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Impact of insecticides on herbivore-natural enemy communities in tropical rice ecosystems

K.L. Heong and K.G. Schoenly

INTRODUCTION

Today, rice pest management in tropical Asia is strongly influenced by the agrochemical era of the 1960s and 1970s. Prophylactic insecticide campaigns were components of rice production intensification programmes, like Masagana 99 in the Philippines (Alix, 1978) and BIMAS in Indonesia (Adjid, 1983). Through agricultural subsidy and loan schemes, farmers were encouraged to apply insecticides on regular schedules (Kenmore *et al.*, 1987; Conway and Barbier, 1990; Conway and Pretty, 1991). The agrochemical industry, through its aggressive advertising and marketing campaigns, also played a role in encouraging pesticide use.

The pest problems farmers and researchers witnessed in tropical Asia in the 1970s, particularly insecticide-induced outbreaks of the rice brown planthopper (*Nilaparvata lugens* Stål [BPH]; Heinrichs and Mochida, 1984; Kenmore *et al.*, 1985), led to IPM strategies that emphasized host-plant resistance, biological control and cultural practices, minimizing the use of pesticides. Since the 1970s however, several studies in tropical Asia have concluded that high levels of host-plant resistance for BPH management are unnecessary under certain circumstances (i.e. large areas of irrigated rice production where farmers use of insecticides is low). Experimental

studies conducted in Indonesia, Vietnam and the Philippines, for example, have shown that (a) hopperburn is rare or absent in fields grown with BPH-susceptible varieties not treated with insecticides (Kenmore *et al.*, 1984; Cook and Perfect, 1985; Cuong *et al.*, 1997: but see Sawada *et al.*, 1993); (b) susceptible varieties rarely show yield loss by BPH populations even when outbreaks occur in adjacent plots (Cuong *et al.*, 1997); and (c) moderately-resistant or even BPH-susceptible varieties grown for several years by a large number of farmers are associated with low and stable BPH populations (Gallagher *et al.*,1994; Cohen *et al.*, 1997). Thus a revised IPM strategy for tropical rice, based on these studies, advocates a shift in priority from host-plant resistance to naturally occuring biological control, while minimizing insecticide inputs, for sustainable and durable rice production systems.

Meanwhile, the global market share of pesticides sold in Asia has increased. For example, in 1988, worldwide sales of rice pesticides reached US$2.4 billion, sufficient to nudge out maize and cotton as the single most important crop for pesticides, with 90% of this market located in Asia (Woodburn, 1990). Insecticides accounted for the largest fraction of the total market (40–50%) until 1992, after which herbicide sales exceeded insecticide sales (MacKenzie, 1996). In 1995, herbicides accounted for 39% of the rice pesticide market, followed by insecticides and fungicides at 34% and 27% respectively. Country-by-country comparisons show that Japan leads all other countries in pesticide sales of approximately 50% of the world's total.

Past and ongoing research indicates that most insect pests of tropical rice are controlled by the activity of not just a few natural enemies but a whole array, through a complex and rich food web of generalist and specialist predators and parasites/parasitoids that live above and below the water surface (Heckman, 1979; Heong *et al.*, 1991, 1992; Schoenly *et al.*, 1996a,b; Settle *et al.*, 1996). Farmer interventions impact target and non-target species in different ways because biocontrol mechanisms span multiple trophic levels and act along spatiotemporal gradients. Determining the biocontrol potential of different components of this rich biodiversity (e.g. spiders, beetles, parasitoids, aquatic predators) and their role as stabilizing and buffering agents in rice production systems still remains to be shown through future research.

In this chapter, we highlight and review community-level approaches that have helped ecologists and entomologists to understand better how insecticides affect pest and natural enemy populations in tropical rice ecosystems. We begin with a review of farmer spraying practices and insecticide use patterns and conclude that, in many instances, farmers spray unnecessarily. In the second part of this report, we limit our review of studies to those directed at the community level of biological organization because farmers normally care about the net effect

of all pests on their crop, not necessarily about individual species. Methods directed at the community level that have been used by different workers include ecostatistical indices, rank-abundance curves, guild and food web approaches, and multiple regression models. We conclude that much practical knowledge can be gained about how, when and to what degree different classes of insecticides impact different arthropod groups when they are studied at the level of entire communities.

FARMER PERCEPTIONS AND INSECTICIDE USE PATTERNS

Farmer surveys conducted by Heong *et al.* (1994) in the Philippines and Vietnam showed that about 90% of all sprays applied by farmers in 1992 were insecticides. Roughly half of these sprays were organophosphates such as methyl parathion, monocrotophos, methamidophos and chlorpyrifos. Cross-listing these insecticides against World Health Organization (WHO) classification of hazardous pesticides reveals that 37% of these sprays rate as 'extremely' (WHO Ia) or 'highly' (WHO Ib) hazardous to human health. Except in Japan, South Korea and Malaysia, WHO I insecticides are readily available and frequently applied on rice in most Asian countries (Heong and Escalada, 1997a).

In many cases, insecticides for rice are unnecessary. In the Philippines, for example, about 80% of insecticides are misused by farmers because they are applied at the wrong time and to the wrong target; consequently, such sprays are unlikely to result in an economic return on farmer investment (Heong *et al.*, 1995a). Moreover, farmers typically applied their first sprays in the first 40 days after crop establishment (Heong *et al.*, 1994; Heong and Escalada, 1997b) on lepidopterous larvae, commonly called 'worms' by farmers.

In early crop stages, leaf damage that is common and visible to farmers is attributable to rice leaf folders (*Cnaphalocrocis medinalis, Marasmia patnalis, M. exgua*), whorl maggots (*Hydrellia* spp.) or thrips (*Stenchaetothrips biformis*). Among these herbivores, rice leaf folders are the most common target for sprays by farmers in Asia. Under favourable conditions, a leaf folder larva can consume 25 cm^2 (or 25%) of leaf area (Heong, 1990) while leaf folder densities average less than two larvae per hill (Wada and Shimazu, 1978; Guo, 1990). In highly fertilized crops, densities of leaf folders can reach five larvae per hill (deKraker, 1996); however, the fraction of damaged leaves at such densities rarely exceeds 50%. Miyashita (1985) has shown that crops with leaf damage as high as 67% and occurring as late as the tillering stage do not suffer yield loss. Similarly, computer simulation has shown that larval densities need to reach (unrealistic counts of) 15 individuals per hill before yield loss can be detected (Fabellar *et al.*, 1994). Thus, most early-season sprays

reflect farmer misperception of insect problems by overestimating yield losses that the larvae are likely to cause.

ECOLOGICAL EFFECTS OF INSECTICIDE SPRAYS

In this section, we review results of studies conducted in the Philippines and Indonesia that evaluated community-wide impacts of insecticides on different functional groups of invertebrates (herbivores, predators, parasitoids, detritivores) in the rice ecosystem.

