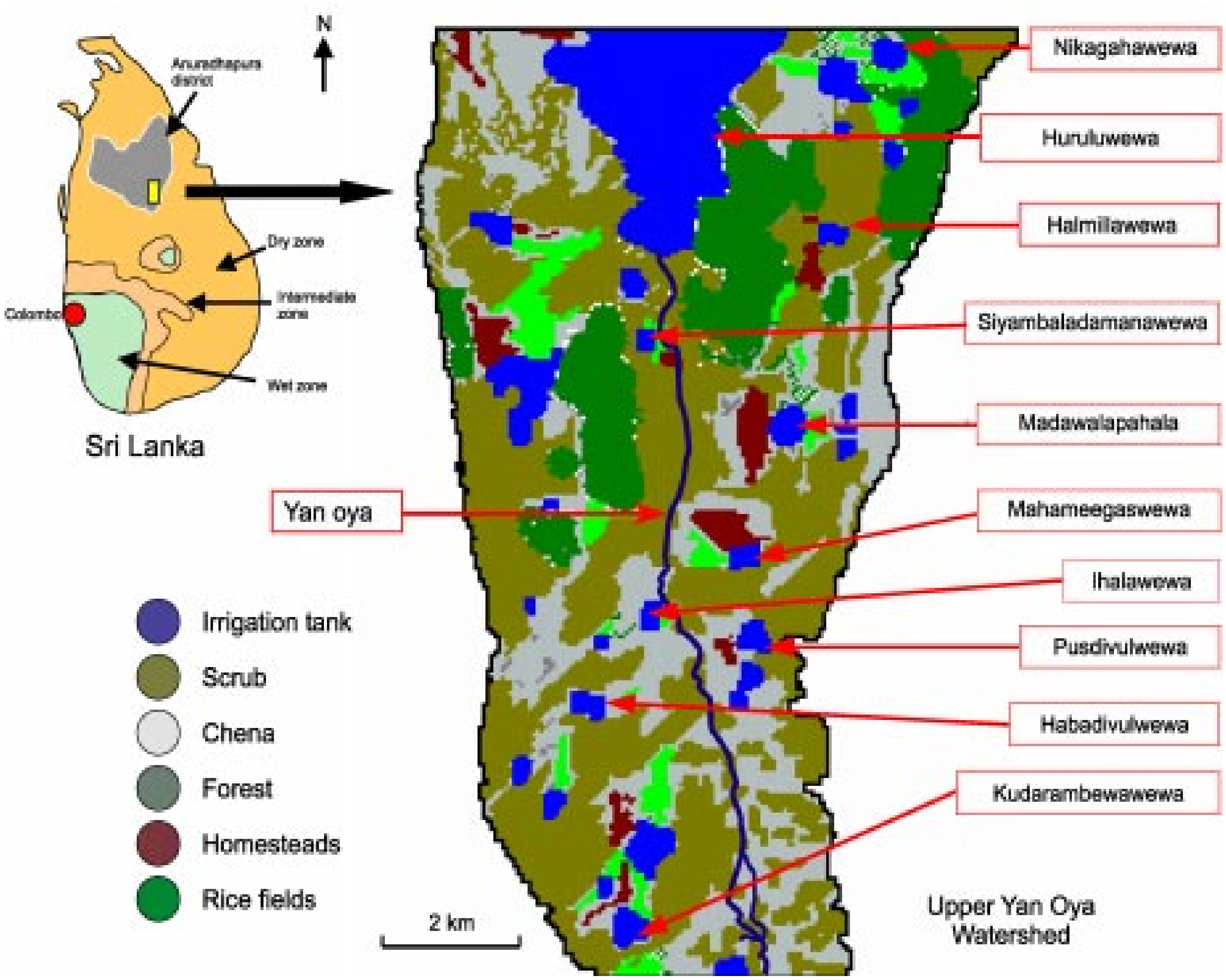
Methodology

Upper Yan Oya Watershed

The Upper Yan Oya watershed is located south of the Huruluwewa reservoir in the Anuradhapura district in the dry zone of north-central Sri Lanka. It consists of degraded, dry, evergreen, tropical secondary forestland and scrubland within which are located villages of varying sizes, each with 20–400 inhabitants. Within the watershed are located 14 small tank cascades (Panabokke 1999) that provide water for irrigated rice cultivation, livestock, and domestic use. The complex of tank cascades eventually feeds into the large Huruluwewa reservoir (7,500-ha capacity) (figure 1).

FIGURE 1.

Study area in the low-country dry zone of north-central Sri Lanka, indicating land use patterns and sampled small irrigation tanks.



Study Tanks

Six irrigation tanks were selected for the study commencing in October 1995. They were the Madawalapahalawewa (MPW), Halmillawewa (HMW), Pusdivulwewa (PDW), Kudarambewawewa (KRW), Habadivulwewa (HDW) and Nikagahawewa (NGW). In May 1996, sampling in three tanks (KRW, HDW and NGW) was discontinued, three additional tanks were included, and sampling was continued until December 1997. The new tanks were the Ihalawewa (IHW), Mahameegaswewa (MGW) and Siyambaladamanawewa (SDW) (figure 1). Tanks were selected on the basis of location along a north-south axis within the watershed. Selected tanks were arbitrarily sized into two classes: small (<15-ha maximum water-spread area) and large (>15 ha). The first survey period (October 1995–April 1996) included two small- and four large-sized tanks. The second period (May 1996–December 1997) included four small- and two large-sized tanks.

Survey of Tank Characteristics

The following selected physical and biological characteristics of the tanks were recorded at fortnightly intervals: a) the water level (in meters) was measured at the gauge located at the outlet of each tank; b) the water-spread area was estimated by eye, as a percentage of the maximum possible area under water; c) the width (in meters) of the area along the water margin that contained water pools was measured; d) the number of water pools on the tank margin and tank bed was recorded, together with the dominant type of pool (i.e., animal footprint, borrow pit, hunting pit, natural pool); e) the percentage of water area covered by emergent and surface vegetation was estimated by eye; f) the extent of the tank margin covered by vegetation was estimated as a percentage of the total length of the tank water margin; g) the width (in meters) of the seepage area below the tank bund was measured; and h) the degree of seepage area covered by surface or standing vegetation was estimated by eye as a percentage of the total seepage area.

Survey of Mosquitoes

There are many ways of classifying mosquito-breeding habitats, based on size, location, method of formation, characteristics of the water (flowing/standing), vegetation, fauna, etc. In the present instance, the habitat has been classified from a water-management perspective: tanks are a well-defined entity within irrigation systems, and are one of several macro-habitat types available (others are, for example, rice fields and canals). Three tank-associated sub-habitats that can be easily recognized by a layman are defined here: *tank margins*, where shallow water and vegetation provide mosquito-breeding habitats, *water pools on the tank bed* formed during the dry period when the water level is low, and water accumulations in *seepages* below the tank bund.

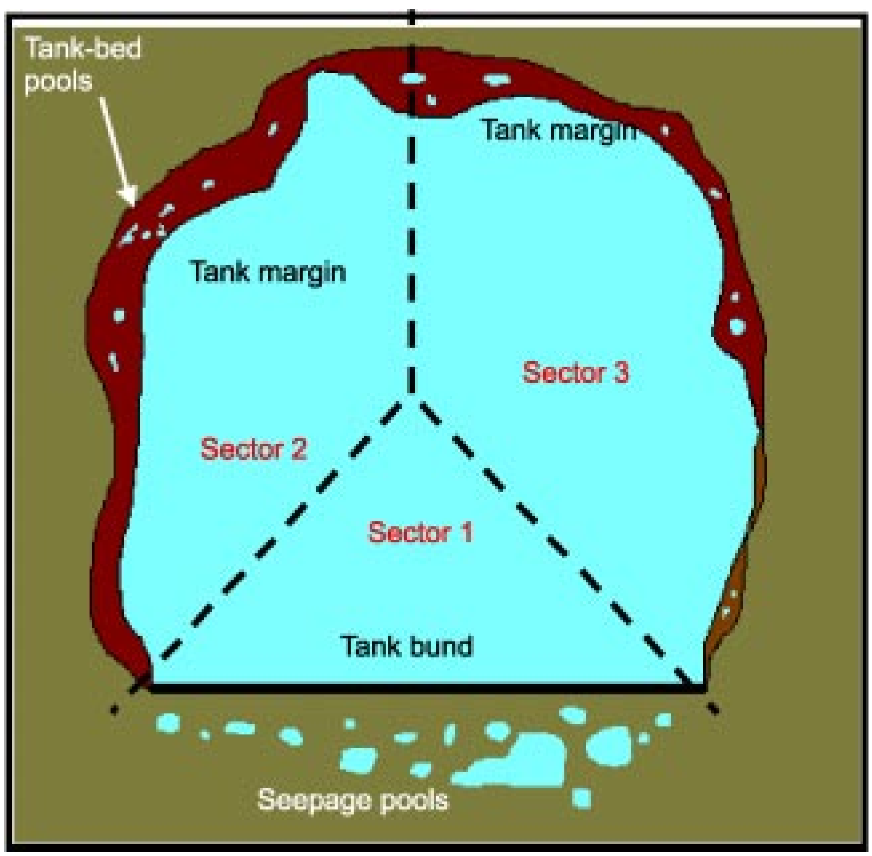
Mosquitoes were collected by a standard dipping technique using 350 ml dippers (similar in appearance to a large soup ladle), as described previously (Amerasinghe et al. 1997). Dipping was done at the rate of 6 dips per square meter of water surface. Small pools (<10 m^2 area of water surface) were dipped according to area. Larger pools and tank margins were sampled by dipping 0.5x10 m quadrats.

A maximum of 50 water pools on the tank bed ("tank-bed pool" samples) and 20 water pools below the tank bund ("seepage pool" samples) were sampled from each tank on each sampling occasion. The tanks proper were sampled only along their shallow margins ("tank margin" samples), as immature stages of mosquitoes do not usually occur at a free water depth greater than 1 m. For purposes of sampling the margins, each tank was divided into three sectors as illustrated in figure 2, with Sector-1 having the tank bund as its margin, and Sectors-2 and -3 located to the left and right, respectively. A maximum of 30 samples from the margins of each "small" tank and 50 samples from the margins of each "large" tank were taken on each sampling occasion, assuming that tanks were at 100 percent capacity. Samples were divided equally between the three designated sectors to ensure an even spread of sampling. When less water was present, the extent of water cover was estimated, and the number of samples to be taken was adjusted accordingly (i.e., if a small tank was estimated to be 50 percent filled, only 15 samples were taken, divided equally between the three sectors; in the case of a large tank at 50 percent capacity, 25 samples were divided between the three sectors in the ratio 9:8:8). This strategy was adopted to adjust sampling intensity to the size of tanks and to fluctuations in the extent of their water cover.

Mosquito larvae and pupae in each sample were identified to species in the case of *Anopheles* mosquitoes, and to genera in other cases, using taxonomic keys (Amerasinghe 1992, 1995). Samples were characterized by site, substratum, exposure to sunlight (scored as exposed, partially shaded or fully shaded), condition of the water (scored as clear, turbid or foul), presence and types of vegetation (scored as marginal grasses and herbs, algae, aquatic plants, and decaying vegetation), and presence and types of macrofauna (scored as fish, predatory insects and other fauna).

FIGURE 2.

Division of tanks into sectors for sampling.



