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An aquatic wild plant as a keystone species in a traditional Philippine rice growing system: its agroecological implications

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ABSTRACT

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In the province of Ifugao, Northern Luzon, Philippines rice cultivation on irrigated terraces has been practiced since centuries ago. The traditional system is characterized by one harvest per year from permanently flooded fields.The macrophyte *Najas graminea* Del. is the most abundant submerged wild plant in this agroecosystem. It is argued that this plant can be seen as a keystone species, because of its crucial role in maintaining the organization and diversity of the aquatic community which also has impacts on the terrestrial community of the agroecosystem. This conclusion was drawn from two aspects studied: (1) The food web of the aquatic community depends on the presence of *N. graminea* since it provides Aufwuchs and detritus, on the surfaces of its leaves, to primary consumers such as crustaceans, the larvae of Ephemeroptera and Chironomidae, and Gastropoda which in turn serve as prey for a number of predators, mainly the larvae of Odonata, certain Coleoptera and *Diplonychus rusticus* (Fabricius). (2) The golden snail *Pomacea canaliculata* (Lamarck), a recent invader into Southeast Asian rice fields from tropical America and a serious pest of rice seedlings in modern production systems, caused no appreciable damage in the Ifugao rice terraces so far. The most probable explanation for that is the presence of a high biomass of wild aquatic plants mainly *N. graminea* and the floating fern *Azolla pinnata* R. Br. which serve as alternative food sources for *P. canaliculata* when the rice plants are most vulnerable to its attacks. Comparison of snail fauna in different fields before and seven years after the invasion of *P. canaliculata* showed that it had no clear negative impacts on the native species. Possible future impacts of the species on the agroecosystem are discussed.

Keywords: agroecosystem. aquatic fauna. food web. golden snail. Ifugao rice terraces. *Najas graminea*. *Pomacea canaliculata*.

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INTRODUCTION

Agroecosystems are characterized by regular cultivation practices and activities that influence the composition and dynamics of the associated flora and fauna. The peculiar feature of irrigated rice growing systems is the existence of an aquatic subsystem. Depending on the management, the body of water provides a habitat for a variety of organisms which may be unwanted such as weeds, or of economic importance such as fishes.

Traditional wet rice systems have changed with the introduction in the late 1960s of high-yielding dwarf varieties with short growth periods. While traditional systems are mainly subsistence-oriented operating with few non-farm inputs, modern systems employ new varieties which are highly responsive to fertilizers and which perform best in areas with assured water control. In suitable areas farmers are thus encouraged to invest for the improvement of the physical environment as well as to adopt advanced management practices. Irrigation water, fertilizers and pesticides have become profitable inputs. Although human and farm animals are still the main source of farm power, farm equipment such as rotary tillers, transplanters and threshers have become more and more popular (Greenland, 1997).

One example of the traditional rice growing systems that stands out from the others around the globe, are the rice terraces of Ifugao in the Central Cordillera of Northern Luzon, Philippines. These terraces were created centuries ago and have been designated as a World Heritage Site by the UNESCO in 1995. In this traditional system, only one crop of traditional varieties is produced every year from the irrigated fields which are permanently flooded with an average water depth of 10 cm. The main water sources are: (1) natural springs which lead directly into the terraces; (2) water diverted from brooks which run through the terraces; and (3) field-to-field irrigation. Rice growing season is from December (installation of seed beds) to July (harvest). Pesticides and chemical fertilizers are not used in the system. Pest outbreaks and high yield losses are unknown (Conklin, 1980; Voggesberger, 1988; Martin, 1994).