Species richness in sprayed and unsprayed plots

In an irrigated rice field in Central Luzon, Philippines, species richness (N0) for herbivores and predators was found to be significantly lower in chlorpyrifos-sprayed than unsprayed plots after insecticides were applied at 29 and 43 days after transplanting (DT) (Figure 41.1a,b). After the second spray at 43 DT, species richness in sprayed and unsprayed plots was nearly identical for herbivores and predators at 57 and 63 DT, respectively, suggesting that herbivore richness recovered from chlorpyrifos sprays one week earlier than predators. For herbivores the number of abundant species, measured by $N1 = \exp[H']$, where H' is the Shannon diversity index (Ludwig and Reynolds, 1988, section 8.2.2), decreased and recovered after each spray (Figure 41.1c). Conversely, the number of abundant predators increased significantly after the second spray (Figure 41.1d) until the end of the trial. Thus, species richness of all herbivores (Figure 41.1a), all predators (Figure 41.1b) and abundant herbivores (Figure 41.1c) recovered relatively quickly (through recolonization) from the cumulative effect of two chlorpyrifos sprays; whereas the sharp rise in number of abundant predators (Figure 4.1d) after the second spray (at 43 DT) suggests overcompensated recovery aided in part by numerical response behaviour.

Species abundance in sprayed and unsprayed plots

In the same twice-sprayed, chlorpyrifos plot in Central Luzon, herbivore abundance was significantly reduced immediately after each spray but climbed to unsprayed abundances one week after the second spray (Figure 41.2a). Over the remaining post-spray dates, differences in herbivore abundance gradually lessened between sprayed and unsprayed plots. Recovery of predators in the sprayed plot reach unsprayed abundances one week after the first spray, but after the second spray predators did not reach unsprayed levels until 63 DT (Figure 41.2b). Herbivore and predator abundances in sprayed and unsprayed plots, when summed over all sampling dates, differed by 1% and 42%, respectively (Table 41.1).
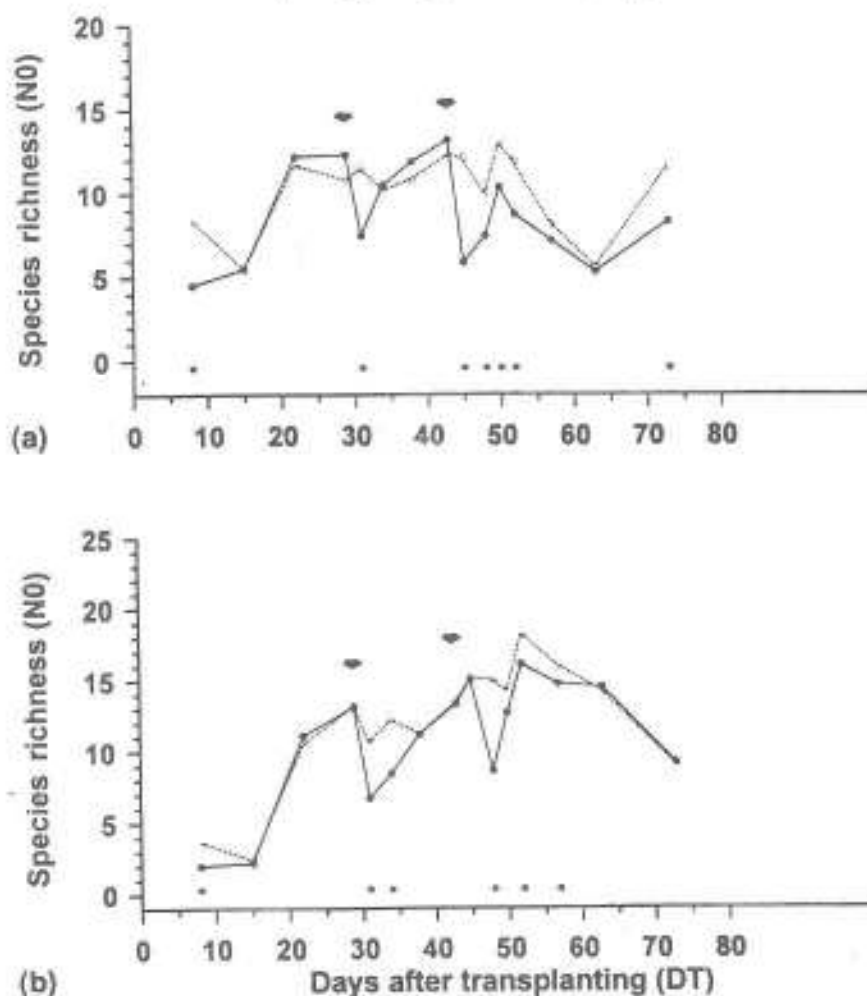
Figure 41.1 (a and b) Mean counts, based on 10 samples, of (a,b) species richness and (c,d) the most abundant species for (a,c) herbivores and (b,d) predators in chlorpyrifos-sprayed (●) and unsprayed (○) rice plots in Nueva Ecija, Philippines. Arrows denote spray days; * indicates that mean counts in sprayed and unsprayed plots were significantly different at $P = 0.05$. (See text for details.)

Chlorpyrifos reduced cicadellid homopterans, mainly *Nephotettix virescens* (Figure 41.3a), by 12% and increased delphacid homopterans, mainly *Nilparvata lugens* and *Sogatella furcifera*, by 23% (Figure 41.3b,c). Predators affected most by sprays included lycosid spiders (61% reduction, Figure 41.4a) and veliid bugs (55%, Figure 41.4b). Mirid bugs, particularly *Cyrtorhinus lividipennis*, though reduced after each spray, recovered
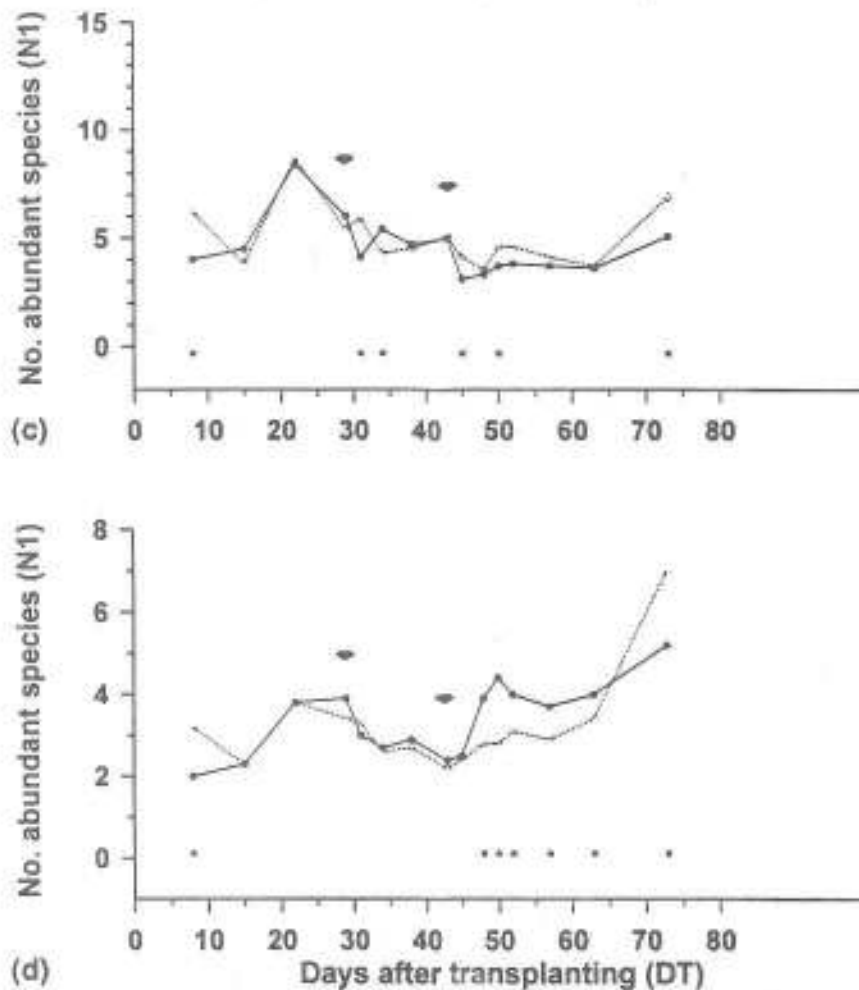
Figure 41.1 (c and d)

