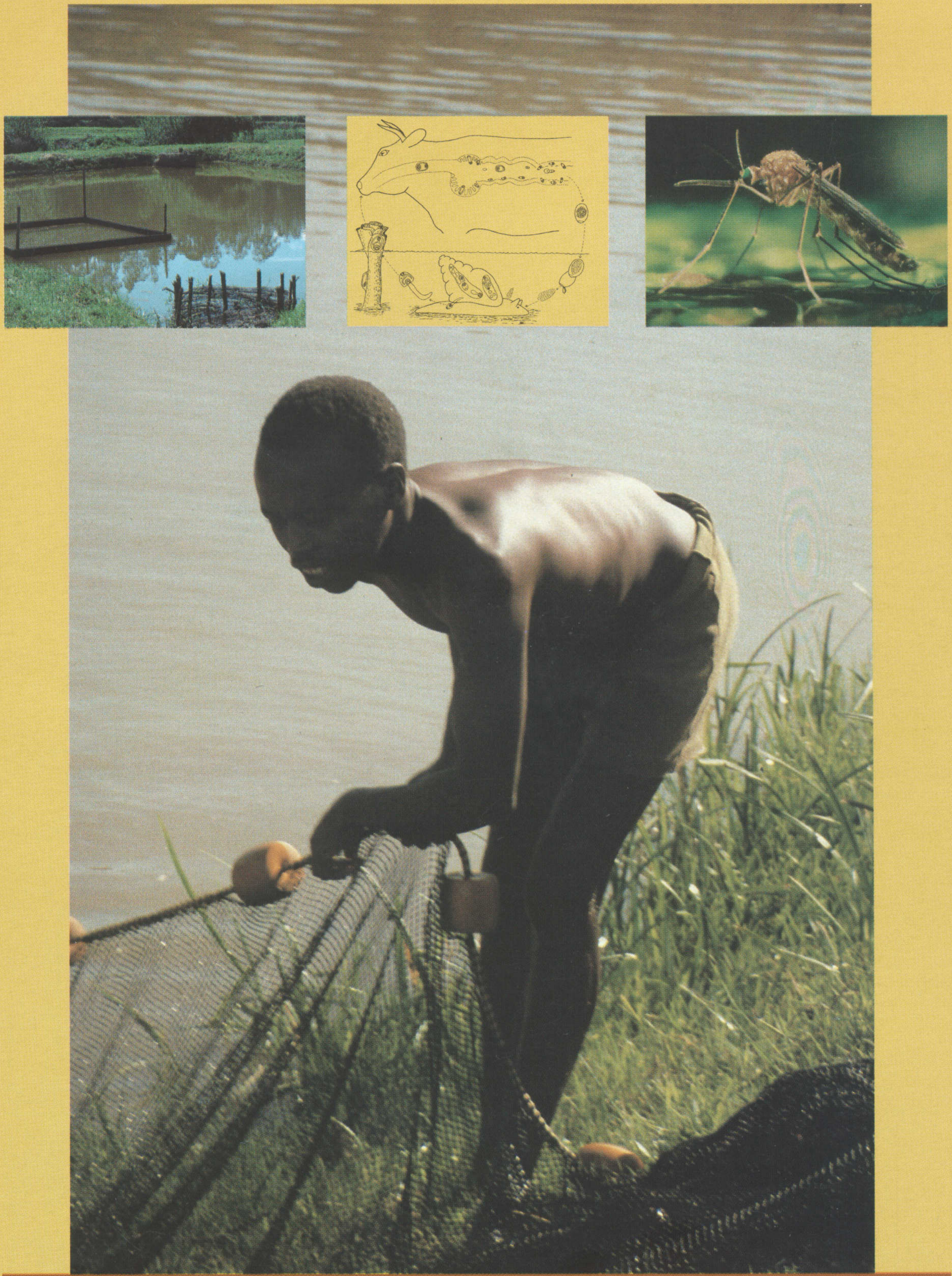

Environmental Assessment of Ten Aquaculture Sites in Rwanda, Africa

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EXECUTIVE SUMMARY

From August 6-17, 1990, an environmental assessment was conducted at 10 potential sites (in seven prefectures) for cooperatively managed, integrated aquaculture farms in the *marais* (wetland valleys) of Rwanda. Sites were evaluated for existing pond construction and management practices, and recommendations were made to minimize the risk of waterborne disease and other negative environmental impacts.

Snail hosts for schistosomiasis and sheep and cattle liver fluke occurred at more than half of the 10 ponds sampled. Mosquito larvae were less common, and anopheline mosquitos (vectors of malaria) were found at only one site. Most snails and mosquitos occurred at poorly built and managed ponds. The presence of a well-trained extension agent at a site was a critical factor to ensure well-managed ponds and thus reduce risk of waterborne disease.

Two supply canals and three discharge canals were sampled for macroinvertebrates to determine possible downstream impacts of fishponds. Benthic communities were characterized by low biodiversity and high tolerance to organic enrichment, probably because of frequent dredging of canals, intermittent water flows, and organic runoff from human and livestock activity. No negative environmental impact directly attributable to fish culture activity was detected.

At the scale and management intensity of the proposed aquaculture centers, fishponds would have relatively low volume and infrequent discharges that should not cause undue environmental degradation downstream.

Four streams with a wide range of organic pollution were sampled for macroinvertebrates to evaluate methods for a biomonitoring program. Use of a biotic index proved appropriate and practical for assessing stream water quality in Rwanda. Protocols with field methods, data interpretation tables, and a cumulative list of macroinvertebrate taxa in Rwanda are provided.

Risks of indiscriminate introduction of non-native species to Rwanda are discussed, and a review and decision model for evaluating proposed exotic fish introductions is presented.

SUMMARY OF RECOMMENDATIONS

Training and placement of extension agents should remain a high priority of the National Fish Culture Project. To reduce the risk of waterborne diseases (schistosomiasis, malaria, and liver fluke), extensionists should especially help farmers to design ponds and eliminate shoreline vegetation.

To prevent livestock disease and excess organic loading of ponds, extensionists should help farmers to determine the number of animals that can be kept well-fed and clean in appropriately sized enclosures. Because cut shoreline vegetation may contain snail vectors of disease (eggs and adults) and parasitic cysts, it should be thoroughly dried or composted away from the pond and from sheep, goats, and cattle.

Quarterly biomonitoring of at least four "trend stations" (e.g. small streams on watersheds with integrated aquaculture projects) is recommended to document long-term impact of fish farming, pesticide pollution, and other potential disturbances.

Introduction of non-native fishes to Rwanda has altered natural aquatic ecosystems and future introductions should only follow a thorough justification and description of the non-native species, as well as detailed and controlled studies on the predicted environmental consequences.

Environmental Assessment of Ten Aquaculture Sites in Rwanda, Africa

William G. Deutsch[1]

INTRODUCTION

Recent research has greatly increased the potential for fish production in Rwanda (*45*). At the completion of a 5-year, USAID-sponsored technical assistance program with the National Fish Culture Project (PPN) of Rwanda (*44*) it was concluded that proper construction and management of fishponds can result in more than a four-fold increase in tilapia production, relative to previous culture practices (*29*).

Because commercial feeds and fertilizers are generally unavailable, aquaculture in Rwanda is usually limited by nutrient inputs to fishponds. Present research at the Kigembe Station of the PPN has focused on integration of fish culture with small livestock husbandry. These integrated systems have successfully used animal manures to improve pond fertility and further increase fish production.

In an effort to extend improved aquacultural techniques to rural farmers, the PPN has proposed the establishment of up to seven cooperatively managed fish culture centers. These centers would be dispersed throughout regions of Rwanda where aquaculture is now practiced, and would receive technical support from the PPN so that they function as model farms for training and extension. USAID-Kigali supported the PPN proposal but requested both an engineering and environmental assessment of potential sites prior to funding the project.

The objective of this study was to conduct an environmental assessment of potential sites for PPN-integrated aquaculture centers. This involved an evaluation of present fish culture practices and recommendations for fishpond construction and management that would minimize negative environmental impacts. Special attention was given to fishponds and waterborne disease, and effects of pond discharge on the downstream environment. Protocols for environmental impact assessment and evaluation of exotic species introductions also are provided.

