Golden Apple Snails in the World: Introduction, Impact, and Control Measures

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Abstract

The golden apple snail (GAS), *Pomacea canaliculata* (Lamarck), is a large freshwater snail native to tropical and subtropical South America that later spread to Taiwan, Japan, southeast People's Republic of China, and the Philippines. Many potential benefits of GAS have been recognized, including its use as a food source; use in the aquarium trade; for biological control of weeds; as a protein source for fish, ducks, pigs, and crocodiles; and as liquid biofertilizer. In its native environment GAS has not become a major threat to the ecosystem, but it has become an invader in new ecosystems due to its physiological adaptability and ability to move a long distance within a water system. *Pomacea* is now a major pest in rice and taro crops. In Thailand it seriously damages *Ipomoea aquatica,* a popular vegetable. Heavy economic losses as well as high costs of control have been reported in some Asian countries. Furthermore, *Pomacea* has threatened some native aquatic plants in these countries. It acts as a vector for *Angiostrongylus cantonensis* (rat lungworm), which causes fatal eosinophilic meningoencephalitis in humans.

Eradication of GAS has become a cumbersome and costly task. Studies have shown that GAS can be controlled by integrating chemical, mechanical, and biological measures at different stages of cultivation. Biological methods would be more effective for GAS control, as it is a source of food for many birds, in particular water birds like ducks, open bills (*Anastomus oscitans*), the common scope owl (*Otus sunica*) and greater coucal (*Centropus sinensis*), and prey birds such as kites and egrets in rice fields. The fish species common carp (*Cyprinus carpio*) and *Piaractus brachypomus* effectively predate on GAS. Botanical antisnail preparations such as dried tobacco leaves and neem extracts have been reported to control GAS populations. Many approaches have been tried. Sustainable management of GAS needs extended studies on ecological and biological behavior patterns, which are the main knowledge gaps required to minimize the spread of GAS.

Integration of such information and control measures identified so far along with suitable legislation and policies have become a need at present to prevent introduction and to manage the GAS population at nonthreatening levels, but implementation has been limited due to lack of resources.

Key words: *Pomacea canaliculata*, golden apple snail, GAS, invasive species, aquatic rice pest, biological control

Introduction

The golden apple snail (GAS), *Pomacea canaliculata* (Lamarck), is a large freshwater snail native to tropical and subtropical South America (Halwart 1994c). It was initially introduced to Taiwan from South America in 1980 for aquaculture for both local food consumption and export (Naylor 1996). Within 5 years from its introduction, GAS became abundant in Japan, southeast People's Republic of China, and the Philippines. In 2002, there were large populations in most Southeast Asian countries. The snail is also found in Hawaii (Lach and Cowie 1999) and the southern United States (US) (Neck and Schultz 1992, Thompson 1997). Recent reports indicate that it has now invaded Australia (Baker 1998) and exists in Bangladesh and India (Baker 1998 cited in Yusa et al. 2006). Although GAS was reported in Sri Lanka (Bambaradeniya 2005), recent communications have confirmed that it is not yet found there (B. Marambe, Dean of the Faculty of Agriculture, University of Peradeniya, Sri Lanka, personal communication).

This species exhibits rapid breeding and strong adaptability to harsh environments. Although GAS has been introduced in many countries, consumers have not reacted as enthusiastically as snail farmers. The snails were initially expensive, but their market value soon plummeted. Additionally, it was discovered that GAS is just as likely as the native apple snail to transfer the rat lungworm parasite, which can infect humans and passes through undercooked snail meat. As the market disappeared, snails were discarded and released into the wild, and they spread to cultivated and noncultivated areas via waterways. The snails have a brachial respiration system, which helps them to adapt quickly to changing environmental conditions. Their ability to search for food—leaving the water when the food supply below the surface is inadequate—makes them adaptable to any environment. Females lay egg masses containing up to 500 eggs once a week. Such adaptations, along with high population densities, have made these organisms a serious pest in many cultivated areas in Asia.

Control of GAS is costly and not easy. Various types of cultural, mechanical, and biological methods are used in countries, but they have so far been unsuccessful in fully controlling it. Current measures include quarantine, collection and destruction of eggs and adults, and use of ducks to feed on the snails. Sometimes the snails are collected, crushed, and fed to penned ducks.

Current GAS Situation

Pomacea canaliculata is currently found in Australia, Bangladesh, Cambodia, southern People's Republic of China, Guam, India, parts of Indonesia and Malaysia, Japan, Republic of Korea, Lao People's Democratic Republic (Lao PDR), Papua New Guinea, Philippines, Singapore, Taiwan, and Vietnam.. It is also found in the Dominican Republic, Hawaii (all islands except Molokai and Lanai), Florida (Collier, Hillsborough, and Palm Beach counties), Texas (Cameon and Harris counties), and California. In Florida and Texas, snail populations seem to have stemmed from unwanted aquarium snails (Neck and Schultz 1992).

In Florida, GAS has been implicated in ecological problems, including displacing a native apple snail and compromising the food supply of an endangered Everglades kite, *Rostramus sociabilis* (Beissingear et al. 1994). In Texas, GAS has been predicted to cause ecological problems in the near future, although such has not been the case to date. The potential threat that this snail poses to American agriculture is relatively new (Howells and Smith 2005).

Currently farmers in Taiwan and the Philippines rank GAS as the main pest after earthworms and rats in lowland rice (Neck and Shultz 1992, Thomson 1997). Molluscicides were initially employed to control GAS, but their use gradually decreased in favor of integrated management approaches.

