Efficacy of Common Carp and Nile Tilapia as biocontrol agents of rice insect pests in the Philippines

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Replicated field plot trials were carried out to evaluate the role of fish as biocontrol agents of insect pests of rice in the Philippines. Evidence from suction sampling, examination of fish gut contents, and rice plant damage assessment strongly suggest that Common Carp \textit{Cyprinus carpio} (L.) and Nile Tilapia \textit{Oreochromis niloticus} (L.) do significantly reduce the densities of stemboring moths and chironomid midges, while the abundance levels of other arthropods are not significantly affected. This impact by fish often was more important in the wet season when heavy rains and wind likely caused the arthropods to become dislodged from the plant and fall onto the water. Predation by fish was particularly evident during the first 45 days of the crop during the wet season when adult chironomid midge abundance was high. The fish gut content analysis revealed that all insect guilds are represented in the diet of both of the fish species regardless of whether the life-cycle of the arthropod prey is aquatic, semi-terrestrial, or terrestrial. Thus, fish in rice fields are part of the assemblage of natural enemies of rice pests. While fish alone cannot completely suppress rice pest populations below the economic threshold, their significant contribution should not be overlooked.

Keywords: biological control; insect pests; insect predators; insect parasitoids; rice-fish culture

Introduction

The practice of rearing fish in rice fields is at least a 2000-year-old tradition in large parts of Asia (Bray 1986; Fernando 1993; Cai et al. 1995). As a result of the Green Revolution in the 1960s, long-duration, traditional rice cultivars were replaced by semi-dwarfs of shorter duration, and insecticides were seen as indispensable for achieving high yields (Litsinger 2008); these activities led to a rapid decline of cultured fish (Moulton 1973; Koesoemadinata 1980; Li 1988). As fish are highly sensitive to pesticides, the wide-scale adoption of pesticides by farmers in rice-growing communities is often cited as one of the major constraints upon the popularization of rice-fish farming (Koesomadinata 1980; Cagauan and Arce 1992). Irrigation water often flows from field to field; thus, even farmers who do not use pesticides are affected. However, beginning in the 1980s several factors including the use of pest-resistant rice cultivars, the realization of the importance of natural enemies in suppressing and regulating pest populations, and integrated pest management, all mitigated against the need for insecticides (Heong and Schoenly 1998). Thus the door was opened for a rebirth of rice-fish farming.

Rice-fish farming is often reported to be a mutually supporting system. It has been observed that fish grow better in rice fields than in ponds (Ardiwinata 1957), while a rice crop benefits from the presence of fish in terms of a more diverse source of nutrients along with reduced rice pest incidence (Coche 1967; Litsinger 1993; Halwart 1994). A wide diversity of rice pests has been reported to be food for fish: insects, snails, weeds, and even sclerotia of plant-pathogenic fungi such as the causal agent of sheath blight (Halwart 1994). The studies that provided these data, however, often were not rigorously carried out, particularly regarding a proper experimental design and appropriate statistical analyses of results (Halwart 1994); thus, the conclusions drawn were often based on anecdotes or they were surveys of adjacent fields, each having different management practices.

Despite the fact that rice and fish are the mainstays of local diets, there is not a tradition of fish culture in rice fields in the Philippines. This is due mainly to a lack institutional support and the willingness of farmers to collectively raise fish, as well as the need to protect against theft and to refrain from pesticide use in the watershed. Rainfed wetland rice farmers have a long history of capturing aquatic wildlife in rice fields.

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(especially soon after harvest when the fields are drained) as a source of protein – for example, fish, frogs, clams, snails, and shrimps – which enter rice fields from rivers, canals, and land run-off after storms (Halwart 2006). The diversity of fauna in rice fields is comparable to that found in marshlands. This practice is different from the deliberate stocking of fish in rice fields, where the yields obtained are low. Nowadays, there are national institutions which culture and provide fingerlings to farmers for the purpose of rice-fish farming.

The food of the two most popularly cultured fish, Common Carp Cyprinus carpio L. and Nile Tilapia Oreochromis niloticus (L.), often consists of immature and mature insects, grass seeds, and assorted aquatic flora (Fernando 1993, 1996). Carp is a benthos feeder while tilapia prefers to take prey from the water column. The feeding habit of Nile Tilapia is characterized as predominantly phytoplanktivory with a preference for blue-green algae. Invertebrates are found at very low densities in fish guts (Harbott 1982), but their role as a dietary component is incompletely known. Bowen (1982) stated that the inclusion of invertebrates in the diet may be an important variable in the feeding strategy of tilapias. More quantitative data are needed to describe circumstances as to how prey is selected. Thus, a collaborative project was organized to overcome these deficiencies by the Freshwater Aquaculture Center of Central Luzon State University (FAC/CLSU), the International Rice Research Institute (IRRI), and the Institute of Landscape Planning and Ecology of the University of Stuttgart in Germany with support from the World Fish Center. The purpose of the study was to expand on the previous studies, to document the arthropod food items of Common Carp and Nile Tilapia, as well as provide more evidence of the benefit of fish in rice pest control. The expected outcome, if favourable, would promote rice-fish culture and further reduce the need for pesticides, and also slow the destruction of wetlands for expansion of aquaculture or rice culture.

Common Carp and Nile Tilapia are both present in the Philippines and are important to aquaculture in Asia. Both are adapted to shallow ponding, are dependent on detrital aggregates for food, and can adjust their feeding preferences (Spataru 1978). These two fish species were compared to a non-fish control in experimental plot trials over four seasons on the FAC/CLSU campus under natural and artificial infestation with fish ponds were constructed. Artificial infestation took place with yellow stemborer Scirpophaga incertulas and rice leafopper Cnaphalocrocis medinalis (both are pyralid moths). Various arthropod sampling methods were employed to measure moth and other arthropod densities over each season. Timing of the trials reflected nearby farms that practise double-cropped transplanted rice culture. As the aim was to characterize fish predation of various arthropod guilds in typical rice fields, modern pest-resistant rice cultivars were used.

Materials and methods

Screens were placed to exclude indigenous carnivorous fish from the permanent experimental fields maintained at the research station. A refuge trench or pond was constructed in one part of each field 0.5 m deep that occupied about one-tenth of the 200-m² field plots. After 2 weeks, water was maintained for the fish, at a depth of 10 cm. Deep ponding controls weeds; phytoplankton oxygenates the water. There were two rice crops per year and trials were conducted on four crops.

Field trials

Three treatments were set out in rice field plots in a randomized complete block design with six replicates each season. All plots were maintained at 10 cm water depth using water from a well. Earthen bunds delineated the plots. Water inlets and outlets to individual plots were covered by wooden frames with wire mesh screens to keep stocked fish in and prevent wild predatory fish from entering. Rice varieties used were IR64, a 112-day variety in the two crops of 1991, and IR42, a 138-day variety in the wet season (WS) of 1992, and IR72, a variety with 110-day maturity in the dry season (DS) of 1992. These varieties are resistant to brown planthopper Nilaparvata lugens and green leafhopper Nephotettix virescens and are moderately resistant to stemborers. Rice was transplanted with 5 to 8 seedlings per hill, with hills at a 20 cm × 20 cm distance in both directions. Inorganic 90-45-45 kg NPK/ha was applied in two splits with N and PK basal and a second N application at 40 days after transplanting (DT). No pesticides were used and fields were hand weeded. Arthropods collected from the field were identified and counted in the laboratory by technicians trained in the Taxonomy Laboratory of IRRI Entomology Department by A.T. Barrion.