METHODS

From August 6-17, 1990, an environmental assessment was made at 10 pond sites (in seven prefectures) in the *marais* (wetland valleys) of Rwanda, figure 1. Each site was evaluated for the construction and management of existing ponds as well as the potential environmental impact of an expanded aquacultural facility that might include integration with small livestock (*47*).

Construction features that were noted included pond surface dimensions and depth and characteristics of the dikes and canals that supplied water and received discharge. Management features noted included the method of fertilization, water color and clarity, and shoreline vegetation control. All ponds were stocked with fish, Nile tilapia (*Oreochromis niloticus*), and were managed by families, school groups, or small cooperatives .

[1]Deutsch is an environmental and training specialist in the International Center for Aquaculture and Aquatic Environments.

Several points along the shoreline of at least one pond at each site were sampled for snails, mosquito larvae, and other macroinvertebrates using a dip net. The presence and relative abundance of the following human and livestock disease vectors were especially noted:

1. *Biomphalaria* spp. (*B. pfeifferi* and *B. sudanica*) - snail intermediate hosts for *Schistosoma mansoni* (blood flukes causing human intestinal schistosomiasis).
2. *Bulinus* spp. (*B. globosus* and *B. strigosus*) - snail intermediate hosts for *Schistosoma haematobium* (blood flukes causing human urinary schistosomiasis).
3. *Lymnaea natalensis* - snail intermediate host for *Fasciola gigantica* (sheep and cattle liver fluke)
4. *Anopheles* spp. - mosquito intermediate host for *Plasmodium falciparum*, *P. malariae*, and *P. vivax* (human malaria).

If the supply or discharge canal of a pond site had a current velocity of at least 5-10 cm/s, and an area relatively free of vegetation, it was sampled for macroinvertebrates to determine a family-level biotic index (*28*). The index is a relative measure (on a scale of 0 to 10) of organic pollution in flowing water, and is based on the tolerance level of each family of macroinvertebrates in the sample, table 1.

TABLE 1. EVALUATION OF STREAM WATER QUALITY USING THE FAMILY-LEVEL BIOTIC INDEX[1]

Family Biotic Index[2]	Water quality	Degree of organic pollution
0.00-3.75	Excellent	Organic pollution unlikely
3.76-4.25	Very good	Possible slight organic pollution
4.26-5.00	Good	Some organic pollution probable
5.01-5.75	Fair	Fairly substantial pollution likely
5.76-6.50	Fairly poor	Substantial pollution likely
6.51-7.25	Poor	Very substantial pollution likely
7.26-10.00	Very poor	Severe organic pollution likely

[1]Field methods used: (A) sample as often as necessary to obtain 100-200 invertebrate specimens sufficiently mature to identify to family, using a dip net in a riffle or shallow run (ideally where current is greater than 30 cm/s); (B) place net contents in a shallow white pan with water for observation (specimens clinging to the net should be included); (C) sort specimens by family into containers of 70% ethanol, excluding Hemiptera and Coleoptera (other than Dryopoidea) and individuals too small to identify; and (D) record number of specimens per family.

[2]Calculate FBI by multiplying the number in each family (n_1) by the tolerance value for that family (t_1), summing the products and dividing by the total number of arthropods (N) in the sample (i.e. $FBI = \Sigma (n_1 t_1) / N$).

A biotic index was also determined for macroinvertebrate communities at four stream sites, figure 1, that had a wide range of organic pollution. One station was relatively pristine and in an area of low human population density (Karamba, in the Nyungwe Forest). Two sites were in areas of moderate human and livestock activity (Rushashi and a tributary of the Nyabarongo River), and one site received heavy organic loading from an upstream butchery area (Kamabuye). Results from stream samples were used to evaluate the applicability of bioassessment techniques (developed in the United States) for Rwan-

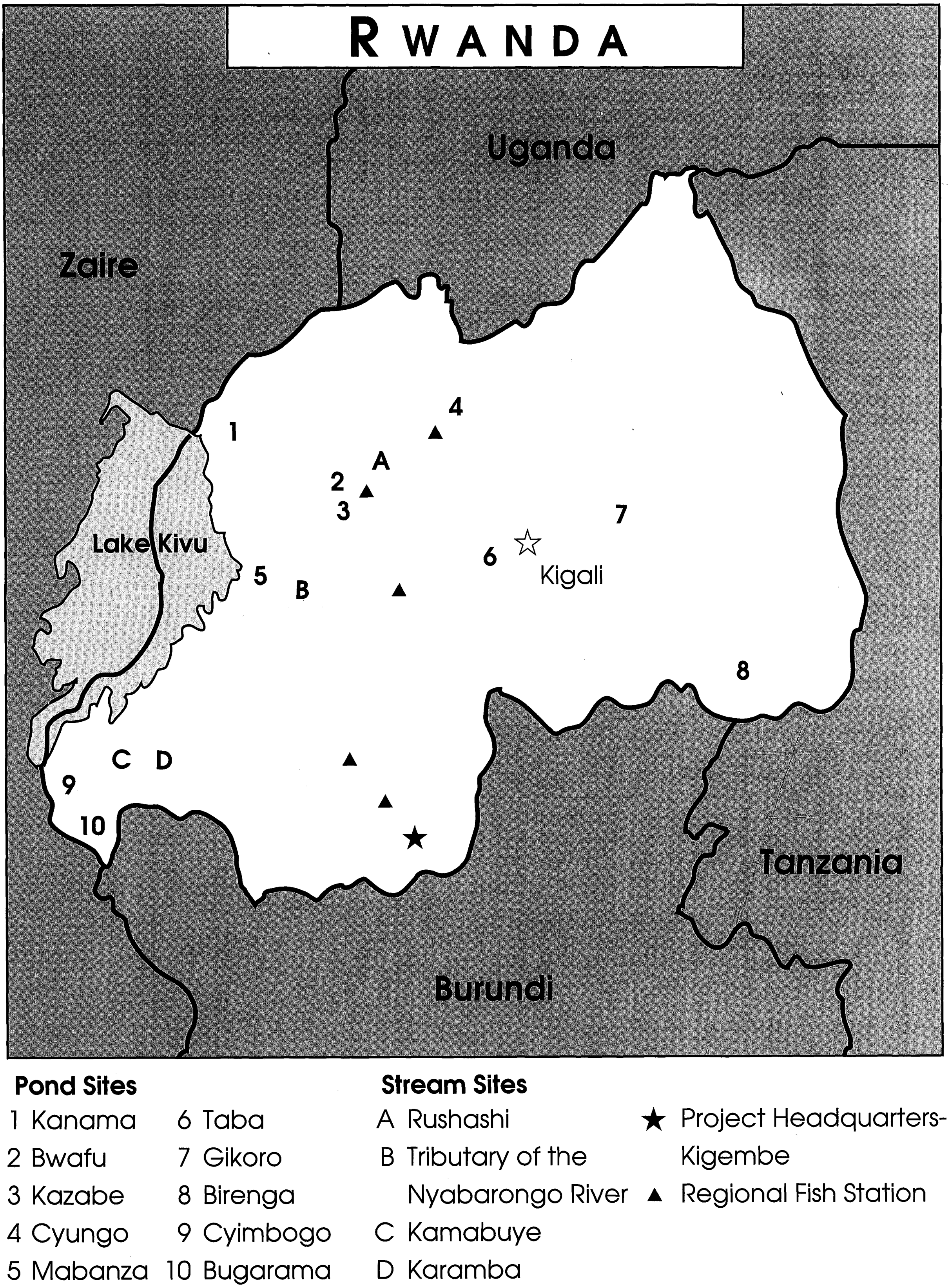

FIG. 1. Map of Rwanda with pond, canal, and stream sampling sites.

da, as well as to relate indices from fishpond canals to a spectrum of organic pollution levels.

Organisms collected at ponds, canals, and streams were hand sorted from shallow trays of water and preserved in 70% ethanol. Samples were returned to the laboratory of the Rwasave Fish Culture Center and organisms were enumerated and identified using a dissecting microscope, hand lens, and taxonomic keys of Durand and Lévêque (*20,21*).