Food Item, Aquarium Trade, and Aquatic Weed Control

The rapid spread of GAS has been due to its potential as a food item and in the aquarium trade (Cowie 1996) and for biological control purposes against both aquatic and terrestrial weeds (Carlsson et al. 2004). In addition, GAS is used as a specimen for dissections for educational purposes in Texas (Howells 2005).

GAS is a popular aquarium pet because of its attractive appearance and size. It has been introduced to many parts of the world via the aquarium trade, and also as a protein source. In Thailand, GAS was imported by the aquarium trade, yet it is also probable that it was introduced as a source of food, as elsewhere in Southeast Asia (Sinives 2005). In Hawaii, in addition to being a food source, GAS is available in aquarium stores (Cowie 1996).

In Japan, introduction of *P. canaliculata* has been reported as a possible agent for weed control (Okuma et al. 1994, Wada 2004).

GAS has the ability to move a long distance within the water system (Fig. 1). In a canal, GAS can move more than 100 m upstream or more than 500 m downstream in 1 week (Ozawa and Makino 1989). However, Ichinose and Yoshida (2001) reported that the snails could not expand their range to the upper areas of a water system because of the fast water flow. Moreover, one population (established about 20 years ago) in northern Japan is restricted to an area of only 1.5 km x 0.5 km in quiet water canals (Ito 2003), and the snails have not so far been observed outside this range for at least 3 years. But the factors restricting the dissemination of snails within a water system are not fully understood (Ito 2003).

Government Legislation and Policies

The prevention and management of GAS in most Asian countries are still in the infancy stage due to the lack of qualified staff; financial constraints; the paucity of appropriate information; the lack of a legal framework, notably concerning implementation; and the low level of societal awareness concerning the negative impacts of the pest on the population and the economy (Duong 2002).

In the US, Mississippi has prohibited all members of the apple snail family, Ampullariidae, calling them "destructive plant eating apple snails" (Cowie 1994). California, Hawaii, Louisiana, and Texas have identified *P. canaliculata* as an agricultural pest that can negatively impact the production of rice, taro, and other aquatic plants. The US Animal and Plant Health Inspection Service may begin enforcing existing regulations for any plant pest species, which will include *P. canaliculata*. The channeled apple snail has been distributed and used in the US to control nuisance aquatic plants, for research and educational purposes, and as a water garden or aquarium item (Howells and Smith 2005)

In Vietnam, the Ministry of Agriculture and Rural Development (MARD, formerly the Ministry of Agriculture and Food Industry), published a list of plant quarantine pests of the country. GAS was considered in this list as being in group II: "pests not widely distributed in the territory of Vietnam" and group III: "dangerous pests of potential serious damage for Vietnam," which mandates prohibition of rearing, selling, and transportation.

The Prime Minister of Vietnam launched Directive number 151/TTg emphasizing the mobilization of all human resources for emergency GAS control. A National Steering Committee on GAS control was set up with three ministries involved: MARD, the Ministry of Science-Technology-Environment, and the Ministry of Fisheries. Two GAS control campaigns

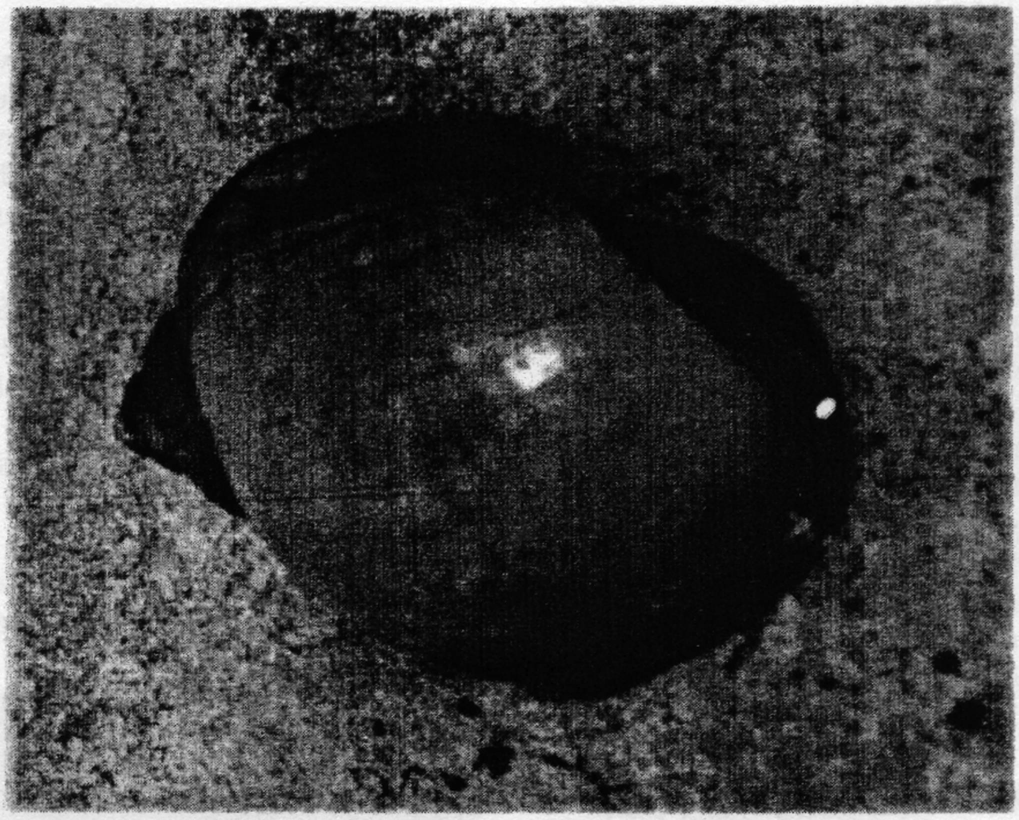

Fig. 1. Golden apple snail moving in a film of water.

were launched in the country, during which many farmers, pupils, students, and soldiers were mobilized to participate in GAS control. Importing organisms in general or invasive species in particular should comply with the Ordinal on Plant Protection and Quarantine, Regulations on Plant Quarantine (Duong 2002).