Data Analyses

Basic data on mosquito occupation of potential breeding habitats are reported for the entire study period. Preliminary analyses indicated that the three tanks (HMW, MPW and PDW) common to both study periods had different physical and biological characteristics during the two study periods. They were thus considered as separate entities for purposes of analysis, labeled as HMW-A, MPW-A and PDW-A for the 1995/96 dataset and HMW-B, MPW-B and PDW-B for the 1996/97 dataset. The combined datasets for the two study periods thus consisted of 12 "tanks."

Statistical analyses were done using SPSS release 8.02 (SPSS© Inc. 1989–1997). Data relating to the physical and biological characteristics of the tanks approximated to normality, but variances were unequal, and were not improved by data transformations. Thus, statistical comparisons were done by analysis of variance (ANOVA) followed by Dunnett multiple comparisons tests, assuming unequal variance. Temperature effects in different tanks, habitats and light conditions were analyzed using a GLM full factorial model with the main effects as fixed factors.

Mosquito occurrence in different tanks was compared by logistic regression analyses, using the HDW as the reference tank. Results are reported as Odds Ratios (OR) and their 95 percent confidence limits. The selection of the reference tank was based on the outcome of the analyses of tank characteristics where the tank with the greatest water-holding capacity, as indexed by the largest mean percentage water-spread area and the highest mean water level at the outlet, was selected.

Relationships between mosquito occurrence and the characteristics of breeding habitats were also analyzed by logistic regression and results are reported as Odds Ratios (OR) and their 95 percent confidence limits. Predicted probabilities of the occurrence of species under different conditions were obtained from these analyses. A simplified schematic of likely mosquito occurrence under combinations of different conditions (habitats, light, water, vegetation and predators) was derived from these analyses. Only potential vector species with a probability of occurrence of $\geq$10 percent in any combination of habitat characters are included in this schematic.

Results and Discussion

Tank Characteristics

Three tanks, HMW, MPW and PDW, were common to both study periods. Some characteristics of these three tanks differed sharply in the two study periods. For instance, the width of the seepage area and percentage vegetation cover of seepage area of each tank differed significantly (independent samples t-test, $P<0.01$) in the two study periods. The mean water level at the outlet differed in HMW and in MPW ($P<0.01$), and the mean number of tank-bed pools differed in HMW ($P<0.01$). Thus, as mentioned previously, the 1995/96 and 1996/97 datasets for these three were considered as separate "tanks" in the combined analyses.

There were significant differences between tanks in respect of the eight physical and biological characteristics measured (table 1). Salient points to be noted are as follows:

TABLE 1.

Comparisons of physical and biological characteristics of tanks.

Parameter	MPW-A	PDW-A	HMW-A	KRW	HDW	NGW	MPW-B	PDW-B	HMW-B	MGW	IHW	SDW
Maximum water-spread area (ha)	26.1	17.1	14.1	25.4	16.3	9.3	26.1	17.1	14.1	13.8	7.8	4.5
Mean % water-spread area	31.6 ± 19.6^{abc}	31.6 ± 20.6^{abc}	23.4 ± 23.0^{bcd}	29.2 ± 16.0^{bc}	55.3 ± 27.8^{a}	10.9 ± 6.1^{d}	39.0 ± 28.1^{ab}	33.5 ± 26.9^{abc}	12.5 ± 20.7^{cd}	38.1 ± 23.6^{ab}	28.5 ± 25.2^{abc}	25.5 ± 29.3^{bcd}
Mean water level at outlet (m)	0.6 ± 0.4^{ab}	0.3 ± 0.5^{bcd}	0.2 ± 0.5^{bcd}	0.3 ± 0.2^{bc}	1.1 ± 0.6^{a}	-0.088 ± 0.3^{de}	0.089 ± 0.3^{cd}	0.2 ± 0.4^{bcd}	-0.4 ± 0.4^{e}	0.3 ± 0.2^{bc}	0.006 ± 0.4^{cde}	0.089 ± 0.7^{bcde}
Mean margin width with pools (m)	43.3 ± 26.5^{ab}	38.1 ± 49.3^{abcd}	57.8 ± 37.9^{a}	19.8 ± 20.6^{bc}	0.5 ± 2.2^{d}	35.1 ± 8.1^{abc}	33.3 ± 23.2^{ab}	28.1 ± 28.4^{ab}	61.3 ± 54.6^{ab}	32.8 ± 25.4^{ab}	20.2 ± 22.6^{bc}	6.5 ± 9.1^{cd}
Mean no. of tank-bed pools	34.7 ± 22.5^{abc}	13.8 ± 13.1^{abcde}	16.6 ± 13.4^{abc}	3.6 ± 3.8^{ef}	0.5 ± 2.2^{f}	35.7 ± 24.3^{a}	19.2 ± 14.6^{ab}	11.5 ± 9.9^{bcd}	7.1 ± 7.2^{cde}	11.9 ± 10.7^{bcd}	7.6 ± 1.7^{bcde}	3.8 ± 8.1^{def}
Mean % vegetation cover, water area	31.3 ± 20.6^{ab}	45.8 ± 21.9^{a}	36.2 ± 25.6^{ab}	37.1 ± 22.8^{a}	13.3 ± 13.6^{bc}	37.4 ± 27.2^{ab}	34.5 ± 29.5^{ab}	44.7 ± 29.0^{a}	38.8 ± 39.5^{ab}	9.9 ± 11.6^{c}	54.8 ± 30.2^{a}	33.0 ± 31.0^{ab}
Mean % water margin with vegetation	57.8 ± 37.2^{abcd}	56.7 ± 32.2^{bcd}	61.0 ± 25.7^{bc}	65.7 ± 36.6^{abc}	29.1 ± 27.0^{d}	69.7 ± 38.8^{abc}	55.1 ± 42.6^{abcd}	73.8 ± 30.9^{ab}	45.3 ± 46.6^{bcd}	53.1 ± 36.7^{bcd}	87.4 ± 24.7^{a}	38.2 ± 42.0^{cd}
Mean width of seepage area (m)	19.8 ± 5.3^{a}	16.1 ± 9.7^{ab}	12.1 ± 8.5^{abc}	15.7 ± 9.3^{ab}	21.4 ± 18.4^{a}	2.8 ± 5.3^{de}	8.3 ± 9.3^{bcd}	3.4 ± 6.5^{de}	3.6 ± 7.8^{de}	4.2 ± 7.6^{cde}	0.6 ± 1.9^{e}	1.2 ± 2.7^{e}
Mean % vegetation cover, seepage area	68.8 ± 21.8^{a}	56.4 ± 34.1^{ab}	48.1 ± 27.5^{ab}	56.2 ± 33.6^{ab}	51.9 ± 21.8^{ab}	15.8 ± 31.2^{c}	25.9 ± 30.7^{bc}	12.4 ± 25.8^{c}	10.3 ± 23.8^{c}	9.4 ± 17.5^{c}	11.6 ± 27.4^{c}	15.7 ± 32.5^{c}

Notes: Standard Deviations are provided for each mean value. Different superscripts after means indicate significant differences (P< 0.05). HDW = Habadivulwewa; HMW-A = Halmillawewa in 1995/96; HMW-B = Halmillawewa in 1996/97; IHW: Ihalawewa; KRW = Kudarambewawewa; MPW-A = Madawalapahalawewa in 1995/96; MPW-B = Madawalapahalawewa in 1996/97; MGW = Mahameegaswewa; NGW = Nikagahawewa; PDW-A = Pusdivulwewa in 1995/96; PDW-B = Pusdivulwewa in 1996/97; SDW = Siyambaladamanawewa (based on ANOVA and Dunnett tests assuming unequal variance).

- HDW came out as the tank with the "best" characteristics in terms of water retention (as indexed by water-spread area and outlet water level), the minimum pooling (as indexed by the margin width with pools and number of pools), and the least vegetation (as indexed by vegetation cover of water area and margin). However, this tank also provided the largest seepage area and a high degree of vegetation cover in the seepage area below the bund, indicating a steady leakage of water through the bund.

- In contrast, the NGW tank showed the least water-retention capacity, the greatest degree of pooling and high levels of aquatic and marginal vegetation, whilst also showing a small seepage area below the bund and low vegetation in this seepage area. It is possible that the poor water-holding capacity of this tank contributed to the low seepage area parameters.

- Other tanks had intermediate characteristics. For instance, MGW came out as a tank with a high water-spread area and water-level characteristics, low water-area vegetation, and moderate levels of pooling and seepage characteristics. In contrast, HMW-B showed low water-holding capacity, moderate tank vegetation and low seepage extent and vegetation characteristics. Although a wide tank margin was available for pooling, actually a few pools were recorded.

Characteristics such as the extent of the water margin, the vegetation cover of the margin and free water area, degree of pooling, and degree of seepage could be expected to have impacts on mosquito breeding depending on the preferences of individual species.

Mosquito Occurrence in Tanks

Overall, 53.6 percent of samples of potential breeding habitats were mosquito-positive (range 42.3–65.5% in individual tanks), and 39.9 percent were positive for mosquito larvae of the genus *Anopheles* (range 17.4–51.4 in individual tanks) (details in appendix A). Altogether 56,805 mosquito larvae were collected, of which 27.9 percent were *Anopheles*, 36.9 percent *Aedes* and 35.2 percent *Culex* (table 2). Fourteen species of *Anopheles* mosquitoes were identified. Four of them (*An. aconitus, An. culicifacies, An. maculatus* and *An. tessellatus*) were encountered only occasionally; one of these (*An. culicifacies*) is the major vector of malaria in Sri Lanka (Konradsen et al. 2000). However, species encountered more frequently, such as *An. annularis* and *An. subpictus* are recognized as important secondary vectors (Amerasinghe et al. 1991; Ramasamy et al. 1992), while species such as *An. barbirostris, An. nigerrimus, An. pallidus, An. peditaeniatus, An. vagus* and *An. varuna* have been implicated in malaria transmission in the country (Amerasinghe et al. 1991, 1992, 1994, 1999; Mendis et al. 1990, 1992). Among the *Culex* and *Aedes* mosquitoes were also potential vectors of viral diseases. In addition, several species of *Anopheles*, and *Culex* and *Aedes* mosquitoes in general, can also be considered as nuisance mosquitoes because of their frequent biting activity (table 2).

TABLE 2.

Species and numbers and importance of mosquitoes collected from irrigation tanks (1995–97).

Species	Total	Percentage	Major Malaria Vector	Secondary Vector	Involved in Malaria Transmission	Potential Viral Disease Vector	Nuisance Mosquito
An. aconitus	06	0.01	—	—	+	—	—
An. annularis	833	1.5	—	+	+	—	—
An. barbirostris	1,622	2.9	—	—	+	—	—
An. barbumbrosus	4,412	7.8	—	—	—	—	—
An. culicifacies	16	0.03	+	—	+	—	—
An. jamesii	1,088	1.9	—	—	—	—	—
An. maculatus	02	0.004	—	—	—	—	—
An. nigerrimus	928	1.6	—	—	+	—	—
An. pallidus	2,031	3.6	—	—	+	—	—
An. peditaeniatus	848	1.5	—	—	+	—	+
An. subpictus	1,383	2.4	—	+	+	+	+
An. tessellatus	14	0.02	—	—	+	—	—
An. vagus	2,093	3.7	—	—	+	—	+
An. varuna	320	0.6	—	—	+	—	—
Anopheles spp (unidentified)	241	0.4	—	—	—	—	—
Aedes spp	20,947	36.9	—	—	—	+	+
Culex spp	20,021	35.2	—	—	—	+	+
Total	56,805	100.0					

Based on statistical analyses (details in appendix B) table 3 presents a simplified schematic of the occurrence of mosquitoes in different tanks. HDW was used as the reference tank for the logistic analysis. This tank had the greatest mean water-spread and seepage area, and the least pooling and vegetation among all tanks studied. Overall, the reference tank was in an intermediate position in relation to *Anopheles* breeding, with other tanks having more or less occurrences depending on the species (table 3). The tanks varied considerably in their attractiveness as breeding habitats for individual species of mosquitoes. A comparison of the tank set surveyed in both years (HMW-A/B, MPW-A/B and PDW-A/B) shows that most mosquito species fluctuated widely in the two sampling periods (appendix B), indicating the transient nature of conditions that favored one or the other species in a particular tank.