RESULTS

POND SITE EVALUATIONS

Gikoro (Kigali Préfecture)

The Gikoro site had one pond (150 m^2) stocked with tilapia, though other ponds were being constructed. Ponds were managed by a group of local women. An extension agent has not been assigned to Gikoro, but one is presently in training at the Kigembe facility. Soils had a high clay content and were suitable for pond construction. The stocked pond had a compost enclosure filled with vegetation, household scraps, and manure. A large amount of plant fragments was floating in open water, outside of the enclosure. The shoreline was irregular with numerous indentations that were filled with emergent vegetation. The pond was constructed without levelling instruments and had an excessive bottom slope. About 25-30% of the pond was too shallow, as evidenced by emergent vegetation 3-5 m from shore in the shallow end. Depth near the discharge was 1-1.2 m.

Dip net samples in shoreline emergent vegetation revealed that there were hundreds of snails (especially *Biomphalaria pfeifferi* with some *Lymnaea natalensis*) per linear meter of pond bank. These and other macroinvertebrates incidentally collected with snails are listed in table 2. No mosquito larvae were observed.

Birenga (Kibungo Préfecture)

The Birenga site had one pond (500 m^2) managed by about 17 young adults. They intend to build more ponds on either side of the existing pond and raise pigs. An extensionist for this area is in training at Kigembe. This area of the *marais* was relatively undeveloped and was being cleared of trees. Dikes were straight and steep-sided, but had tree stumps imbedded in them that would probably result in water leakage. The small amount of compost in a corner enclosure had not been turned recently, as evidenced by 50-cm-high grasses growing in the floating vegetation. Some vegetation was floating on the pond surface, outside of the enclosure.

The pond was wider than the available harvesting net, and had been stocked a second time after a partial harvest. Present stocking density was, therefore, unknown. Construction of the discharge canal for this pond was not completed, so an adequate method of complete harvest was not available.

Some floating vegetation (*Nymphaea* sp.) was observed in the pond 2-3 m from shore. Emergent grasses at the shoreline contained the snail, *L. natalensis*. No mosquito larvae were observed, table 2.

Cyungo (Byumba Préfecture)

The Cyungo site had a large (2,500-3,000 m^2) single-family pond with about 15 compost enclosures around its perimeter. Farmers have chosen to raise rabbits and chickens at this site, and pigs will be raised in the area at other ponds. The dike is broken to drain the pond and is rebuilt after harvest.

This pond was well managed. There was a healthy phytoplankton bloom and tilapia actively fed on *Colocasia* leaf fragments thrown on the water surface. The pond was well built with little shoreline vegetation. Only one snail, *Bulinus* sp., and a single mosquito larva was found after sampling several meters of shoreline, table 2.

Taba (Gitarama Préfecture)

The Taba site had two ponds (200 m^2 each), with six additional ponds planned that would be 1,500-2,000 m^2 each (3 ha total surface area). Ponds were managed by students of a CERAI school, and rabbits and cows are already raised at the site. Being close to Kigali, there is a good market for meat and fish produced here. Ponds had relatively straight, steep-sided dikes and no emergent vegetation in open water. Shoreline vegetation was abundant, however, and the emergent grasses and smartweed (*Polygonum* spp.) contained three genera of snails, *Bulinus* sp., *L. natalensis*, and *B. pfeifferi*, table 2. No mosquito larvae were found.

Kanama (Gisenyi Préfecture)

The Kanama site had about 40 ponds that have been built over the last 3 to 5 years. Ponds were of various sizes and shapes, and were disorganized in their layout. Soils have a high organic matter content and dikes of some ponds were poorly compacted and unstable.

In general, ponds were poorly built and managed. Water levels varied and some ponds had large areas that were less than 20 cm deep. Some ponds were completely covered with duckweed and water meal (*Lemna* sp. and *Wolffia* sp., respectively); others had large amounts of floating vegetation (*Potamogeton* sp.) in open water. Most ponds were infertile, with little to no compost. Pond water was generally clear and some ponds were darkly stained with humic compounds. Shoreline grasses and smartweed were abundant and contained the snail, *L. natalensis* and numerous mosquito larvae, table 2.

TABLE 2. CUMULATIVE LIST OF SNAILS, MOSQUITOS, AND OTHER MACROINVERTEBRATES COLLECTED FROM SHORELINES OF PONDS AT TEN SITES IN RWANDA AUGUST 6-17, 1990

Taxon	Pond Site[1]									
	1	2	3	4	5	6	7	8	9	10
Snails (Gastropoda)										
Bulinidae										
Bulinus sp.			P	P					P	P
Lymnaeidae										
Lymnaea natalensis	P	P		P	P	P				P
Planorbidae										
Biomphalaria pfeifferi	P			P		P		P	P	P
Thiaridae										
Melanoides tuberculata							P	P		
Mosquitos (Diptera)										
Culicidae										
Anophelinae								P		
Culicinae			P		P					
Other Macroinvertebrates										
Ephemeroptera										
Baetidae	P	P	P		P	P	P	P		
Caenidae		P								
Odonata										
Aeshnidae				P			P			P
Coenagrionidae	P	P	P	P	P		P		P	
Libellulidae							P	P	P	
Macromiidae				P						
Hemiptera										
Belostomatidae		P	P	P	P	P		P		
Corixidae						P		P	P	
Gerridae	P	P								
Hydrometridae		P								
Mesoveliidae	P	P					P		P	
Naucoridae			P	P			P			
Nepidae			P	P	P				P	P
Notonectidae			P	P	P	P		P		
Pleidae		P						P		
Coleoptera										
Dytiscidae		P			P	P		P		
Gyrinidae					P			P		
Hydrophilidae	P									
Diptera										
Ceratopogonidae		P								
Chironomidae		P	P		P		P			
Ephydridae					P					

[1]Sites of study: 1 = Gikoro; 2 = Birenga; 3 = Cyungo; 4 = Taba; 5 = Kanama; 6 = Mabanza; 7 = Cyimbogo; 8 = Bugarama; 9 = Bwafu; 10 = Kazabe; P = present

Mabanza (Kibuye Préfecture)

The Mabanza site had four large ponds (3,000-4,000 m^2 each) that were constructed about 15 years ago. This was previously a governmental station that cultured *O. macrochir* and common carp (*Cyprinus carpio*) with minimal feed or compost inputs. It was managed by a cooperative of local men who use compost enclosures to fertilize ponds stocked with *O. niloticus*. A woman extensionist, in training at Kigembe, will be stationed there.

Ponds were generally well constructed but needed repair. Dikes were high (1-1.5 m above water surface) and undercut in several places. Shoreline vegetation was abundant and contained the snails, *L. natalensis* and *B. pfeifferi*, table 2; no mosquito larvae were observed. A cow grazed near the ponds and a boy swam in one of them at the time of sampling. This indicated that there may be regular human and animal contact with pond water that contained snail hosts for schistosomiasis and cattle liver fluke.

Cyimbogo (Cyangugu Préfecture)

The Cyimbogo site had 300-400 m^2 ponds managed by families that own the land of the *marais*. Cultured *Tilapia rendalli* and *O. macrochir* were replaced by *O. niloticus* within the past 5 years. The people are willing to convert the surrounding sweet potato and cassava fields into fishponds because of the high demand for animal protein within this Préfecture and from nearby Zaire. They wish to integrate fish culture with chickens and goats, and they also may raise rabbits. An extension agent was active at Cyimbogo and has previously improved pond design. Farmers have kept good fish production records.

Ponds were well built and managed. Dikes were straight with little shoreline vegetation. Compost enclosures were properly maintained, and ponds had healthy phytoplankton blooms. Water from the supply canal was filtered with a screen before it entered the ponds. No mosquito larvae or snail hosts for schistosomiasis or liver fluke were observed after sampling several meters of shoreline, table 2. A single specimen of the predaceous snail *Melanoides tuberculata* was found.

Bugarama (Cyangugu Préfecture)

The Bugarama site had four ponds (200-300 m^2) managed by a group of Boy Scouts. Ponds were at the lowest elevation in Rwanda (900 m). A rice/fish culture project has been proposed for this area, and farmers are willing to replace existing rice fields with fishponds. An extensionist is presently being trained at Kigembe, and a neighboring extensionist assists here occasionally.