Plants that are considered as major weeds in modern wet rice growing systems are several species of the Cyperaceae and Poaceae family, as well as *Marsilea* spp. (Marsileaceae), *Ludwigia octovalis* (Jacq.) Raven (Onagraceae), and *Monochoria vaginalis* (Burm. f.) Presl (Pontederiaceae) (Ampong-Nyarko & De Datta, 1991). These taxa, however, are not important in the rice terraces of Ifugao. This can be mainly attributed to the fact that the terraces remain permanently flooded. Thus, the plants that emerge during the cropping season are almost exclusively hydrophytes, the most abundant species of which is the submerged macrophyte *Najas graminea* Del. (Najadaceae). Other submerged macrophytes are *Hydrilla verticillata* (Linn. f.) Royle and *Utricularia aurea* Lour., but they are very rare and restricted to a few areas around the outflows of spring water. *Najas graminea* occurs in patches in many fields during the cropping season but weeding is rarely observed. The largest expansion of *Najas graminea* is reached during the fallow period (August-December), where large stands of the species may completely cover the fields. These communities are, however, destroyed by weeding at the beginning of the new cropping season. Other hydrophytes with changing abundance during the cropping season and the fallow period are floating plants, namely *Azolla pinnata* R. Br., *Spirodela polyrrhiza* (L.) Schleid. and *Lemna perpusilla* Torr.

The first part of this study dealt with the ecological and agroecological aspects of *Najas graminea* in the Ifugao rice growing system. Submerged macrophytes are known to be of specific relevance for the abundance and composition of animal species in aquatic systems (Rosine, 1955; Soszka, 1975; Dvorak & Best, 1982; Carpenter & Lodge, 1986; Hargeby, 1990), including rice fields (Berczik, 1973). This is, however, not due to the consumption of the plant biomass by herbivores, which are only a minor group among the primary consumers in freshwater ecosystems. Instead, submerged macrophytes provide grazers and detritivores with Aufwuchs and detritus as resources on the surface of their leaves. Aufwuchs is the assemblage of microscopic organisms mainly bacteria, algae, fungi and protozoans (Sladeckova, 1962). Detritus is a biogenic material in various stages of microbial decomposition (Darnell, 1967) from allochthonous and autochthonous sources in aquatic systems. In addition, the macrophytes offer habitat and shelter for both primary consumers and predators. In 1988/89, the fauna associated with *Najas graminea* was recorded and the food web of this community was analyzed. The results are discussed in the context of the overall importance of *Najas graminea* for the agroecosystem.

The second part of the study dealt with the ecological and agroecological consequences of the recent invasion of an exotic aquatic species, the golden snail *Pomacea canaliculata* (Lamarck) (Mesogastropoda: Pilidae), into the Ifugao rice terraces. The species originated from swampy areas and floodplains in tropical South America and was first introduced into Taiwan in 1980. From there, it was brought to the Philippines officially with the expectation that it could be grown as a high-protein food source for domestic consumption and export. However, due to its bad taste, consumers refused to eat it resulting to the plummeting of its market value soon after its introduction. Instead, due to negligence, the snail escaped from the raising ponds and spread into all types of aquatic habitats, including rice fields. Within a decade, the golden snail invaded almost all rice producing countries of Southeast Asia (Halwart, 1994; Naylor, 1996) and soon became a serious pest feeding on young rice seedlings. Rice farmers in the Philippines have suffered greatly from the invasion in terms of yield loss and costs of control. Yield losses as high as 40% have been reported from infested rice fields of Luzon in 1990 (Rice IPM Network, 1991). In the province of Nueva Ecija, almost half of the farmers suffered from a 25% rice yield reduction in 1990-91. Over 10% of the farmers reported to have had no harvest at all (Revilla *et al.*, 1991). Molluscicide and insecticide application as well as hand picking, the destruction of egg masses and the feeding of snails to ducks have been the main approaches to control snail infestations. So far, none of these methods are effective enough to solve the problem. In addtition, there is no known specific parasitoid or predator of the golden snail from South America that might be used for its biological control in Asian paddy environments. The golden snail was first seen in the Ifugao rice terraces in 1990 (Martin, personal observation). In 1997, it was a member of the aquatic community in nearly all fields. We report on the preliminary consequences of the golden snail invasion on rice production and on the native snail fauna by comparing the situation before (1988/89) and after (1997) the appearance of *P. canaliculata*.The role of *Najas graminea* and other aquatic plants is likewise discussed.

