THE ADVANTAGES OF MOSQUITO BIOCONTROL BY STOCKING EDIBLE FISH IN RICE PADDIES

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Abstract. Edible fish stocked in rice fields at a density of 600-800 fry per mu (1 mu = 1/15 hectare) for 150-170 days may act as an effective mosquito biocontrol agent. Common carp *(Cyprinus carpio)*, grass carp *Ctenopharyngodon idella)* and *Tilopia* spp. killed late stage larvae and pupae of *Anopheles sinensis* and *Culex tritaeniorrhyncus* in laboratory and field trials. Stocking of fish in experimental rice fields decreased larval numbers significantly in comparison with control areas. Expansion of fish stocking in rice fields on a large scale over several years correlated with a marked decrease in malaria transmission. The addition of fish to the rice fields also resulted in increased yields. A ditch-ridge system of field arrangements is described for optimization of fish handling. Preliminary cost-benefit analysis indicates that this approach to mosquito control conveys considerable economic advantage and thus provides incentive to the community to participate in vector control programs. Farmers' experience in Guangxi over a number of years indicates that the use of edible fish for this purpose can be carried on a large, commercially viable scale.

INTRODUCTION

A number of papers have reported using *Gambusia* spp. as a biocontrol agent against mosquito larvae in rice paddies (Reube, 1989; Gerberich, 1985). However, the potential of larvivorous fish demonstrated in pilot studies has been difficult to extend to large scale operational larval control programs.

The present paper is based on a general survey of popular experience of edible fish stocked in rice fields in relation to an evaluation of the efficacy of mosquito control. The study aimed to determine the relationship of expansion of pisciculture in rice fields to malaria prevention, as well as to the development of the farming economy. The evaluation was based on both entomological and epidemiological data, together with some information on soil science, rice plant physiology and economic analysis.

MATERIALS AND METHODS

Background of the study area

Quanzhou county is located in the northeast part of Guangxi Zhuang Autonomous Region, China. The county has a population of 760,000. The main crop is rice, with one or two crops per year. The main malaria vector is *Anopheles sinensis,* which breeds in the rice fields. In recent years the stocking of rice fields with edible fish has been advocated in Quanzhou county: there are 440,000 mu (1 mu = 1/15 hectare) which can be used for stocking fish. Half of these paddies have now been stocked with fish, especially around residential areas. Baibao is one village in Quanzhou county which is relatively isolated by hills and has more than 1900 mu of rice fields, 90% of which are stocked with fish.

Quanzhou and two other neighboring counties were selected to study the relationship between the expansion of fish stocking in paddies and the annual incidence of endogenous malaria, while Baibao was selected for observations of the dynamics of the population density of mosquitos after rice fields were stocked with fish.

Method of stocking fish in rice fields

Three to five days after rice seedlings were planted, fingerlings or fry were released into paddies, there to remain for 3-6 months. Generally no supplementary feed or special management was

given. The main species of fish raised for this purpose were the common carp *(Cyprinus carpio)*, the grass carp *(Ctenopharyngdon idella)* and *Tilopia* spp. The release rate was 600-800 fry per mu, 90% were common carp or *Tilopia* spp., 10% were grass carp.

Entomological data collection

Two cattle shelters as well as rice fields near the village were selected at Baibao as control areas for monitoring the dynamics of mosquito population size. Measurement of the density of adult mosquitos was carried out by the suction tube method once per 10 days, one hour after sunset; the density of larvae was assesed by the dipper method, with 500 dips once per 10 days around the rice fields. An open area near houses was selected to estimate the landing rate, once per 15 days, with a man seated inside an open door curtain as bait, the mosquitos attracted into the curtain being caught.

Preference of fish for different instar larvae

Laboratory trials: A known number of 1st to 4th instar larvae and pupae were placed together with a young carp and some animal feed in an enamel pan. After 24 hours the remaining larvae and pupae were counted, then the rate of consumption of different instar larvae and pupae by the fish was calculated. The rate of consumption was used to express the preference of the fish.