The Philippines totally prohibited the introduction of alien species to protected and critical habitats in the country under the Wildlife Act (No. 9147). In the Lao PDR, only suggestions have been made about such prohibition.

Potential Impacts of GAS

GAS is macrophytophagous, showing preferences among different food plants but relatively indiscriminate when the preferred plants are absent. Its rate of growth correlates with its feeding on preferred plants. Interestingly, GAS is able to detect its food from some distance using chemical cues in the water (Estebenet 1995). When compared with other ampullariids, GAS is a particularly voracious creature (Neck 1986).

When the habitat dries out, GAS burrows into the mud. *P. canaliculata* is reported as the only species that can survive buried in the earth up to 3 months (Schnorbach 1995). As far as temperature variations are concerned, the lower limits seem more variable, but the species is able to tolerate freezing temperatures of 0°C for 15-20 days and even 2 days at -3°C, but only 6 hours at -6°C (Neck and Schultz 1992). Mortality was higher at water temperatures above 32°C (Mochida 1988, Eversole 1992). It can sufficiently tolerate seawater long enough to survive being carried over distances by currents from one stream mouth to another, thereby effectively expanding its distribution (Cowie 1996). Hence this species should not be overlooked as a pest of crops in water-based agricultural environments.

Agricultural Ecosystems

GAS is not a serious pest in its native range because of ecological balance with population-controlling mechanisms already existing in those environments. But several researchers have shown that, when introduced outside its natural range, GAS becomes a pest in the absence of natural enemies such as predators and parasites. *Pomacea* spp. have become by far the most serious ampullariid pests, attacking a wide range of crops, with the most serious impact being on rice in Southeast Asia.

Rice. Rice culture suffers very much from the destruction caused by GAS. Escaped and discarded snails quickly spread through waterways and irrigation canals, eventually infesting rice fields (Cowie 1996, FAO 1998). Rice fields are an ideal habitat; the snails feed during the night and at dawn on young succulent plants such as newly transplanted rice seedlings (Fig. 2) and emerging tillers as well as weeds, increasing their population. With only a few natural enemies to constrain them, the snails rapidly developed into a serious pest in many areas of cultivated rice lands in Asia (Fig. 3, Table 1). Their rapid growth and reproduction (a female lays egg masses containing up to 500 eggs once a week) leads to increases in the population that can destroy entire crops (FAO 1998). One or more species of *Pomacea* (usually identified as *P. canaliculata*) have become pests of wetland rice in many places including Thailand, Vietnam, parts of Malaysia and Indonesia, People's Republic of China, Taiwan, and Japan, but probably the most seriously in the Philippines (Dela Cruz et al. 2000). The snail infestation in Vietnam has been mapped, and the geographical information system is increasingly used as an important tool to evaluate both the spread of snails and the impact of control measures (Fig. 4).

Fig. 2. A rice nursery being attacked by golden apple snails.

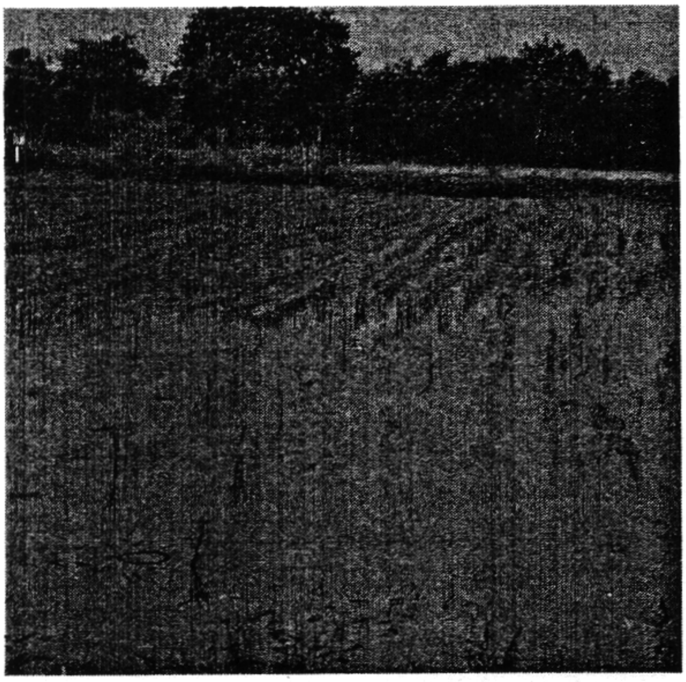

Fig. 3. A rice field damaged by golden apple snails.