MATERIALS AND METHODS

Study sites

The study area is located near Banaue, Ifugao Province (Northern Luzon, Philippines) with an elevation of 1000-1100 m asl. The climate is wet tropical with an annual rainfall of about 3700 mm. Highest rainfall (>400 mm/month) occurs from July to October. Average annual temperature is 21.3 °C (IRRI, 1988). The warmest period is from April to August.

Food web and aquatic snail studies were carried out in three selected rice fields of the Tam-an district, about one km south of Banaue in 1988-89. In 1997, studies on snails were conducted in the sites including fields in other districts around Banaue.

Sampling procedures

The source of data for the compilation of the cumulative version of the food web were 17 samples taken from *Najas graminea* stands in different fields in the Tam-an district. Three samples were taken from plant patches during the rice growing season. The remaining 14 were taken during the fallow period. The span of time covered by the investigations was 10 months between May 1988 and February 1989.

Collection of samples from the field was carried out as follows: a self constructed dredge-like net (mesh size 0.4 mm, about 40 cm deep) with a metal frame (25 cm in diameter) was used to remove completely parts of the submerged stands of *Najas graminea* including the associated fauna. This procedure was conducted easily since the water was shallow and the *Najas* plants were not firmly rooted in the soft muddy bottom. The content of the filled net was placed on a set of sieves and washed out. All animals >3 mm in body length were selected and preserved in dilute alcohol.

In collecting the animals <3 mm in size, a jar was dipped into the submerged *Najas* stands. The water with the animals therein that streamed into the jar were poured into a planktonic net with a collecting glass at its base. Different sites of the plant stand were sampled until a volume of 5 l had been collected. The organisms were preserved in a 3% formalin solution.

The animals of the two types of samples together represent a community sample of the fauna associated with *Najas graminea*. The taxa were identified as accurately as possible. For the compilation of the food webs, the food spectrum of the species (or higher order taxa) and their respective life and size stages were identified by (1) aquarium and field observations, (2) investigation of gut and stomach contents and (3) additional information from the literature.

Another method was applied especially for the quantitative recording of the aquatic snail fauna of the rice fields. Many species were not associated with *Najas graminea*; however, they lived in the bottom of the fields. Samples were taken in vegetation-free field areas in the following way: A flat-bottomed sieve (mesh size 0.5 mm, diameter 20 cm, height 5 cm) was pressed into the mud upside down. Then it was covered from below with a flat metal disc and removed from the field. The content of the sieve (muddy soil material) was packed into a plastic bag. The material was washed out in a sieve set. The remaining sample material (stones, sand, and plant material) was placed on a flat plate. All living snails were selected, identified, and counted. Samples were taken in December 1988 and in March 1997.

Field surveys of seed beds and newly transplanted fields as well as interviews with farmers were carried out to assess the damage on rice plants caused by the golden snail. Stomach analysis and choice feeding trials in containers have were carried out to identify the food sources of the golden snail.

RESULTS AND DISSCUSSION

Figure 1 shows the simplified, cumulative aquatic food web of *Najas graminea* stands in the Ifugao rice terraces, compiled from the community composition of the 22 samples taken. It includes all the common taxa present in all or almost all samples. There were no seasonal changes in the occurence of the taxa and their trophic interactions. Many of the rare elements of the community are omitted in this figure. (Details on the composition and structure of the food web are given in Martin, 1994). However, it is precise enough to show the food web's principal structure and interactions.