Ponds were fertilized with cut sedges (*Cyperus* sp.) in compost enclosures. Dikes were higher than necessary and shoreline grasses were abundant. One pond seemed to have the water level recently lowered and contained emergent vegetation in open water. Two snail species, *B. pfeifferi* and *M. tuberculata* were found there. table 2. This was the only site at which anopheline mosquito larvae were collected from fishponds.

Bwafu (Gisenyi Préfecture)

The Bwafu site had five government-owned ponds (about 2,000-3,000 m^2 each), adjacent to a Dutch agricultural project. An extensionist from the PPN had not been assigned here. Local farmers were interested in producing more fish and beginning livestock husbandry. Ponds were terraced with about a 3-m difference in the water level of the first and fifth ponds. Dikes were extremely high (up to 2 m above the water surface) and large portions of them were subsiding into the ponds. Some ponds were greater than 2 m deep at the water level control monks, and the outer slope of all ponds was up to 3-m high and leaking.

In general, ponds were too large and deep to effectively manage under current conditions. There was little or no compost in ponds and existing compost enclosures were grossly undersized. Water was infertile and brown except in the smallest pond which was composted and used to produce tilapia fingerlings for stocking in other ponds. Stocking and harvest records were unavailable, but only about 5 kg of *O. niloticus*, stocked from Kigembe 1 year ago, have been harvested.

There was little emergent vegetation, and dip net samples revealed that shoreline macroinvertebrates were generally scarce. A few *Bulinus* sp. and *B. pfeifferi* snails were collected along the shoreline, but no mosquito larvae were observed, table 2.

Kazabe (Gisenyi Préfecture)

The Kazabe site had eight government-owned, terraced ponds (200-300 m^2 each) and eight additional ponds that were drained. Ponds were designed and managed much like those at nearby Bwafu and an extensionist from the PPN had not been assigned here. A group of local women was interested in improving these ponds and integrating them with small livestock. Ponds were not fed or composted and water was infertile and brown. Shoreline vegetation contained three snail species, *Bulinus* sp., *L. natalensis*, and *B. pfeifferi*. No mosquito larvae were found, table 2.

Stream and Canal Site Evaluations

A biotic index (BI) was determined for four streams and five canal sites, table 3 and figure 2. Macroinvertebrate data which formed the basis for the BI for each site are presented in Deutsch (*15*). The BI of streams reflected known conditions of organic pollution and, therefore, seemed applicable for bioassessment in Rwanda. The most pristine stream, at Karamba, had the greatest biodiversity and the lowest BI, figure 2. Water quality for this stream was rated "very good, near excellent", table 1. The Kamabuye stream, with known organic pollution, had only one-third the biodiversity of that at Karamba, and the highest BI, figure 2. One genus of Chironomidae (*Chironomus* spp.) composed more than 90% of the total number of organisms present. Water quality for this stream was rated "very poor, severe organic pollution likely", table 1. Streams at Rushashi and near the Nyabarongo River had intermediate biodiversity and water quality ratings of "good, some organic pollution probable", table 1. Results suggested that macroinvertebrate families in Rwanda were "ecologically equivalent" to their counterparts in North America in terms of pollution tolerance, and that criteria of the BI were appropriate for this study.

Most canals at pond sites were not evaluated with a BI because they did not have flowing water or were overgrown with vegetation. Canal sites that were sampled had macroinvertebrate communities with low biodiversity (few taxa) and high tolerance to organic enrichment.

Cyimbogo, where fishponds were located downstream from a large agricultural area, had the fewest number of taxa and highest BI of the canals sampled, figure 2. Gikoro, in a less developed *marais*, had benthic communities in canals that were slightly more diverse and with a lower BI. At the two sites where both the supply and discharge canals were sampled (Cyimbogo and Gikoro), macroinvertebrate communities were relatively similar upstream and downstream of fishponds, figure 2. This indicated that negative environmental impacts on benthos were not attributable to fish culture activities.

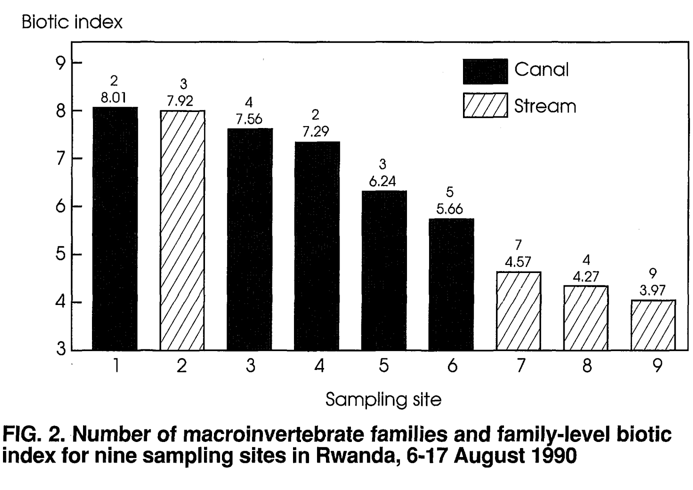

FIG. 2. Number of macroinvertebrate families and family-level biotic index for nine sampling sites in Rwanda, 6-17 August 1990

Table 3. An Example Field Sheet for Calculation of the Family-level Biotic Index at a Stream at Karamba, Rwanda August 13, 1990[1]

	n_l	t_l	$(n_l t_l)$		n_l	t_l	$(n_l t_l)$
EPHEMEROPTERA				ISOPODA			
Baetidae	119	4	476	Asellidae		8	
Caenidae		7		__________			
Ephemerellidae		1					
Ephemeridae		4					
Heptageniidae		4		TRICHOPTERA			
Leptophlebiidae	3	2	6	Hydropsychidae	11	4	44
Oligoneuridae		2		Hydroptilidae		4	
Tricorythidae		4		Lepidostomatidae	1	1	1
__________				Leptoceridae	1	4	4
__________				Limnephilidae		4	
__________				Philopotamidae		3	
__________				Polycentropodidae	2	6	12
__________				Psycomyiidae		2	
				Phyacophilidae		0	
				Sericostomatidae		1	
ODONATA				__________			
Aeshnidae		3		__________			
Calopterygidae		5		__________			
Coenagrionidae		9		__________			
Corduliidae		5					
Gomphidae		1					
Lestidae		9		COLEOPTERA			
Libellulidae		9		Elmidae		4	
Macromiidae		3		__________			
__________							
__________							
__________				DIPTERA			
__________				Blephariceridae		0	
				Ceratopogonidae	1	6	6
				Chironomidae (red)		8	
PLECOPTERA				Chironomidae (pink)		6	
Perlidae		1		Ephydridae		6	
__________				Psychodidae		10	
				Simuliidae	1	6	6
				Tabanidae		6	
AMPHIPODA				Tipulidae	3	3	9
Gammaridae		4		__________			
Talitridae		8		__________			
__________				__________			

Family Level Biotic Index (FBI) = $\Sigma (n_l t_l) / N = 564 / 142 = 3.97$

[1]The list of macroinvertebrate families in Rwanda is from Durand and Lévêque (*20,21*).
Sampling Site: *Stream at Karamba (Cyangugu Prefecture), Rwanda, Africa*
Date: August 13, 1990 Collector(s): *WGD, MC* Identifier(s): *WGD, MC*
Notes: *Biotic Index of 3.97; Number of Families = 9; 6 Hydrophilidae and 3 Gyrinidae (Coleoptera) were also collected.*

In general, the benthos of canals upstream and downstream of ponds seemed to be altered from such factors as frequent disturbance of the substrate (dredging of canals), intermittent water flow, and organic enrichment from nearby human and livestock activities. It is important to note that the BI of canals is not directly comparable to the BI of streams, and canal water quality should not be interpreted according to table 1. The canal aquatic environment is unstable, and usually had flows less than those required for appropriate application of the BI . Canal water quality would be better evaluated using chemical or bacteriological (fecal coliform and streptococcus) methods.