Fish

Prior to introducing fish, the field was seined and the water electrified biweekly (Regis et al. 1981; Zalewski 1985) to remove all indigenous fish. The fish fry were supplied by the Philippine Bureau of Fisheries and Aquatic Resources, the Tanay Carp Hatchery, and FAC’s own stock and were introduced into the field plots, 7–16 DT. Individual initial fish weight was estimated from a 20% sample of the stocked fish one day before stocking. In 1991 the introduced carp and tilapia weighed an average of 19.9 g and 24.7 g/fish, respectively, in the DS, and 9.0 g and 2.6 g/fish in the WS. In 1992 DS, carp and tilapia weighed 7.7 g and 16.4 g/fish, respectively, and 1.5 g and 4.8 g/fish in the WS. Fish were stocked at 10,000 fish/ha, except in the 1991 WS with only 5000 fish/ha.

Vacuum sampling of arthropods

A motor driven, portable D-Vac® suction machine (EcoBlower D-Vac Model 122 http://www.rinconvitova.
com/d-vac.htm) was used to remove arthropods from rice foliage. Arthropods were vacuumed from rice foliage biweekly between 7 a.m. and 10 a.m. during four consecutive seasons. A conically shaped Mylar® plastic cylinder was placed over each randomly selected hill; 20 hills were sampled per replication. Arthropods were transferred from a plastic bag to a cyanide killing jar and preserved in vials of 70% ethanol for later identification in the laboratory using stereo-microscopes. Arthropods were grouped into guilds: rice pests, predators, parasitoids, detritivores, and “indifferents”. Detritivores also included plankton feeders and were composed of mainly chironomid midges, while indifferents included non-rice feeding herbivores as well as transients/tourists that did not fit into the other categories. Some insect species were placed into more than one guild. For example, corixids are predators, detritivores, and “pests” that can feed on roots of rice seedlings. The ephydrid fly Notiphila is both a detritivore and a herbivore of grasses, and was classified as an indifferent. Chironomids are known detritivores and plankton feeders, and like corixids feed on roots of rice seedlings. In some countries chironomid larvae that feed on roots of rice seedlings cause loss of stand in directly seeded rice (Clement et al. 1977). Feeding injury from corixids and chironomids is considered to be sub-economic in the Philippines (Barrion and Litsinger 1984).

**Sticky traps**

Sticky traps were set out in the three treatments with and without fish only in the 1992 WS crop on IR42. Transparent Mylar® sheets were cut into 0.25-m diameter circles with an opening cut in the centre to fit around a rice hill. Pieces of Styrofoam® were attached to the bottom to make the disk float. The upper surface was coated with Tanglefoot® (http://www.contech-inc.com), a sticky substance designed to immobilize arthropods. Sampling was done biweekly from 22–90 DT. Traps were placed around three randomly selected rice hills per plot, and on each sampling occasion remained in the field for 12 h, one set during the day, 6 a.m. to 6 p.m., and the other set at night, 6 p.m. to 6 a.m. After each sampling period the sticky traps were taken to the laboratory for arthropod identification and counting. Specimens were cleaned in kerosene as needed. In most cases identification was to the family level only.

**Fish gut analysis**

The method for examining fish gut contents to note food preferences was based on that developed by Hyslop (1980). Fish (298 in the DS and 268 in the WS) were sampled six times per season at 12–16-day intervals from 36–106 DT in the DS and 31–99 DT in the WS. Sampling occurred between 8 a.m. and 10 a.m. by seining or electrofishing. It was considered adequate to sample both Nile Tilapia and Common Carp in the morning hours. Sampling of fish in rice fields is difficult and sometimes seining had to be repeated several times until a sufficient number of fish was caught. Seining causes stress to fish in the rice fields and should not be performed during the hours of peak sunlight. On each sampling date a total of 5 fish per plot were removed and replaced (in exceptional cases, even repeated sampling was unsuccessful and fewer fish were taken as indicated). Fish were immediately killed and placed in a deep freezer in the lab where they were dissected the same day. Records were kept on individual fish which were weighed and measured for length. Unlike Chapman and Fernando (1994), who identified organisms in tilapia stomachs and carp foreguts, we examined the whole digestive tract, thereby alleviating the confounding effects of variability in both gut fullness and evacuation rates. For both fish species the entire digestive tract was excised and preserved in a 10% sugar-formaldehyde solution and sealed in plastic bags.

**Control of leaffolders**

Gathering of data on the role of fish as predators of rice leaffolders was carried out over four rice crops. The 1991 DS crop was infested artificially and the remaining three crops were naturally infested. Artificial infestation involved releasing 500 greenhouse-reared Cnaphalocrocis medinalis adults in each of two plots at 45 DT. Damaged leaves were assessed at 65 and 85 DT. Three crops where natural infestation was measured had six replicates (1991 and 1992 WS and 1992 DS) whereas the 1991 DS crop was replicated three times. Natural infestation was mainly by C. medinalis and Marasmia spp. (Barrion et al. 1991). Leaffolder damage was assessed visually as percentage of damaged leaves on 20 hills per plot taken by stratified random sampling 10 days before harvest. Damage during the ripening stage is considered to be the most severe in relation to yield loss when the rate of photosynthesis decreases during grain filling (Heong 1990).

**Control of stemborers**

Stemborer damage was monitored for whiteheads (severed panicles) 10 days before harvest in both 1991 crops and the 1992 WS crop in six replications of 20 hills per crop under natural infestation. Percentage whiteheads was calculated from counts of all panicles per hill. In 1992 DS, rice hills were artificially infested with yellow stemborer. Two egg masses were attached to three randomly selected hills per plot at 23, 29, 36, 56, and 64 DT in three replications following the method of Bandong and Litsinger (2005). The same 15 hills were infested on each date. Egg masses, obtained from an insectary, were uniform in size (ca. 50 eggs) and all eggs were unparasitized (final selection was
made at the blackhead stage at which the moth larva’s head capsule becomes visible). At each of the 15 infestation sites, whiteheads were counted 10 days before harvest from a 1-m² area (25 hills).

**Results**

**D-Vac sampling**

Suction sampling carried out over four seasons produced a list of 139 species (44 parasitoids, 36 predators, 24 detritivores, 23 indifferenters, 12 rice pests). There were 92 families, predators topping the list with 30 followed by parasitoids (22), detritivores (18), indifferenters (15), and rice pests (7). Of the total number of arthropods collected, the most abundant were detritivores (42%) dominated by chironomids, predators (18%), rice pests (18%), parasitoids (14%), and indifferenters (8%). Aquatic species barely outnumbered terrestrial in terms of numbers of individuals, viz. 53% to 47%.

The abundance of arthropods collected by D-Vac suction in the four crops (no./hill) over all guilds did not show significant differences between the fish and non-fish treatments in 1991 and 1992 DS (Table 1). However, in the 1991 WS the arthropod density was 22% less with Common Carp than rice alone, with Nile Tilapia being statistically intermediate at 14% less. In the 1992 WS the degree of arthropod reduction by each fish species was significant and similar. Carp reduced arthropod density by 10% while tilapia depressed densities by 9%. In both WS crops the dominant arthropods were chironomids.

Detritivores suffered a 40% reduction with both fish species in the 1991 WS over the 29–85 DT sampling period (Table 1). The main detritivores were adult chironomids (Chironomus spp. and Cryptochironomus spp.) as well as adults of the chloropid shining flower fly Mepachymerus (= Steleocerellus) ensifer which also is a combined detritivore and predator.