Only one primary consumer species, the larvae of *Parapoynx diminutalis* (Snellen), feeds on the living tissues of *Najas graminea.* Majority of the primary consumers, with Copepoda, Ephemeroptera and Chironomidae as the most common taxa, feed on Aufwuchs and/or detritus associated with the surface of *Najas* leaves. The trophic level of the predators, with Odonata larvae as the most abundant taxon, has these groups as the main prey. *Diplonychus rusticus* (Fabricius) and the larvae of the Hydrophilidae mainly feed on snails. In sum, the surfaces of the leaves of *Najas graminea* form the substrate for the Aufwuchs and detritus, the main resources for the primary consumers which in turn serve as prey for the predators.

Table 1 shows the taxa and the number of snails per 0.125 m^2 recorded in the study sites in 1988 and 1997. In all the samples from 1988, members of the family Thiaridae (at least three species which

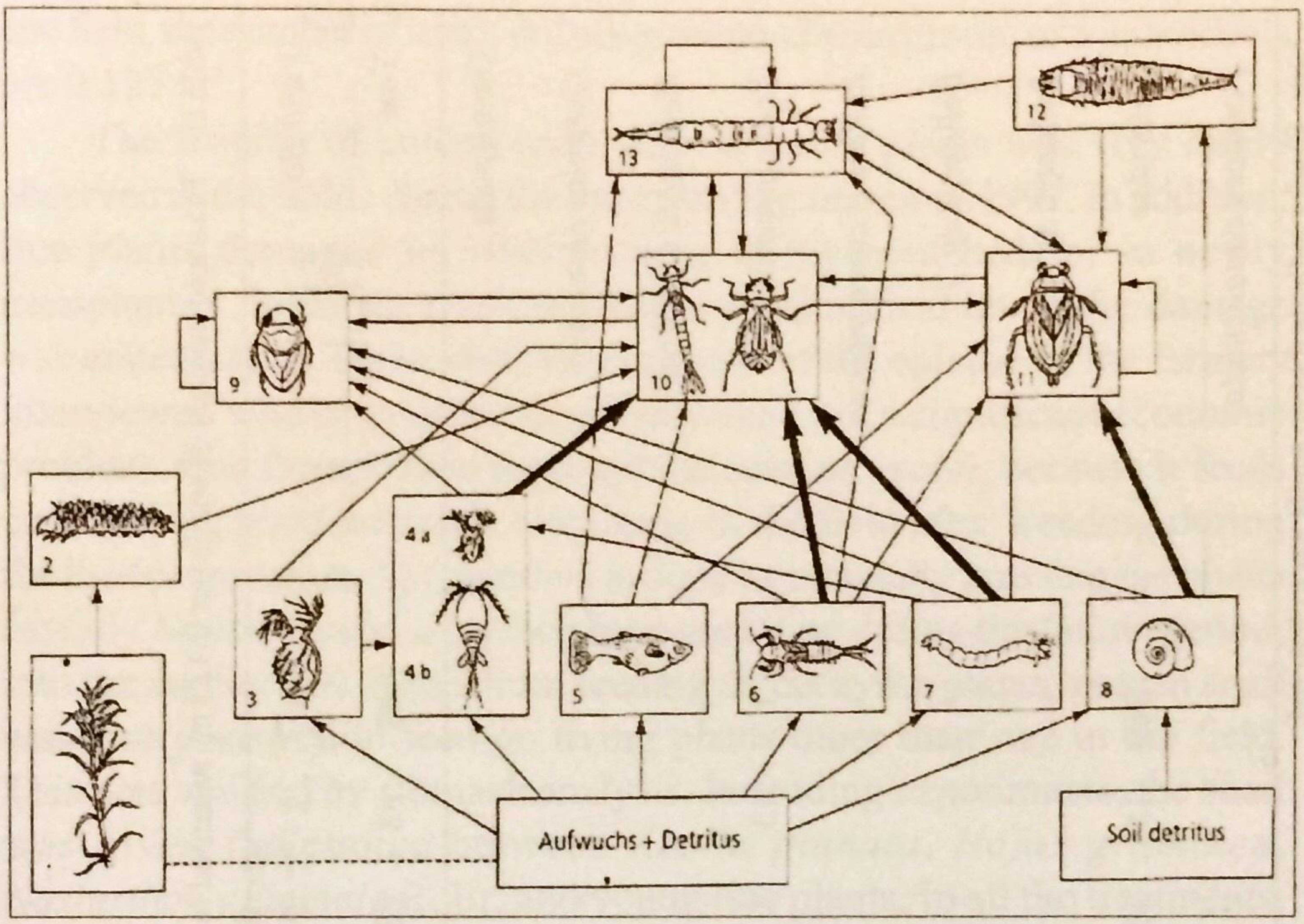

Figure 1. Highly simplified cumulative food web of the *Najas graminea* communities in the Ifugao rice terraces. Arrows point from the resource to the consumer, including cannibalistic links. Reciprocal relationships indicate size-dependent interactions. Bold arrows indicate the dominant feeding relationships of the species involved.
1 = *Najas graminea*, 2 = *Parapoynx diminutalis* (Nymphulinae), 3 = Cladocera, 4a = Nauplii and copepodit stages of the Cyclopoida, 4b = adult Cyclopoida, 5 = Guppy (*Lebistes reticulatus*), 6 = Ephemeroptera (mainly Baetidae), 7 = Chironomidae, 8 = Gastropoda, 9 = *Paraplea* spp. (Pleidae), 10 = Odonata (Zygoptera and Anisoptera), 11 = *Diplonychus rusticus* (Belostomatidae), 12 = Hydrophilidae (larvae), 13 = Dytiscidae (larvae)

could not be distinguished in the juvenile stages) had the highest individual numbers, followed by *Radix quadrasi* (Moellendorf). The same is true for most of the fields (Nos. 5 and 7-10 in Table 1) investigated in 1997. However, in two of the fields which were studied in both years (Nos. 4 and 6 in Table 1), the abundance of the common species have changed. The Thiaridae were present in 1988 but were rare or absent in 1997. Instead, *Radix quadrasi* increased in number and became the dominant species. In six out of seven fields studied in 1997, the golden snail *(Pomacea canaliculata)* has been recorded. With the exception of

