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MOSQUITO AND AQUATIC PREDATOR COMMUNITIES IN GROUND POOLS ON LANDS DEFORESTED FOR RICE FIELD DEVELOPMENT IN CENTRAL SULAWESI, INDONESIA

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ABSTRACT. Aquatic habitats, mosquitoes, and larvivorous predators were studied on deforested lands in Central Sulawesi, Indonesia. Open ground pools, mainly in depressions made by the treads of bulldozers and other heavy equipment, were numerous but because of their small size, comprised ca. 1% or less of the total area of the deforested lands studied. The dominant mosquitoes in these pools were *Anopheles vagus*, *Culex vishnui*, *Culex tritaeniorhynchus*, and *Culex gelidus*. The 1st 2 species were dominant in clear pools, whereas the latter 2 species were dominant in turbid pools. The dominant metazoans other than mosquitoes were Crustacea, Ephemeroptera, and Chironomidae. Both aquatic and surface predators were abundant. Dominant among aquatic predators were Anisoptera and Zygoptera nymphs, Dytiscidae, and Notonectidae. These results are discussed in relation to mosquito control on deforested lands that transitionally but inevitably appear during the course of rice field development projects in Indonesia.

KEY WORDS Deforestation, mosquito, *Anopheles*, *Culex*, aquatic predator, Indonesia

INTRODUCTION

Development of irrigated rice field systems on deforested lands brings about drastic changes in the environment. Closed forest ecosystems are eventually replaced by open rice agroecosystems interspersed with farm villages. The transition phase between these 2 sharply contrasting landscapes may last for months or even years once a project is begun. The present study focuses on mosquito and aquatic predator communities occurring during one of the subphases of this transition between predevelopment forests and postdevelopment rice lands.

Mosquitoes in forest and rice ecosystems are well investigated. However, mosquitoes in the transition phase have not been well investigated. An exception is the record of mosquito fauna and abundance during the course of the Mahaweli irrigation development project in Sri Lanka (Amerasinghe and Ariyasena 1990, 1991). These authors also noted sparsity of aquatic predators (fish and insect predators as a whole, without specification) in open rainwater pools on the recently deforested land.

On Indonesia's outer islands, rice field development projects are being implemented extensively to fill the increasing demand for staple food due to human population increases. Many of these projects involve settlement of humans from Java and Bali where malaria has successfully been controlled and people are not immune to malaria. Consequently, epidemics of malaria have been reported in the settlement areas including those on Central Sulawesi (Abisudjak and Kotanegara 1989). The occurrence of filariasis also has been reported in the settlement areas (Partono et al. 1973). As human settlement immediately follows deforestation, malaria epidemics may occur within a few months after settlement (Partono et al. 1973). Mosquito control should be started at the early phase of development projects.

The Government of Indonesia has promoted health programs in settlement areas to overcome disease problems that may hamper development projects (Binol 1983). However, in the case of mosquito-borne diseases, basic information on mosquitoes and their ecology in project areas in eastern Indonesia is virtually nonexistent. One reason for this gap is that remoteness of such project areas impedes surveys.

The aim of this report is to describe aquatic habitats and associated mosquito larvae and larvivorous predator communities on lands deforested for rice field development in Central Sulawesi, eastern Indonesia. Such information could be a basis to establish ecologically sound and comprehensive strategies for control of mosquitoes and mosquito-borne diseases in development project areas.

MATERIALS AND METHODS

Study area: The study was conducted in September 1996 in Toili, Kabupatan Luwuk-Banggai, on the eastern peninsula of Central Sulawesi. The settlement of this area began in the 1970s, and irrigated rice fields already exist around the older villages. However, in the surrounding areas, deforestation, settlement, and development of new rice fields are still progressing.

The area has a slightly seasonal tropical (ca. 1°30′S) climate with a Q index (100 × number of dry months with <60 mm precipitation/number of wet months with >100 mm precipitation) of 14.3–33.3 (Whitten et al. 1988). The mean annual precipitation is 1,500–2,000 mm. The wettest months are usually June and July but may vary from year to year. In 1996, the wet season was extended and considerable rains preceded the census.