quickly to abundances close to or higher than unsprayed abundances; by season's end, total numbers of mirids in sprayed and unsprayed plots differed by only 1% (Figure 41.4c). Numbers of sampled organisms of all taxa, taken over all sampled dates, were higher in the unsprayed plot (75 121 individuals) than the sprayed plot (55 560 individuals).

In the same chlorpyrifos study, rank-abundance curves for herbivore and predator populations manifested different magnitudes of variation before and after the first spray date at 29 DT (Figure 41.5a,b). Interestingly, the rank order of the most common herbivore species remained unaltered between pre- and post-spray dates and between sprayed and
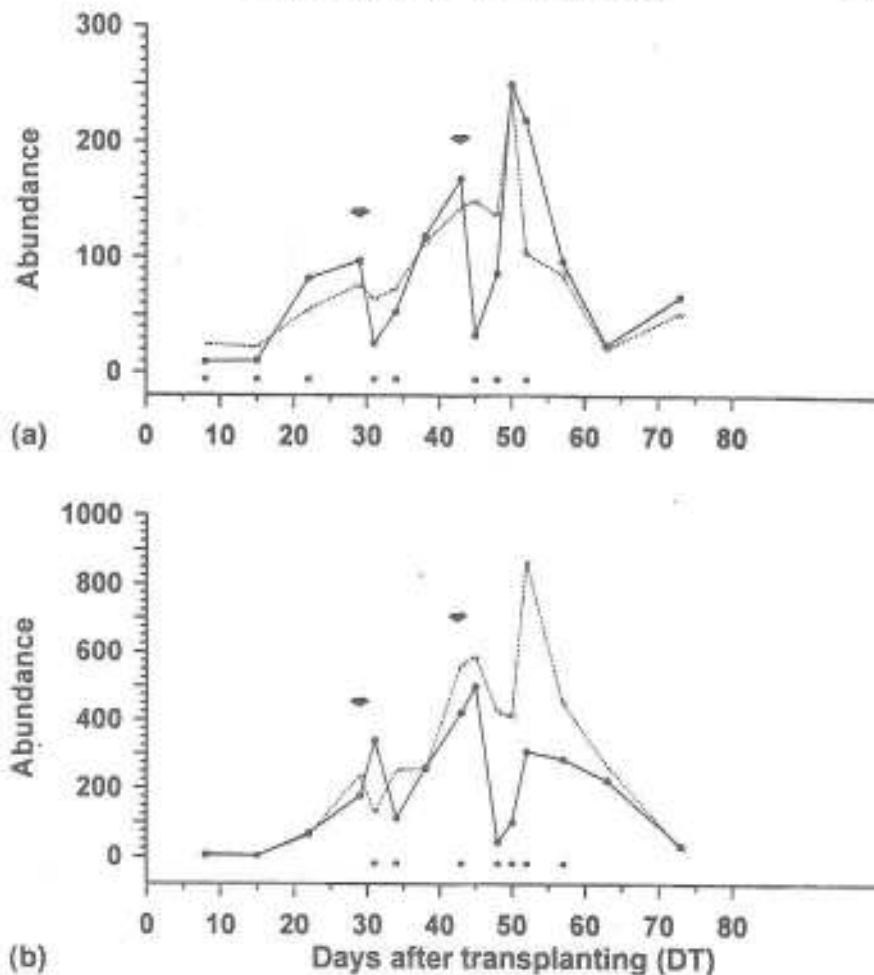
Figure 41.2 (a and b) Mean counts, based on 10 samples, of (a) herbivore and (b) predators in chlorpyrifos-sprayed (•) and unsprayed (○) plots in farmers' fields in Nueva Ecija, Philippines. Arrows denote spray days; * indicates that mean counts in sprayed and unsprayed plots were significantly different at $P = 0.05$.

unsprayed plots, with *Nephotettix virescens* and *S. furcifera* retaining numerically dominant positions throughout, followed (less consistently) by *N. lugens* and aleyrodids (Figure 41.5a). On the other hand, the most abundant predators did differ in rank over pre- and post-spray dates and between sprayed and unsprayed plots (Figure 41.5b). For example, between the pre- and post-spray dates, the top three predators at 29DT were *Microvelia douglasi atrolineata*, *Mesovelia vittigera* and *C. lividipennis*,

Table 41.1 Differential effects of two sprays of chlorpyrifos (29 and 43 DT) on arthropod abundances from different functional groups in a farmer's field in Central Luzon, Philippines

Functional group	Unsprayed plot	Sprayed plot	% Difference
All herbivores	14 402	14 221	−1.2
Cicadellidae	8 191	7 229	−11.7
Delphacidae	3 879	4 776	+23.1
All predators	46 248	26 967	−41.7
Miridae	4 255	4 211	+1.0
Lycosidae	1 063	417	−60.8
Veliidae	39 845	18 012	−54.8
All parasitoids	2 359	1 477	−37.4
All detritivores	12 090	12 829	+6.1

followed at 31 DT by *M. d. atrolineata, Atypena* (= *Callitrichia*) *formosana* and *Tetragnatha javana* in the sprayed plot.

Population studies of rice brown planthopper (BPH), *N. lugens*, show increases of up to 800-fold after sprays of monocrotophos (Heinrichs and Mochida, 1984; Kenmore *et al.*, 1984). Similar increases in BPH populations have been observed on BPH-resistant varieties after insecticide application (Joshi *et al.*, 1992; Gallagher *et al.*, 1994).

Guild and food web structure in sprayed and unsprayed plots

To gauge the ability of guild and food web concepts to reveal effects of insecticide spraying, another farmer's field in Central Luzon was studied using sprayed and unsprayed plots of equal area (Schoenly *et al.*, 1996a). Three foliar sprays of deltamethrin were applied at 28, 38 and 49 DT. Time-specific food webs for the sprayed and unsprayed plots were constructed from time-series samples and a 546-taxa cumulative Philippines-wide food web.