Table 1: Taxa and number of snails per 0.125 m^2 recorded in the fields under investigation in 1988 and 1997

Field No.	1	2	3	4	4	5	5	6	6	7	8	9	10
Year	88	88	88	88	97	88	97	88	97	97	97	97	97
Gastropoda													
Gyraulus chinensis	-	-	-	5	5	-	-	-	5	-	-	2	5
Helicorbis umbilicalis	-	-	-	-	-	-	-	1	-	-	-	-	-
Radix quadrasi	1	13	1	7	28	-	10	22	106	1	5	17	8
Bullastra cummingiana	-	-	-	1	-	-	-	-	-	-	-	-	-
Bellamya sp. 1	-	-	-	-	1	3	-	7	-	-	-	1	-
Bellamya sp. 2	-	-	-	-	-	5	-	-	-	-	-	-	-
Thiaridae	369	153	206	59	-	131	97	287	6	8	293	123	141
Pomacea canaliculata	-	-	-	-	-	-	1	-	3	3	5	2	34

Note: Blanks indicate that no snails were observed.

one field, the number of snails did not go beyond a maximum of 5 individuals per 0.125 m^2.

The feeding of golden snail on young rice plants was very rarely observed in the fields during the transplanting season of 1997. In addition, rice plants damaged by snail feeding in the seed beds or in newly transplanted fields were so rare that any quantification of the damage was unnecessary. These observations support the opinion of the farmers interviewed who considered the golden snail not a significant economic problem. One farmer even regarded the snail as useful, because it feeds on decaying plant materials remaining in the field after weeding during the land preparation. The weeding is done by manually pressing the plants (mainly *Najas graminea*), which have grown up during the fallow period, into the muddy soil. Aside from feeding on decaying plants, golden snail was also observed to feed on living plants other than rice in the field. This was verified by stomach analysis. In feeding experiments, the snail was given the choice between *Azolla pinnata*, *Najas graminea*, *Nasturtium officinale* R. Br. and young rice plants. In all the treatments, the rice plants remained untouched, while all the other plants were eaten up completely. Only after two or three days without alternative food did the snails start to feed on the rice plant.