DISCUSSION

Fish Culture and Waterborne Disease

Fishponds in tropical countries have frequently been implicated in the spread of human and livestock disease (*30,36,39*). Desowitz (*14*) cited examples of fish culture development projects that resulted in expanded mosquito habitat and a large increase in the incidence of human malaria. Others have noted that fishponds may be favorable habitats for snail vectors of schistosomiasis (*5*), and numerous efforts have focused on the control of these snails (*12,41,42,43,56*).

Recent documentation of schistosomiasis in Rwanda (*25*) has resulted in concern over the role of fishponds in the spread of this disease. Malek (*40*) conducted a survey of several fishponds in Rwanda and concluded that the snail hosts for schistosomiasis and sheep and cattle liver fluke were widespread. Ponds have the potential for facilitating the spread of these diseases if infected humans or livestock contaminate them, however, the trematode parasites do not yet seem to be prevalent in Rwanda. Recommendations for controlling mosquito and snail hosts for malaria, schistosomiasis, and liver fluke were related, and included maintenance of fish in ponds at all times, control of shoreline vegetation, removal of floating debris, and screening of supply canal water. Unedited excerpts from the report of Malek (40), which give background information on fish culture and waterborne disease and are pertinent to the present study, are presented in the Appendix.

In the present study, the findings of Malek (*40*) were substantiated in that snail hosts for schistosomiasis and liver fluke were found in more than half of the ponds sampled, table 2. Mosquito larvae were less common and anophelines were observed at only one site.

Control of shoreline vegetation is perhaps the single most important factor in eliminating mosquito and snail habitats in stocked fishponds. Without emergent plants, mosquito larvae and trematode cercariae are vulnerable to fish predation, and snails are deprived of their preferred, firm substrates (plant stems and leaves) for grazing. Because of the prevalence of *L. natalensis* in ponds, shoreline vegetation may contain metacercarial cysts of the liver fluke as well as snails and their eggs. It is, therefore, important to not compost cut shoreline plants in fishponds nor feed them to cattle, sheep, or goats. Shoreline vegetation should be thoroughly dried or composted away from water and livestock to break the life cycle of the parasite.

There was a clear relationship between design and management features of ponds and the occurrence of disease vectors. For example, the poorly built pond at Gikoro had the most snails, and ponds with abundant shoreline and open-water vegetation at Kanama and Bugarama harbored mosquitos. Conversely, well-built and well-managed ponds at Cyungo and Cyimbogo had almost no disease hosts.

The role of an active, well-trained extensionist cannot be underestimated in minimizing risks of waterborne disease. At the sites visited, they seemed to be the critical factor in this regard. The fact that extensionists have effectively helped farmers to keep pond dikes straight and relatively free of shoreline plants is a credit to the training at Kigembe, and continued training and placement of extensionists should remain a high priority of the PPN.

Integrated Aquaculture and Water Pollution

Because most fishponds in Rwanda are nutrient limited, integration of aquaculture with livestock husbandry has the potential for increasing fish production while supplying farmers with additional meat and animal by-products. Integration is one of the most efficient ways to convert manures into edible protein (*38,49*). Although integrated aquaculture has been successfully practiced in Asia for centuries, there is concern that these culture methods may spread disease or pollute the downstream environment. For example, some virologists warn that integrated aquaculture with pigs, poultry, and fish, as practiced in Thailand, creates an environment in which harmful viruses may be transmitted to people (*19,48*). Pigs are particularly implicated as a source of mutated viruses which infect human populations.

To minimize the spread of disease in integrated systems, livestock should be kept well-fed and clean in adequately sized enclosures. Fish culture with livestock in properly built pens at Kigembe has demonstrated that animal manures may be safely metabolized in ponds to increase tilapia production in Rwanda. Use of manures may even reduce disease risks by enhancing pond fertility and phytoplankton blooms that, in turn, shade out emergent vegetation and eliminate snail and mosquito habitat.

Proper matching of pond size with manure inputs (e.g. kg of animal per unit surface area of water) is important to avoid excess organic loading and unhealthy, septic conditions that may pollute the downstream environment when water is discharged. Fortunately, the fish serve as one of the most important checks against over-manuring because the resulting low dissolved oxygen or build-up of toxic metabolites (e.g. ammonia) would preclude their culture. Extensionists at Kigembe should be trained to assist farmers in housing the appropriate number of animals at their ponds.

Although much of the organic inputs from manures would be converted to fish flesh, some will be released downstream when ponds are drained. This study found that the aquatic environment immediately below fishponds is already disturbed from other factors, and that the relatively few taxa that occur there are tolerant of high levels of organic enrichment, figure 2. In large aquacultural systems that receive intensive feed and chemical inputs, fishpond discharges may be of low quality and adversely affect downstream use (*4,6,22,55*). At the scale and management intensity of the proposed aquaculture centers, however, fishponds would have relatively low volume and infrequent discharges that should not cause undue environmental degradation downstream.

As freshwater wetlands, *marais* are among the most productive ecosystems, and much of the excess organics discharged from fishponds will quickly become incorporated into plant biomass (cultivated and natural vegetation). Some organics will probably reach surface streams or ground water and become a source of non-point pollution. For this reason, environmental monitoring of streams is recommended.

Environmental Impact Assessment

Basic ecological information is needed to form a baseline from which sound environmental management decisions can be made. Although there has been some attempt to evaluate and control aquatic pollution in Africa (*1*), baseline information on water quality trends in Rwanda is sorely lacking. This study made a preliminary evaluation of the usefulness of the biotic index for assessing organic pollution in streams and canals of Rwanda, table 1 and figure 2. Several macroinvertebrate families were collected and used in this effort, table 4.

Aquatic macroinvertebrates are typically abundant, relatively immobile, and have a wide range of pollution tolerances. For these reasons, they have been used in pollution studies for a number of years (*26*). Recent research has developed rapid bioassessment methods that require a minimal amount of equipment (*27,28,37*). Fish communities have also been used in impact assessment (*23,34*), and a concurrent study of water chemistry, macroinvertebrates, and fish provides a thorough description of non-point sources of organic pollution in streams (*16*).

The biotic index would be useful in stream studies in Rwanda, and it is one of the most practical ways to determine the long-term impact of fish culture or other human and livestock activities on water quality. Although taxonomic and ecological information on macroinvertebrates in Rwanda is scarce (*7,9,20,21,32*), family-level tolerance values determined for benthos in the United States seemed applicable for this study. The BI could be refined for local conditions and made more accurate by determining tolerance values for organisms at lower taxonomic levels (genus or species). For example, a biotic index that used genera and species of macroinvertebrates was applied to stream assessments in South Africa by Chutter (*8*). The BI is best applied to first and second order streams and is not recommended for use in canals, table 1.

Stream macroinvertebrates also could be used to detect other forms of disturbances such as pesticide pollution. Because invertebrates such as aquatic insects and worms form a critical link in the food webs of Rwandan fishponds, and they are particularly intolerant of most pesticides used in agriculture (*33*), it may be important to monitor upstream use of chemicals that may threaten the feasibility of aquaculture. At a USAID-sponsored aquaculture project in El Salvador, for example, it was impossible to maintain fish in ponds until upstream use of pesticides was controlled (*3*).

Table 4. Cumulative List of Macroinvertebrates Collected from Ponds, Canals, and Streams in Rwanda, August 6-17, 1990

Arthropoda	Arthropoda (cont.)
Insecta	Insecta (cont.)
Ephemeroptera	Coleoptera
Baetidae	Dytiscidae
Caenidae	Gyrinidae
Odonata	Hydrophilidae
Aeshnidae	Diptera
Coenagrionidae	Ceratopogonidae
Libellulidae	Chironomidae
Macromiidae	Culicidae
Hemiptera	Anophelinae
Belostomatidae	Culicinae
Corixidae	Ephydridae
Gerridae	Mollusca
Hydrometridae	Gastropoda
Hydrometra sp.	Bulinidae
Mesoveliidae	*Bulinus spp.*
Naucoridae	Lymnaeidae
Nepidae	*Lymnaea natalinsis*
Nepa sp.	Planorbidae
Ranatra sp.	*Biomphalaria pfeifferi*
Notonectidae	Thiaridae
Pleidae	*Melanoides tuberculata*
Plea sp.	
Tricoptera	
Hydropsychidae	
Hydropsyche spp.	
Macronema sp.	
Lepidostomatidae	
Goerodes sp.	
Polycentropodidae	

It is recommended that several "trend stations" be established on small watersheds in Rwanda for periodic bioassessment studies. A quarterly monitoring of four or five key sites would require approximately four person-weeks per year for a qualified technician with expertise in macroinvertebrate taxonomy. Such a collection of ecological information could be invaluable for determining conditions and appropriate future uses of water in the country.