Triangle graphs are instructive tools for illustrating time-series changes in herbivores (%H), natural enemies of herbivores (%E) and other taxa (detritivore and planktonic) (%O) in sprayed and unsprayed plots (Figure 41.6a). On the three pre-spray dates (8, 15 and 22 DT), sprayed and unsprayed plots had similar levels of %H, %E and %O (Figure 41.6b,c). In both plots, %O declined whereas %H and %E increased over the two-week period. Over the spraying interval (28–49 DT), %H in the sprayed plot exceeded %H in the unsprayed plot. Natural enemy abundances (%E) were much greater in the unsprayed plot than in the sprayed plot (three-date means: 57% and 24%, respectively). Over the remaining eight post-spray dates (50–99 DT), percentage differences in trophic groups gradually lessened between sprayed and unsprayed plots (Figure 41.6b,c). At 78DT, %H,
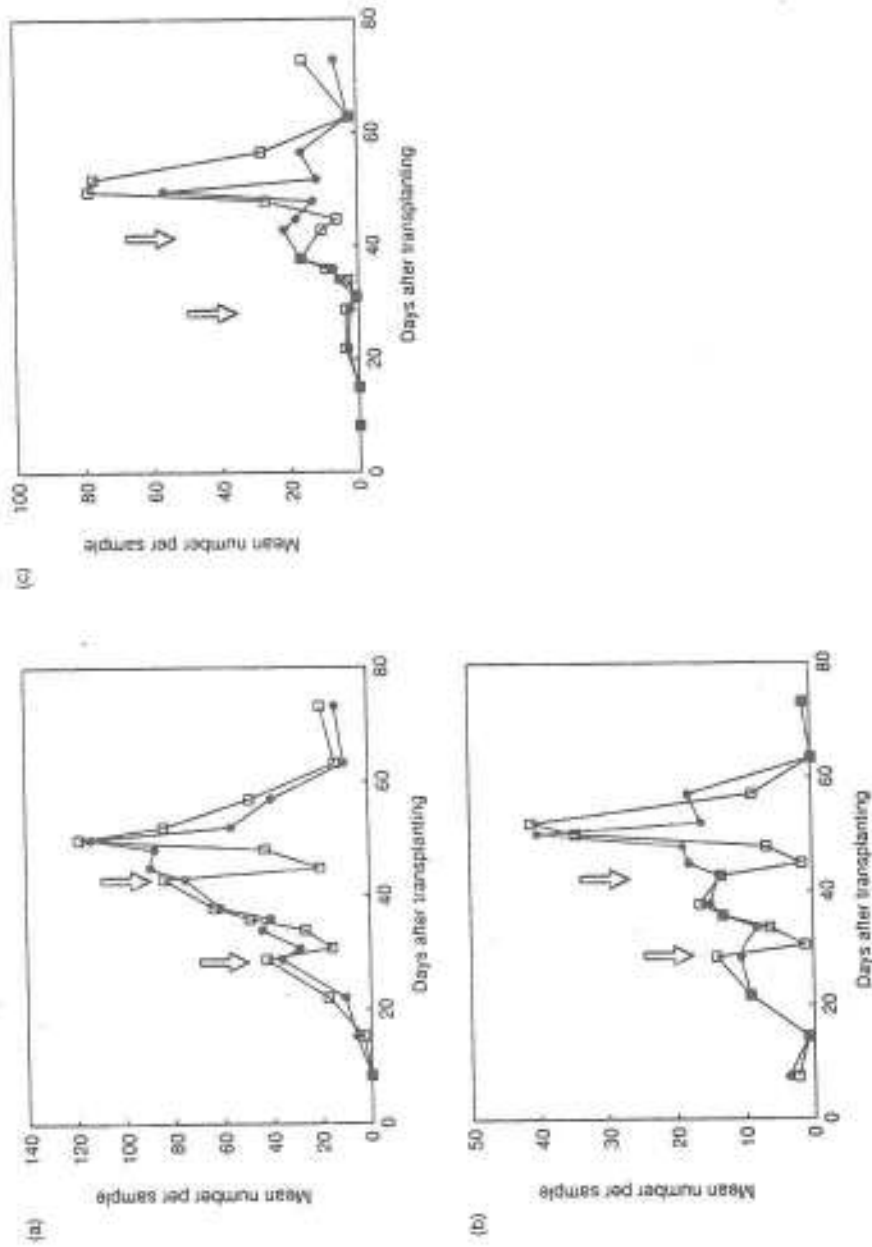
Figure 41.3 Mean counts, based on 10 samples, of abundances of (a) *Nephotettix virescens*, (b) *Sogatella furcifera* and (c) *Nilaparvata lugens* in chlorpyrifos sprayed (□) and unsprayed (*) plots in Nueva Ecija, Philippines. Arrows denote spray days. Counts are based on samples taken from a 0.25 m² enclosure using a motorized suction machine.