The rice pest guild was dominated by the rice whorl maggot *Hydrellia philippina* in the vegetative stage of the 1992 WS crop, where carp produced a 46% reduction at 31 DT but tilapia did not (Table 1). Other rice pests recorded later in the crop were green leafhoppers, *Nephotettix virescens*, and *N. nigropictus*, as well as zig-zag *Recilia dorsalis* and white *Cofana spectra* leafhoppers. Two planthoppers were present: the whitebacked *Sogatella furcifera* and brown *Nila-parvata lugens*. Noted in addition were several rice seed bugs (alydids and pentatomids) and adult moths of *Scirophaga incertulas*, *C. medialis/Marasmania* sp., as well as leaf-feeding larvae of *Noctuidae*.

The predator guild was dominated by the mirid egg-nymph predator *Cyrtorhinus lividipennis*, the velid nymph-adult predator *Microvelia douglasi atrolineata*, spiders of the genera *Artypena* and *Tetragnatha*, and the chloropid *Steleocerellus ensifer* and the phalacrid beetle *Stilbus* sp. Notably, the parasitoid and indifferent guilds did not show any significant difference from the presence of fish compared to no fish on any sampling date in the four crops. Parasitoids were mainly mymarids (e.g. *Gonatocerus* sp.) which attack leafhopper eggs, as well as braconids which parasitize leaffolder and stemborer larvae.

The species of arthropods collected by D-Vac were very similar to those reported by Schoenly et al. (2010) from a nearby location in Nueva Ecija province. The main pest was whorl maggot in the early season, and later on, planthoppers and leafhoppers dominated. Sampling began for the 1991 DS crop during the reproductive stage (50 DT) where beneficials generally outnumbered pests with and without fish culture, a situation which accelerated toward harvest (Figure 1A). Initially, pests without fish predation outnumbered those with fish by about 2 per hill versus 1 per hill, respectively, but after 66 DT, the trend reversed. From 66 DT the number of pests in fish culture

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**Table 1.** Arthropods collected as an average of time series sampling in four rice crops by D-Vac suction in fields with and without fish culture. Total arthropod abundance is presented for each of four crops and in a comparison of pest and detritivore guilds, Muñoz, Nueva Ecija, Philippines, 1991 and 1992.

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>Rice</td>
<td>183.1 a</td>
<td>266.4 a</td>
<td>255.0 a</td>
<td>196.3 a</td>
<td>79.4 a</td>
<td>34.5 a</td>
<td></td>
</tr>
<tr>
<td>Rice-carp</td>
<td>196.1 a</td>
<td>206.7 b</td>
<td>234.9 a</td>
<td>177.0 b</td>
<td>47.3 b</td>
<td>18.8 b</td>
<td></td>
</tr>
<tr>
<td>Rice-tilapia</td>
<td>202.8 a</td>
<td>229.7 ab</td>
<td>268.6 a</td>
<td>179.1 b</td>
<td>47.3 b</td>
<td>18.8 b</td>
<td></td>
</tr>
</tbody>
</table>

1 A ‘hill’ is 3–4 seedlings transplanted in a clump. Single rice hills were suctioned over six sampling dates per crop between the indicated crop ages measured as days after transplanting (DT).

2 In each column, means followed by different letters are significantly different (P < 0.05) by LSD test.

3 A list of pest, predator, parasitoid, detritivore, and indifferent guilds. The indifferent guild was composed of non-rice herbivores and transients

4 Mainly *Hydrellia philippina* whorl maggot.
averaged 1–1.5 per hill, whereas without fish this hovered around 1 per hill. Differences were not significant, however. On the following crop, also with IR64, pests (predominantly whorl maggot) outnumbered natural enemies, viz. 3.5–5 versus 2.5–3.5 per hill from 29–43 DT (Figure 1B). By 57 DT during the crop period when hoppers were abundant, beneficials dominated (4 vs. 2–2.5/hill) with or without fish. Subsequently, pest abundance steadily declined to 1 per hill at 85 DT, whereas beneficials declined to 2.5–3 per hill. The effect of fish was not noted, as both pest and beneficial curves with and without fish strongly mirrored one another.

In the third crop (1992 DS), with the more pest susceptible and longer maturing IR42 (Figure 1C), numbers of pests and their natural enemies rose steeply at 20–65 DT from 0.5–1 per hill to 6–7 per hill with fish and 8–9 per hill without fish. Arthropods in all four treatments rapidly declined to 2–3 per hill at 78 DT, and thereafter natural enemies with and without fish rose again to 8–10 per hill, while pests remained suppressed at 3–4 per hill. In the 1992 WS crop with the more resistant IR72, there was no effect of fish culture on either pests or beneficials whose curves mirrored each other very closely (Figure 1D). Pests declined steadily thereafter from an initial 2 per hill at 31 DT to less than 1 per hill. Beneficials averaged 3–5-fold higher densities than pests throughout the crop.

**Sticky traps**

Sticky traps ensnared arthropods that either had become detached from the foliage or had attempted to land on water. As there was no significant difference in densities collected in respect of the presence or absence of fish, the data were pooled. Greatest collections over the whole season (mean no./hill) were first of all pests (43) followed by predators (29) and detritivores (19). Parasitoids (8) and indifferents (8) made up the fewest collected (Figure 2). The absolute number of arthropods collected declined over the growing season from 240 per hill at 22 DT to 42 per hill at 90 DT. The number of pests, however, changed most over the growing season, declining relatively more than the other guilds, starting at 155 per hill at 22 DT and reaching 22 per hill at 50 DT. This period

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Figure 1. Arthropod densities collected by D-Vac suction machine over four rice crops with and without fish culture. On each sampling date 20 hills were sampled and the arthropods were divided into pest and natural enemy guilds, double rice crops of 1991 and 1992, Muñoz, Philippines.
was dominated by whorl maggot followed mostly by plant- and leafhoppers, ranging from 10 to 5 per hill on the last sampling date. Other pests collected were mole crickets (Gryllotalpidae), stemborer and leaffolder moths, and rice seed bugs (Alydidae and Pentatomidae). Predators declined slowly but steadily in abundance throughout the crop, ranging from 32 per hill at 22 DT to 15 per hill at 90 DT. There was a wide array of predator types dominated by spiders (Araneidae, Lycosidae, Tetragnathidae), but included aquatic (Belostomatidae, Gerridae, Hydrometridae, Hydrophilidae, Mesoveliidae, Notonectidae, Veliidae), and arboreal (Anthocoridae, Carabidae, Coccinellidae, Micraspis crocea, Formicidae, Gryllidae, Miridae, Cyrtorhinus lividipenis, Staphylinidae, and Tettigoniidae) insects.

Detritivores, mainly chironomids, were prevalent during the whole crop, and also Ephydridae, Corixidae, Ephemeroptera, and Tipulidae. Their abundances changed over time, peaking at 35 DT with 31 per hill and then declining slowly to 10–12 per hill on the final three sampling dates. Parasitoid wasps peaked on the first sampling date at 18 per hill and then declined to 3 per hill at 90 DT. These were predominantly Braconidae, Ichneumonidae, Mymaridae, and Scelionidae, but also included Bathyidae, Diapriidae, Elasmidae, Encyrtidae, Eulophidae, Pteromalidae, and Trichogrammatidae. Indifferents were low in number throughout the crop, ranging from 4 to 12 per hill, and included Acari (Oribatellidae), Chrysomelidae, and Phlaeothripidae.