TABLE 3.

Occurrence of mosquitoes in different tanks.

Mosquito Species	Reference Tank	Other Tanks
An. annularis	+	+ / + +
An. barbirostris	+ +	+ / + +
An. barbumbrosus	+ +	+ / + +
An. jamesii	+ +	+ / + + / + + +
An. nigerrimus	+	+ / + +
An. pallidus	+	+ / + +
An. peditaeniatus	+ +	+ / + +
An. subpictus	+	+ / + +
An. vagus	+ +	+ / + + / + + +
An. varuna	+	+ / + +
Aedes spp	+	+ / + +
Culex spp	+ +	+ / + +

Note: Based on statistical analyses presented in appendix B.

Characteristics of Mosquito-Breeding Habitats

Seepage pools, tank-bed pools and tank margins were the three major habitat types surveyed in the study. The substratum consisted mainly of mud (92.3% of all samples) with sand (0.9%), rock (0.1%) and combinations of the three (6.7%) constituting the balance. Water temperature ranged from 20.0 to 41.0 °C. The GLM full factorial analysis showed that temperature was significantly ($P< 0.05$) related to the main effects of tanks, habitats and light conditions but interactions between these were highly significant ($P< 0.001$). Thus water temperatures varied depending on the interplay between light and shade in the different habitat types and tanks. When the main effects of habitat and light were considered alone, the temperature sequence was tank-bed pools>tank margins>seepage pools and sun-exposed> partially shaded>fully shaded habitats. Table 4 presents a summary of light and water conditions in the three habitat types (based on tank-related details provided in appendix C).

The main results are as follows:

- The tank margin and tank-bed pool habitat produced a heavy preponderance of fully exposed samples except at the HDW. Conditions in the seepage areas were more varied, with a mixture of exposed, semi-shaded and fully shaded habitats except at NGW (mostly partially shaded) and SDW (mostly fully exposed).
- In terms of quality, clear and turbid water predominated overall, with obviously foul water being encountered infrequently in all habitats and tanks.
- Extensive vegetation was present in all tanks and related pooled habitats (summary in table 5, details in appendix D).

TABLE 4.

Summary of light and water conditions in different habitats.

Habitat	Light			Water		
	Exposed	Partial Shade	Full Shade	Clear	Turbid	Foul
Seepage pool	51.4 ± 22.5	37.8 ± 23.5	10.8 ± 9.4	74.9 ± 18.2	22.2 ± 19.7	2.9 ± 4.2
Tank-bed pool	96.0 ± 3.8	2.8 ± 2.4	1.2 ± 1.9	57.3 ± 23.3	42.3 ± 23.4	0.4 ± 0.4
Tank margin	81.9 ± 21.7	13.7 ± 15.9	4.4 ± 6.8	81.5 ± 14.1	17.4 ± 14.1	0.1 ± 0.3

Note: Values are mean percentages ± SD of samples positive for the character, based on all the tanks studied.

TABLE 5.

Summary of vegetation and fauna in different habitats.

Habitat	Vegetation						Fauna			
	Absent	Grass	Herbs	Algae	Aq. Plants	Dead veg.	Absent	Fish	Insect	Other
Seepage pool	3.3 ± 4.6	83.6 ± 18.1	11.5 ± 10.3	6.3 ± 6.9	6.9 ±11.0	55.2 ±21.8	23.6 ± 25.6	38.8 ± 24.1	19.5 ±12.6	41.3 ± 28.6
Tank-bed pool	23.6 ± 23.4	61.8 ± 18.9	19.5 ± 14.4	9.4 ± 6.3	19.6 ± 9.8	14.9 ±12.2	42.0 ± 24.9	18.2 ± 12.6	28.9 ± 15.9	20.5 ± 10.5
Tank-margin	3.3 ± 2.5	74.9 ± 20.6	32.7 ± 14.8	11.6 ± 6.4	44.7 ± 26.0	37.5 ± 27.2	27.1 ± 28.3	66.8 ± 33.1	12.2 ± 8.9	25.8 ± 19.2

Notes: Values are mean percentages ± SD of samples positive for the character, based on all the tanks studied. Aq. plants = Aquatic plants; Dead veg. = Dead vegetation.

However, tanks and tank-related breeding habitats differed in the relative degrees of different types of vegetation as follows:

- Grasses and herbs of various types constituted the predominant marginal vegetation in all three habitat types, occurring at a combined frequency>50 percent except at HDW (all habitat types), and in tank-bed pools at the KRW tank.

- Aquatic vegetation, classified as algae and aquatic plants, was common in most tank margin and tank-bed pool samples, except at HDW. In seepage pools, this vegetation occurred frequently only at HMW and MPW, an indication of semipermanent seepage areas related to these two tanks.

- Decaying vegetation predominated only in the seepage pools and margin samples at HDW.

- Vegetation was absent to any marked degree only in tank-bed pools at HDW and KRW.

Tanks also varied in respect of the presence or absence of other aquatic fauna associated with mosquito larvae (summary data in table 5, details in appendix D) with tanks such as HDW, NGW, KRW, IHW, MGW and SDW showing high proportions of samples without fauna. When present, fauna could be further subclassified into potential predators of mosquito larvae (fish and predatory insects such as dragonfly and damselfly larvae, water beetles and water bugs), and non-predators (classified as “other” fauna). Fish were the more frequent of the potential predators found in the samples of tank margins and seepage pools. However, predatory insects rivaled fish in frequency of occurrence in the tank-bed pool habitat of most tanks.

Mosquito Occurrence in Relation to Characteristics of Tank Habitats

The results of multivariate logistic regression analyses of mosquito occurrence in relation to the three major habitats, and selected habitat characteristics are detailed in appendix E, and presented in summary form in table 6. All species showed differences in habitat occupation (controlling for all other factors), occurring at significantly higher or lower frequencies than at the tank margins used as the reference. The results can be summarized as follows:

TABLE 6.

Summary of relationships between mosquitoes and habitat characteristics based on multiple logistic regression analyses.

Species	Habitat Order	Water	Light	Vegetation	Predator
An. annularis	TNK/TBP/SPP	+[C]	+[E]	0	+
An. barbirostris	TNK/SPP/TBP	0	+[S]	+	+
An. barbumbrosus	SPP/TNK/TBP	0	+[E]	0	+
An. jamesii	TBP/TNK/SPP	+[C]	+[E]	−	+
An. nigerrimus	TNK/SPP/TBP	0	0	+	0
An. pallidus	TNK/TBP/SPP	+[T]	+[E]	+	−
An. peditaeniatus	SPP/TNK/TBP	+[C]	0	+	+
An. subpictus	TBP/SPP/TNK	+[T]	0	−	−
An. vagus	TBP/SPP/TNK	+[T]	0	−	+
An. varuna	TNK/SPP/TBP	+[C]	0	−	−
Aedes spp	TBP/SPP/TNK	+[C]	0	−	−
Culex spp	SPP/TBP/TNK	+[C]	+[S]	+	+

Notes: + = Significant positive association; − = Significant negative association; 0 = No significant association; SPP = Seepage pools; TBP = Tank-bed pools; TNK = Tank margins; C = Clear; T = Turbid/Foul; E = Exposed; S = Shaded.

- *Anopheles subpictus, An. vagus, Aedes* spp and *Culex* spp showed a strong trend towards breeding in pools (seepage and tank bed) in preference to the tank margins. However, *An. barbumbrosus* appeared to be more selective, breeding at greater frequency in seepage pools but at lower frequency in tank-bed pools, when compared to tank margins.

- Other species occurred at significantly higher frequency in tank margins than in tank-bed pools (*An. barbirostris,* and *An. peditaeniatus*), or seepage pools (*An. annularis, An. jamesii* and *An. pallidus*), or both types of pools (*An. nigerrimus*).

Tank-bed pool types are of particular importance because they often reflect human and livestock activities. Based on an examination of 3,769 such pools, it was estimated that 60.1 percent were borrow pits resulting from the removal of earth for various human uses such as brick building and strengthening of tank bunds; 3.5 percent were pits used to hunt wild animals at night; 4.4 percent were animal footprints, both domestic and wild; and 32.1 percent were natural depressions on the tank bed.

The analysis of characteristics of breeding habitats (summary in table 6, details in appendix E) provided insights into factors that may affect mosquito breeding in these habitats. Two important breeding determinants were crude water quality and light conditions:

- *Anopheles annularis* and *An. jamesii* favored clear water and sun-exposed conditions; *Culex* spp preferred clear water and shaded conditions; and *An. pallidus* favored turbid water and sun-exposed conditions.

- One or the other of these factors was favored by other species but not both, viz., clear water by *An. peditaeniatus, An. varuna* and *Aedes* spp, turbid water by *An. subpictus* and *An. vagus*, exposed conditions by *An. barbumbrosus* and shade by *An. barbirostris*.

- No significant association with water or light was evident in *An. nigerrimus*.

Vegetation and potential mosquito predators (such as fish, dragonfly and damselfly larvae, water beetles and water bugs) were the biological parameters monitored. The following trends were evident:

- Species such as *An. barbirostris, An. nigerrimus, An. pallidus, An. peditaeniatus* and *Culex* spp were significantly positively associated with vegetation, whereas *An. jamesii, An. subpictus, An. vagus, An. varuna* and *Aedes* spp primarily occurred in the absence of vegetation. No significant association was evident for *An. annularis* and *An. barbumbrosus*.

- *Anopheles annularis, An. barbirostris, An. barbumbrosus, An. jamesii, An. peditaeniatus, An. vagus,* and *Culex* spp were significantly associated with the presence of predators, while *An. pallidus, An. varuna* and *Aedes* spp were significantly negatively associated. *Anopheles nigerrimus* showed no significant relationship with predators.

In general, significant positive associations between predators and prey (in this case the mosquito immature stages) can be interpreted to be indicative of stable predator-prey relationships (Southwood 1966). In the present instance, this was seen for the above-mentioned six *Anopheles* species and the *Culex* spp. Significant negative associations with predators (seen in three *Anopheles* species and *Aedes* spp) can be indicative of nonassociation due to different habitat requirements, or of rapid and complete elimination of the prey by the predators so that effectively, they are nonassociated at the time of sampling.

Conclusions

Malaria Vectors

The study demonstrated that the major malaria vector in Sri Lanka (*An. culicifacies*) did not occur frequently in the small irrigation tanks studied. Secondary malaria vectors and others involved in malaria transmission to a lesser degree did occur in abundance. The study at Mahameegaswewa village (Amerasinghe et al. 1997) demonstrated that at least some tanks could, sporadically and under certain conditions, be involved in generating large numbers of the major malaria-vector mosquitoes that then mediated disease outbreaks (Amerasinghe et al. 1999). More recently, abandoned tanks have been shown to be a possible factor in highly malarious areas of the Walawe basin (Klinkenberg 2001). Thus, the potential for the involvement of tanks in malaria outbreaks does exist. The precise conditions under which such an event would occur remain unresolved at present. However, the malariogenic potential of tanks would certainly be enhanced by the conditions in nearby streams and canals that generate important vectors that would, in turn, "spillover" into breeding in the tanks. Thus, factors such as rainfall and water withdrawal can have important consequences for vector breeding in these tank-stream systems.