Figure 41.4 Mean counts, based on 10 samples, of abundances of (a) *Pardosa pseudoannulata*, (b) *Microvelia douglasi atrolineata* and (c) *Cyrtorhinus lividipennis* in chlorpyrifos sprayed (□) and unsprayed (✳) plots in Nueva Ecija, Philippines. Arrows denote spray days. Counts are based on samples taken from a 0.25 m² enclosure using a motorized suction machine.
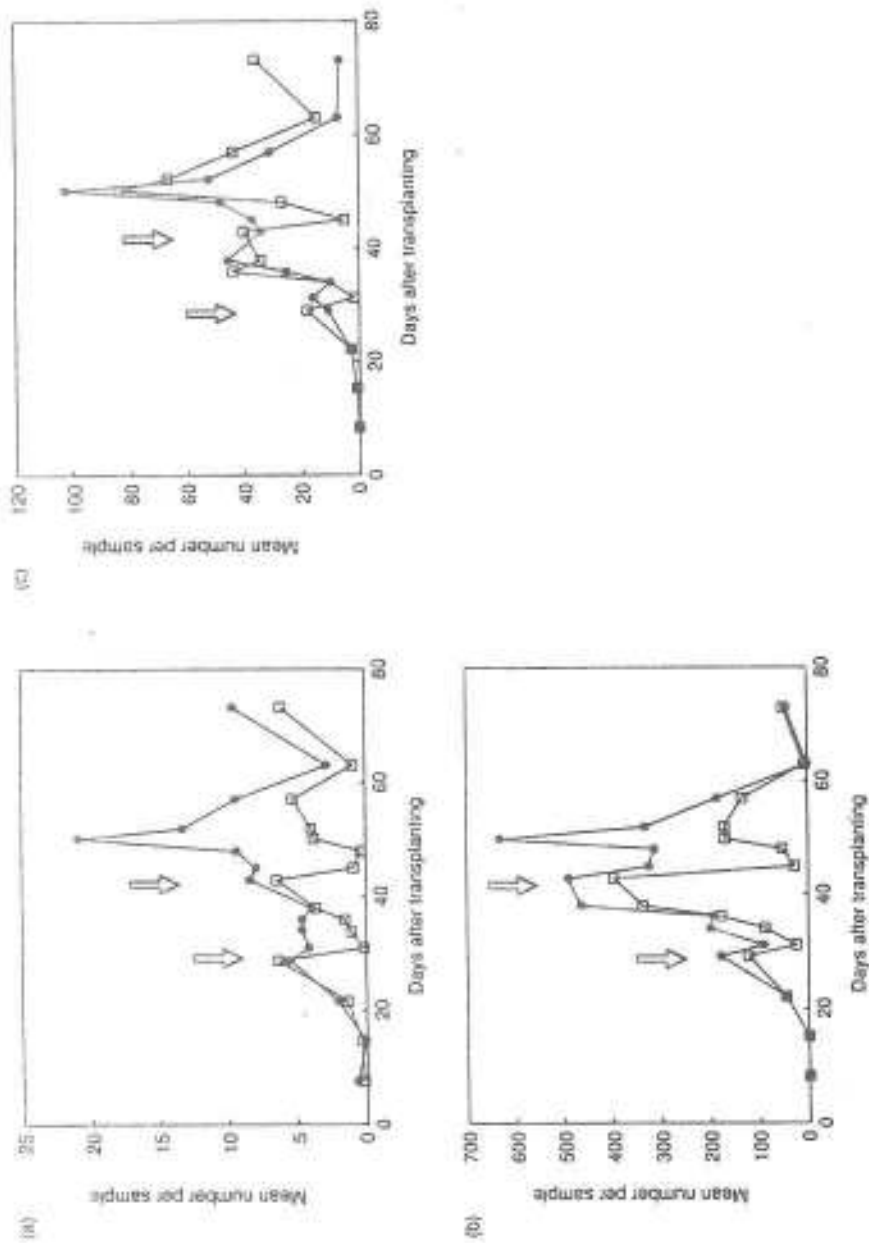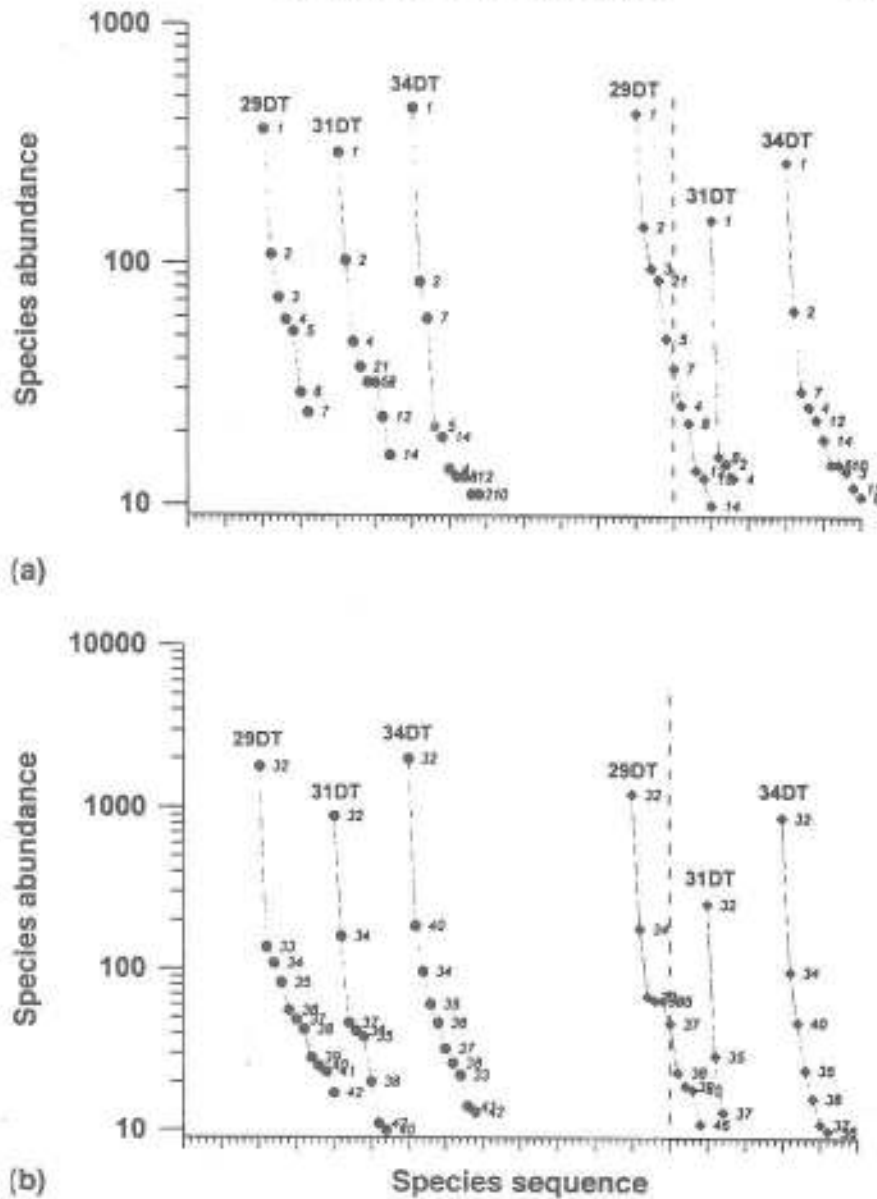
(a)

(b)   **Species sequence**

Figure 41.5 Rank abundance curves for (a) herbivores and (b) predators on chlor-
pyrifos sprayed (♦) (29 DT) and unsprayed (●) rice plots for common species com-
prising 10 or more individuals. Vertical dashed lines separate pre- and post-spray
dates. Numbers next to data points identify the most common species comprising
10 or more individuals. Herbivores: 1, *Nephotettix virescens*; 2, *Sogatella furcifera*; 3,
Brachydeutera longipes; 4, Aleyrodidae; 5, *Nephotettix nigropictus*; 6, *Leptocorisa* sp.;
7, *Nilaparvata lugens*; 8, Coreidae; 9, *Tagosodes pusanus*; 10, *Notiphila similis*.
Predators: 32, *Microvelia douglasi atrolineata*; 33, *Mesovelia vittigera*; 34, *Cyrtorhinus
lividipennis*; 35, *Atypena formosana*; 36, *Pardosa pseudoannulata*; 37, *Tetragnatha
javana*; 38, *T. maxillosa*; 39, *Sternolophus* sp.; 40, *Limnogonus fossarum*; 41, *Hydrome-
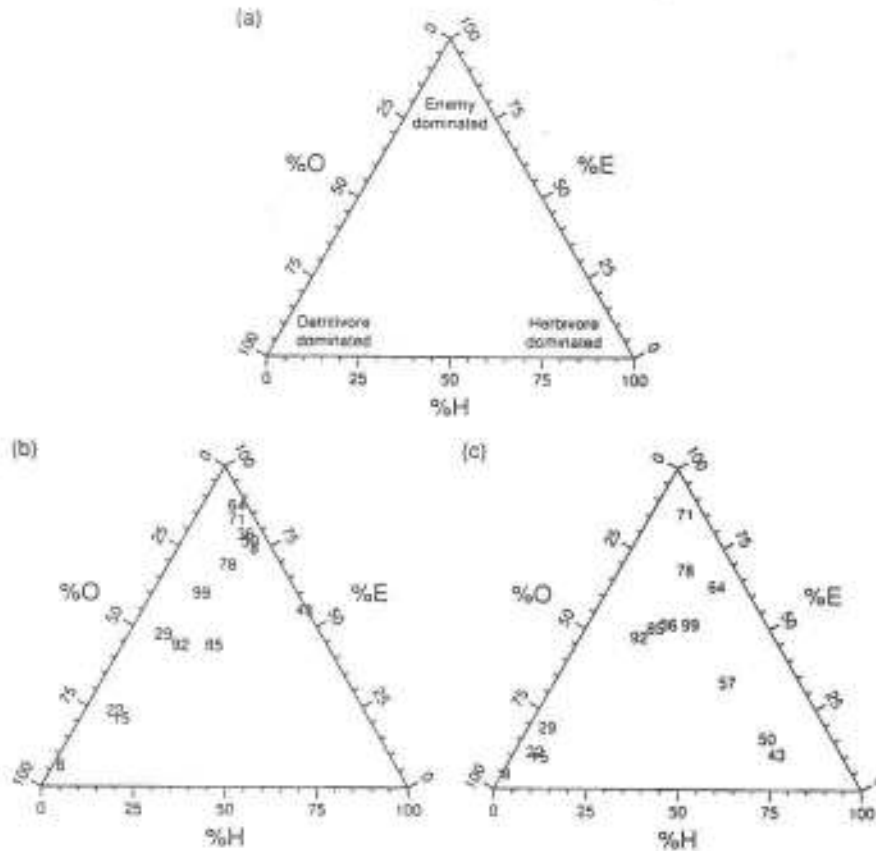tra lineata*.