Exotic Species Introductions

There has been relatively little control over the introduction of exotic fishes to Africa, and some non-native species have irreversibly altered natural aquatic environments. In Rwanda, there have been introductions of the grass carp, *Ctenopharyngodon idella* (1979), the common carp, *Cyprinus carpio* (1960s), the silver carp, *Hypophthalmichthys molitrix* (1979), the clupeid, *Limnothrissa miodon* (1960s), and the tilapias, *O. macrochir* (1950s), and *T. rendalli* (1956), among others (*54*). Ogutu-Ohwayo and Hecky (*46*) noted some of the "species extinctions, introgressive hybridizations, and ecosystem alterations" that occurred following fish introductions in African waters, and a recent study by DeVos et al. (*18*) documented the complete change in a cyprinid-based fishery in Lake Ruhondo, Rwanda, following the introduction of *Tilapia*.

New species of fish are continually being described from Rwanda (*17,51,52*) and there may be hundreds of invertebrates, plants, and other organisms which are unknown to science and potentially useful to humans. Clearly, the indiscriminate introduction of non-native organisms, which may threaten these species, should be strongly discouraged. Introductions should only follow a thorough justification and description of the potentially introduced species, as well as detailed and controlled studies on the predicted environmental consequences. Even the best evaluations may fail to detect negative impacts that become impossible to correct after introduction. A decision model for exotic introductions, figure 3, was developed by Kohler and Stanley (*35*) and has been applied to potential fish transfers in Africa by Slootweg (*50*).

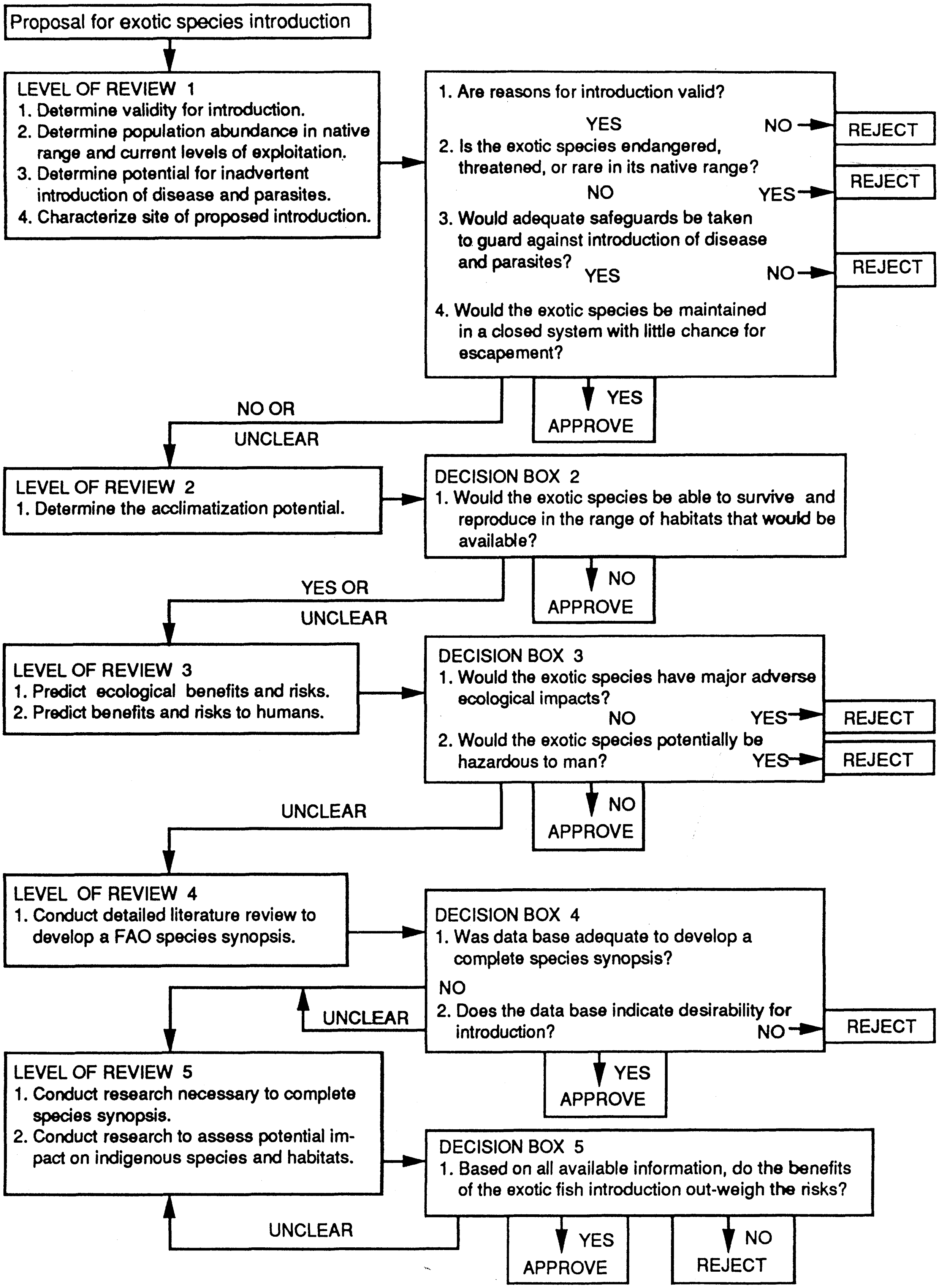

FIG. 3. Review and decision model for evaluating proposed exotic introductions.

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APPENDIX

CHAPTERS 3, 7, AND 8 FROM THE REPORT OF MALEK (1983) CONCERNING THE IMPACT OF FISH PONDS ON PUBLIC HEALTH IN RWANDA

3. Summary and Conclusions

In order to assess the impact of fish ponds in Rwanda on the prevalence of schistosomiasis and malaria, examination of ponds was carried out in five prefectures, namely, Butare, Gikongoro, Gitarama, Gisenyi, and Kigali. In the examination, emphasis was placed on the layout of the ponds, the water supply, the fish species being cultured, presence or absence of aquatic weeds and of bank vegetation hanging in the water, species of snails and their infection with schistosomes and other trematodes, presence or absence of mosquito larvae and use of the ponds by humans. Chemical analysis of pond water was carried out in several ponds.

It was revealed that feeder streams often have snails and aquatic vegetation and no doubt they are the source of infestation of the ponds with these organisms. Ponds with aquatic weeds, with bank vegetation hanging in the water and with flotsam, vegetable matter, and debris have more than one species of snails. On the other hand, well managed ponds without aquatic weeds, where the bank vegetation is trimmed, without debris or vegetable matter do not harbor snails or mosquito larvae.

Several ponds harbor the snail intermediate hosts of *Schistosoma mansoni* (*Biomphalaria pfeifferi* and *B. sudanica*) and the snail hosts of *Schistosoma haematobium*, (*Bulinus* (*Physopsis*) *globosus* and *Bulinus strigosus*). This is the first report of these bulinid snails in Rwanda. Although no infection with *S. mansoni* or *S. haematobium* was found in these snails, their presence in the ponds creates the possibility of transmission of schistosomiasis. Moreover, it is possible that snails may be found infected at a different season of the year. Chemical analysis of the water of some ponds indicated that fish ponds in several prefectures can harbor snails and other molluscs at any time if they are introduced in the ponds.

Fortunately, the majority of ponds examined in this study are not used by the human population, at least at the time of the visit to these ponds. People tend to use nearby streams, if they exist, because the stream water is cleaner than the stagnant and fertilized ponds. However, when the pond is at the edge of a town, such as the one at Nyabisindu, people tend to use it for various purposes, resulting in human-water contact and possible infection with schistosomiasis.