Analysis of the aquatic food web of the fauna associated with the submerged stands of *Najas graminea* has shown that the entire community is based upon the Aufwuchs and detritus. Only the larvae of *Parapoynx diminutalis*, which is relatively a rare species in the system, feeds on the plants. The grazing on Aufwuchs by the primary consumers does not damage the plants. On the contrary, the plants may benefit from grazing, since a large part of the incident light is absorbed by the epiphytic cover thereby reducing the photosynthetic rate of the plant (Brönmark, 1985; Underwood, 1991).

The influence of *Najas graminea* is not limited to the fauna of the aquatic subsystem. There are also several links to the terrestrial community of the rice field. *Najas* stands support a high number of Odonata larvae, the emerging adults of which act as terrestrial predators. They may contribute to the suppression of the population of pests such as planthoppers (Delphacidae), leafhoppers (Cicadellidae) and stem borers and leaf folders (Pyralidae) (Van Vreden & Abdul Latif, 1996; Reissig *et al.*, 1985). The adults of the Ephemeroptera, Chironomidae and Trichoptera emerging from the *Najas* stands are neither predators nor pests of rice, but they serve as prey for terrestrial predators such as dragonflies and spiders. At high population densities, spiders (mainly Tetragnathidae and Lycosidae in Philippine rice fields, Heong *et al*., 1991) have a damping influence on the populations of rice insect pests especially Homoptera (Nyffeler & Benz, 1987; Nyffeler, 1999). However, high spider density in the field can only be expected if sufficient prey is available. Henschel *et al*. (1996) found that spider community richness and biomass are significantly higher in the vicinity of water bodies with emergent insects than in comparable habitats away from water bodies. They suggest that aquatic insect images have an important subsidizing effect on spider populations, which, in turn, can suppress terrestrial insects. This might also be true for spiders in rice fields where the habitat of these predators is directly above the water surface.

Taken together, the multiple effects of the aquatic macrophyte *Najas graminea* on the aquatic and terrestrial community mediated, demonstrate that this plant species has a major influence on the structure and function of the entire agroecosystem. It maintains a high species diversity and biomass of the fauna and contributes to the sustainability and stability of the rice growing system. The presence of *Najas graminea* stands may be one reason why pest outbreaks and high yield losses do not occur in the Ifugao rice terraces. Therefore, it cannot be regarded only as a "weed" but as a keystone species. It implies that the presence of *Najas graminea* is crucial in maintaining the organization and diversity of the community, and that the species is exceptional in importance relative to the rest of the community (Mills *et al*., 1993).

The ecological role of the invading golden snail *Pomacea canaliculata* in the Ifugao rice terraces needs also to be seen in the context of the presence of *Najas graminea* and other aquatic plants. The survey during the transplanting season in March 1997 showed that rice plants are attacked very rarely by the golden snail, even during the plants' vulnerable stage. This observation is in contrast to the situation in the modern rice growing systems in the Philippines where a density of 1 snail per m^2 can reduce the crop stand by roughly 20%, while a density of 8 snails per m^2 can reduce the stand by over 90% (Naylor, 1996). As calculated from Table 1, numbers of much more than 8 individuals per m^2 are the rule in the Ifugao terraces.