The study demonstrated conclusively that tanks provide suitable conditions for the breeding of several *Anopheles* mosquitoes that are established secondary vectors of malaria, or are known to have some involvement in malaria transmission. In addition, tanks generate *Anopheles, Aedes* and *Culex* mosquitoes of nuisance importance to humans, livestock and other domestic animals. Thus, tanks can be considered to make a significant contribution to the maintenance of disease and discomfort in poor rural communities in the dry zone of Sri Lanka.

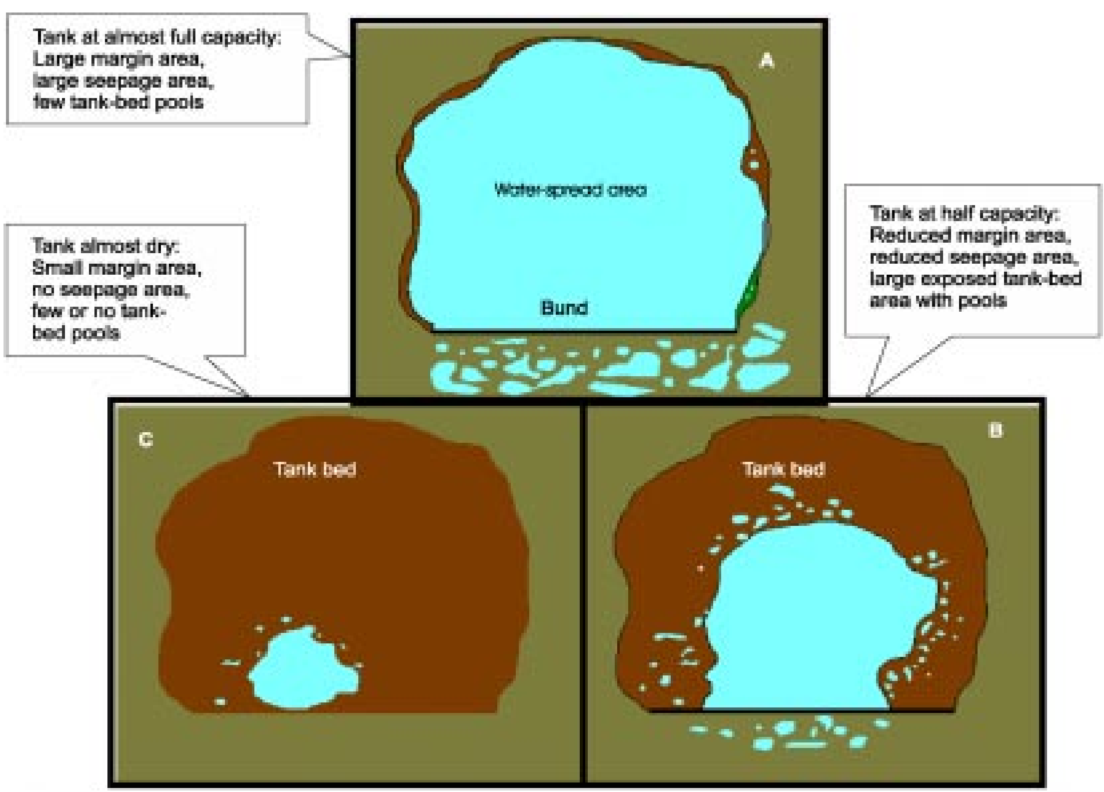
Mosquito-Breeding Schematic

Based on the analyses described previously, the following simplified schematic of mosquito breeding in irrigation tanks can be presented:

- Irrigation tanks typically undergo an annual cycle of filling and drying, providing different opportunities for mosquito breeding in terms of available habitats. At full capacity, the major habitats available are shallow water areas at the tank margin and seepage areas below the tank bund (figure 3A). As the tank dries, tank-bed pools also become available (figure 3B). When

FIGURE 3.

Potential mosquito-breeding habitats at different phases in the annual cycle of an irrigation tank.



water levels are severely depressed, seepage areas dry out completely, as do most of the tank-bed pools. Only a small area of the tank margin is potentially available as a habitat for mosquito breeding (figure 3C). In reality, however, the concentration of other fauna within a very small volume of water and the resultant mortality and putrefaction of dead creatures make the water almost completely unsuitable for the breeding of malaria-vector mosquitoes.

Depending on the type of habitats available, it is possible to provide a broad assessment of the type of potential malaria vectors that are likely to be found breeding in the different habitats (figure 4).

- Prediction of the potential malaria-vector species likely to be present in the major tank-associated habitat types can be further narrowed by considering some of the easily observable habitat characteristics such as water condition, light, vegetation and predators. The schematic presented (figure 5) is based on the calculation of predicted probabilities of occurrence of each species in different combinations of habitat characteristics (details in appendix F). The predicted probability level (≥10%) used as the criterion for inclusion is arbitrary, but provides a practical framework on which to evaluate the potentialities for the occurrence of different species. It does not exclude the

FIGURE 4.

Simplified schematic of potential malaria vectors likely to be associated with different components of the irrigation tank ecosystem. Asterisks indicate major habitats for species.

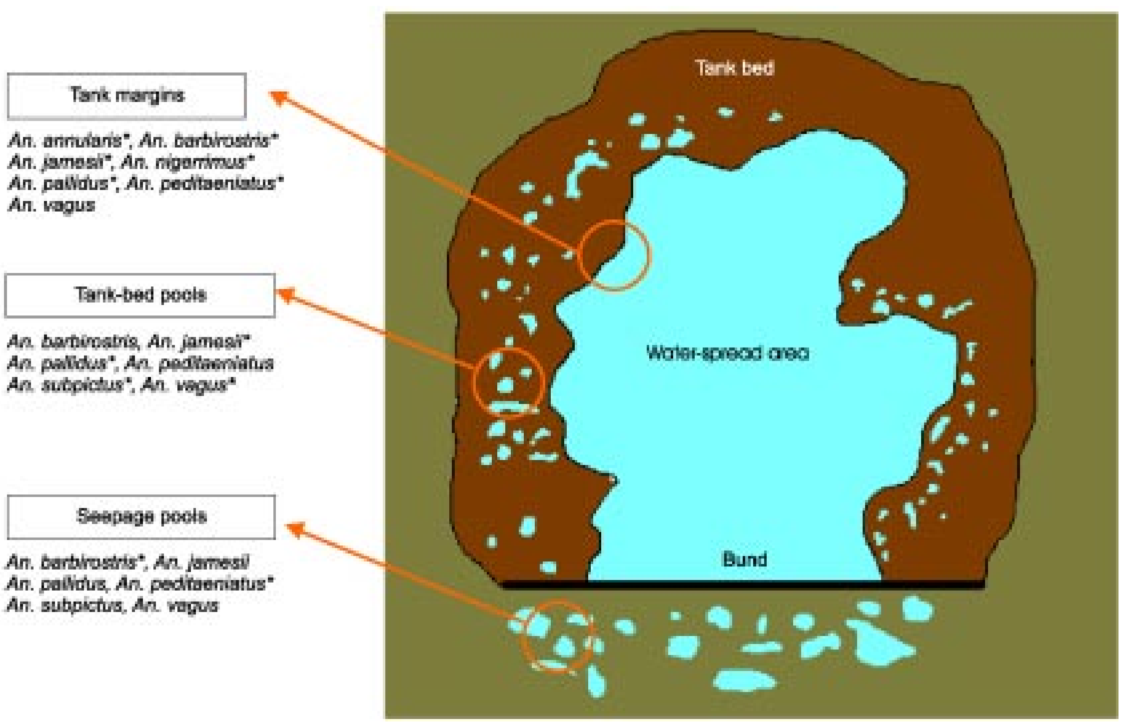
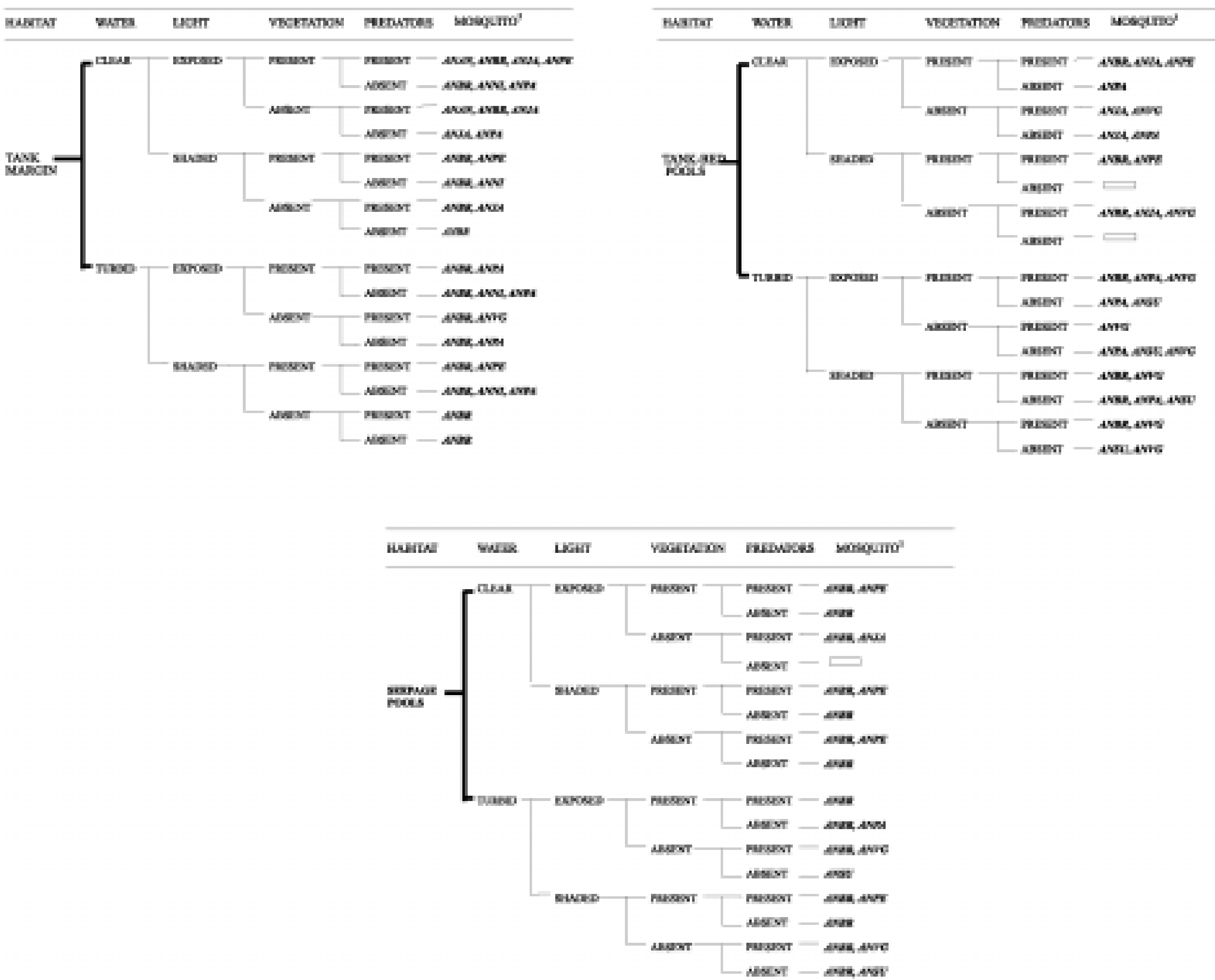


FIGURE 5.