Recommendations made, if followed, will minimize or possibly eliminate the chances of infection with schistosomiasis and malaria. Environmental means of snail and mosquito larvae control are strongly encouraged. Removal of aquatic and bank vegetation and of all flotsam and debris should be done regularly to discourage snail and mosquito larvae breeding. Ponds should be drained occasionally and vegetation, mud on the bottom and the banks removed, and indentations along the sides of the pond should be eliminated. Because most feeder streams were found to harbor snails and weeds, a small metal screen with 16 meshes to the linear inch, should be installed across the inlet of each pond to detain snails, weeds, and snail eggs adhering to the weeds. These weeds when found should be removed so that they do not interfere with passage of water. Introduction of malacophagous fish and mosquito larvae-eating fish is encouraged. However, well-controlled observations have to be carried out to determine the efficacy of these fish under Rwandan conditions. Ponds should always be stocked with fish because such ponds stocked with even the species which are presently being cultured, do not contain mosquito larvae. All persons who have anything to do with fish ponds should have urine and fecal examinations every six months to determine if they are infected with schistosomes. If found infected they should be treated in a nearby hospital with the available effective chemotherapeutic agents. This examination should be done as soon as possible because the snail intermediate hosts are already present in a large number of ponds. Arrangements have been made with the Laboratory of Parasitology at the Medical School in Butare to carry out the examination.

A monitoring or surveillance and control program for snails and mosquito larvae should begin as soon as possible, and should be considered an important activity of the Fish Culture Project. A part of the training course for monitors, which will start at Kigembe in September 1983, should be devoted to the impact of fish ponds on the prevalence of schistosomiasis and malaria. Supervisors and agronomes also should receive such training. If monitors find any snails or mosquito larvae in their areas they should alert the supervisors who subsequently will contact the team leader and the fish culture extension specialist. Control measures, mainly environmental, should be taken immediately, after which monitoring should continue every two months. During the first year (1983-1984) emphasis will be placed on monitoring fish ponds for snails and mosquito larvae in the prefectures of Butare, Gikongoro, and Gitarama. In the second and third years, the monitoring will be carried out in other prefectures. The fourth year will be devoted to evaluation of the program.

This study indicates that fish ponds in Rwanda prove satisfactory in terms of high fish productivity, without or with a minimal risk of transmission of schistosomiasis and malaria, if they are well managed and if a few simple and affordable control measures are undertaken. However, a more detailed study will be required to verify that the disease vectors can be controlled over time.

7. Field Observations of Fish Ponds in Rwanda Regarding Water-Related Diseases

Fish ponds in Rwanda, if not well managed, could be a health hazard in transmitting schistosomiasis and malaria. Some viral diseases transmitted by mosquitoes also could be contracted. However, the ponds are not suitable habitats for the breeding of the larvae of black flies, *Simulium* spp. which transmit onchocerciasis.

In Rwanda, fish ponds have been in existence for a long time and thus are not a new environmental impact. It should be noted that in any country the area used by fish ponds is very small compared to the area containing natural streams, rivers, small and large impoundments and swamps with which the human population is in contact. With regard to the impact of fish ponds on public health, several factors have to be taken into consideration, for example, their management, their size and number, their attractiveness to the human population, the vectors they harbor, the infection rates among these vectors, and the prevalence of diseases among the human population.

Fortunately, the majority of ponds examined in this study are not used by the human population, at least at the time of the visit to these ponds. People tend to use the nearby streams if they exist, because the stream water is cleaner than the stagnant and fertilized ponds. However, when the pond is at the edge of a town, such as the one at Nyabisindo, people tend to use it for various purposes resulting in human-water contact and possible infection with schistosomiasis. This is especially true when there are only a few other alternatives in the form of streams or rivers or piped water. Moreover, when fish ponds are in the proximity of towns, the stream feeding the pond is usually surrounded by dwellings which pollute the stream as well as the ponds. Such is the case in the prefectural fish ponds at Kigali.

The present study of fish ponds in Rwanda showed that the majority harbor the snail intermediate hosts of the human and animal schistosomes. Moreover, chemical analyses of water in several fish ponds showed that all are suitable habitats for existence and breeding of molluscs. Thus it is only a matter of time until all become infested with certain snail species which they do not harbor at present. Although no schistosome intermediate hosts collected were infected with the schistosomes, certain studies on fish ponds in other African countries revealed the presence of snails infected with the human schistosomes.

The snails collected during this study in Rwanda were all browsing on plant surfaces rather than mud surfaces although they occasionally occur on mud. If macrophytic vegetation is allowed to grow in a pond or marginal vegetation overhangs into the water, snails are likely to be found in large numbers. Another favorite substrate is provided by decaying vegetable matter such as leaves or grass cuttings which fall into the pond or may be deliberately thrown in as food for the fish, often in excessive quantities.

Fortunately, the situation can be remedied with regard to both snail and mosquito vectors of schistosomiasis and malaria respectively. Disease control should be a primary objective in pond management. We can have fish ponds with minimal health hazards. Well managed ponds in which aquatic vegetation and all debris are removed and marginal vegetation are trimmed are not favorable habitats for snails and mosquito larvae. Larvae of *Anopheles gambiae* and *A. funestus* are usually found on mats of floating debris or in the semi-submerged vegetation at the edges of the water. This is a similar habitat to that for snails. Snails and aquatic weeds also should be detained at the inlet of each pond from the feeder stream, so that they will not be introduced into the ponds.

It was observed during this study that when the pond is stocked with fish, any species which are presently cultivated in Rwanda, then there are no mosquito larvae. Evidently the larvae were being consumed by the fish. Therefore the ponds always should be stocked with fish until they are drained and dried out.

Important Snails Found In Rwandan Fish Ponds

The important snail species which were encountered in the fish ponds which were examined are the following:

Lymnaea natalensis

This is a common snail in many African countries and is the snail intermediate host of the cattle and sheep liver fluke *Fasciola gigantica*. None from fish ponds was found infected with this fluke, however, some specimens collected from an irrigation ditch near Butare were infected, and when the snails were isolated in water with grass blades, metacercarial cysts of *F. gigantica* were observed on the grass blades. However, there were other trematode cercariae emerging from the specimens collected from fish ponds.

In Zaire, this lymnaeid species in fish ponds was found infected with a strigeid trematode of the family Diplostomatidae. The cercariae after leaving the snails encyst in fish to form metacercariae. When the fish is eaten by birds the metacercariae develop to the adult worm *Diplostomum* sp. Infection with the metacercariae in the fish may cause a serious effect on the fish population and results in low fish productivity.

Thus snail control in fish ponds is not only for health reasons but also to ensure high fish productivity by eliminating metacercarial infections in fish.

Biomphalaria pfeifferi and *B. sudanica*

These planorbid snails, especially *B. pfeifferi*, are common in many African countries. They are recognized and effective intermediate hosts of *Schistosoma mansoni*, which causes human intestinal schistosomiasis. None were found infected with *S. mansoni* in the fish ponds that were examined. They might, however, be found infected at another season of the year. The snails were found infected with other trematodes, not of medical importance.

B. pfeifferi and *B. sudanica* are intermediate hosts of another schistosome *Schistosoma rodhaini*, a parasite of small rodents and dogs in Zaire, Uganda, and Kenya. It occasionally infects humans in Zaire. Whether it occurs in Rwanda is not known.

Bulinus (Physopsis) globosus and *Bulinus (Bulinus)* sp. probably *B. (B.) strigosus*

These are intermediate hosts, in other countries, of *Schistosoma haematobium*, the causative agent for human urinary schistosomiasis.

This is the first report of these snails in Rwanda, and they are probably the intermediate hosts of the few cases of *S. haematobium* found recently in Rwanda. Early reports indicated the absence of these bulinid snails and the absence of urinary schistosomiasis in Rwanda. The only bulinid snail which was reported in Rwanda is *Bulinus (Bulinus) forskalii*, a different bulinid snail which is not an intermediate host of urinary schistosomiasis in any African country.

B. globosus, and *B. forskalii* are intermediate hosts of another schistosome, *Schistosoma intercalatum*, although related to *S. haematobium*, it produces human intestinal schistosomiasis in Cameroon, Zaire, Gabon, and the Central African Republic. Whether it is found in Rwanda is not known. It is possible that the case near Butare, which was diagnosed as *S. haematobium*, where the eggs were found in the feces, is caused by *S. intercalatum*.