**Gut contents**

A variety of food items was identified in dissected guts, but the bulk was mainly detrital aggregate, which refers to a mixture of plant debris (i.e. organic detritus), zooplankton, and phytoplankton. Plant material was occasionally found within the guts of tilapia, while weed seeds were often encountered in the guts of carp. Animal food items that could be recognized included molluscs, small fingerlings, as well as members of 23 families of arthropods. Only 43% of carp and 13% of tilapia contained arthropods in their guts in the DS, whereas 79% and 75%, respectively, did in the WS (Table 2). At most, 10 arthropods were recovered per fish (Figure 3), but the average was 4.6 from carp and 1.6 from tilapia. Carp consumed an average of 2.4 arthropods/fish in the DS and 6.8/fish in the WS. Tilapia consumed 0.5/fish in the DS and 2.7/fish in the WS. Significantly more arthropods were consumed in the wet than dry season for both fish species (283 versus 949 arthropods per 100 fish) and carp consumed significantly more arthropods than tilapia (318 versus 914) (Table 2). The likely reason more arthropods were consumed in the WS is that there were frequent monsoon storms which dislodged them from the foliage onto the water. Slapping the foliage is a commonly used sampling method, as the insects are easily dislodged and end up on the water surface.

A taxonomically wide range of arthropod groups was encountered in the digestive tracts of both fish species; seven of the eight dominant families were aquatic, so naturally in harm’s way to fish (Table 3). The exception was formicid ants, which maintain nests in the rice bunds, but as the fields are continuously flooded they stay on the rice foliage preying on arthropod eggs and larvae. They travel from plant to plant and can be blown off the plants by high winds. Ephydrids included larvae and pupae from the...
detritivore relatives of whorl maggot. Adult ephydrids were mostly whorl maggots. Interestingly, chironomids made up 60% of the intake of carp with 32% being predators, whereas the opposite was the case for tilapia where 59% of the arthropods were predators and only 32% were chironomids. However, as carp consume three times as many arthropods per fish as tilapia, their toll also on predators is probably similar.

Some 7–8% of the arthropods from both fish species were insect pests, which were mostly whorl maggots. Most of the predators were dytiscids, formicids, notonectids, and corixids. Eight of the 11 families of predators in fish guts were aquatic. Parasitoids and indifferents made up the smallest fraction of collected arthropods (≤0.4%). These were adults that had probably been blown onto the water.

There was no significant \((P > 0.05, n = 566)\) correlation between the length of fish or their weight and number of arthropods recovered from their guts, either by season or fish species. The range in weight for carp was 3.5–150 g and for tilapia 7.9–82.9 g, which reflects the periodic sampling over the entire season.

### Control of stemborers and leaffolders

Significantly less stemborer damage was recorded in two of the four seasons (Table 4). In 1991 DS, both fish species registered significantly less (61–69%) stemborer whitehead damage, namely 2.2–2.7% compared to 7% without fish. In the 1992 WS there was a higher infestation level with 18.1% whiteheads in the non-fish control and 12.7% with carp and 15.1% with tilapia. This translated into 30% less damage with carp and 17% less with tilapia. These were natural infestations. In the 1992 DS, even with high artificial infestation levels, there was no significant difference between any of the treatments. It is also notable that in each of the four seasons, the plots with carp had lower, but not always significant, infestation levels than tilapia.

### Table 2. Number of arthropods identified in the digestive tracts of common carp and Nile Tilapia, Muñoz, Nueva Ecija, Philippines, 1992.

<table>
<thead>
<tr>
<th>Fish</th>
<th>Arthropod abundance (no./100 fish)</th>
<th>% Fish with arthropods</th>
<th>Average (no. arthropods/fish)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dry season (DS)</td>
<td>Wet season (WS)</td>
<td>DS</td>
</tr>
<tr>
<td>Common carp</td>
<td>235 ± 93 b</td>
<td>679 ± 136 a</td>
<td>43.2</td>
</tr>
<tr>
<td>Nile Tilapia</td>
<td>48 ± 36 c</td>
<td>270 ± 87 b</td>
<td>13.3</td>
</tr>
<tr>
<td>Total</td>
<td>283</td>
<td>949</td>
<td>28.3</td>
</tr>
</tbody>
</table>

1Means in both columns and rows followed by different letters are significantly different \((P \leq 0.05)\) by LSD test.
2120 fish in the DS and 178 fish in the WS.
3120 fish in the DS and 148 fish in the WS.

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**Figure 3.** Frequency of occurrence of arthropods recovered from the digestive tracts of carp (CC) and tilapia (ON) cultured in IR64 rice fields, Muñoz, Nueva Ecija, Philippines, 1991 wet (WS) and dry (DS) seasons.
Table 3. Identification of the arthropods found in the dissected guts of common carp and tilapia, Muñoz, Nueva Ecija, Philippines, 1992 DS and WS.

<table>
<thead>
<tr>
<th>Guild</th>
<th>Taxa</th>
<th>Common Carp</th>
<th>Nile Tilapia</th>
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<tbody>
<tr>
<td>Pest</td>
<td></td>
<td>6.8</td>
<td>7.6</td>
</tr>
<tr>
<td></td>
<td>Ephydridae²</td>
<td>6.7</td>
<td>7.6</td>
</tr>
<tr>
<td></td>
<td>Other³</td>
<td>0.1</td>
<td>0.01</td>
</tr>
<tr>
<td>Predator</td>
<td></td>
<td>28.4</td>
<td>48.7</td>
</tr>
<tr>
<td></td>
<td>Dytiscidae⁴</td>
<td>13.6</td>
<td>16.2</td>
</tr>
<tr>
<td></td>
<td>Formicidae</td>
<td>8.5</td>
<td>14.9</td>
</tr>
<tr>
<td></td>
<td>Notonectidae</td>
<td>3.9</td>
<td>13.9</td>
</tr>
<tr>
<td></td>
<td>Coenagrionidae</td>
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<td>1.6</td>
</tr>
<tr>
<td></td>
<td>Veliidae⁶</td>
<td>0.2</td>
<td>1.9</td>
</tr>
<tr>
<td></td>
<td>Other⁷</td>
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<td>0.6</td>
</tr>
<tr>
<td>Parasitoid</td>
<td></td>
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<td>0.4</td>
</tr>
<tr>
<td>Detritivore</td>
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<td>43.3</td>
</tr>
<tr>
<td></td>
<td>Chironomidae</td>
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</tr>
<tr>
<td></td>
<td>Corixidae⁹</td>
<td>2.9</td>
<td>10.4</td>
</tr>
<tr>
<td></td>
<td>Ephydridae¹⁰</td>
<td>2.2</td>
<td>1.1</td>
</tr>
<tr>
<td>Indifferent¹¹</td>
<td>0.01</td>
<td>0.02</td>
<td></td>
</tr>
</tbody>
</table>

¹ Gut dissection of 178 carps and 148 tilapias, ² Hylæctena philippina, ³ Pyralidae larvae (probably leaffolder), ⁴ Cricidae (Recilia dorsalis), ⁵ Laccophilus sharpi, ⁶ Anisops sp., ⁷ Microvelia douglasi, ⁸ Belostomatidae, Carabidae, Coccinellidae, Gerridae, Hydrometridae, Hydrophilidae (Helochares sp.), ⁹ Braconidae, Mymaridae, Phoridae (Megaselia sp.), ¹⁰ Scelionidae (Telenomus sp.), ¹¹ Cryptostigmata (Oribatei), Cucujid.

Table 4. Stemborer damage recorded in four crops with and without fish culture, Muñoz, Nueva Ecija, Philippines, 1991–92.