Simplified schematic of potential malaria vectors likely to be encountered in tank-associated habitats under different observable conditions.



[1]Based on predicted probabilities of occurrence arising from multiple logistic regression analysis (details in Appendix E). Only potential malaria vectors with a ≥ 10% probability of occurrence under a particular set of conditions are included in this schematic. Cases where all species occur below this level of probability are signified by a rectangle.

presence of species other than those listed under the different combinations of characters, but predicts that the probability of their occurrence will be less than 10 percent. This schematic could be used as a rapid guide to the presence of potential malaria-generating mosquitoes in tank-associated habitats.

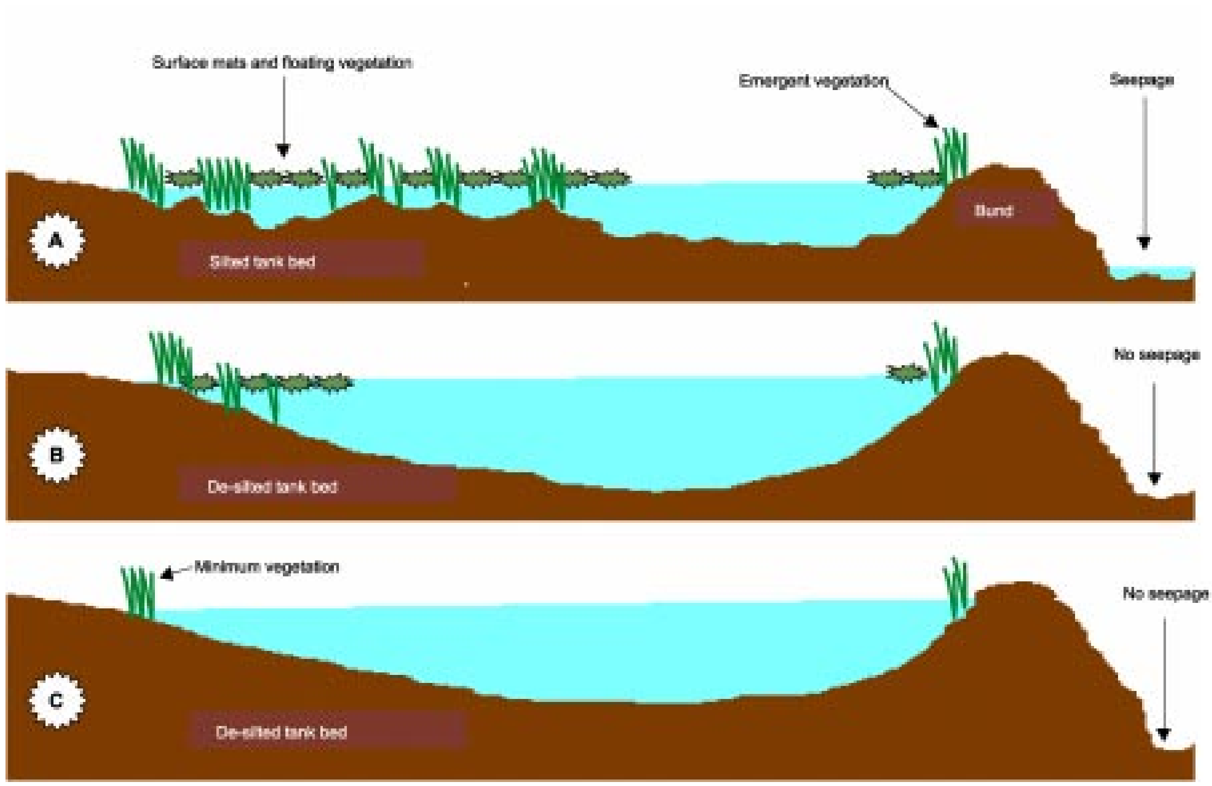
Tank Rehabilitation and Management

The study provides insights into several aspects relevant to the rehabilitation and management of irrigation tanks. Silted tanks, which provide shallow water areas, marginal, emergent and floating vegetation that provide refuges, and seepage across the bund that results in the creation of new breeding habitats (figure 6A), can all be considered to provide opportunities for mosquito breeding. Seepage-proofing and selective desiltation to remove depressions can address two of the problems (figure 6B), and the management of vegetation can address the third, resulting in tanks that present the minimum opportunities for mosquito breeding (figure 6C). Seepage, in particular, is an important issue in irrigation tank rehabilitation: a recent study showed that up to 75 percent of stored water can be lost due to seepage within a 2-month period (Tasumi 1999). Reduced seepage would have the double benefit of better water storage and fewer supplementary mosquito-breeding sites. Selective desiltation to remove depressions will reduce the extent of pooling during the dry season, and could also help deepen the water column, thereby discouraging vegetation growth and mosquito breeding.

However, a further issue of importance is the use of the tank bed for human activities and livestock wallowing. It is clear that the dug pits and animal wallows on the tank bed will provide new mosquito-breeding habitats as water levels recede or rain recharges the dry tank bed. Indeed, previous research has shown that freshly dug borrow pits favor the breeding of the major malaria vector, *An. culicifacies* (Russel and Rao 1942). Thus, both rehabilitation and continuing management are necessary to maintain tanks in a condition in which they pose the minimum risk of generating disease-causing or nuisance mosquitoes that affect the lives and livelihoods of poor rural communities.

FIGURE 6.

Irrigation tank profiles. (A) Silted bed, extensive floating and emergent vegetation, and seepage through the bund provide opportunities for mosquito breeding. (B) De-silted, seepage-proofed tank, with fairly extensive areas of vegetation. (C) De-silted, seepage-proofed tank, with minimum vegetation, providing the least opportunities for mosquito breeding.



APPENDIX A

Occurrence of mosquitoes in irrigation tanks and tank-associated habitats.

Tank	Seepage pools	Tank-bed pools	Tank margins	Total
MPW-A				
No. of samples	385	496	330	1,211
Mosquito positivity (%)	55.6	50.4	43.9	50.3
Anopheles positivity (%)	37.1	33.1	35.8	35.1
PDW-A				
No. of samples	271	366	208	845
Mosquito positivity (%)	75.6	44.3	45.2	54.6
Anopheles positivity (%)	56.1	38.8	38.9	44.4
HMW-A				
No. of sample	316	496	243	1,055
Mosquito positivity (%)	80.4	58.5	69.1	67.5
Anopheles positivity (%)	60.4	38.9	54.7	49.0
KRW				
No. of samples	276	133	304	713
Mosquito positivity (%)	64.5	34.6	48.7	52.2
Anopheles positivity (%)	47.8	27.2	34.2	38.7
HDW				
No. of samples	406	26	343	775
Mosquito positivity (%)	50.5	100.0	43.3	48.9
Anopheles positivity (%)	28.1	42.2	32.1	30.3
NGW				
No. of samples	42	660	93	795
Mosquito positivity (%)	61.9	65.8	65.6	65.5
Anopheles positivity (%)	52.4	50.8	55.9	51.4
MPW-B				
No. of samples	400	815	828	2,043
Mosquito positivity (%)	70.0	52.0	54.1	56.4
Anopheles positivity (%)	54.0	41.9	49.9	47.5
PDW-B				
No. of samples	81	418	547	1,046
Mosquito positivity (%)	61.7	57.2	43.9	50.6
Anopheles positivity (%)	44.4	46.9	42.8	44.6
HMW-B				
No. of samples	219	259	276	754
Mosquito positivity (%)	62.1	57.5	52.2	56.9
Anopheles positivity (%)	37.9	37.8	39.1	38.3
MGW				
No. of samples	200	434	693	1,327
Mosquito positivity (%)	58.0	45.6	35.6	42.3
Anopheles positivity (%)	40.0	37.6	31.0	34.5
IHW				
No. of samples	15	354	389	758
Mosquito positivity (%)	13.3	52.3	35.7	43.0
Anopheles positivity (%)	0.0	15.5	19.8	17.4
SDW				
No. of samples	30	230	312	572
Mosquito positivity (%)	60.0	66.1	50.3	57.2
Anopheles positivity (%)	30.0	48.7	28.8	36.9
Grand total				
No. of samples	2,641	4,687	4,566	11,894
Mosquito positivity (%)	63.8	54.5	46.8	53.6
Anopheles positivity (%)	44.5	39.2	37.9	39.9

Notes: MPW-A = Madawalapahalawewa (1995/96); PDW-A = Pusdivulwewa (1995/96); HMW-A = Halmillawewa (1995/96); KDW = Kudarambewawewa (1995/96); HDW = Habadivulwewa (1995/96); NGW = Nikagahawewa (1995/96); MPW-B = Madawalapahalawewa (1996/97); PDW-A = Pusdivulwewa (1996/97); HMW-A = Halmillawewa (1996/97); MGW = Mahameegaswewa (1996/97); IHW = Ihalawewa (1996/97); SDW = Siyambaladamanawewa (1996/97).

APPENDIX B

Logistic regression analyses of mosquito distribution in different tanks.