One important difference between the modern system and the Ifugao system is the abundance of wild aquatic plants in the latter. In modern systems in the lowlands, intensive weeding and the application of herbicides reduce the population of wild plants. In the Ifugao system, high densities of *Najas graminea* and other plants such as *Azolla pinnata* occur during the fallow period, and to a lesser extent also during the rice growing period. Even during transplanting time after the field has been thoroughly cleaned, high amount of decaying plant material on the soil surface remains from the biomass produced in the fallow period. In addition, swimming *Azolla* is present. These materials serve as the main food source for the golden snail at this time. In accordance with the results of our field observations, feeding experiments and stomach analysis, Basilio & Litsinger (1997) reported that the golden snail has a wide host range and feeds on almost all kinds of rice field weeds. They tested eight common species of weeds and found that all of them were consumed by the golden snail. For this reason, it cannot be assumed that the golden snail prefers rice as a favorite food source. Rather, it can be argued that rice is mainly consumed when alternative food is rare or absent. In the Ifugao system, the presence of a high biomass of wild aquatic plants is the most probable reason why rice is usually not attacked by the golden snail.

The influence of golden snail on the native snail fauna is not easy to assess. It has been noticed that all snail species in the Ifugao terraces recorded in 1988 were still present in 1997, although their population densities in certain fields may have changed. A negative influence of *P. canaliculata* on native snail species can only be expected if there is competition. This means that the invader has at least one resource in common with one or more of the native species. The invader is able to take over the niche of a native species if it is more sucessful in terms of reproduction and resource utilization.

In 1988, stomach analysis and observations on the feeding behavior of native snail species were conducted. The results indicated that all snail species living in the muddy ground of the rice fields (*Radix quadrasi*, *Pila luzonica* Reeve, *Bellamya* spp., *Melanoides tuberculatus* (O. F. Müller) *Brotia* sp. and *Tarebia* sp.), consume detritus as the main part of their diet. This means that they feed on highly degraded particulate organic matter. These observations agree with the results of Reavell (1980), who also stressed the importance of detritus as a food of aquatic snails which normally do not feed on living plants. This is the most important difference in the feeding behavior of the native snails compared to the golden snail which mainly feeds on living plants. In addition, most of the dead plant materials consumed by the golden snails during transplanting period, consist of larger parts of structured plant tissue. This is different from the material ingested by the native species. Altogether, the overlap in the diet of native snails and the golden snail seems to be very small, if it exists at all.

The above information suggest that competition for food is negligible and cannot be expected to be a factor which may lead to the repression or extinction of native snail species. Rather, the answer to the question on why the golden snail invaded the aquatic community of the Ifugao rice terraces with no significant consequences for the agroecosystem so far, is most probably that it met an empty food niche. This niche is made up of living and decaying aquatic plants as a food resource. This resource is used to a limited extent only by other aquatic animal species (see Fig. 1). This assessment agrees with the view that alien species successfully invade a community because they meet an unexploited resource (Crawley, 1987), and therefore, competition is not necessarily a force involved in the process of invasion. However, the survey reported here was carried out only seven years after the first observation of the golden snail in the Ifugao rice terraces. This situation is probably not yet the final stage of the invasion. The numbers of golden snails might still increase until the biomass of *Najas graminea* and other aquatic plants is reduced significantly if food turns out to be the limiting factor for the population density of the golden snail. If this would be the case, strong influences on the entire aquatic community, including the rice plants, are to be expected. The golden snail will then take over the status of a keystone species in the system.

CONCLUSIONS

This study provides empirical evidence for the hypothesis that enhanced biodiversity contributes to higher stability and sustainability of agroecosystems. Wild plants can particularly be important components of agroecosystems because they may positively affect the biology and dynamics of beneficial species as shown in numerous studies (see Altieri, 1994 for review). However, submerged plants in rice fields have not been considered previously under this aspect probably because they represent a special case since they enhance the population of beneficial and non-pestiferous insects via their aquatic larvae. This study likewise indicates that wild plants can even be important as a buffer against invading pest species. Altogether, it is concluded that community approach analysis of the complex biotic interactions in agroecosystems is needed for a better understanding of the processes important in the management and design of such systems.

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