GAS directly affects the livelihood of Asian farmers by infesting and damaging over half of the rice fields in the Asian region (Halwart 1994c). The damage is extensive, and economic losses are enormous due to cost of control, replanting, yield losses—even loss of the entire growing season in areas where there is no supplementary irrigation available to overcome water stress—and loss of farmers'

Table 1. Estimated snail-infested areas in the Asian region.

Location	Estimated Area (ha)	Year	Reference
Taiwan	171,425	1986	Teo 2005
Japan	65,000	2001	Takashi 2004
Philippine	4,000,000	1989	Teo 2005
Vietnam	50,000	1999	Duong 2005
Malaysia	1,817	1999	Teo 2005
Thailand	141,257	2001	Sinives 2005

time for growing other crops and/or attending to other farming and nonfarming activities. The cost of control increases annually, which seriously affects the livelihood of the farmers.

Other Crops. Taro is the main traditional staple for Pacific island people, not only in Hawaii but also in many of the Pacific nations. *P. canaliculata* has been deliberately released into taro patches, the environment of which is ecologically similar to rice fields (Cowie 1996), and has also become a major pest of taro (Cowie 2001). In Thailand, GAS feeds on kankun (*Ipomoea aquatica*), a common vegetable growing in water habitats that has become an attractive plant for GAS. However, no data are recorded in the literature. Figure 5 shows the egg masses deposited by GAS on different materials in water habitats.

Health Hazards

GAS is associated with human health threats including skin irritations by being an intermediate host of trematodes (Naylor 1996) and digestive tract infections (Mochida 1991, Halwart 1994a, Cowie 1996, Naylor 1996). It can act as a vector of *Angiostrongylus cantonensis*, the rat lungworm, which can infect humans with potentially fatal eosinophilic meningoencephalitis (Mochida 1991, Halwart 1994c, Naylor 1996). The chemicals that are used for the control of GAS are mostly persistent, dose-cumulative organotins that create health effects such as loss of nails, skin problems, blurred vision, and blindness (Mochida 1991).

Environmental Impacts

Concerns about the natural environment due to GAS include the impact on native snail species. *Pomacea* has been implicated in the decline of native species of *Pila* in Southeast Asia (Acosta and Pullin 1991, Halwart 1994c), although Ng et al. (1993) found little competition between introduced *Pomacea* and the native *Pila scutata* (Mousson) in Singapore. In the Philippines, native *Pila* has declined as a result of extensive application of pesticides for the control of *Pomacea* (Anderson 1993).

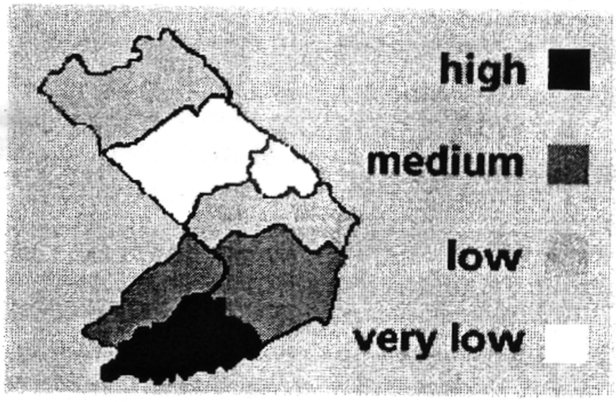

Fig. 4. Density of snail infestation in rice in Can Tho Province, Vietnam (FAO 1998).

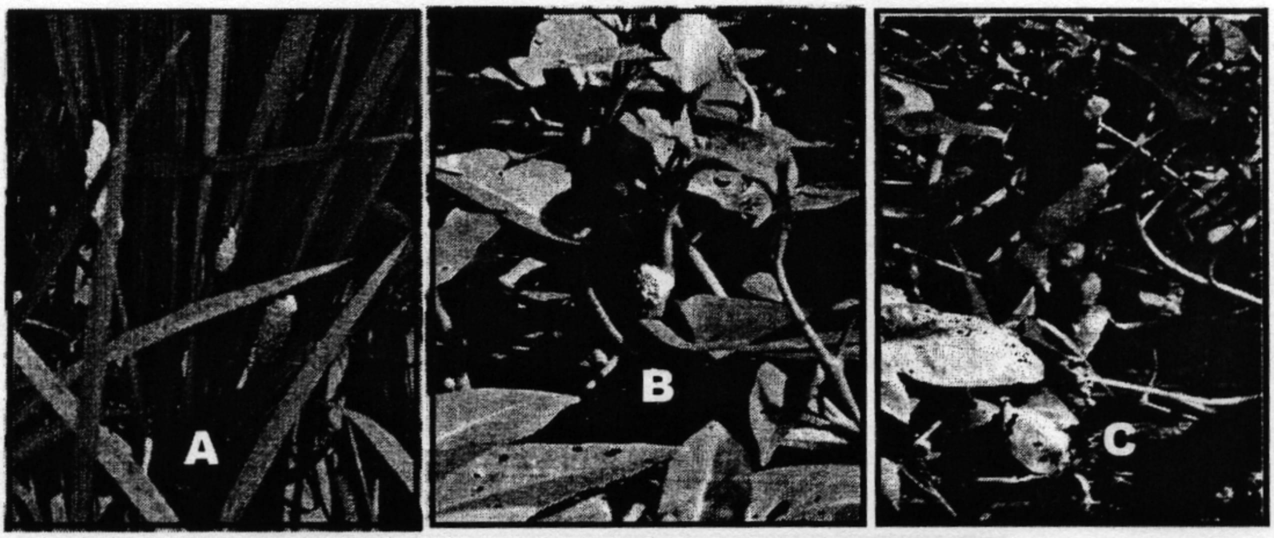

Fig. 5. Egg masses of golden apple snails deposited on A = rice, B = kankun (*Ipomoea aquatica*) plants, and C = plant debris.