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The study was done at 2 sites where deforestation, which started 3 months before, had almost been completed. Large trees and their roots had been removed and the lands had been bulldozed. One site, Moilong Atas (Moilong hereafter), was 70 ha of dry land with light and heavy forests before deforestation. The other site, Topo Delapan (Topo hereafter), was 129 ha. Before deforestation, two thirds of Topo was dry with light forests but one third was wet with semiaquatic grass, bushes, and some taller trees. Moilong and Topo are <20 m above sea level, and ca. 15 km apart.

Census: The entire area of each study site was inspected on foot. The sizes of all pools were recorded, with approximation to rectangles (length × width) or circles (diameter). Water depths were <10 cm, except for a few large pools in the wet area of Topo.

Fifty-five sampling pools were arbitrarily selected from sites where presence of mosquito larvae was visually confirmed. Mosquitoes and predators were collected by a dipper, with 1–30 dips per pool, depending on pool size. The dip contents from a single pool were combined and sieved through a 100-mesh net. Mosquitoes were sorted out in situ. Mosquitoes and the remaining contents were preserved separately in 10% formalin solution for later identification under microscopes. This procedure was adopted to determine the main mosquito species most efficiently under the limitations of labor and time available for sampling.

Identification: Mosquito larvae and pupae were identified to species with keys of Reid (1968) and Sirivanakarn (1976, 1977). Other aquatic metazoans were identified to family or higher levels with keys of Ueno (1973) and Kawai (1985).

Analysis: Degree of similarity between faunas was examined with Spearman's coefficient of rank correlation. Differences in frequencies of occurrence were tested with Fisher's exact probability test, because frequencies less than 5 are included in most taxa. The calculations follow Sokal and Rohlf (1981).

RESULTS

Pool conditions

Most pools were small (Fig. 1). At Topo, more than 70% of pools had areas less than or equal to 1 m^2, with a peak frequency at the range of 0.5 (exclusive)–1 (inclusive) m^2. A few pools (1%) in the wet area were larger than 250 m^2, with a maximum of 4,000 m^2. At Moilong, more than 75% of pools had areas less than or equal to 2 m^2, with a peak frequency at the range of 1–2 m^2. The maximum pool size at Moilong was 500 m^2. This pool was formed by the flooding of a tributary blocked by downed trees that had been thrown into this tributary. This was the only pool exceeding 250 m^2 in Moilong. Almost all pools less than 2 m^2 were in

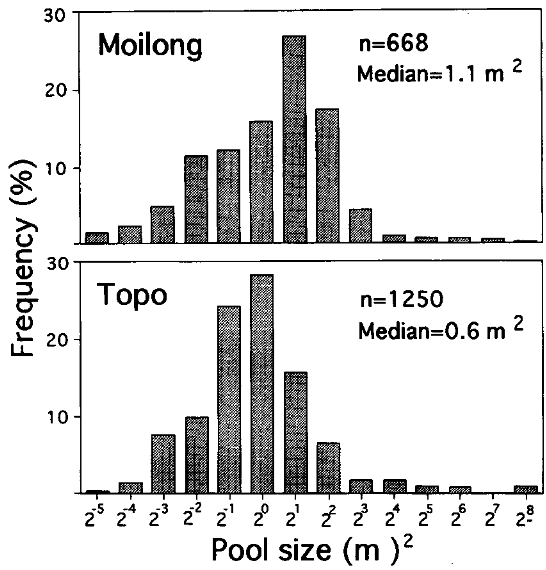

Fig. 1. Frequency distributions of pool size on 2 deforested sites (Moilong and Topo), Central Sulawesi, Indonesia. Size was expressed as exponents of 2.

depressions made by the treads of vehicles engaged in deforestation and leveling. Total areas of the surface water in Moilong and Topo were 1,934 m^2 and 15,119 m^2, respectively. The surface water occupied 0.3% (Moilong) and 1.2% (Topo) of the total deforested area.