Field trials: The total numbers of different instar larvae and pupae which were collected for a whole year for the surveillance of larval density were calculated. If the sampling conditions are the same the percentage of different instar larvae and pupae in any sample should be similar. If there was a significant difference between the experimental and control fields, any instar larvae which decreased disproportionately in the experimental fields was taken as evidence of preference of the predator fish.

Malaria data collection

Malaria case numbers were collected from the records of the local Anti-epidemic and Sanitary Station; diagnosis was by microscopy (Guangxi Institute of Parasitic Diseases Control, 1988).

Agricultural data collection

Macro data were collected from the local Agricultural Bureau, while at the pilot county the micro data proferred by the farmers was rechecked.

Experimental field

A 2.7 mu rice field was divided into 3 sections, each section being divided in turn into 9 sub-areas which were selected at random. Eighteen sub-areas were used for fish stocking. A ridge-ditch system was arranged and supplementary animal feed was added, 20 kg per mu, before rice blooming, otherwise the conditions were the same as those used by local farmers. Nine sub-areas were set aside as controls. All of the 27 sub-areas were covered by polythene membrane on the high bank to prevent fish escape and seepage of fertilizer. For 3 successive years, 1987-1989, the physical and chemical properties (see Table 4) of the surface soil in the rice fields were measured (Chinese Special Committee on Agricultural Chemistry, 1983) and the physiological characters (see Table 5) of rice plants (Shandong Agricultural College, unpublished) were analyzed. The configuration of the ridge-ditch system is shown in Fig 1: the ridges are for rice planting and the ditches are for fish stocking.

Samples of soil and rice plants were taken from 5 points in each sub-area, mixed thoroughly, then a small sample (0.5-1.0 g) was analyzed in duplicate. Sampling was done one every 10-20 days in different developmental stages over the whole growth period of the rice plants.

Statistical analysis was by Student's t test to compare test and control areas.

RESULTS

Mosquito density

The main mosquitos breeding in the rice fields were *Anopheles sinensis* and *Culex tritaeniorrhyncus*. When fish were stocked in an expanded area of rice paddies the population size of these two species of mosquito, both larvae and adults, was diminished and the landing rate also decreased (Figs 2-4).

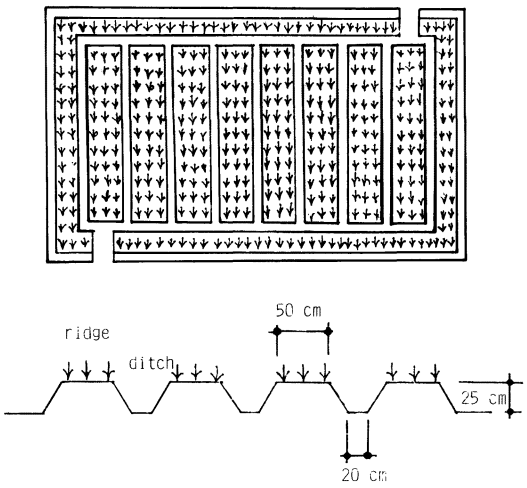

Fig 1—Sketch of the ridge ditch arrangement for pisciculture in rice field.

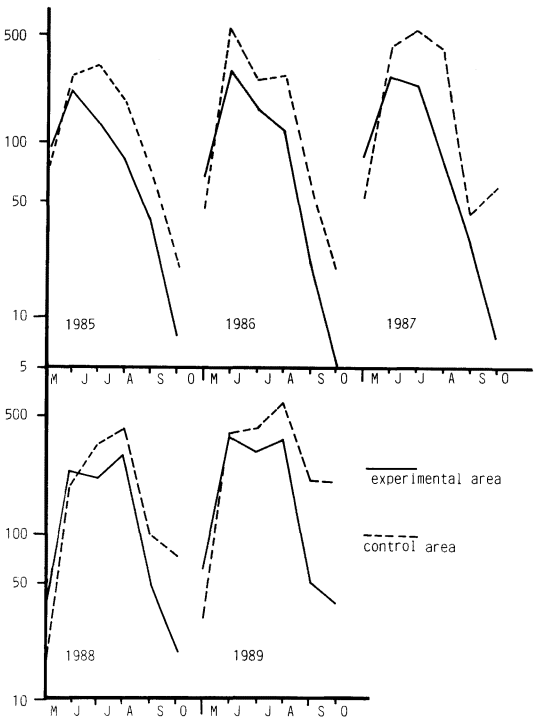

Fig 2—Mosquito density in cattle shelter mosquitos caught/person/30 minutes.