Most of the wetlands in Hawaii, Texas, and northern Australia have become vulnerable due to invasion by *Pomacea* spp. (Neck 1986, Cowie 1996). GAS appears to have been introduced by aquarists in a deliberate attempt to control aquatic plants. It feeds indiscriminately on many desirable native plant species, which not only destroys those plants but also severely impacts native animals and insect species that depend on them (Simberloff and Stiling 1996).

Use of synthetic pesticides for GAS control pollutes the aerial, soil, and aquatic environments and poses hazards to applicators; farm workers; work animals; and other nontarget organisms such as fish, frogs, and beneficial arthropods (Dela Cruz et al. 2003). There are also significant and long-lasting downstream effects of these pesticides on marine ecosystems.

Some farmers have begun to treat GAS not as a pest of rice, but as an "environmentally friendly" biological control agent for weeds (Okuma et al. 1994). Aquatic snails are used as good bio-indicators for monitoring the level of water pollution due to pesticides and trace metals because of their sensitivity.

Economic Losses

Yield losses caused by GAS can be massive but are variable. Available information on quantitative yield and economic losses is scanty. In Taiwan, loss of rice was estimated as US$2.7 million in 1982, which increased rapidly to US$30.9 million by 1986 (Mochida 1991). Large areas were treated with pesticides (103,350 ha in 1986), incurring enormous cost. In Japan, control of the snail on just 176 ha cost US$64,385 (Mochida 1991). In the Philippines between 1987 and 1990, farmers spent US$10 million on pesticides for the control of GAS (Anderson 1993).

Detailed analysis of economic cost and losses has not been done in many countries. Naylor (1996) and Vitousek et al. (1996) reported detailed analysis only for the Philippines, which included not only the cost of loss of rice, but also the costs of replanting, application of pesticides, and handpicking snails. Total cost in 1990 due to GAS infestation was estimated at US$28 million–US$45 million. This was 25%-40% of what the Philippines spent on rice imports in 1990. In Vietnam, infestation had not reached the extreme levels observed in the Philippines, and hence handpicking and duck pasturing were relatively more feasible and effective in keeping snail populations down (Dela Cruz et al., 2003).

Utilization

Methods of utilization of *P. canaliculata* have varied from country to country, but many countries use this species as a protein source in food. Table 2 summarizes the utilization of GAS in different places.

Future Threats of Golden Apple Snail

The damage and economic losses due to GAS have been overwhelming. The snails consume tender tissues at the base of rice seedlings and feed on newly transplanted rice (Halwart 1999a, Wada 1997). the overall costs related to controlling the snails, replanting, and rice yield losses account for economic loss. The snails destroy plants and affect the food web. They may easily outcompete even the endangered native species with many economic and medicinal or biological values. GAS have caused the decline of native *Pila* apple snails in Southeast Asia.

For regions that have not been infested and threatened so far by GAS, prevention of its introduction must be the primary strategy. Officials must be aware of the potential problems and be prepared to act quickly if an introduction is detected. Eradication at a very early stage might still be possible, but there will be only a very narrow window of opportunity.

Management Options

Research based on a sound understanding of the life cycle and biology of GAS must be directed towards reducing the use of pesticides, identifying new approaches to cultural control,

Table 2. Uses of *P. canaliculata*.

Location	Utilization	References
Philippines	Protein source for fish, ducks, and humans; aquarium trade.	Cowie 1997
Japan	Human consumption, aquatic weed control, and aquarium trade	Okuma et al. 1994
Taiwan	Aquarium trade and human consumption	Joshi 2005
Vietnam	Protein source for fish, ducks, and humans; aquarium trade	Duong 2002
Malaysia	Aquarium trade and human consumption	Teo 2005
Indonesia	Aquarium trade and human consumption	Suharto 2005
Singapore	Protein source, aquarium trade, and indicator for pollution	Ng *et al.* 1993
Lao PDR	Protein source for pigs and humans	Kaensombath 2005
Thailand	Feed for ducks (see annex), chickens, fish, crocodiles, and prawns, liquid biofertilizer (see annex) or compost, gift sets; human consumption	Sinives 2005
Texas, USA	Human consumption, aquarium trade, and protein source for Everglades kite (*Rostramus sociabillis)*	Howells and Smith 2005

and combining both new and existing strategies into fully integrated pest management protocols that can be tailored to the needs of controlling GAS (Cowie 1996).

It is extremely difficult to eradicate alien species once populations have been established (Carlsson et al. 2004). Therefore, suitable and applicable methods must be developed to reduce their populations and the degree of damage they cause economic activities. Although many of the following measures are said to reduce snail numbers, at least to some extent, their impacts on yield losses are essentially unknown. Most of the control measures and management practices have already been tried (Dela Cruz et al. 2003, Wada 2004); they have found that snails can be basically controlled by mechanical, biological, and chemical measures at different stages of cultivation.