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Rice</td>
<td>7.0 a</td>
<td>2.2 a</td>
<td>17.5 a</td>
<td>18.1 a</td>
<td>11.2 a</td>
</tr>
<tr>
<td>Rice-carp</td>
<td>2.2 b</td>
<td>1.8 a</td>
<td>14.7 a</td>
<td>12.7 b</td>
<td>7.9 b</td>
</tr>
<tr>
<td>Rice-tilapia</td>
<td>2.7 b</td>
<td>2.2 a</td>
<td>17.2 a</td>
<td>15.1 b</td>
<td>9.3 ab</td>
</tr>
</tbody>
</table>

¹In each column, means followed by a different letter are significantly different (P ≤ 0.05) by LSD test. Plots were sampled 10 days before harvest.
²There were six replications in each of three seasons under natural infestation where 20 hills were sampled per replicate
³Artificial infestation was carried out in three replications where two egg masses were attached to 3 randomly selected hills per plot on five infestation dates (23, 29, 36, 56, and 64 DT) giving a total of 15 infested hills per replicate. 25 hills were sampled per replicate for whiteheads at 126 DT.

Leaffolder damage was not affected by the presence of fish and there was no significant difference between any of the treatments in all four crops. The artificially infested 1991 DS crop registered the highest infestation level of 11.0–16.7% damaged leaves, whereas both 1992 crops had very low injury levels (0–0.4% damaged leaves). The 1991 WS crop was intermediate, ranging from 1.9% to 2.4% damaged leaves. Averages for the four crops were 4.9% damaged leaves without fish, and 4.4% for carp and 3.4% for tilapia, but these values were not significantly different.

Discussion

Fish food selection

Detrital aggregate is the major food of both the Common Carp and Nile Tilapia; it is derived from the rice-field bottom by carp and periphyton by tilapia (Chapman and Fernando 1994). In California rice fields, chironomid larvae are also the single most important arthropod found in Common Carp (Washino and Hokama 1967). Halwart (1994) concluded that chironomids were the dominant food of Common Carp because of their benthic feeding behaviour, during which mud is filtered and insect larvae, oligochaete worms, weed seeds, and other digestible matter are retained. Chironomid larvae live in the mud and form silken cases which might protect the larvae against aquatic predators. The larvae mostly feed on decaying organic matter that accumulates at the interface of the soil surface and ponded water. Fish predation on chironomids affects not only the larvae, but also the adults during emergence from the pupa, alighting on the water surface when ovipositing, or accidentally falling into the water. In Indonesian rice fields, Ardwinata (1957) noted that Common Carp mainly feed on chironomids and oligochaetes. Halwart (1994) stressed the importance of macrofauna (molluscs, chironomids, mayflies, caddis flies, and dytiscids) and macroflora (especially Echinochloa spp. grass seed) for Common Carp and noted a dietary difference compared to pond-reared carp, which preferred copepods and cladocerans (zooplankton). Meien (1940) reported that carp in Russian and Italian rice fields consumed large numbers of insect larvae (mainly chironomids and Anopheles spp.), algae, macrophytes and large amounts of grassy weed seeds.

Nile Tilapia, however, feed in the water column where aquatic predatory arthropods forage for prey. From gut analysis in this study, arthropods from 25 families were found to be food items of carp and tilapia, and carp consumed three times as many arthropods per fish than did tilapia. Most of the arthropod intake by tilapia was invertebrate predators, while that of carp was chironomids. Seven of the eight arthropod families consumed by tilapia were aquatic with only ants being terrestrial; therefore it is unsurprising that many ended up in the gut of tilapia. Thus, the difference in feeding behaviour of the two types of fish explains their differing food selection. Chironomids usually peak early in the season in rice fields (Simpson et al. 1994). Our study corroborated...
this fact, based on sticky trap data (Figure 2). Chironomids are also an important food source of natural enemies, particularly for spiders early in the season (Settle et al. 1996). It is at this time that both pests and beneficials are building up in numbers and if the latter are to be able to contain pests during the crop they need an early start.

Chapman and Fernando (1994) also found that arthropods make up only a small proportion of the diet of both carp and tilapia, in agreement with our results. Arthropod rice pests, with the exception of whorl maggot, made up only a small fraction of the diet of carp and tilapia but provided vital protein. Based on the data from Table 2, carp averaged 4.6 while tilapia averaged 1.6 arthropods per fish in their guts. This total for carp is within the same range reported by Wan et al. (1995), who found in Shan-Gao, China, that Common Carp weighing 150 g ate 1.3 g of insects/day (a black widow spider weighs about 1 g) (http://animals.nationalgeographic.com/animals/bugs/black-widow-spider/?source=A-to-Z).

Mosquitoes were not found in fish guts in our study, as populations appeared to be low and only a few adults of two genera were found in D-Vac sampling. The consumption of mosquito larvae has been reported in China for both the Common Carp and Nile Tilapia (Pao 1981). Fish have been used for mosquito control in rice fields in China for many years (Wu 1995). There is even a report that predation by fish on mosquitoes dramatically reduced malaria incidence in Guangxi, Zhuang (Wu et al. 1995).

Between 75% and 79% of fish had arthropods in their gut in WS compared to only 13–43% in DS. What could be the reason for this? Phytoplankton is the primary source of energy in the aquatic arthropod food cycle which is limited by solar radiation. Following this reasoning, then, the DS should give rise to the higher arthropod counts. Comparing abundance over the four seasons in the D-Vac samplings, the 1992 DS had the highest mean density, but the 1991 WS had the second largest density. The 1992 DS was sown to the very pest susceptible IR42. But comparing the two seasons in 1991, where the same variety was grown (IR64), the WS averaged 21% more. Muñoz lies at the edge of the large irrigation system in C Luzon and is bordered by extensive rice areas. The larger rice area in the WS presumably contributed to the higher arthropod densities from dispersal. Monsoon winds also caused more arthropods to fall into the floodwater providing food for fish. Thus the larger rice area of the WS plus the monsoon winds were probably responsible for the higher arthropod numbers in the digestive tracts of the fish.

**Which rice insect pests are more vulnerable to fish predation?**

The main aim of this study was to describe and quantify the role of fish as biocontrol agents of rice pests. Up to 10 arthropod species were found in the guts of individual fishes with only 7–8% being rice insect pests. The low incidence of insect pests is attributable to their rarity in rice-field pond water. Fish gut content analysis revealed that prey were predominantly aquatic or neustonic (at or near water surface) invertebrates with only modest numbers of terrestrial groups. Pests monitored by D-Vac were predominantly whorl maggot during the vegetative stage which were replaced by non-economically important levels of leaf- and planthoppers until crop senescence, a period when arthropod numbers declined. D-Vac is best suited for sampling less-mobile species living on the rice plant and water surface. Although disturbance of arthropods can be minimized by experienced staff such as was achieved in this study, highly mobile insects such as odonatans (dragonflies and damselflies) and orthopterans (grasshoppers and crickets) normally escaped capture. Aquatic species living in the water column such as odonatan nymphs, water beetles, and water bugs were collected, albeit in lower numbers than if the water column had been directly sampled. Previous field studies have shown that purely aquatic predators interact little with rice insect pests in the Philippines, except when they inadvertently fall into, or alight on, the water. Other pests are also recorded as being preyed upon by aquatic arthropods (Hemiptera, Coleoptera, Odonata), and can be noted in the food webs of leaf- and planthoppers as well as stemborers, but these occur infrequently (Jahn et al. 2007; Kandibare et al. 2007).