Preference of fish for different instar larvae

Both laboratory and field trials demonstrated that the carp prefer later stage larvae and pupae (Figs 5-6).

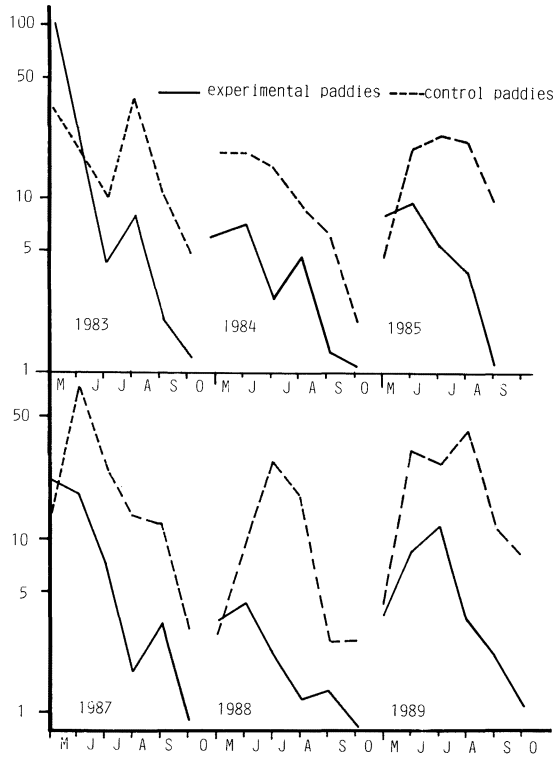

Fig 3—Larvae density, larvae/dipper.

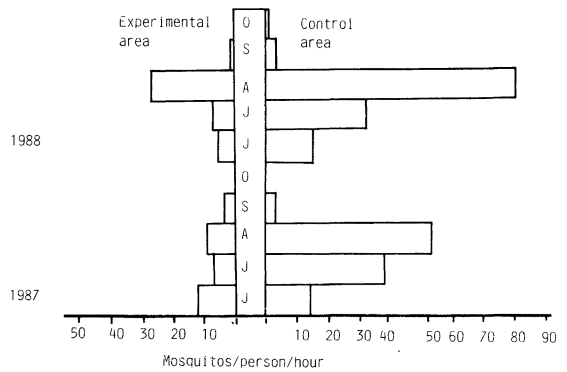

Fig 4—Mosquito landing rate, June-October one two years.

Malaria incidence

From the retrospective survey of the relationship between the expansion of pisciculture in the rice fields and the endogenous malaria incidence in Quanzhou county and two other counties (Sanjiang, Longlin, where the area stocked with fish

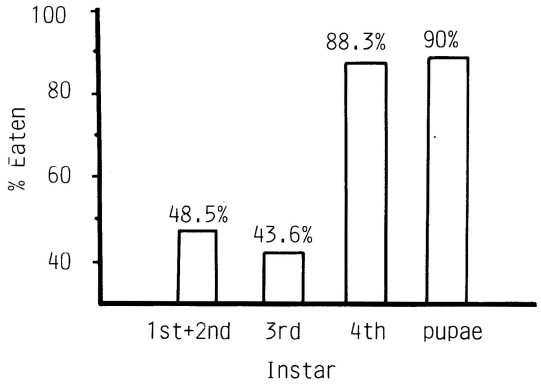

Fig 5—The carp preference for different instar larvae and pupal.