Cultural/Mechanical Control

Various cultural methods of control have been practiced in Asian countries. This includes different types of direct seeding methods, i.e., dry seeding and wet seeding. Snail damage is somewhat low in dry-seeded fields, where rice seeds are sown and young plants are raised under dry conditions. These seedlings are somewhat hardy, more fibrous, and hence probably less vulnerable than wet-seeded rice because their palatability to the snails is less. But dry seeding is not frequently practiced, due mainly to weed problems and the formation of cracks in dikes, which causes water leaks during and after irrigation. But various types of wet seeding are practiced in wet and well-puddled rice fields in Asia. Proper water management after sowing is highly influential in snail management.

Another effective measure to control GAS is to attract them to a canal containing water, as they prefer to live in such environments. Construction of small canals of 25 cm wide and 5 cm deep along the edges of direct-seeded rice plots and leaving water in the canals can attract the snails so that they can be collected more easily and faster. The collection of snails can be done by hand, with hand tools, or by pulling a sack containing a heavy stone along the canal areas. This method of control is applicable for transplanted rice, too. Such canals can be dug for a distance of 5-15 m depending upon the degree of infestation of snails.

In transplanted rice, the mobility of GAS can be restricted when the water level is maintained at a shallow depth (i.e., 2-3 cm) starting from 3 days after transplanting. Alternate flooding and drying will greatly reduce the mobility of GAS and its feeding.

Removal of snails from the rice field by handpicking during the period from the final harvest of the preceding crop to the final harrowing for the succeeding crop reduces the snail threat for the next crop (Wada 2004). Handpicking is best in the mornings and afternoons, during which times the snails are most active, and hence collection and destruction are easier (Cowie 1995).

Collecting and destroying egg masses in the field is another method commonly used for controlling GAS. The egg masses are often very visible, as they are pink in color and glued on plant stems and sometimes on sticks above the water surface (Fig. 5c).

Erecting bamboo stakes within the rice field can stimulate and attract the snails for egg laying on the stakes, as the snail prefers to deposit egg masses above the water level to avoid damage to the eggs from predators in the water, including fish. The egg masses can be easily seen, collected, and destroyed.

Entry of GAS into rice fields can be restricted by placing wire mesh at the water inlet. The GAS will collect on the wire mesh and can later be destroyed.

GAS damage is usually higher among young seedlings than mature ones. Therefore, transplanting older seedling helps reduce the snail attack. In this respect, older wet-bed grown seedlings are more appropriate than younger ones. Accordingly, 25-30-day-old seedlings for early maturing (90-105 days) rice crops and 30-35-day-old seedlings for late-maturing varieties help save the crop from attack.

Traditionally, farmers use traps for many pests, and for GAS, they use rotten jackfruit as bait. This method has proven highly successful in Malaysia. In Vietnam, pig brains kept on the water surface are used (Ngoc 2002).

There are no varieties resistant to the feeding of GAS. However, modern high-tillering plant types have better potential to compensate for damaged tillers over time than low- and medium-tillering types. This may be helpful in long-duration (late-maturing) varieties, but may not help in short-duration (early-maturing) ones.

Crop rotation is a practical way to cope with the snail problem in direct-seeded rice fields as observed by Wada (2004) in Japan. When the soil is drained for the dryland crop, GAS will find it unsuitable and hence will burrow until the conditions become suitable for them. Using highland crops that require good soil aeration can render GAS inactive until they starve and die. An alternate crop planted in rice fields is often soybean. This is common in Japan. Two limitations to crop rotation are (a) there are no research results on the minimum time period during which GAS can survive buried in the absence of a water environment, and (b) in marshy areas and those with frequently high water levels or stagnant water, rotation may not be practical.

Biological Methods

Biological methods can be effective in controlling GAS, which is a source of food for many birds, in particular, waterbirds like ducks, waders such as open bills, and prey birds such as kites and egrets. But their numbers are normally too small to make a significant impact. Open bills (*Anastomus oscitans;* Fig. 6), the common scope owl (*Otus sunica*), and the greater coucal (*Centropus sinensis*) have been observed feeding on GAS. Sometimes there is damage to egg masses in the field due to birds, but the exact birds are not known (Fig. 7). In Thailand, GAS-infested fields are frequently inhabited by the red-wattled lapwing (*Vnellus indieus*) and the grey wagtail (*Motacilla cinerea*); the latter is a migratory bird common in tropical countries from late August to early April.

Ducks and fish have the greatest potential for reducing the population of GAS. Herding of ducks through the rice fields immediately after harvest until the last harrowing for the succeeding crop helps reduce the GAS problem. The remaining GAS can be reduced by allowing ducks in the rice field around 30-35 days after transplanting (DAT) for early-maturing varieties, and 40-45 DAT for late-maturing varieties.

Fish that eat young snails can be reared in the water source before entry and also in the drainage areas where snails usually move around. In addition, integration of trenches and fishponds with rice culture provides better opportunities

Fig. 6. Open bill in golden apple infested rice fields.

to control GAS. Carp with pharyngeal teeth have a high potential for preying on snails. In fact, the common carp (*Cyprinus carpio*) and *Piaractus brachypomus* revealed effective predation in field experiments (Halwart 1994a, Anonymous 2001, Ngoc 2002). However, use of fish in the rice fields may not be practical in most cases, since fish culture requires maintaining a deep water level. But integration of fish culture with sufficiently deep ponds for fish to live and allowing fish to move around the rice crop by monitoring the water level is an effective method for the control of GAS, as observed by Arumughen (2002) in an experiment conducted on the management of rice weeds in Thailand using grass carp and silver barb (Fig. 8). Although egg masses of GAS were observed in the control plots, there were no egg masses found in the rice plots associated with the two fish species. This indicated the effectiveness of biological control of GAS using fish