Our study has shown that rice pests that live in the water are the most vulnerable to fish. Aquatic chironomids and corixids feed on the roots of rice seedlings, but they are never sufficiently abundant in the Philippines to be counted as economically important pests. Of all the insects pests of rice, the semi-aquatic rice caseworm *Nymphula depunctalis* (Lepidoptera: Pyralidae) is probably the most vulnerable to fish predation in the Philippines, as its larvae float on the water surface within cases made of rolled rice leaves (Litsinger et al. 1994a, 1994b). Floating larvae accumulate at the tail end of irrigation systems or at the basins of a toposequence where they can cause large losses. Larvae protrude from their cases while navigating to new plants, so alerting fish to their presence. Females oviposit underneath floating leaves making themselves as well as eggs vulnerable. Thus the rice caseworm is exposed for most of its life-cycle. In Vietnam, Vromant et al. (1998) found that a polyculture (Thai Silver Barb *Barbonymus gonionotus*, Common Carp and tilapia) was able to reduce the number of rice caseworm larvae >93% and quelled an outbreak.

Several species of aquatic water weevils feed on rice roots. In Hubei, *Echinocnemus squamous* adults were found in dissected fish with more found in fish >7 cm long (Wu 1995). Two other studies in northern China...
also noted that fish consumed water weevil adults. Early in the season, eggs are laid next to rice roots, making adults highly vulnerable to predation. Adults also could have been blown by wind into the floodwater, or fish found them when they emerged from underground pupal cells (Luo 1995; Pan et al. 1995).

Rice whorl maggot is a minor pest of vegetative-stage rice and occurs throughout the Philippines. It thrives in fields with standing water, but no stage lives in water. Its attraction to flooded fields may be a predator avoidance strategy (Jahn et al. 2007). Females of this ephydrid fly lay single eggs, which adhere tightly to the foliage, and the larvae feed within the developing leaf buds. Pupation takes place at the leaf bases, thus the adult is the most vulnerable stage to fish predation, as flies rest on plants near the water or when they alight on the surface. Immature stages could, however, become accessible to fish if the paddy water rose as a result of heavy rainfall or irrigation. Ephydrid larvae and puparia were found in fish guts, but most probably were from related species. Adults of several ephydrids of the genera Notiphila and Psilopa were prevalent, but they are not considered to be pests, although they do feed on rice and weeds (Barrion and Litsinger 1986). There were two species of Notiphila (N. similis and N. latigenis) whose larvae feed mainly on detritus. All of the ephydrids were commonly found in sticky traps and fish guts as well as in D-Vac samplings. Common Carp in particular may be an effective predator as it reduced ephydrid adult densities by 46% (see Table 1).

As the whorl maggot is an early colonizer of rice fields, fish may not be of great importance as predators, as they are generally introduced into the fields several weeks after transplanting. Fish predation may play a more important role in areas of staggered plantings by suppressing the overall whorl maggot population. In Bangladesh, fish in rice fields significantly reduced the number of dipteran insects sampled by a vacuum suction device from an average of 6.6/m² to 1.0/m² (Frei et al. 2007).

In the literature, plant- and leaffoppers are the most commonly mentioned insect pests whose populations have been reduced by fish. Most of the studies where the greatest effects have been found have been in China, with one study from each of Vietnam and Indonesia. Fourteen reports found in the literature give data which averaged 60% ± 22% suppression (range 16%–98%) (Xiao 1992; Halwart 1994; Hendarsih et al. 1994; Tuan 1994; MacKay 1995; Weimin 2010), and four studies from China on green leaffoppers reported 49% ± 32% suppression (range 30%–88%) (Xu and Guo 1992; Halwart 1994; Xiao-Fan 1995; Weimin 2010). These reports were based on field counts of hoppers comparing fields with fish to those without from the same area. In Hubei, fish guts were analysed and leaf- and planthoppers were found in Common Carp and Silver Carp Hypophthalmichthys molitrix. Wu (1995) claimed that the presence of fish did away with the need to apply insecticide. Li et al. (1995) observed that carp even jump from the water surface to reach planthoppers on nearby tillers.

Leaffoppers and planthoppers are vulnerable during most of their life-cycle. Carp which consume tillers would therefore consume hopper eggs deposited inside. Brown planthopper (Nilaparvata lugens) is particularly vulnerable, as it is alone among the main hopper pests in preferring to reside on tillers near to the water surface. On the other hand, white-backed planthopper and green, white, and zig-zag leaffoppers reside more in the upper canopy. If the water level were to rise suddenly, brown planthoppers would be particularly vulnerable. Carp and tilapia are known to collide with rice plants during feeding, which can cause nymphs and adults to detach and fall in the floodwater (Sinhababu and Majumdar 1981; Chapman and Fernando 1994). Even without fish collisions or a strong wind, studies have shown that hoppers readily become dislodged from the tillers even in protected environments such as greenhouses. In a greenhouse study, Nakasuji and Dyck (1984) found that two-thirds of brown planthopper adults and late-instar nymphs fell onto the water. Alamazon and Heong (1992) found that dislodgement rates were density dependent, and that dislodgement mostly occurred during the monsoon WS due to high winds. Another reason for detachment is to escape terrestrial predators while feeding. The surface tension of water prevents hoppers from sinking, but the ripples caused by the impact on the water surface alerts nearby fish.

In the D-Vac study there was no significant difference between leaffoppers and planthoppers in any of the four seasons due to the presence of fish. Leaffoppers and planthoppers colonize a young crop and build up over two to three generations to become more important as pests in the later crop growth stages. The only significant reduction of pests occurred at 31 DT, when hopper numbers were only modest and the observed differences were due to whorl maggot.

Yellow stemborer larvae possess aquatic characteristics in so far as they can develop from larva to adult in completely submerged rice plants (Catling and Islam 1995). Tillers are sealed off and made water-tight by the larvae secreting several layers of silk over the entrance hole. Neonate larvae undertake dispersal behaviour soon after emergence by secreting silk threads from which larvae dangle in the wind to reach new plants (Shiraki 1917). This occurs early in the morning when the wind speed is typically low, but during this process the larvae may fall to onto the water. They can float due to their waxy cuticle and low body mass, and they move by wiggling to reach another plant, which would alert the fish. Older larvae also disperse; like rice caseworm larvae, they can make a case from a cut rice leaf (which naturally rolls into a cylinder when cut) and float on the water surface, eventually reaching a new plant. Here again stemborer
larvae are potential prey of fish. This dispersal stage can last around two to eight days (Shiraki 1917). Adult moths cling to rice plants during the day and become active at night to avoid predators such as Odonata or birds. Winds, however, can cause them to become dislodged and fall to the water’s surface. Disturbed moths fly away when one walks through the fields. If fish can disturb them, then higher predation of moths may occur. Shiraki (1917) reported that after a storm many dead moths were seen floating on the water. Apparently moths are not preferred food for fish, since adults or other evidence such as parts of wings were not found in fish guts.

Ten trials were found in the literature, twelve from China and one in the Philippines, where stemborers averaged 49%±24% suppression (range 11%–100%) (Xiao 1992; Xu and Guo 1992; Halwart 1994; MacKay 1995; Halwart and Gupta 2004). Various carp were involved in all trials, with Common Carp in eight, but also polycultures with Grass Carp Ctenopharyngodon idella, Silver Carp, Japanese Crucian Carp Carassius carassius, and/or tilapia in six of the cases. Among fish species, the lowest degree of control was from Common Carp. Grass Carp eat the lower leaves, a behaviour which would disturb moths (Yu et al. 1995). As rice stemborers are the most important chronic insect pests of rice in Asia, their predation by fish that reduced damage 17–29% is of high population dynamic significance.