	HDW %OCC OR(CI)	HMW-A %OCC OR(CI)	MPW-A %OCC OR(CI)	PDW-A %OCC OR(CI)	KRW %OCC OR(CI)	NGW %OCC OR(CI)	HMW-B %OCC OR(CI)	MPW-B %OCC OR(CI)	PDW-B %OCC OR(CI)	MGW %OCC OR(CI)	IHW %OCC OR(CI)	SDW %OCC OR(CI)
An. annularis	0.3 1.0	9.4 39.4 (5.4–285)	11.8 51.2 (7.1–370)	10.2 43.3 (5.9–315)	3.2 12.6 (1.6–97.1)	10.5 45.0 (6.2–326)	0.9 3.6 (0.4–32.3)	4.3 17.0 (2.3–123)	4.8 19.2 (2.6–141)	3.2 12.7 (1.7–95.8)	1.9 7.2 (0.9–60.0)	0.0 0.04 (0–>1,000)
An. barbirostris	17.5 1.0	6.8 0.3 (0.2–0.5)	8.9 0.5 (0.3–0.7)	16.2 0.9 (0.6–1.3)	15.7 0.9 (0.6–1.3)	16.9 0.9 (0.7–1.4)	10.9 0.6 (0.4–0.9)	13.1 0.7 (0.5–0.9)	12.4 0.7 (0.5–0.9)	4.3 1.3 (0.9 1.8)	6.7 0.2 (0.1–0.4)	21.3 0.3 (0.2–0.7)
An. barbumbrosus	39.9 1.0	31.2 0.7 (0.5–0.9)	27.4 0.6 (0.4–0.7)	35.1 0.8 (0.6–1.1)	45.4 1.2 (0.9–1.7)	34.7 0.8 (0.6–1.1)	20.3 0.4 (0.3–0.5)	23.5 0.5 (0.4–0.6)	16.3 0.3 (0.2–0.4)	23.3 0.6 (0.5–0.6)	10.8 0.2 (0.1–0.3)	10.4 0.2 (0.1–0.3)
An. jamesii	3.9 1.0	16.3 4.8 (2.8–8.3)	12.8 3.6 (2.0–6.5)	12.1 3.4 (1.9–6.1)	8.8 2.4 (1.3–4.4)	14.2 4.1 (2.3–7.2)	1.6 0.4 (0.2–1.0)	6.9 1.8 (1.1–3.2)	1.4 0.4 (0.1–0.8)	1.6 0.4 (0.2–0.9)	4.3 1.1 (0.5–2.3)	1.8 0.5 (0.2–1.2)
An. nigerrimus	2.9 1.0	5.2 1.8 (0.9–3.7)	4.8 1.7 (0.8–3.4)	4.3 1.5 (0.7–3.2)	3.7 1.3 (0.6–2.9)	5.0 1.8 (0.9–3.6)	15.4 6.1 (3.1–11.8)	10.9 4.1 (2.1–7.7)	7.9 2.9 (1.5–5.7)	11.1 4.2 (2.2–8.1)	8.3 3.1 (1.5–6.3)	5.8 2.1 (0.9–4.4)
An. pallidus	0.1 1.0	11.9 51.4 (7.1–371)	0.7 2.5 (0.3–22.7)	0.7 2.5 (0.3–24.1)	0.5 2.0 (0.2–22.6)	0.0 0.04 (0–247)	26.6 138 (19–995)	15.0 67.6 (9.4–484)	13.9 62.1 (8.6–448)	20.1 95.9 (13.3–690)	15.1 67.8 (9.3–494)	38.4 238 (33.0–>1,000)
An. peditaeniatus	13.1 1.0	12.6 0.9 (0.6–1.4)	16.3 1.3 (0.9–1.8)	17.5 1.4 (0.9–2.0)	16.9 1.3 (0.9–1.9)	15.7 1.2 (0.8–1.8)	1.9 0.1 (0.06–0.3)	0.9 0.06 (0.03–0.1)	1.2 0.08 (0.04–0.2)	0.4 0.02 (0.01–0.1)	0.9 0.06 (0.02–0.2)	0.9 0.06 (0.02–0.2)
An. subpictus	0.8 1.0	0.8 1.1 (0.3–4.3)	2.1 2.8 (0.8–9.8)	1.3 1.7 (0.4–6.7)	0.3 0.3 (0.03–3.2)	2.7 3.5 (0.9–12.2)	1.2 1.5 (0.4–6.3)	9.6 13.5 (4.3–42.8)	12.0 17.3 (5.4–55.5)	8.1 11.1 (3.4–36.0)	0.3 0.4 (0.04–3.8)	3.1 3.9 (1.1–14.6)
An. vagus	4.2 1.0	2.9 0.7 (0.4–1.3)	8.5 2.1 (1.2–3.8)	14.1 3.8 (2.1–6.6)	3.9 0.9 (0.5–1.9)	13.9 3.7 (2.1–6.5)	2.6 0.6 (0.3–1.3)	5.7 1.4 (0.8–2.4)	2.8 0.7 (0.3–1.4)	2.5 0.6 (0.3–1.2)	1.2 0.3 (0.1–0.9)	3.4 0.8 (0.4–1.7)
An. varuna	1.1 1.0	0.0 0.001 (0–>1,000)	0.3 0.3 (0.05–1.7)	0.4 0.4 (0.08–2.3)	0.3 0.3 (0.03–2.3)	0.0 0.001 (0–>1,000)	0.7 0.7 (0.1–3.0)	6.0 5.7 (2.1–15.7)	0.5 0.5 (0.1–2.3)	2.4 2.3 (0.7–6.9)	0.6 0.6 (0.1–3.2)	0.0 0.001 (0–>1,000)
Aedes spp	2.1 1.0	1.7 0.8 (0.3–1.9)	2.6 1.3 (0.5–2.9)	1.3 0.6 (0.2–1.8)	2.1 1.0 (0.4–2.7)	4.2 2.1 (0.9–4.7)	16.8 9.4 (4.5–19.9)	5.3 2.6 (1.2–5.5)	7.8 3.9 (1.8–8.5)	10.0 5.2 (2.5–11.1)	21.5 12.8 (6.0–27.2)	14.0 7.6 (3.6–16.4)
Culex spp	72.6 1.0	77.8 1.3 (0.9–1.7)	62.7 0.6 (0.5–0.8)	46.3 0.3 (0.2–0.4)	61.0 0.6 (0.4–0.8)	63.0 0.6 (0.5–0.9)	41.7 0.3 (0.2–0.4)	32.2 0.2 (0.1–0.2)	16.6 0.1(0.05–0.1)	29.0 0.2 (0.1–0.2)	48.6 0.4 (0.3–0.5)	42.7 0.3 (0.2–0.4)

Notes: Percent OCC = Percentage occurrence of species/group in mosquito-positive samples in each tank. Odds Ratios (OR) and 95 percent Confidence Intervals (CI) were derived from logistic regression analyses, with the HDW set as the reference tank. Decimals are not reported for upper CI values in excess of 100, and those in excess of 1,000 are represented as “>1,000.” Abbreviations of tank names are as in appendix A.

APPENDIX C

Details of light and water conditions in different tanks.

		Light			Water		
		Exposed	Partial shade	Full shade	Clear	Turbid	Foul
MPW-A	Seepage pool	42.3	48.6	9.1	72.7	27.0	0.3
	Tank-bed pool	98.6	1.2	0.2	57.9	42.1	0
	Tank margin	97.0	2.1	0.9	92.7	7.3	0
PDW-A	Seepage pool	47.2	37.6	15.1	88.9	11.1	0
	Tank-bed pool	93.4	4.1	2.5	24.0	75.4	0.6
	Tank margin	89.4	10.6	0	77.9	22.1	0
HMW-A	Seepage pool	56.9	32.2	10.8	79.4	20.3	0.3
	Tank-bed pool	99.6	0.4	0	59.9	39.7	0.4
	Tank margin	95.9	4.1	0	94.7	5.3	0
HDW	Seepage pool	56.7	38.9	4.4	85.5	10.1	4.4
	Tank-bed pool	100	0	0	100	0	0
	Tank margin	29.7	52.8	17.5	95.9	4.1	0
NGW	Seepage pool	26.2	73.8	0	64.3	35.7	0
	Tank-bed pool	99.2	0.8	0	51.0	48.2	0.8
	Tank margin	100	0	0	72.0	26.9	1.0
KRW	Seepage pool	43.5	29.7	26.8	90.9	8.7	0.4
	Tank-bed pool	92.5	6.8	0.7	57.9	42.1	0
	Tank margin	88.8	10.5	0.7	92.1	7.9	0
IHW	Seepage pool	20.0	73.3	6.7	86.7	0	13.3
	Tank-bed pool	95.5	2.8	1.7	85.8	13.1	1.1
	Tank margin	93.3	6.2	0.5	91.5	8.5	0
MPW-B	Seepage pool	45.9	40.6	13.5	68.9	29.3	1.8
	Tank-bed pool	98.3	1.3	0	50.9	48.6	0.5
	Tank margin	95.8	3.7	0.5	84.3	15.7	0
PDW-B	Seepage pool	66.3	15.0	18.7	23.8	76.2	0
	Tank-bed pool	86.5	4.3	9.1	23.1	76.7	0.2
	Tank margin	82.2	12.5	5.3	79.4	20.6	0
HMW-B	Seepage pool	75.8	15.5	8.7	86.6	9.6	3.7
	Tank-bed pool	98.8	1.2	0	58.3	40.9	0.8
	Tank margin	95.3	4.3	0.4	94.2	5.8	0
MGW	Seepage pool	59.2	18.4	22.4	32.3	65.2	2.5
	Tank-bed pool	91.7	6.2	2.1	36.2	63.3	0.5
	Tank margin	71.3	13.8	14.8	65.6	34.4	0
SDW	Seepage pool	96.7	3.3	0	86.7	10.0	3.3
	Tank-bed pool	97.8	2.2	0	48.5	51.5	0
	Tank margin	78.1	20.9	1.0	56.5	43.5	0

Notes: Values are percentages of samples positive for the character. Abbreviations of tank names as in appendix A.

APPENDIX D

Details of vegetation and fauna in different tanks.

		Vegetation						Fauna			
		Absent	Grass	Herbs	Algae	Aq. plants	Dead veg.	Absent	Fish	Insect	Other
MPW-A	Seepage pool	1.6	79.0	16.4	15.6	28.3	24.2	8.3	7.3	5.5	58.2
	Tank-bed pool	20.8	42.3	30.2	9.1	62.7	1.8	22.4	49.0	19.6	36.1
	Tank margin	2.1	53.9	44.2	3.0	91.5	3.9	11.2	75.8	0.3	61.2
PDW-A	Seepage pool	0.7	88.9	16.6	3.3	3.7	41.0	4.1	78.6	13.3	36.9
	Tank-bed pool	21.9	29.0	28.1	8.7	38.3	12.6	25.7	39.6	26.2	25.4
	Tank margin	5.3	46.2	29.8	1.4	93.3	12.5	3.4	84.1	1.0	74.5
HMW-A	Seepage pool	2.2	82.3	5.4	12.3	27.5	45.6	10.1	83.5	6.0	27.2
	Tank-bed pool	18.3	59.9	3.2	14.1	35.5	3.6	25.4	29.0	33.7	28.8
	Tank margin	1.2	93.0	8.6	15.2	95.1	4.1	11.5	79.8	0.8	32.1
HDW	Seepage pool	3.0	39.7	0	8.6	0	75.4	7.9	67.0	15.5	46.8
	Tank-bed pool	76.9	23.1	0	0	0	0	100	0	0	0
	Tank margin	5.5	27.1	10.8	0	7.0	99.7	3.8	95.9	1.5	13.1
NGW	Seepage pool	14.3	85.7	9.5	0	0	19.0	42.9	28.6	28.6	4.8
	Tank-bed pool	22.0	73.8	24.2	9.4	13.2	0	22.0	23.9	35.9	18.9
	Tank margin	7.5	84.9	50.5	19.4	19.4	8.6	7.5	91.4	8.6	22.6
KRW	Seepage pool	1.1	98.9	4.0	5.4	8.0	42.8	4.7	54.3	39.5	18.5
	Tank-bed pool	45.9	44.4	0	3.8	19.5	12.8	49.6	22.6	21.8	21.8
	Tank margin	4.6	67.4	32.9	13.2	89.1	11.8	5.3	92.4	3.9	15.1
MPW-B	Seepage pool	0.8	80.2	40.6	27.1	13.3	80.7	21.6	30.6	33.6	46.6
	Tank-bed pool	10.2	74.8	42.6	9.8	10.9	49.3	43.7	20.5	29.0	18.0
	Tank margin	5.8	68.6	44.4	14.4	41.1	63.4	18.1	73.6	26.7	43.1
PDW-B	Seepage pool	1.3	93.8	22.5	6.3	1.3	75.0	3.8	1.3	42.5	81.3
	Tank-bed pool	7.7	55.8	41.6	7.7	11.8	34.4	8.4	32.2	42.5	36.5
	Tank margin	0.9	88.4	41.8	17.4	43.1	34.5	5.0	84.8	22.8	43.1
HMW-B	Seepage pool	1.4	93.6	10.0	10.5	33.3	54.8	14.6	8.7	7.3	80.8
	Tank-bed pool	17.0	69.5	22.0	6.9	18.1	14.3	21.6	2.7	32.4	51.4
	Tank margin	1.8	89.5	25.4	13.0	41.7	36.6	19.6	15.2	13.4	68.8
IHW	Seepage pool	6.7	93.3	6.7	0	0	93.3	0	0	0	100
	Tank-bed pool	4.3	83.0	19.0	12.2	27.3	13.6	51.7	9.7	25.3	20.7
	Tank margin	0.3	87.4	14.2	20.4	50.0	36.6	75.8	25.0	19.8	11.6
MGW	Seepage pool	1.0	78.1	25.9	6.0	0	69.7	68.7	7.0	32.8	10.0
	Tank-bed pool	7.6	80.9	33.1	7.1	18.4	33.1	44.4	20.7	39.8	13.3
	Tank margin	3.6	82.5	41.5	6.4	21.8	49.5	58.2	86.3	27.7	4.6
SDW	Seepage pool	0	100	3.3	0	0	40.0	56.7	26.7	13.3	43.3
	Tank-bed pool	9.7	70.5	15.9	22.9	13.7	12.3	34.4	0	57.7	17.2
	Tank margin	0.3	93.2	43.9	7.1	35.5	34.8	57.1	6.1	5.2	13.5

Notes: Values are percentages of samples positive for the character. Aq. plants = Aquatic plants; Dead veg. = Dead vegetation. Abbreviations of tank names as in appendix A.