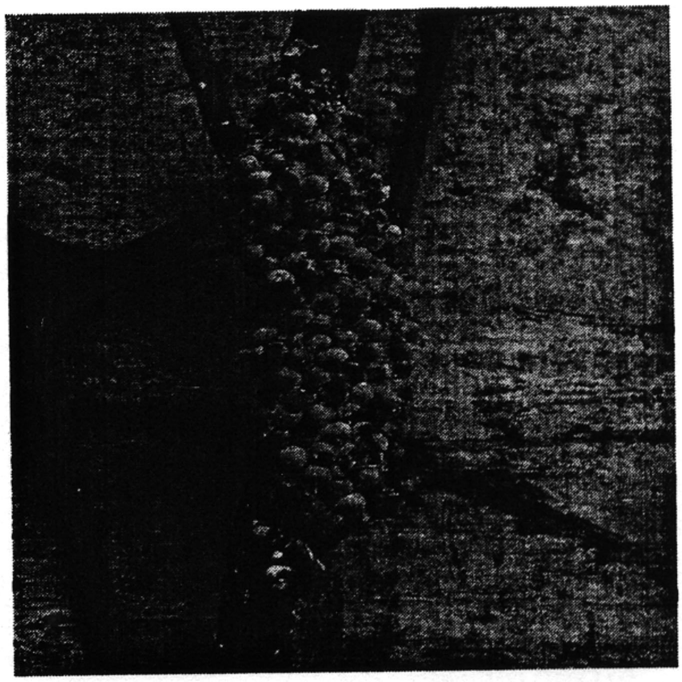

Fig. 7 . Golden apple snail's egg mass damaged by birds.

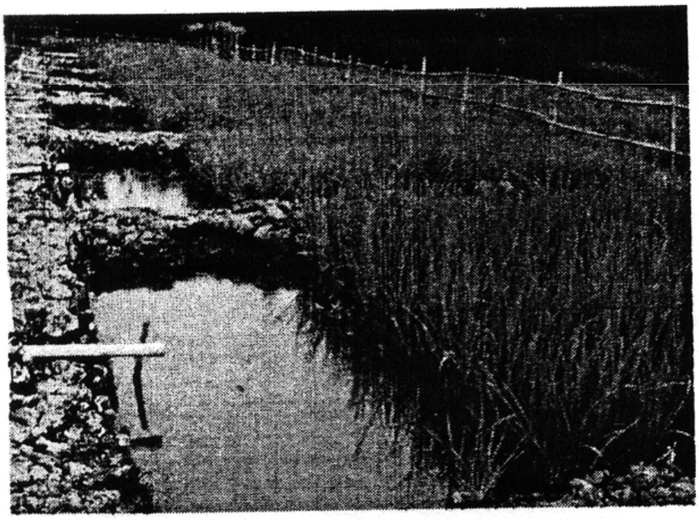

Fig. 8. Rice- fish integration for golden apple snail control.

Red ants feed on eggs and newly hatched snails (Dela Cruz et al. 2003). Both rats and snakes have also been observed to prey on GAS (Ngoc 2002, Dela Cruz et al. 2003). In Thailand, GAS is collected and fed to crocodiles on a crocodile farm. In both Thailand and Vietnam, GAS is used for human food (personal communication with Thai and Vietnamese nationals).

Pesticide Use/Chemical Methods

Pesticides are also used for GAS control. One commonly used is Niclosamide (at the rate of 390 g/ha active ingredient [a.i.]), which is usually recommended to apply immediately after transplanting rice (Dela Cruz and Joshi 2001). In addition endosulfan, fentin acetate (60% WP at a rate of 0.5 kg/ha), and camellia seed cake (residue) are commonly used. In Thailand, GAS is effectively controlled using copper sulfate at 6–7 kg/ha. Wada (2004) reported that metaldehyde (10% a.i.) is a promising pesticide for GAS in direct-seeded fields in the Philippines. Calcium cyanamide is also an environmentally friendly molluscicide (Halwart 1994b, Dela Cruz and Joshi 2001); it was originally used as a fertilizer containing nitrogen and calcium. Since 25 kg of calcium cyanamide corresponds to 5 kg nitrogen, it is advisable to adjust the doses of other nitrogen fertilizers with the use of calcium cynamide (Dela Cruz et al. 1999, Ngoc 2002).

Botanical preparations such as dried tobacco leaves and neem extracts have been reported to control GAS (Dela Cruz and Joshi 2001). As there are many traditional methods of pest management adopted by local communities, it would be worth surveying them for their potential.

As reported by Dela Cruz et al. (2003), basal application of complete fertilizer in combination with urea at the recommended rate incorporated into the soil has been found to reduce the GAS population by 54%, thus preventing damage to the crop during the first few days after transplanting.