Figure 41.6 Triangle graphs showing temporal variation in percentage abundances of herbivores (%H), natural enemies (%E) and other taxa (detritivores and planktonic) (%O) from farmers' fields in Zaragosa, Philippines. Percentages of (a) herbivore-, enemy- and detritivore-dominated regions of the graph, and of H, E and O abundances for each of 14 sampling dates in (b) unsprayed and (c) deltamethrin-sprayed plots. Numbers within each graph are days after rice seedling transplantation. Percentages in sprayed and unsprayed plots are means of 10 samples based on counts per 1.6 m^2 per sampling date. Modified after Schoenly *et al.* (1996a).

%E and %O in the sprayed and unsprayed plots were nearly identical, suggesting a (roughly) one-month recovery period of trophic guilds from deltamethrin sprays.

For each time-specific food web, mean chain length (μ) was calculated using the most common taxa that captured 90% of the total abundance (90%A web; Schoenly *et al.*, 1996a). Mean chain length was defined as the average length (counting links, not species) of all maximal food

chains from a basal species to a top predator (Cohen, 1978), calculated using the long-way-up algorithm of Cohen and Luczak (1992).

On pre-spray dates, the 90%A webs of the sprayed and unsprayed plots each had food chains up to three links in length: rice/pests/specialist enemies/generalist enemies (Figure 41.7). Following the first deltamethrin spray, μ in the sprayed plot fell from 2.6 at 22 DT to 2.0 at 29 DT, yielding a web that contained only two-linked chains (rice/pests/enemies). Over the same 7-day period, μ in the unsprayed plot increased slightly from 2.4 to 2.6 (Figure 41.7). Subsequent sprays at 38 and 49 DT sustained the treatment effect first seen at 29 DT but did not amplify it.

Over the next five post-spray dates (36–64 DT), six natural enemy species that were present in 90%A webs of the unsprayed plot were absent in 90%A webs of the sprayed plot. In decreasing order of occurrence they were *A. formosana* (six out of six post-spray dates), *C. lividipennis* and *Micraspis* spp. (three out of six dates each) and *Pardosa pseudoannulata*, *Stilbus* sp. and *Tetragnatha* sp. (one out of six dates each). Based on food chain lengths in Figure 41.7, the estimated time to web recovery following three deltamethrin sprays at 28, 38 and 49 DT was 22 days.
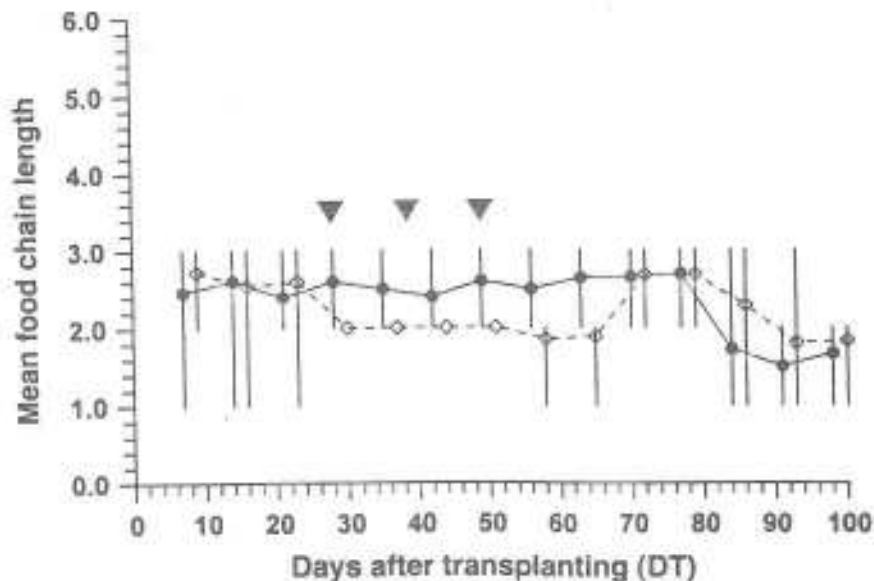

Figure 41.7 Temporal variation in mean food chain lengths (μ) for unsprayed (●) and deltamethrin-sprayed (◇) plots. Vertical lines show range in food chain lengths for sprayed and unsprayed webs on each sampling date. Calculation of μ is based on the most common taxa whose population sizes made up 90% of the total abundance on each sampling date in sprayed and unsprayed plots. ▼, dates of deltamethrin sprays. Modified after Schoenly *et al.* (1996a)

Ecological costs of insecticide sprays to rice farmers

Differences between sprayed and unsprayed plots in herbivore and natural enemy abundances can be translated into ecological costs that farmers can understand (Schoenly *et al.*, 1996a). To assess ecological costs of insecticides, the magnitude and direction of differences in %H (herbivores) and %E (natural enemies) abundances were calculated between sprayed and unsprayed plots and then converted to numbers per hectare per sampling date.

This analysis revealed that deltamethrin sprays brought an additional four million herbivores per hectare per sampling date (Figure 41.8a). Of the 12 putative pest species in both plots, the majority of additional herbivores in the sprayed plot were three delphacids (*S. furcifera*, *N. lugens* and *Tagosodes pusanus*). A second ecological cost attributable to deltamethrin sprays was one million fewer natural enemies per hectare per sampling date in the sprayed plot by mid-season (Figure 41.8b). The timing of enemy losses partly overlapped the hump of extra herbivores at 36–50 DT (Figure 41.8a,b); however, the additional herbivores over this overlapping interval went unchecked in the sprayed plot because there were fewer natural enemy individuals. Of the 34 natural enemy taxa in both plots, *M. d. atrolineata* and *C. lividipennis* comprised the largest fraction of natural enemies affected by deltamethrin sprays. By season's end, the sprayed plot netted an estimated 279 000 more natural enemies per hectare per sampling date than the unsprayed plot. However, early season losses increased the likelihood of pest damage in the sprayed plot.