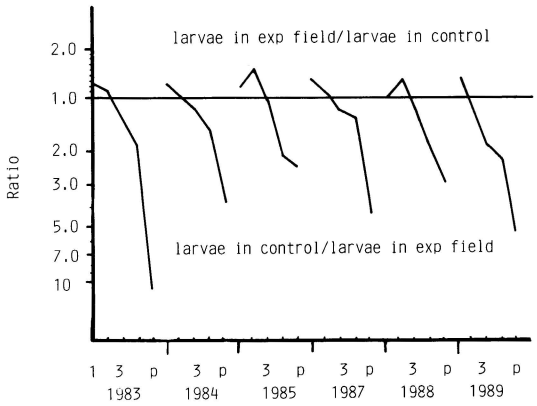

Fig 6—The ratio of structural composition of different instar larvae between the population of experimental rice field and check.
(*An. sinensis* and *Cx. tritaeniorhyncus)*

was less than in Quanzhou), the data from the three counties showed a negative correlation between presence of the fish in the expanded rice field area and malaria incidence (Tables 1-3).

Soil data

After edible fish were stocked in rice fields the N, P and K contents of the soil and the oxidation-reduction potential increased significantly during all stages of rice plant growth. Wild grass also markedly decreased in these fields (Table 4).

Physiology of rice plants

The N, P, K and chlorophyll contents, the surface coefficient of the leaves and the activity of the root system were higher in rice plants which grew in the experimental paddies over the whole developmental stage (Table 5).

Economic benefit

Data collected from the pilot county and from three successive years analyses of the experimental rice field showed that rice yield in both the pilot county and in the experimental rice fields increased by about 10%. However, the fish yield was quite different: in the pilot county the fish yield reached only 10-12 kg/mu whereas in the experimental rice field it was 44.4 kg/mu (Table 6). In some areas where farmers with specialized knowledge of pisciculture kept written records these showed evidence of substantial fish production. On the basis of the data in experimental versus control fields approximate cost-benefit analysis was done: the net return from the concurrent rice--fish crop system was 755.59 yuan/mu (1 yuan = $1/4.7 in the summer of 1990), an increase of 52% above that of the rice crop alone (Table 6).

DISCUSSION

The crucial feature of a mosquito biocontrol agent is the developmental stage of larvae which is affected, because mosquitos have a compensatory effect on the population size of the early stage larvae (Service, 1985; Bang and Pant, 1983). Thus the effectiveness of the control measure may depend in part on the type and extent of mortality from the natural regulation of the population size. If the predators kill the larvae at a stage in the life cycle after density dependent mortality has acted, they should have greater effect in reducing the population than if they acted earlier and allowed the natural regulatory process to compensate for this additional mortality. From the results of both laboratory and field studies it was shown that the carp preferred the elder larvae and pupae to young instar larvae, so the fish as predators acted after the stage of the compensation effect. Hence they should have a greater effect in reducing the population of both larvae and adults. Furthermore, the fish not only reduced the mosquito population but also were associated with a decrease in endogenous malaria incidence: of course the latter may well be multifactorial. In Quanzhou county from 1978 to 1989 pisciculture in rice fields

Table 1

The relationship between endogenous malaria incidence and expansion of pisciculture in rice fields.

Year	Expansion % * fish stocking in paddies (1)	Malaria cases in Quanzhou county (2)	Malaria incidence per 100,000	
			Quanzhou county (3)	whole Guangxi (4)
1976	0	60	9.0	117.6
1977	0	95	15.0	69.4
1978	0	73	11.6	45.1
1979	11	30	4.7	43.5
1980	25	35	5.3	47.6
1981	29	16	2.4	41.3
1982	35	4	0.6	33.9
1983	35	2	0.4	19.2
1984	34	4	0.4	13.0
1985	34	2	0.3	12.6
1986	43	1	0.1	10.3
1987	43	0	0.0	9.5
1988	43	1	0.1	7.5
1989	42	1	0.1	5.1

* : (rice field stocked fish) / (total rice field able to be fish stocked in this county)

Data source :
(1) Aquaculture bureau of Quanzhou
(2) Anti-epidemic and Sanitary Station of Quanzhou
(4) Guangxi Institute of Parasitic Diseases Control

Table 2

The relationship between pisciculture in ricefield and annual malaria cases in Sanjiang, Guangxi.