APPENDIX E

Multiple logistic regression analyses of relationships between mosquitoes and breeding-habitat characteristics.

	ANAN	ANBR	ANBB	ANJA	ANNI	ANPA	ANPE	ANSU	ANVG	ANVR	AESP	CXSP
HABITAT												
Tank margin	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Tank bed	0.8 (0.6-1.1)	0.6 (0.5-0.7)	0.7 (0.6-0.8)	1.1 (0.9-1.3)	0.5 (0.4-0.7)	0.9 (0.8-1.1)	0.7 (0.6-0.9)	2.5 (1.8-3.6)	6.8 (4.3-10.9)	0.2 (0.1-0.4)	2.3 (1.7-3.0)	1.7 (1.5-2.0)
Seepage	0.4 (0.3-0.5)	0.9 (0.8-1.1)	1.8 (1.5-2.1)	0.5 (0.4-0.7)	0.8 (0.6-0.9)	0.5 (0.4-0.6)	1.1 (0.9-1.4)	1.5 (0.9-2.3)	1.3 (0.7-2.4)	0.8 (0.5-1.3)	2.1 (1.5-2.9)	2.3 (2.0-2.7)
WATER												
Turbid/Foul	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Clear	1.8 (1.4-2.5)	0.9 (0.7-1.1)	1.1 (0.9-1.3)	2.6 (2.0-3.5)	1.1 (0.9-1.4)	0.7 (0.6-0.8)	1.6 (1.2-2.1)	0.4 (0.3-0.5)	0.3 (0.2-0.3)	2.3 (1.3-4.3)	1.3 (1.04-1.6)	1.7 (1.5-1.9)
LIGHT												
Shaded	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Exposed	1.6 (1.1-2.3)	0.8 (0.7-0.9)	1.2 (1.1-1.4)	1.7 (1.2-2.3)	1.0 (0.8-1.3)	2.3 (1.7-3.0)	0.9 (0.7-1.1)	1.1 (0.7-1.7)	1.4 (0.8-2.2)	1.3 (0.7-2.5)	1.0 (0.7-1.4)	0.8 (0.7-0.9)
VEGETATION												
Absent	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Present	1.0 (0.7-1.5)	1.3 (1.0-1.8)	1.2 (0.9-1.4)	0.6 (0.4-0.7)	2.5 (1.6-3.7)	1.8 (1.4-2.3)	1.7 (1.1-2.7)	0.6 (0.4-0.7)	0.3 (0.2-0.4)	0.6 (0.4-1.1)	0.7 (0.6-0.9)	1.3 (1.1-1.5)
PREDATORS												
Absent	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Present	1.5 (1.2-1.9)	1.5 (1.4-1.9)	2.1 (1.9-2.4)	1.7 (1.4-2.1)	0.9 (0.7-1.1)	0.5 (0.4-0.5)	2.7 (2.2-3.3)	0.4 (0.3-0.5)	2.5 (2.0-3.2)	0.2 (0.1-0.3)	0.1 (0.07-0.1)	1.5 (1.3-1.6)

Notes: Results are reported as Odds Ratios with 95% Confidence Intervals in parentheses. The value of the reference category for each characteristic is set at 1.0. ANAN = *An. annularis*; ANBR = *An. barbirostris*; ANBB = *An. barbumbrosus*; ANJA = *An. jamesii*; ANNI = *An. nigerrimus*; ANPA = *An. pallidus*; ANPE = *An. peditaeniatus*; ANSU = *An. subpictus*; ANVG = *An. vagus*; ANVR = *An. varuna*; AESP = *Aedes* spp; CXSP = *Culex* spp.

APPENDIX F

Matrix of predicted probabilities of mosquito occurrence under different habitat conditions (based on logistic regression analyses).

HAB	WATER	LIGHT	VEG	PRED	ANAN	ANBB	ANBR	ANJA	ANNI	ANPA	ANPE	ANSU	ANVG	ANVR	AESP	CXSP
TNK	Clear	Exposed	Present	Present	0.10	0.36	0.17	0.13	0.10	0.09	0.13	0.01	0.01	0.01	0.01	0.46
TNK	Clear	Exposed	Present	Absent	0.07	0.21	0.12	0.08	0.11	0.19	0.05	0.02	0.00	0.04	0.07	0.37
TNK	Clear	Exposed	Absent	Present	0.10	0.32	0.14	0.21	0.04	0.06	0.08	0.01	0.04	0.01	0.01	0.39
TNK	Clear	Exposed	Absent	Absent	0.07	0.19	0.09	0.13	0.05	0.11	0.03	0.04	0.01	0.07	0.09	0.31
TNK	Clear	Shaded	Present	Present	0.07	0.31	0.20	0.08	0.10	0.04	0.15	0.01	0.01	0.01	0.01	0.50
TNK	Clear	Shaded	Present	Absent	0.05	0.18	0.14	0.05	0.11	0.09	0.06	0.02	0.00	0.03	0.07	0.40
TNK	Clear	Shaded	Absent	Present	0.07	0.28	0.16	0.14	0.04	0.03	0.10	0.01	0.03	0.01	0.01	0.43
TNK	Clear	Shaded	Absent	Absent	0.05	0.16	0.11	0.08	0.05	0.06	0.04	0.03	0.01	0.05	0.09	0.34
TNK	Turbid/Foul	Exposed	Present	Present	0.06	0.33	0.19	0.05	0.09	0.13	0.09	0.02	0.04	0.00	0.01	0.34
TNK	Turbid/Foul	Exposed	Present	Absent	0.04	0.19	0.13	0.03	0.10	0.24	0.03	0.05	0.02	0.02	0.05	0.26
TNK	Turbid/Foul	Exposed	Absent	Present	0.06	0.30	0.15	0.09	0.04	0.08	0.05	0.03	0.12	0.01	0.01	0.28
TNK	Turbid/Foul	Exposed	Absent	Absent	0.04	0.17	0.10	0.06	0.05	0.15	0.02	0.09	0.05	0.03	0.07	0.21
TNK	Turbid/Foul	Shaded	Present	Present	0.04	0.29	0.23	0.03	0.09	0.06	0.10	0.02	0.03	0.00	0.01	0.37
TNK	Turbid/Foul	Shaded	Present	Absent	0.03	0.16	0.16	0.02	0.10	0.13	0.04	0.05	0.01	0.02	0.05	0.29
TNK	Turbid/Foul	Shaded	Absent	Present	0.04	0.26	0.18	0.06	0.04	0.04	0.06	0.03	0.09	0.00	0.01	0.31
TNK	Turbid/Foul	Shaded	Absent	Absent	0.03	0.14	0.12	0.03	0.04	0.07	0.02	0.09	0.04	0.02	0.07	0.24
TBP	Clear	Exposed	Present	Present	0.09	0.27	0.11	0.14	0.06	0.09	0.10	0.02	0.07	0.00	0.02	0.59
TBP	Clear	Exposed	Present	Absent	0.06	0.15	0.07	0.08	0.07	0.18	0.04	0.05	0.03	0.01	0.14	0.50
TBP	Clear	Exposed	Absent	Present	0.09	0.24	0.09	0.22	0.02	0.05	0.06	0.03	0.20	0.00	0.02	0.53
TBP	Clear	Exposed	Absent	Absent	0.06	0.13	0.06	0.14	0.03	0.11	0.02	0.09	0.09	0.02	0.19	0.43
TBP	Clear	Shaded	Present	Present	0.06	0.23	0.13	0.09	0.06	0.04	0.12	0.02	0.05	0.00	0.02	0.63
TBP	Clear	Shaded	Present	Absent	0.04	0.12	0.09	0.05	0.06	0.09	0.05	0.05	0.02	0.01	0.14	0.54
TBP	Clear	Shaded	Absent	Present	0.06	0.20	0.11	0.15	0.02	0.02	0.07	0.03	0.16	0.00	0.02	0.57
TBP	Clear	Shaded	Absent	Absent	0.04	0.11	0.07	0.09	0.03	0.05	0.03	0.08	0.07	0.01	0.18	0.47

APPENDIX F (Continued).

HAB	WATER	LIGHT	VEG	PRED	ANAN	ANBB	ANBR	ANJA	ANNI	ANPA	ANPE	ANSU	ANVG	ANVR	AESP	CXSP
TBP	Turbid/Foul	Exposed	Present	Present	0.05	0.25	0.13	0.06	0.05	0.12	0.07	0.05	0.22	0.00	0.01	0.47
TBP	Turbid/Foul	Exposed	Present	Absent	0.03	0.13	0.08	0.03	0.06	0.23	0.03	0.13	0.10	0.00	0.11	0.37
TBP	Turbid/Foul	Exposed	Absent	Present	0.05	0.22	0.10	0.10	0.02	0.07	0.04	0.08	0.49	0.00	0.02	0.40
TBP	Turbid/Foul	Exposed	Absent	Absent	0.03	0.12	0.06	0.06	0.03	0.15	0.02	0.21	0.27	0.01	0.15	0.31
TBP	Turbid/Foul	Shaded	Present	Present	0.03	0.21	0.15	0.03	0.05	0.06	0.08	0.04	0.17	0.00	0.01	0.51
TBP	Turbid/Foul	Shaded	Present	Absent	0.02	0.11	0.10	0.02	0.06	0.12	0.03	0.12	0.08	0.00	0.11	0.41
TBP	Turbid/Foul	Shaded	Absent	Present	0.03	0.19	0.12	0.06	0.02	0.03	0.05	0.08	0.41	0.00	0.02	0.44
TBP	Turbid/Foul	Shaded	Absent	Absent	0.02	0.10	0.08	0.04	0.02	0.07	0.02	0.19	0.22	0.01	0.15	0.35
SPP	Clear	Exposed	Present	Present	0.04	0.50	0.16	0.07	0.08	0.05	0.14	0.01	0.01	0.01	0.01	0.66
SPP	Clear	Exposed	Present	Absent	0.03	0.32	0.11	0.04	0.09	0.09	0.06	0.03	0.01	0.03	0.13	0.57
SPP	Clear	Exposed	Absent	Present	0.04	0.46	0.13	0.13	0.03	0.03	0.09	0.02	0.05	0.01	0.02	0.60
SPP	Clear	Exposed	Absent	Absent	0.03	0.29	0.09	0.08	0.04	0.06	0.03	0.05	0.02	0.05	0.17	0.51
SPP	Clear	Shaded	Present	Present	0.03	0.44	0.20	0.05	0.07	0.02	0.16	0.01	0.01	0.00	0.01	0.70
SPP	Clear	Shaded	Present	Absent	0.02	0.27	0.13	0.03	0.09	0.04	0.07	0.03	0.00	0.03	0.13	0.61
SPP	Clear	Shaded	Absent	Present	0.03	0.41	0.15	0.08	0.03	0.01	0.10	0.02	0.04	0.01	0.02	0.64
SPP	Clear	Shaded	Absent	Absent	0.02	0.25	0.10	0.05	0.04	0.03	0.04	0.05	0.01	0.04	0.17	0.55
SPP	Turbid/Foul	Exposed	Present	Present	0.02	0.47	0.18	0.03	0.07	0.06	0.09	0.03	0.05	0.00	0.01	0.54
SPP	Turbid/Foul	Exposed	Present	Absent	0.02	0.30	0.12	0.02	0.08	0.13	0.04	0.08	0.02	0.02	0.10	0.44
SPP	Turbid/Foul	Exposed	Absent	Present	0.02	0.44	0.14	0.05	0.03	0.04	0.06	0.05	0.16	0.00	0.02	0.47
SPP	Turbid/Foul	Exposed	Absent	Absent	0.02	0.27	0.10	0.03	0.03	0.08	0.02	0.13	0.07	0.02	0.14	0.38
SPP	Turbid/foul	Shaded	Present	Present	0.01	0.42	0.22	0.02	0.07	0.03	0.11	0.03	0.04	0.00	0.01	0.58
SPP	Turbid/Foul	Shaded	Present	Absent	0.01	0.26	0.15	0.01	0.08	0.06	0.04	0.07	0.02	0.01	0.10	0.48
SPP	Turbid/Foul	Shaded	Absent	Present	0.01	0.39	0.17	0.03	0.03	0.02	0.07	0.05	0.12	0.00	0.02	0.51
SPP	Turbid/Foul	Shaded	Absent	Absent	0.01	0.23	0.12	0.02	0.03	0.04	0.03	0.12	0.05	0.02	0.14	0.42