In Java, Indonesia, Settle *et al.* (1996) used insecticides to demonstrate a link between early-season natural enemies and late-arriving pests. Insecticides reduced natural enemy populations and caused pest populations to resurge, particularly rice brown planthoppers. By season's end, sprayed fields netted higher predator populations than unsprayed fields. However, rebounding populations only partly overlapped the resurgence hump of extra herbivores seen earlier in the season, as in the Schoenly *et al.* (1996a) study.

Multiple regression models

Cohen *et al.* (1994) used data from the Philippines-wide food web and multiple regression models to predict population fluctuations of insect pests in a rice field at the International Rice Research Institute (IRRI) in the Philippines. Independent variables of the seven pest models included the biomass of rice plants in the field, the abundance of each pest, and the abundances of five highly correlated enemies of each pest, all as functions of time.
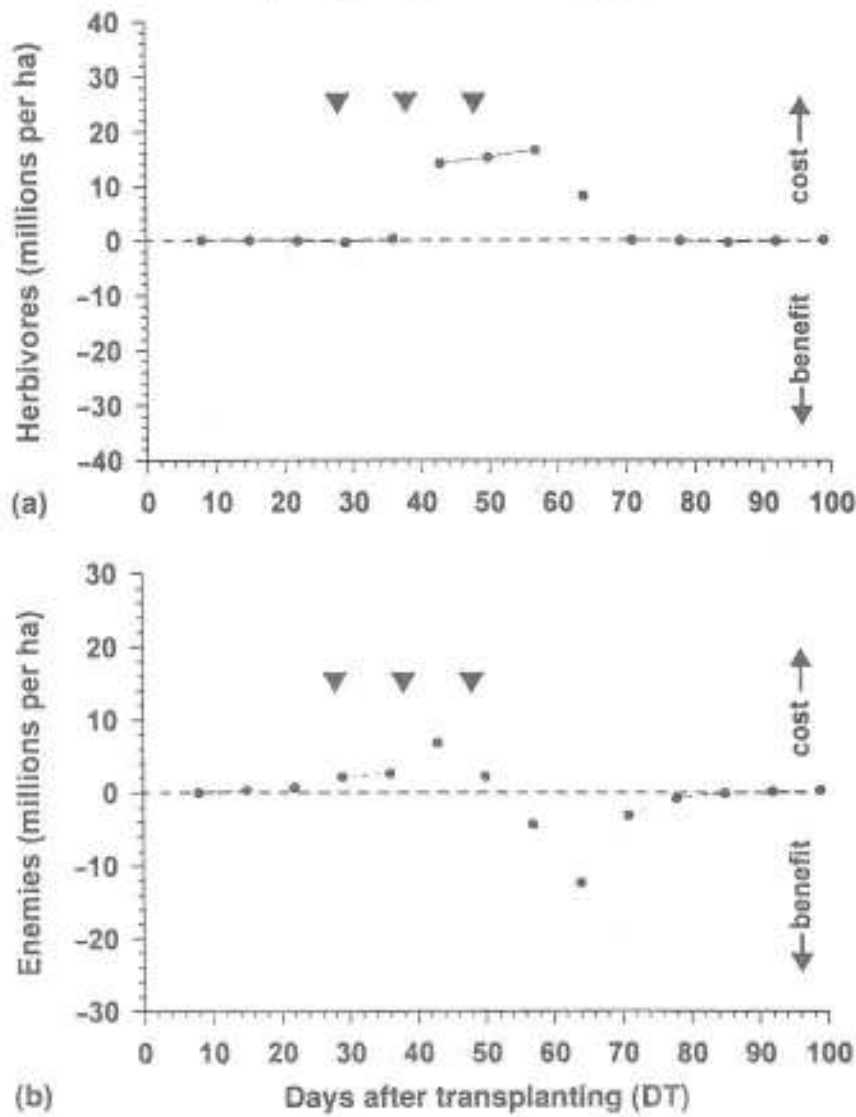
Figure 41.8 Ecological effects of deltamethrin sprays: (a) extra herbivores and (b) early-season losses of natural enemies. ▼, spray dates. Modified after Schoenly *et al.* (1996a).

In this study, deltamethrin sprays disorganized the population dynamics of insect species feeding in the IRRI field. Multiple regression models were less able in the sprayed plot than in the unsprayed plot to forecast the population fluctuations of pest species on the basis of various

numbers and combinations of independent variables. In the unsprayed plot, independent variables were significant predictors of future pest abundance in four of seven initial models, compared with one of seven models in the sprayed plot. Stepwise removal of independent variables in the models enhanced the forecasting power in both the sprayed and unsprayed plots, but significant models in the unsprayed plot nearly always outnumbered those in the sprayed plot. In general, models that included interaction terms and either the presence or absence of sprays among the independent variables did not improve the forecasting power of sprays in either the sprayed or unsprayed plot.

DISCUSSION

The magnitude of the pesticide problem in tropical Asia requires that rice ecologists and IPM practitioners get the most from results of farmer surveys and ecological experiments conducted at the community and ecosystem levels of biological organization. Temporal trends in guild- and community-level measures, and comparisons between sprayed and unsprayed plots, can be translated into ecological costs (increased herbivores, decreased natural enemies and slow recovery times) that farmers can understand. For example, ecostatistical measures (species richness and abundance), guilds and mean food chain length revealed variable recovery times of 1–4 weeks from insecticide sprays which depended on the chemical used (e.g. deltamethrin, chlorpyrifos), its timing of application (e.g. 29 vs. 43 DT) and the functional group (e.g. herbivores, predators). As well as revealing additional economic costs to the farmer, these studies showed that insecticides negatively impact non-target beneficial organisms in predictable ways. Indeed, when rice insect pests are exposed to both natural enemy additions (ie. *P. pseudoannulata*) and insecticide applications (ie. mono crotophos) the treatments cancel each other out (Fagan *et al.*, in press) confirming the incompatible and counterproductive nature of chemical and biological pest control tactics for tropical rice ecosystems. Thus, there is practical value for IPM workers and farmers in concepts and methods that can evaluate the effects of insecticide sprays on entire communities of pests and natural enemies.

Differential effects on guilds

By design, insecticides are biocides with the potential for causing differential mortality in different invertebrate (and vertebrate) species when applied to the rice ecosystem. Besides direct killing action, insecticides alter rates of reproduction, feeding and dispersal, and synchrony of pest and natural enemy interactions. General classes of insecticides such as pyrethroids have been found to increase reproductive rates of the

brown planthopper (Heinrichs *et al.*, 1982; Heinrichs and Mochida, 1984), whereas buprofezin reduces searching efficiency of egg predators (e.g. *C. lividipennis*; Suvaparp, 1993). In addition, parasitoids may be more vulnerable to pesticides in the rice ecosystem owing to their smaller size and high mobility. Pyrethroids also have higher toxicity effects on spiders (Kenmore, 1980; Croft, 1990) and hymenopteran parasitoids (Croft, 1990), whereas buprofezin is less toxic to natural enemies (Suvaparp and Heong, 1992).