All pools were fully exposed to sunlight, without emergent and floating macrophytes. However, water quality differed between dry and wet areas. In dry areas, either in Moilong or Topo, the land surface was largely bare due to loss of or inversion of the surface soil. Consequently, pools there were generally clear except some muddy pools recently disturbed by working vehicles. A few clear pools had submerged clumps of filamentous green algae.

Pools in the wet area (one third of Topo) were generally turbid with rich infusions from tall grass partially buried in the soil at the time of leveling or occasionally from grass piled up and left by bulldozers. This incomplete work apparently was the result of difficulty of manipulating heavy vehicles on the wet land. Below, data for pools in the dry areas of both Moilong and Topo were combined and compared with those in the wet area of Topo.

Mosquitoes

Fourteen mosquito species were collected (Table 1). Specimens belonging to the *fraudatrix* subgroup of subgenus *Lophoceraomyia* of the genus *Culex* were not identified to species because of loss of key setae. The same mosquito species occurred in dry and wet areas, with a few minor exceptions. However, for the order of dominance, no correlation was

Table 1. Mosquito species collected from open ground pools on deforested lands in central Sulawesi, Indonesia.

Species	Dry area			Wet area			Difference between frequencies[2]
	Total no.	No./dip	Frequency[1] (%)	Total no.	No./dip	Frequency[1] (%)	
Anopheles peditaeniatus	6	0.02	6	3	0.01	17	NS
Anopheles vagus	420	1.31	72	24	0.08	33	$P < 0.05$
Culex bitaeniorhynchus	544	1.70	10	0	0	0	NS
Culex fuscanus	4	0.01	10	69	0.23	42	$P < 0.05$
Culex gelidus	2	0.01	3	2,096	6.99	58	$P < 0.001$
Culex infula	66	0.21	3	0	0	0	NS
Culex nigropunctatus	17	0.05	10	341	1.14	42	$P < 0.05$
Culex pseudovishnui	49	0.15	10	2	0.01	8	NS
Culex tritaeniorhynchus	164	0.51	31	1,263	4.21	83	$P < 0.01$
Culex vishnui	812	2.54	79	101	0.34	50	NS
Culex (*Lophoceraomyia*) sp.	0	0	0	43	0.14	14	NS
Mansonia sp.	1	0.003	3	0	0	0	NS
Mimomyia sp.	1	0.003	3	0	0	0	NS
Uranotaenia (*Uranotaenia*) sp.	14	0.04	7	0	0	0	NS
Total	2,100			3,942			

[1] Percentage no. positive pools/no. all pools.
[2] NS, not significant.

found between the areas (Spearman's coefficient of rank correlation $r_s = 0.079$, df = 12, $P > 0.05$).

In dry area pools, *Culex vishnui* Theobald and *Anopheles vagus* Doenitz were encountered most frequently. *Culex bitaeniorhynchus* Giles exceeded *An. vagus,* in numbers collected, but larvae of *Cx. bitaeniorhynchus* were concentrated in a few pools with clumps of filamentous green algae. In wet area pools, the dominant species were *Culex tritaeniorhynchus* Giles and *Culex gelidus* Theobald. They were followed by *Culex nigropunctatus* Edwards, *Cx. vishnui,* and *Culex fuscanus* Wiedemann. There, *An. vagus* was a minor component. Differences in frequencies of occurrence were significant for *An. vagus, Cx. gelidus, Cx. tritaeniorhynchus, Cx. nigropunctatus,* and *Cx. fuscanus.*

High numbers per dip recorded for *Cx. gelidus* and *Cx. tritaeniorhynchus* in the wet area were the result of high concentrations of these species in some pools with rich infusions of accumulated grass. In such pools, densities frequently reached >10 individuals per dip.

Metazoa other than mosquitoes and predators

In addition to mosquitoes, dipper samples included a variety of Metazoa (Table 2). The most abundant were Crustacea, Ephemeroptera, and Chironomidae in both dry and wet areas. Members of these groups were collected more frequently (significant for Ephemeroptera and Chironomidae) with more numbers per dip in wet areas. The difference in frequencies between areas was also significant for Gastropoda. Nevertheless, the metazoan fauna (including predators but excluding mosquitoes) was correlated significantly between the 2 areas (Spearman's $r_s = 0.638$, df = 20, $P < 0.01$).