In the current study, lower stemborer damage levels were recorded in two of the four seasons and larvae were observed in the guts of both Common Carp and Nile Tilapia, indicating that predation had occurred (see Table 3). It would be expected that the effect of fish predation would be greater in the WS’s due to the rainfall and wind washing larvae and moths into the water, but in this study equally significant predation occurred in both seasons.

Rice leaffolders are also chronic pests in all parts of Asia and some studies have shown that they can become vulnerable prey for fish. The average of five trials (four in China and one in Indonesia involving Common Carp in all but also with tilapia in Indonesia) suppression averaged 49%±13% (range 30%–64%). It is interesting to note that unidentified pyralid larvae were found in fish guts, which most likely were leaffolder larvae blown from plants by the wind. In the our study, only the artificially infested plots registered significant damage (11–17% damaged leaves), whereas in the other trials, damage ranged from 0 to 2%. Leaffolders are normally under heavy pressure from a wide range of natural enemies (Barrion et al. 1991). Egg predation and larval parasitism generally are high. Like stemborers, the adult moths remain in the foliage during the day and become active at night. They lay eggs on the foliage and do not come into contact with the floodwater. Larvae do not disperse by making cases as do stemborers, but move directly from plant to plant. They typically occupy the top half of the foliage. Observations in field studies have been made of carp colliding with plants, probably inadvertently during their feeding, and this action has been found to startle leaffolder moths into flight, which are then preyed upon by Odonata and birds (Litsinger 1993).

Three reports support our findings that there was no significant control of leaffolders by fish. Studies in Vietnam (Vromant et al. 2003), Bangladesh (Frei et al. 2007), and Malaysia (Teo 2006) found no effect of fish on leaffolders. On the other hand, three surveys done in Zhejiang Province, China revealed a large increase in leaffolders in association with fish (Yu et al. 1995). In Xiaoshan, there was a 6.5-fold greater quantity of leaffolder-damaged leaves in association with fish in 1986 and 1.9-fold in the following year. In Shangyu there was a 57% increase in larvae with Grass Carp alone, but only a 30% increase in a polyculture of Grass Carp, Common Carp and tilapia. Reasons given as to why leaffolder was more abundant in fish culture were that the benthos-feeding carp churn the soil, aerating it, and their faeces add to organic fertilizer, making the leaves greener, and the more humid microclimate from the deeper water favours oviposition and larval survival (Yu et al. 1995). On the other hand, the same authors claimed that control of sheath blight disease was from the lower humidity due to removal of excess tillers and diseased leaves by the fish which opened the canopy to let in more light and wind. The most probable explanation is the higher level of N, which is well known to increase fecundity and survivorship (Litsinger et al. 2011).

Weimin (2010) also recorded suppression of the green-semilooper Naranga aenesecens (80% predation) and the skipper butterfly Parnara guttata (50% predation) due to fish. Rice seed bugs (Leptocorisa spp.) are pests of developing grain and were detected in the D-Vac sampling, but their numbers were small and no significant difference was noted. Wind could knock them into the water, but it remains to be seen whether fish would eat them, as they secrete a defensive chemical when disturbed, which may be repellent to fish. Teo (2006) reported a large infestation of rice bugs in Malaysia, but the presence of fish did not affect their densities.

Why fish are not always effective predators
Several studies have failed to show insect pest suppression in rice-fish cultures (Vromant et al. 2002; Teo 2006; Frei et al. 2007). Our study also found that fish did not significantly reduce densities of hoppers and leaffolder, whereas in other studies, suppression was high. Lack of control in some studies may have been due to several possible causes:

(1) The pest population was not sufficiently high for us to be able to measure differences.
This probably explains why hoppers were not suppressed by fish in the current study. The most likely reason for the low pest population was that insect-resistant rice cultivars were used in our trials. The three cultivars used were highly resistant to the green leafhopper and brown planthopper, although IR42 was only moderately resistant. IR cultivars, however, are not resistant to either whitebucked planthopper or white or zig-zag leafhoppers. However, because insecticides were not used, high densities of beneficials were allowed to build up, particularly in a double rice-crop system (Litsinger 2008). Only sub-economic densities of <10 hoppers/hill were recorded from the four field trials where beneficials mostly dominated (see Figure 1). Seven reports from China and Thailand, where control was noted, as previously reported, averaged 38 planthoppers per hill, which is above the 20 per hill action threshold used to trigger insecticide application (Way et al. 1991). Hopper populations are higher in China and Thailand than in the Philippines due to a lack of genetic resistance in common rice cultivars, higher use of N, single rice crop systems, and migration of planthoppers from south to north into crops with low levels of beneficials (Litsinger 2008). The long rice-free fallow in single crop systems reduces beneficials more than pests, while double crop systems favour both beneficials and pests. Thus, insecticide usage and genetic resistance dictate the outcome in both systems locally. Leaf folders also behave much like hoppers, in that populations are stimulated by both N fertilizer and insecticide resurgence (Bandong and Litsinger 1986; de Kraker et al. 2000). Hopper predation by fish occurs more under higher pest densities on a crop as detachment is density dependent (Almazon and Heong 1992; Hendarsih et al. 1994). Weather can also play a similar role in lowering infestation level. Frei et al. (2007) during the winter months noted low arthropod densities in Bangladesh where cool temperatures curtailed population development.

(2) Sampling pests too late in the season. It is no wonder that Teo (2006) did not find evidence of fish predation, as sampling for arthropods was done only once and just before harvest when the crop was in senescence. Few insect pests are active when the crop is senescing. Whiteheads can be readily seen at this stage, but leaf folder damaged leaves may have withered away, and certainly early-season insect pests would leave no evidence. Pests should be sampled periodically to detect peaks of injury or density.

(3) Grass Carp versus Common Carp. Within carp, Grass Carp aggressively consume rice tillers disturbing plants; this flushes out moths and, it is believed, leads to more predation by Odonata and birds. Stems also contain eggs of hoppers and other insect pests that would be consumed. Therefore Yu et al. (1995) believed that Grass Carp is superior to Common Carp in reducing densities of insect pests. But most reports from China where both fish are prevalent show that Common Carp exert greater control of rice insect pests (Mackay 1995).

(4) Selection of larger-bodied fish should result in higher predation rates. Yu et al. (1995) concluded that large, more mature Common Carp, Grass Carp, and Nile Tilapia were better than younger fish as biocontrol agents. However, a significant difference was found in the current study between fish size and the number of arthropods found in fish gut analyses, with carp weighing 3.5–150 g and tilapia weighing 7.9–82.9 g per fish.

(5) A higher stocking rate should lead to greater predation. Stocking rates in reports from China ranged from 3000 to 15,000/ha for mature fish and 20,000–225,000/ha for fingerlings (Mackay 1995). In our study, however, there was no difference between the two rates tested, viz. 5000 and 10,000 fish/ha. In fact more predation was noted in the 1991 WS with a stocking rate of 5000 fish/ha. This was one of the crops where fish exerted significant suppression of arthropods as well as detritivores/predators (see Table 1), and all other crops were stocked at 10,000/ha.