Notes: HAB = Habitat; VEG = Vegetation; PRED = Predators; TNK = Tank margins; TBP = Tank-bed pools; SPP = Seepage pools. Abbreviations of mosquito names as in appendix E.

Literature Cited

Amerasinghe, F. P. 1992. A guide to the identification of the *Anopheles* mosquitoes (Diptera: Culicidae) of Sri Lanka: II. Larvae. *Ceylon Journal of Science (Biological Science)* 22: 1–13.

Amerasinghe, F. P. 1993. Rice field breeding mosquitoes (Diptera: Culicidae) in a new irrigation project in Sri Lanka. *Mosquito-Borne Diseases Bulletin* 10: 1–7.

Amerasinghe, F. P. 1995. A guide to the identification of the *Anopheles* mosquitoes (Diptera: Culicidae) of Sri Lanka: III. Pupae. *Journal of the National Science Council of Sri Lanka* 23: 115–129.

Amerasinghe, F. P.; and T. G. Ariyasena. 1990. A larval survey of surface water-breeding mosquitoes during irrigation development in the Mahaweli Project, Sri Lanka. *Journal of Medical Entomology* 27(5): 789–802.

Amerasinghe, F. P.; and N. G. Indrajith. 1994. Postirrigation breeding patterns of ground water mosquitoes in an area of the Mahaweli Project, Sri Lanka. *Journal of Medical Entomology* 31: 516–523.

Amerasinghe F. P.; P. H. Amerasinghe; J. S. M. Peiris; and R. A. Wirtz. 1991. *Anopheles* ecology and malaria infection during the irrigation development of an area of the Mahaweli Project, Sri Lanka. *American Journal of Tropical Medicine and Hygiene* 45: 226–235.

Amerasinghe, F. P.; F. Konradsen; K. T. Fonseka; and P. H. Amerasinghe. 1997. *Anopheles* (Diptera: Culicidae) breeding in a traditional tank-based village ecosystem in northcentral Sri Lanka. *Journal of Medical Entomology* 34: 290–297.

Amerasinghe, P. H.; F. P. Amerasinghe; R. A. Wirtz; N. G. Indrajith; W. Somapala; L. R. Pereira; and M. S. Rathnayake. 1992. Malaria transmission by *Anopheles subpictus* (Diptera: Culicidae) in a new irrigation project. *Journal of Medical Entomology* 29: 577–581.

Amerasinghe, P. H.; F. P. Amerasinghe; F. Konradsen; K. T. Fonseka; and R. A. Wirtz. 1999. Malaria vectors in a traditional dry zone village in Sri Lanka. *American Journal of Tropical Medicine and Hygiene* 60: 421–429.

Amerasinghe, P. H.; G. M. Yapabandara; W. Somapala; and F. P. Amerasinghe. 1994. Incrimination of malaria vectors in a gem mining area (Elahera, Matale district) during the wet season. *Proceedings of the Sri Lanka Association for the Advancement of Science* 50: 13 (Abstract).

Klinkenberg, E., ed. 2001. *Malaria risk mapping in Sri Lanka—results from the Uda Walawe area.* Working Paper 21. Colombo, Sri Lanka: International Water Management Institute.

Konradsen, F.; F. P. Amerasinghe; W. van der Hoek; and P. H. Amerasinghe. 2000. *Malaria in Sri Lanka: Current knowledge on transmission and control*. Colombo, Sri Lanka: International Water Management Institute.

Konradsen, F.; W. van der Hoek; P. H. Amerasinghe; and F. P. Amerasinghe. 1997. Measuring the economic cost of malaria to households in Sri Lanka. *American Journal of Tropical Medicine and Hygiene* 56: 656–660.

Konradsen, F.; W. van der Hoek; P. H. Amerasinghe; F. P. Amerasinghe; and K. T. Fonseka. 1997. Household responses to malaria and their costs: a study from rural Sri Lanka. *Transactions of the Royal Society of Tropical Medicine and Hygiene* 91: 127–130.

Lacey, L. A.; and C. M. Lacey. 1990. The medical importance of riceland mosquitoes and their control using alternatives to chemical insecticides. *Journal of the American Mosquito Control Association* 6: 1–93. Suppl. #2

Mendis, C.; A. C. Gamage-Mendis; A. P. K. de Zoyza; T. A. Abhayawardena; R. Carter; P. R. J. Herath; and K. N. Mendis. 1990. Characteristics of malaria transmission in Kataragama: A focus for immuno-epidemiological studies. *American Journal of Tropical Medicine and Hygiene* 42: 298–308.

Mendis, C.; P. R. J. Herath; J. Rajakaruna; S. Weerasinghe; A. C. Gamage-Mendis; K. N. Mendis; and A. P. K. de Zoyza. 1992. Methods to estimate relative transmission efficiencies of *Anopheles* species (Diptera: Culicidae) in human malaria transmission. *Journal of Medical Entomology* 29: 188–196.

Panabokke, C. R. 1999. *The small tank cascade systems of the Rajarata: Their setting, distribution patterns, and hydrography.* Colombo, Sri Lanka: Mahaweli Authority of Sri Lanka.

Panabokke, C. R. 2000. Personal communication.

Ramasamy, R.; R. de Alwis; A. Wijesundere; and M. S. Ramasamy. 1992. Malaria transmission in a new irrigation project in Sri Lanka: The emergence of *Anopheles annularis* as a major vector. *American Journal of Tropical Medicine and Hygiene* 47: 547–553.

Reuben, R. 1971. Studies on the mosquitoes of North Arcot District, Madras State, India. Part 5. Breeding places of the *Culex vishnui* group of species. *Journal of Medical Entomology* 8: 363–366.

Russel, P. F.; and T. R. Rao. 1942. On the ecology of larvae of *Anopheles culicifacies* Giles, in borrow pits. *Bulletin of Entomological Research* 32: 341–361.

Southwood, T. R. E. 1966. *Ecological methods, with particular reference to the study of insect populations.* London: Methuen.

Tasumi, M. 1999. Water balance and return flow in reservoir cascade irrigation systems of Sri Lanka. M.Sc. thesis. Graduate School of Tottori University, Japan.

WHO (World Health Organization). 1999. *WHO Expert Committee on Malaria. Twentieth Report.* Technical Report Series, No. 892. Geneva.

43. *Integrated Basin Modeling.* Geoff Kite and Peter Droogers, 2000.

44. *Productivity and Performance of Irrigated Wheat Farms across Canal Commands in the Lower Indus Basin.* Intizar Hussain, Fuard Marikar, and Waqar Jehangir, 2000.

45. *Pedaling out of Poverty: Social Impact of a Manual Irrigation Technology in South Asia.* Tushaar Shah, M. Alam, M. Dinesh Kumar, R. K. Nagar, and Mahendra Singh, 2000.

46. *Using Remote Sensing Techniques to Evaluate Lining Efficacy of Watercourses.* R. Sakthivadivel, Upali A. Amarasinghe, and S. Thiruvengadachari, 2000.

47. *Alternate Wet Dry Irrigation in Rice Cultivation: Saving Water and Controlling Malaria and Japanese Encephalitis?* Wim van der Hoek, R. Sakthivadivel, Melanie Renshaw, John B. Silver, Martin H. Birley, and Flemming Konradsen, 2000.

48. *Predicting Water Availability in Irrigation Tank Cascade Systems: The CASCADE Water Balance Model.* C. J. Jayatilaka, R. Sakthivadivel, Y. Shinogi, I. W. Makin, and P. Witharana, 2000.

49. *Basin-Level Use and Productivity of Water: Examples from South Asia.* David Molden, R. Sakthivadivel, and Zaigham Habib, 2000.

50. *Modeling Scenarios for Water Allocation in the Gediz Basin, Turkey.* Geoff Kite, Peter Droogers, Hammond Murray-Rust, and Koos de Voogt, 2001.

51. *Valuing Water in Irrigated Agriculture and Reservoir Fisheries: A Multiple Use Irrigation System in Sri Lanka.* Mary E. Renwick, 2001.

52. *Charging for Irrigation Water: The Issues and Options, with a Cast Study from Iran.* C. J. Perry, 2001.

53. *Estimating Productivity of Water at Different Spatial Scales Using Simulation Modeling.* Peter Droogers, and Geoff Kite, 2001.

54. *Wells and Welfare in the Ganga Basin: Public Policy and Private Initiative in Eastern Uttar Pradesh, India.* Tushaar Shah, 2001.

55. *Water Scarcity and Managing Seasonal Water Crisis: Lessons from the Kirindi Oya Project in Sri Lanka.* R. Sakthivadivel, Ronald Loeve, Upali A. Amarasinghe, and Manju Hemakumara, 2001.

56. *Hydronomic Zones for Developing Basin Water Conservation Strategies.* David J. Molden, Jack Keller, and R. Sakthivadivel, 2001.

57. *Small Irrigation Tanks as a Source of Malaria Mosquito Vectors: A Study in North-Central Sri Lanka.* Felix P. Amerasinghe, Flemming Konradsen, Wim van der Hoek, Priyanie H. Amerasinghe, J. P. W. Gunawardena, K. T. Fonseka and G. Jayasinghe, 2001.

Postal Address:
P O Box 2075
Colombo
Sri Lanka

Location:
127, Sunil Mawatha
Pelawatta
Battaramulla
Sri Lanka

Tel:
+94-1-867404

Fax:
+94-1-866854

E-mail:
iwmi@cgiar.org

Website:
http://www.iwmi.org

International Water Management Institute

FUTURE HARVEST
IWMI is a Future Harvest Center supported by the CGIAR

ISSN 1026-0862
ISBN 92-9090-461-5