Predators

More than 90% of Crustacea were Cyclopoida. Some Cyclopoida are predacious but Crustacea were treated here as nonpredators, because Cyclopoida contributed little to predation mortalities in mosquito larvae in rice fields (Mogi et al. 1986). Predator taxa grouped at family or higher levels were common to dry and wet areas, except for fish and water mites. Fish were collected in only 2 pools in the dry area of Topo, but those pools were on the boundary between dry and wet areas. Water mites were collected only from 2 pools in the wet area.

In the dry area, Anisoptera nymphs, Notonectidae, and Dytiscidae were dominant aquatic predators, whereas Zygoptera was a minor component. In the wet area, Dytiscidae, Zygoptera, and Anisoptera were dominant. Differences in frequencies of occurrence were significant for Zygoptera. Average numbers of all aquatic predators per dip were between 1 and 2. Surface predators all belonged to Hemiptera. They were less abundant than aquatic predators.

DISCUSSION

Rain is the principal source of water on the deforested lands studied, so the number and size of pools would vary according to precipitation. The study was conducted after a period of abundant rain, so both pool numbers and size were probably at a high level. Without rainfall, pool areas may decrease rapidly and under severe drought all pools except some in the wet area may disappear. However, this transition phase, typically characterized by numerous temporary open ground pools, is un-

Table 2. Metazoa other than mosquitoes collected from open ground pools on deforested lands in Central Sulawesi, Indonesia.

Taxon[1]	Dry area Total no.	Dry area No./dip	Dry area Frequency[2] (%)	Wet area Total no.	Wet area No./dip	Wet area Frequency[2] (%)	Difference between frequencies
Gastropoda	10	0.03	7	34	0.11	42	$P < 0.05$
Acari							
Hydrachnellae[3]	0	0	0	5	0.02	17	NS[4]
Crustacea	1,616	5.05	62	1,499	5.00	76	NS
Insecta							
Ephemeroptera (L)	629	1.97	66	959	3.17	100	$P < 0.05$
Zygoptera (L)[3]	9	0.03	21	204	0.68	67	$P < 0.01$
Anisoptera (L)[3]	155	0.48	76	64	0.21	58	NS
Mesoveliidae[5]	16	0.05	24	18	0.06	50	NS
Veliidae[5]	79	0.25	69	49	0.16	83	NS
Gerridae[5]	13	0.04	13	9	0.03	25	NS
Notonectidae[3]	83	0.26	59	17	0.06	33	NS
Belostomatidae[3]	19	0.06	17	6	0.02	17	NS
Corixidae	5	0.02	7	1	0.003	8	NS
Trichoptera (L)	0	0	0	7	0.003	8	NS
Dysticidae[3]	100	0.31	52	134	0.45	83	NS
Hydraeridae	1	0.003	3	8	0.03	8	NS
Hydrophilidae (L)[3]	11	0.03	17	3	0.01	17	NS
Hydrophilidae (A)	14	0.04	17	4	0.01	17	NS
Helodidae (L)	4	0.01	7	8	0.03	33	$P = 0.05$
Ceratopogonodae (L)	14	0.04	7	0	0	0	NS
Chironomidae (L)	546	1.71	72	2,687	8.96	100	$P < 0.05$
Teleostomi[3]	3	0.01	7	0	0	0	NS
Anura (L)	6	0.02	7	1	0.003	8	NS
Total aquatic predators[6]	384	1.19		497	1.66		
Total surface predators	108	0.34		76	0.25		

[1] L or A in parentheses indicates larvae/nymphs and adults, respectively. Taxa without this designation include both larvae and adults.
[2] Percentage no. positive pools/no. all pools.
[3] Aquatic predator.
[4] NS, not significant.
[5] Surface predator.
[6] Aquatic predators + *Culex fuscanus* in Table 1.

avoidable in the course of rice field development preceded by deforestation.