The bulinid snails *B. globosus* and *B. strigosus* also serve as hosts for *Schistosoma bovis*, a schistosome of cattle and sheep. It was reported in Rwanda by van den Berghe (*53*), where it also infects antelopes.

Thiara tuberculata = Melanoides tuberculata

This species was found in fish ponds in Kigali and in Lake Ruhundo near Ruhengeri. *T. tuberculata* and another species *T. granifera* have been advocated as biological control agents of snails of medical or veterinary importance. The observations in Rwanda (also in Senegal and the Sudan) indicate that it coexists with biomphalarid, bulinid and lymnaeid snails.

8. Control of Snails and Mosquito Larvae in Fish Ponds

Snail Control

In general, snails can be controlled by chemical, environmental and biological measures.

Chemical Control

Most if not all the molluscicides available at present are toxic to fish and are, therefore, unsuitable for use in fish ponds unless completely harvested prior to the treatment period; a requirement not likely to be met in most rural situations. Moreover, there is the problem of the necessary training for the technical helpers who will apply the molluscicide. There are some herbicides which also have molluscicidal value and they are reputedly not toxic to fish and which may be of potential use in fish ponds. However, they have not been tested under field conditions; moreover, attention should be given to their effect on the micro and macroflora of the ponds which constitute the food supply of the fish.

Certain parts and extracts of plants which grow in many African, Asian, and South American countries have molluscicidal value, for example, *Sapindus saponaria* and *Phytolacca* spp., but these also kill fish. Most of them have generally become known through their use by the local populations as fish poisons and thus their use should be prohibited in fish ponds.

The conclusion is that chemical control by use of molluscicides is not considered to be really satisfactory or feasible in fish ponds.

Environmental Control

Several malacologists working in Africa have observed that careful maintenance of ponds will often prevent the buildup of large populations of snails. Weeds and overhanging vegetation should be regularly removed. Occasional drying of ponds may have some effect on snails, but it seems that this is only likely to be very temporary.

Biological Control

Predators and competitors of snails include insects, fish and other snails. The most promising biological control measure in fish ponds is stocking these ponds with mollusc-eating (malacophagous) fish. DeBont (*10,11*) and DeBont and DeBont Hers (*12,13*) reported great success with *Haplochromis mellandi* Blgr. (identified in a previous publication as *Serranochromis macrocephala* Blgr.) in fish ponds in Zaire. This fish is reported to be good eating. Another fish, *Astatoreochromis alluaudi* (Pellegrin) has been taken from Uganda to Cameroon where pond trials have been carried out which showed that snails were effectively controlled, and that *A. alluaudi* could be successfully cultured together with *T. nilotica* (*2,24*).

McMahon et al. (*43*) conducted an experiment in water impounded by earth dams, for local water supply, in Nyanza Province, Western Kenya. Control of snails was attempted by introduction of the malacophagous fish *Astatoreochromis alluaudi*; other species (*Tilapia zillii* and *T. leucosticta*) also were introduced. One reservoir was left as a control without any introduction of fish. Assessment of snail control was made by scooping for snails, catches being expressed per man-hour of effort. This was carried out both before and after introduction of fish, over a total period of 15 years. The data indicated that *A. alluaudi* did reduce the numbers of some species of snails, particularly *Biomphalaria pfeifferi* (intermediate host of *Schistosoma mansoni*) and, to a lesser extent and with less certainty, *Bulinus* spp. (some are intermediate hosts of *S. haematobium*). The other two introduced fish species, *Tilapia zillii* and *T. leucosticta*, did not appear to be associated with reduction in snail numbers. There can be no doubt, however, that in this study *Biomphalaria pfeifferi* formed the principal diet of *A. alluaudi*.

In Brazil, the fish *Astronotus ocellatus ocellatus* was very effective in considerably reducing populations of the snail *Biomphalaria glabrata*, intermediate host of *Schistosoma mansoni*. The capacity of *A. ocellatus* and *Tilapia rendalli* in eliminating snails was also demonstrated in Brazil. They are medium-size fish which are adapted to ponds and reservoirs. Smaller predatory fish also exist which, although unable to swallow adult snails of such species as *Biomphalaria glabrata* and *B. tenagophila*, kill these snails by wounding their exposed soft parts. These smaller species of fish include *Hemichromis bimaculatus*, the jewel fish, *Macropodus opercularis*, the paradise fish, and *Haplochromis mellandi*. The jewel fish, *Hemichromis bimaculatus*, when introduced into a 75 m^2 pond in Brazil infested with *Biomphalaria tenagophila*, and which had a substantial area of shallow water, eliminated the snails in six months. At the same time, itself increasing from 20 introduced specimens, to more than 500. A lake nearby populated with a fish of the same family, *Geophagus brasiliensis*, showed no infestation with snails (*41*). *Astronotus ocellatus* and *Geophagus brasiliensis* are Brazilian in origin; *Tilapia rendalli, Haplochromis bimaculatus* are exotic species but are found in certain bodies of water in Brazil. *Astronotus ocellatus* swallows the snail whole, while *Tilapia* spp. reduces or eliminates the vegetation which shields the snails and their eggs.

Some species of voraciously herbivorous freshwater fish, for example, the Chinese grass carp, *Ctenopharyngodon idella*, may play a useful role in suppressing, but rarely eliminating, snail host population densities, particularly in such lentic habitats as drainage and small feeder canals in irrigation schemes, ponds, etc. In Egypt and the Sudan trials using herbivorous fish, not only incidentally to suppress snail host population, but more to control aquatic weed growth, are in progress. On the other hand there are reports that other herbivorous fish such as *Tilapia zillii* and *T. melanopleura* were not effective in eliminating snails by preventing the growth of macrophytic vegetation in ponds and rendering them less suitable for the snails. McMahon et al. (*43*) found that *T. zillii* had little or no effect on snail populations in the reservoirs which they studied in Kenya. Also at Mahiwa, Tanzania, Berrie (*5*) found that fish ponds containing *T. melanopleura* were generally fairly free from weeds whereas those containing *T. nilotica* were not, but the snails were still able to thrive on decaying leaves and other rubbish which the fish did not seem to eat.

Mosquito Larvae Control

As is the case with snail control certain environmental and biological measures have been recommended for the control of mosquito larvae.

Lockhart et al. (*39*) after studying fish ponds in the North Nyanza District of Kenya, recommended that the sides of the ponds should be regular as indentations in the banks reduce wave action and provide ideal habitats for mosquito larvae breeding. Vegetation on the banks should be kept short because overhanging vegetation provides ideal cover, especially for *Anopheles funestus* larvae.

Biological control of mosquito larvae by the use of certain species of fish has been advocated by many workers. Irvine (*31*) in Ghana, states that *Tilapia* are effective predators of mosquito larvae. Others have noted that ponds stocked with fish had few or no mosquito larvae as compared with other ponds which contain no fish.

In a recent report on Biological Control of Vectors of Disease by the World Health Organization (*56*) the use of fish in the control of mosquito larvae has been advocated. In general, the use of indigenous rather than introduced fish is encouraged. *Oreochromis spilurus* is to be used operationally against *Anopheles* spp. Other examples of fish with considerable promise include members of the families Cyprinodontidae (e.g. *Aphanius* spp., *Aplocheilus* spp. and *Oryzias* spp.), Hemirhamphidae, Anabantidae, and Cichlidae (including *Tilapia* spp.).

Several species of *Gambusia* spp. are operational in some areas to control mosquito breeding, but may destroy local fish and therefore should not be introduced into new areas without careful study of the ecology and the fish fauna. Similarly, the use of other exotic fish is to be avoided, with the notable exception of annual fish such as *Nothobranchius* spp.

Several species of bacteria have been recommended for biological control of mosquito larvae and blackfly larvae (vectors of onchocerciasis), but their use is still at an experimental stage. Among these bacteria are *Bacillus thuringiensis* H-14 and *Bacillus sphaericus*. Also certain species of fungi are lethal to mosquito larvae, but their use is still at an experimental stage.