Because insecticides are often administered over the entire crop cycle, they can evoke whole-community disruptions similar to climatic catastrophes, such as drought or flooding. Such disruptions can re-set predator-prey oscillations and create asynchrony. This effect, referred to as catastrophic asynchronization (Perera *et al.*, 1988), favours herbivore species with high reproductive, survival and recruitment rates and with short life spans (e.g. delphacid homopterans). In rice ecosystems, the delphacids, *S. furcifera* and *N. lugens*, embed their eggs into the rice tissue, which reduces their exposure to insecticide sprays.

When a pesticide is applied to an oscillating predator-prey interaction it kills the most susceptible stages. The result is synchronization of pest population development (Waage, 1989). At one extreme, where only one stage survives, a uniform pest age-structure is created. For a natural enemy species that exhibits a shorter generation time than the pest, such synchronization can cause short-term gaps in availability of the necessary pest stage. Examples of pest resurgences from catastrophic synchronization have been documented for pests of coconut (Perera *et al.*, 1988), tropical plantation crops and coffee (Waage, 1989). On the other hand, when natural enemies have longer generation times than the pest, synchronization creates periods of low natural enemy populations that can markedly reduce the pest's natural control. In the case of *N. lugens* and *S. furcifera* in the rice ecosystem, natural enemies with both longer and shorter generation times exist, suggesting that catastrophic synchronization from insecticide sprays can promote pest outbreaks of a large and persistent nature.

Effects due to recolonization

Ecological disruptions caused by pesticides, unlike those caused by winter, drought and floods, are usually localized. When a farmer sprays his crop, his neighbours may not. Arthropods from neighbouring crops are potential sources of recolonization, rates of which differ for different pest and natural enemy species. For example, post-spray population densities of herbivores *N. lugens*, *S. furcifera* and *N. virescens* in the chlorpyrifos study recovered to densities of the unsprayed plot within one week after each spray. Populations of predators *M. d. atrolineata* and

P. pseudoannulata recovered within two weeks after the first spray but remained significantly lower than unsprayed densities after the second spray. Recolonization rates of the predator *C. lividipennis* were similar to those of several pest species, probably because of similar mobility rates. The generally higher recolonization rates of pest species than predator species, coupled with their high reproductive rates and reduced natural control after insecticide sprays, play important roles in secondary pest developments.

Brown planthopper: a secondary pest caused by early-season insecticide use

Flint and van den Bosch (1981) described two models depicting effects of pesticide impact that illustrate the phenomenon of target pest resurgence and secondary pest outbreaks. It is now well established that some insecticides, when used on rice, induce planthopper increases that can lead to outbreaks (Heinrichs and Mochida, 1984; Kenmore *et al.*, 1984; Joshi *et al.*, 1992; Cohen *et al.*, 1994). In most cases, these insecticides were not targeted for planthopper control. Instead, as indicated earlier, farmers used them to control leaf-feeding insects during early crop stages (Heong *et al.*, 1994). In Vietnam, about 42% of the sprays farmers used were targeted at leaf-feeding insects and 34% at planthoppers (Heong *et al.*, 1994). Organophosphates and pyrethroids accounted for 72% of the sprays used for leaf-feeding insects.

The brown planthopper problem in tropical rice has been attributed to pest resurgence (Heinrichs and Mochida, 1984; Gallagher *et al.*, 1994; Rombach and Gallagher, 1994), implying that farmers were using insecticides to control BPH that resulted in having higher BPH populations. Subsequently the resurgence-causing insecticides were not recommended (and in some cases were banned) for use for BPH control but continued to be promoted for use on other rice pests, such as leaf-feeding insects, stemborers and rice bugs in many countries. Consequently, ecological disruptions that favour BPH development continue to occur, which probably accounts for the few recent BPH outbreaks (Way and Heong, 1994). Farmers' use of these resurgence-causing insecticides, especially in the early crop stages, have been shown to be unnecessary and their removal has had no significant yield consequences (Heong *et al.*, 1995b, IRRI, 1996a,b; Heong and Escalada, 1997a). In addition, natural mortalities and natural enemy abundances build up from the early crop stage to mid season (Kenmore *et al.*, 1984; Cook and Perfect, 1989; Fowler *et al.*, 1992; Heong *et al.*, 1992) and computer simulation shows that early-season spraying is inefficient (Heong, 1989; Cheng *et al.*, 1990). Thus, there are significant policy implications for tropical rice management that depend on whether BPH is regarded as a secondary or a resurgence pest.

Implications for rice pest management

Like other ecosystems, tropical rice agroecosystems have mechanisms for resisting and recovering from external stresses (within finite limits), which led Way and Heong (1994) to conclude that IPM in tropical irrigated rice should be based on the contention that insecticides are not needed, rather than that they are, and that 'pests' should now be critically re-assessed and proved guilty before insecticide use is contemplated. The validity of natural control mechanisms is supported by farmer experiences in Vietnam (Heong *et al.*, 1995b), the Philippines (Way and Heong, 1994; Heong and Escalada, 1997a; IRRI, 1996a) and Indonesia (Matteson *et al.*, 1994). On the other hand, the insecticide-based approach is costly and involves uncertain and complicated choices about which insecticides to use and when and how to use them for different pests. Moreover, some insecticides can create secondary pest problems and ecological and health costs to farmers (Rola and Pingali, 1993; Pingali and Roger, 1995).

The studies discussed above and the work of several others have led to the conclusion that prevention of outbreaks, particularly from planthopper populations, depends on protection of early-season natural enemies through suspension of insecticide sprays in the first 40 days after crop establishment (Way and Heong, 1994). However, there remains widespread, unnecessary insecticide use in tropical rice during early crop stages due to wide gaps in farmers' knowledge and perceptions for rational decisions. One way to bridge this knowledge gap is to change farmer perceptions and risk-averse attitudes towards leaf-feeding pests. When such conflict information ('insecticide spraying for leaf folders in the first 30 days after transplanting is not needed') is presented to farmers as a heuristic (or rule-of-thumb), farmers are motivated to test the rule (Heong and Escalada, 1997a). After participating in such experiments, farmers changed their perceptions about leaf folders and stopped spraying against them. Vietnamese farmers have participated in such experiments and have stopped early-season insecticide spraying (Heong *et al.*, 1995b).

This perception seems strongly held by thousands of farmers and there is a need to explore different ways to communicate this information effectively and as rapidly as possible to change current perceptions. For example, a pilot project was established in Long An Province, Vietnam, to evaluate the use of media materials (leaflet, poster and radio drama) to communicate and encourage farmers to test the heuristic (IRRI, 1996b). Sixteen months after the project was launched, farmers in the project area reduced the number of insecticide sprays per season from 3–4 to 1–2. The proportion of farmers who perceived that leaf folders would cause severe yield loss and sprayed to control them decreased from 67–77% to 17–27%. If farmers resist using insecticides in the early crop stages, then opportunities for insecticide misuse are reduced. The degree to which other

herbivores of tropical rice require chemical control measures and under what management options remain open questions for future research.

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