Dominant mosquito species were influenced by pool conditions that at least partly depend on the predeforestation conditions (dry vs. wet) of the area. As the 2 areas were continuous in Topo, the difference is attributed to differential responses of ovipositing females to pool conditions. All of the dominant species are breeders in temporary open ground pools, including irrigated rice fields. In Sri Lanka, dominance ranks of rice field mosquitoes did not rise until the start of irrigation (Amerasinghe and Indrajith 1994). This more comprehensive study included any kind of surface water habitats with larger surface areas (e.g., marshes), so abundance of mosquitoes in temporary pools remained relatively low.

Anopheles vagus and *Cx. vishnui* are known as colonizers of rice fields with sparse vegetation shortly after transplantation (Mogi and Miyagi 1990, Mogi et al. 1995). *Anopheles vagus* and *Cx. tritaeniorhynchus* were among several species dominant in open rainwater pools on deforested lands in Sri Lanka (Amerasinghe and Ariyasena 1990). *Anopheles vagus* is a potential vector of malaria and filariasis (Abisudjak and Kotanegara 1989), whereas *Cx. tritaeniorhynchus, Cx. vishnui,* and *Cx. gelidus* are potential vectors of Japanese encephalitis virus (Burke and Leake 1988).

A shortcoming of this study is that frequencies of occurrence for all pools were not determined (samples were taken only from mosquito-positive pools). Inspection of all pools in a small area (ca. 500 m^2) in Moilong indicated that both anophelines and culicines occupied ca. 80% of pools (Sunahara et al., unpublished data). The study areas were located at the periphery of irrigated rice field areas, which facilitated mosquito colonization. Domestic animals such as cattle and horses in the nearby rice production villages also must have favored those mosquitoes by providing blood-meal sources.

Unexpectedly, aedine species utilizing open ground pools were not found. In the study area, potential species are *Aedes vexans* (Meigen) and *Aedes lineatopennis* (Ludlow) (Bonne-Wepster 1954). Abundance of these floodwater species with drought-resistant eggs would fluctuate irregularly in response to rainfall patterns. The absence of these species in the limited samples does not exclude the possibility of occasional population bursts under certain circumstances.

Colonization of ground pools by forest species was not confirmed. In Sri Lanka, Amerasinghe and Ariyasena (1990) reported colonization of rainwater pools on deforested lands by shade-loving *Aedes jamesi* (Edwards). Possibilities of such unexpected events also should not be ruled out in Indonesia under drastic and rapid changes in environment.

In view of poor housing conditions of settlers, mosquito bites could be at a level where disease epidemics can occur once pathogens are introduced. For prevention of vector mosquito outbreaks on deforested lands, the 1st tactic to consider is to implement deforestation in the early dry season and rapidly execute succeeding phases of land development projects to avoid leaving waste lands that cannot be manipulated.

Aquatic and surface predators colonized open ground pools immediately following deforestation. Sparsity of Zygoptera in the dry area is due to their requirement of plant tissues, either alive or dead, as oviposition substrates. Notonectid densities were underestimated by dipper samples, because notonectids are strong and agile swimmers and not easily caught. By sight inspection in a small area in Moilong, all pools >1 m^2 were inhabited by adult notonectids (Sunahara et al., unpublished data). High frequencies of predator occurrence contrast with observations in Sri Lanka (Amerasinghe and Ariyasena 1990); there, aquatic predators were rare in open ground pools during construction, settlement, and new irrigation phases over 2 years.

Fish, common in irrigated rice fields in Sulawesi (Mogi et al. 1995), were encountered only twice in pools on the boundary between dry and wet areas. These fish probably invaded from the wet area when water levels rose and were trapped in isolated pools as water receded. Fish certainly existed in large and deep pools in the wet area but were not caught by dippers. Absence of fish from isolated pools could have favored insect predators.

The role of predators in control of mosquitoes on deforested lands is yet to be evaluated. Preliminary analyses suggested that adult notonectids played a key role in determining mosquito densities in individual pools (Sunahara et al., unpublished data). Use of insecticides for control of mosquitoes on deforested lands should be avoided if possible because it could destroy predator populations and thus induce resurgence of mosquitoes after the loss of insecticide efficacy.

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