Village	1982		1983		1984	
	PFS %	AMC	PFS %	AMC	PFS %	AMC
TZ	0.8	152.7	0.5	66.7	4.0	25.2
LB	20.3	46.8	29.1	41.0	9.1	2.9
LK	56.4	7.6	55.3	4.2	55.1	1.5
LX	69.5	10.4	50.8	7.5	84.8	5.4
DT	77.7	0.9	96.2	0.3	80.2	1.6

PFS % = (rice field stocked fish/total rice field of the village) × 100
AMC = annual malaria cases found per 100,000 population
The correlation coefficient between PFS % and log (AMC) $r = -0.7846$ $t = 4.5625$ $p = 0.0005$.

was expanded from zero to more than 40% of the total rice field area which can be fish stocked. In the same time period the malaria API in Quanzhou decreased from 11.6 to 0.1 per 100,000 population, an apparently highly significant negative correlation between fish stocking and malaria incidence. Precise quantitative relationships are difficult to ascertain: another county in which fish stocking was on a smaller scale than in Quanzhou county showed a similar relationship. However, it is tentatively concluded that predation by fish on the larvae and pupae of the malaria vector is likely to have been a contributory factor in decreasing the malaria incidence.

Table 3

The relation between pisciculture in rice field and annual malaria cases in Longlin county, Guangxi.

Village	Situation of rice field	AMC/10,000	
		1982	1983
KC	fish stocked	0	0
BY	without fish	4.65	0.51
LH	"	1.40	0.47
YC	"	6.46	2.59
SC	"	0.81	0
DE	"	0	0.25
ZL	"	2.20	0.37

Although the total rice field area of Quanzhou county has not yet been stocked with fish, the rice fields for fish rearing have extended from the nearest paddies around the villages to areas distant therefrom. Recently Chen *et al* (1990) reported that larvae distribution was closely correlated with the distance from the human residential area, most larvae being distributed in the rice field no more than 1 km from the houses, while more than 50% of larvae were distributed no more than 0.5 km from the edge of the village, unrelated to the developmental stage of the rice plants. Thus, if the breeding of *An. sinensis* near residential areas is largely brought under control by the fish, malaria transmission should be substantially reduced.

Table 4

The chemical and physical properties of soil in experimental rice field after fish stocked.

Item	Compared with control	p
Total nitrogen content	+ 13.7%	< 0.05
Effective phosphorous content	+ 14.3%	< 0.05
Effective potassium content	+ 16.7%	< 0.05
Oxidation-reduction potential	+ 37.5%	< 0.01
Cultivated area	− 16.8%	
Wild grass	− 99.4%	< 0.01

Table 5

The effect on the rice plant after fish stocked in rice field.

Item	Compared with check	p
Nitrogen content in leaf	+ 16.3%	< 0.05
Phosporous content in leaf	+ 14.0%	< 0.05
Potasium content in leaf	+ 16.9%	< 0.05
Chlorophyll content in leaf	+ 16.2%	< 0.01
Activity of root system	+ 34.8%	< 0.01
Effective grains per ear	+ 18.7%	< 0.01

Table 6

The economic benefit after fish stocked in rice field.

Item	Data from farmers compared with control	Data from experimental field compared with control
Rice yield	+ 9-10%	+ 10.7%
Fish yield kg/mu	10	44.4
Protein content in rice		+ 4.8%
Net gain yuan/mu/year		+ 52.0%

Cost-effectiveness is a top priority for consideration in bringing an effective vector control method into practical use in mosquito control programs. *Gambusia* spp. has long been known as a good mosquito biocontrol agent, but it is expensive to produce a large number of fry for releasing into a large area of rice fields for larval control. Using edible fish in place of *Gambusia,* an expensive control method can be converted into a profitable one: however, precise cost comparisons between *Gambusia* and locally bred carp are difficult, so that data are lacking of the relative costs of mass breeding for this purpose.

Economic benefit will play a significant role in attracting community participation in mosquito control programs. In the present situation, the methods of the farmers for raising fish in rice fields need to be improved, for example by arranging a ditch-ridge system in the paddies. This facilitates draining off the water from the ditch when required for expediting plant growth and development: at this time the fish can be kept in the ditch, with the addition of supplementary feeding (Cruz and Lopez, 1980), before the blooming stage of the rice. As a result of the increased economic benefit from fish sale or local consumption community participation in the mosquito control program should be greater. Detailed consideration of the effects of pisciculture in rice fields on agricultural yield as carried out in this study will be the subject of a separate publication.

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