(6) Polyculture – by employing different species of fish, each specializing in a different feeding mode or part of the aquatic habitat to feed – should offer improved predation over single species. The current trial showed that tilapia and carp feed in different parts of rice field profiles, and perhaps predation would be greater if they were mixed. The scant evidence of trials where comparisons have been made between polyculture and single species does not seem to bear this out. Yu et al. (1995) found polyculture did not increase predation of planthoppers over single species, whereas polyculture increased leaf folder only 30% whereas grass carp alone increased it more (57%), but the differences may not have been statistically significant.

(7) Poor design of a trench system could minimize predation, if fish would spend most of their time in the trench rather than in the field. The current study had one 0.5-m deep trench running along the length of the field. Halwart et al. (1996) showed that the fish spent more time in the field than in the trench, thus the design aided predation opportunity. In most of the literature the design of the refuge system is not described.
Pest behaviour is a significant factor in predisposition to fish predation. Stemborers, leaf-folders, and rice-seed bugs are terrestrial as they feed on aerial portions of the plant and only occasionally will fall from the plant and land on the water, so they are less affected by fish. Stemborers are more predisposed than leaf-folders to fish predation owing to the aquatic behaviour of dispersing larvae. Leaffolder larvae, because they reside in shelters of folded leaves, are less likely to detach and fall onto the water. This is probably why artificially infesting high numbers of moths had no effect. Veliids, gerids, lycosids, ephydrids, and other predators that inhabit or frequent the water surface are more in harm’s way (Frei et al. 2007). Aquatic predatory arthropods that live in the water column such as water beetles (dytiscids, hydrophilids), water bugs (notonectids, hydrometrids, corixids), and culicids (mosquitoes), as well as chironomids that frequent the sediment are most available to fish and were consequently most impacted by fish.

**The role of fish in the arthropod food web**

The results of this study support those of other studies which showed that rice fields have a rich and diverse arthropod food web where beneficials generally dominate over pests (Schoenly et al. 1998). Thus sustainability of rice integrated pest management in the Philippines is based, to a large degree, on natural enemy conservation, particularly in double rice-cropping systems. Normally, there is little need for farmers to apply insecticides owing to the action of beneficials (Ooi and Shepard 1994; Way and Heong 1994; Heong and Escalada 1999). Farmers have their own action thresholds which are much lower than those of researchers (Bandong et al. 2002). Consequently the majority of Filipino farmers still spray, despite the fact that most applications are uneconomical, thus there is the constant potential for insecticide resurgence (Litsinger et al. 2005).

Fish can play a role in the arthropod food web as predators. Phytoplankton, the basis for fish food, decreases in quantity as the crop grows. Invertebrates increasingly play a key role as food, as the season progresses. More natural enemies than pests are truly aquatic, thus beneficials come into contact with fish more than do pests. Fish feed indiscriminately on invertebrates irrespective of guild but take a higher toll on aquatic predatory arthropods (coenagrionid damselflies, belostomatids, hydrometrids, notonectids, corixids) than those that inhabit the neuston zone and least among terrestrial than aquatic, neustonic or semi-aquatic beneficials. This is borne out by the fact that 49% of the arthropods recovered from tilapia guts and 28% from carp were predators, whereas only 9% were pests. The most common semi-aquatic predators are veliids, gerids, as well as wolf spiders and mycrophid spiders, which run across the water surface in search of prey or make webs just above the waterline.

Interestingly, no spiders were recovered from fish guts. Semi-aquatic wolf spiders related to *Paradosa pseudoannulata* dive into the water after prey (Bleckmann and Lotz 1987). Such spiders have evolved behaviours that aid them to avoid being prey themselves to fish. This evasive behaviour may also occur with rice field Araneae. In an aquarium it was noted that spiders were readily consumed by fish, but in such an environment there was no shelter. Xu and Guo (1992) in Fujian, China found that spiders increased three-fold in abundance in an azolla + fish (polyculture of grass, common, and crucian carp) compared to rice monoculture without fish or azolla. The presence of the azolla floating fern provided a refuge from predation, above the water level. In rice fields spiders can seek shelter in between rice tillers and on weeds.

Our results indicate that fish prey more heavily on natural enemies than pests do. Does this upset the balance of this important group of pest deterrents? Gupta et al. (1998) in Bangladesh found that predator (lady beetles, spiders, and damselflies) densities were 5–48% higher in rice-fish farms than rice-only farms up to 10–12 weeks after transplanting, but nearer to harvest the converse was observed. However, pest infestation was 40–167% higher in rice-only farms during all stages of rice growth. From Figure 1 we note from D-Vac collections that there were times when pests outnumbered predators, as in 1991 WS and briefly in 1992 DS, but most of the time the opposite was true.

Fortunately, the natural enemy guild includes a greater number that reside in the crop canopy in association with most insect pests. It is generally believed that predators are more important than parasitoids in suppressing rice pests (Ooi and Shepard 1994). Notably, relatively few parasitoids were represented in the D-Vac collections (14% of the arthropods), sticky traps (8%), and gut analyses (<1%). Whorl maggot has few documented parasitoids, but egg parasitoids play a key role against leaf- and planthoppers as well as stemborers. Larval parasitoids are important against leafrollers, more so than against the more protected stemborers. As a food for fish in rice fields, parasitoids are of minor importance. Natural enemies tend to be low in density at the beginning of the season, but then increase to levels above those of pests during the last half of the rice crop. This does not always occur, however (see Figure 1). Because each natural enemy usually will kill more than one individual, it is not necessary that beneficials outnumber pests in order to contain their densities. It is estimated, for example, that lycosid spiders kill an average of five hoppers per day (Kenmore et al. 1984). But arthropod predators prey on one another, even within members of the same species. More often than
not (Figure 1), comparisons with and without fish showed greater similarity than difference, thus it is concluded there was no significant effect of fish selectively diminishing beneficials over pests. We expect that at times there will be brief upsets in the densities of beneficials, particularly if farmers use insecticides. This is one argument in support of farmers using preventive means of pest control, such as genetic resistance or a long dry fallow between rice crops, to complement natural enemies. We saw that in association with fish during four crops under natural infestation, only stemborers reached an action threshold in the 1992 WS. The food chain is so rich that other, more terrestrial predator groups fill the gap.

Fish replace aquatic invertebrates as predators. They make useful predators, as they exist at a constant density 0.5–1/m² that declines only slightly over a season, whereas beneficials tend to fluctuate dynamically over the season (see Figure 1). The flora and fauna of a rice field together have formed a stable agroecosystem for many millennia, and fish have been a part of it. The introduction of large numbers of exotic fish did not appear to upset the pest–natural-enemy balance. Fish play a role as predators and any additional link to the food chain strengthens integrated pest management.

Insecticides may be unnecessary or even detrimental to insect pest control in the Philippines, since natural enemies typically keep pests at manageable levels and varieties possess genetic resistance. The main benefit of rice-fish culture, therefore, is to give farmers an additional reason not to use insecticides and thus spare beneficials (Rothuis et al. 1998). Research has shown that farmers stocking fish tolerate a higher action threshold due to the value of the fish (Waibel 1992). Fish may play a larger role in pest suppression in countries where rice varieties do not have genetic resistance against green leafhoppers and brown planthopper or where, due to long fallows, the natural enemy densities are low. Because of the value of fish, farmers manage their rice crops better. Better agro- nomic management has been shown to increase the compensatory ability of the crop to tolerate pest damage (Litsinger et al. 2011). Increased crop compensation is another benefit of rice-fish culture.

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References


Meien VA. 1940. Fish culture in rice fields. Moscow, Russia: Food Industry Publishers. Macháckova B, translator; Fernando CH, editor.