Recommendations

During Land Preparation

- Removal of GAS during field/land preparation will help reduce its population and threat. GAS is most active and easy to find in the morning and late afternoons. Therefore before the final harrowing, GAS can be easily collected and destroyed.
- Some plants contain substances toxic to GAS (Anonymous 2001). These include *gugo* bark (*Entada phaseikaudes* K Meer), *tubangkamisa* leaves, *sambong* leaves (*Blumea balsamifera*), *tuba-tuba* leaves, *gabihan* leaves (*Monochoria vaginalis*), tobacco leaves (*Nicotiana tabacum* L.), *calamansi* leaves (*Citrus microcarpa* Bunge), *tubli* roots, *makabuhay* leaves (*Tinospora rumphii* Boerl), and red pepper fruit (Anonymous 2001). Leaves of *Ocimum basilicum*, *Melia azedarach*, *Derris elliptica*, and *Nerium oleander* are commonly used in Vietnam (Ngoc 2002). These plant species could be added to soils at or after land preparation to kill GAS. In addition, starflower leaves (*Calatropis giganta*), neem tree leaves (*Azadirachta indica*), and asyang (*Mikania cordata*) contain substances that can kill GAS (Anonymous 2001) and are highly recommended to be added to the soil before transplanting rice. Construction of small canals to confine GAS and then adding the leaves of these plants containing toxic material into such drains where GAS will usually gather could help alleviate the menace of this pest.
- GAS is attracted to the leaves of gabi (*Colocasia esculenta*), banana (*Musa paradisiaca* L.), papaya (*Carica papaya* L.), and trumpet flower, and even to old newspapers (Anonymous 2001, Ngoc 2002). These plants and other materials containing attractants could be used for easy collection of GAS.
- GAS prefers deep over shallow water levels (Wada 1997). Therefore, during final field preparation, construction of deep strips of drains (at least 25 cm wide and 5 cm deep) at a spacing of 10-15 m in the rice fields will help concentrate GAS where they are clearly visible. In this situation, GAS can be collected with the help of a hoe or crushed by pulling a sack containing a heavy object over them. Small canals of the same dimensions can also be constructed along the edges of rice fields for easy collection of GAS.

- With the help of wire meshes, wire nets, woven bamboo screens, and like material—placing them at the main water inlets and outlets—GAS can be trapped. Baited traps filled with lettuce, cassava, and taro leaves are also used to attract the snails and to facilitate collection (Cowie 2001).

During Transplanting

It is advisable to follow the standard seeding rate and planting distance recommended based on the rice variety and duration group. This not only speeds establishment but also promotes development of sturdy stems. Increasing the seeding density to compensate for plants lost to GAS does not work due to the snails' rapid feeding habit, leading to unrecoverable growth with complete disappearance of young and tender seedlings unless other precautions are taken.

GAS attack is most severe when the seedlings are young, and rare when the seedlings are sturdy and more fibrous. Therefore, transplanting slightly mature seedlings is mostly preferred over direct seeding. Furthermore, transplanting 25-30-day-old seedlings of early-maturing varieties and 30 to 35 day-old seedlings of late-maturing varieties has been found to be a practical way of minimizing damage by the snails.

Use of high-tillering rice varieties such as PSB Rc36, Rc38, Rc40, and Rc68 has been suggested (Anonymous 2001). However, the fast feeding habit, rapid population buildup, and high palatability of very young seedlings may even cause heavier damage to seedlings of these varieties unless other measures are integrated.

Providing egg-laying sites during the final stage of field preparation can be done by erecting sticks or bamboo stakes in waterlogged areas of the field before transplanting or even broadcasting and watching for the movement of GAS. The snails as well as their eggs can be easily collected and destroyed with these traps.

It is best to maintain a shallow water level (2-3 cm) in rice fields starting at 3-4 DAT (Wada 1997). This restricts the mobility of GAS (Ito 2003), as GAS are freely mobile in the water environment. Observations made by us by collecting GAS from the field into a tray with no water showed that they remained inactive for a fairly long period, but within 10-20 seconds after water was added they began to sense the environment and became mobile. Therefore, with suitably deep drains and slightly higher rice beds, the mobility of GAS could be conveniently restricted by managing the field water level. Lowering the water level by draining from time to time until the rice seedlings reach a resistant age could be used to save the rice plants from GAS damage.

As practiced traditionally in many countries such as the Philippines, Thailand, and Vietnam, use of GAS for human consumption (Dela Cruz et al. 2003) or for crushing and feeding to ducks (Sinives 2005) or pigs (Kaensombath 2005) is a way to reduce the threat. Use of plants as attractants, making deep drains in the edges of rice fields, and draining the field water level so as to attract the snails to the drains make the collection of snails easier and control more possible. Dela Cruz et al. (2000) suggested using the readily available leaves of gabi and papaya, and trumpet flowers to enable snails to be collected easily.

When heavy damage is expected, copper sulfate at the rate of 6-7 kg/ha can be used, repeating application after heavy rains as well as when irrigating the field using a water source suspected to be infested with GAS.

After Harvesting

Passing a herd of ducks through the fields from the time of harvest up to the last harrowing will help remove GAS. This practice can also be repeated even at 30-35 DAT for early-maturing varieties and at 40-45 DAT for late-maturing varieties without damaging the crop (Dela Cruz et al. 2003). However, GAS invasion can take place through irrigation water. Therefore, due attention needs to be paid to the quality of the water.

Monitoring GAS Infestation

Farmers should be vigilant and check the water sources used for irrigating rice fields. As has been seen in Thailand, the presence of birds such as open bills (*Anastomus oscitans*) and ducks is a sign that GAS has invaded. These birds can easily be seen in the early morning and late afternoons. Protecting such birds in the long run will help reduce GAS populations.

Public Education

It is crucial that the further spread of GAS be arrested. This requires strict implementation of many precautionary measures including quarantine regulations. Such measures are also cost effective. Once the invasion begins, it is not easy to arrest the pest. Most important, then, is raising the awareness among people, including farming communities, about the threat of alien species like GAS. Publicity must be directed to the general public, aquarists, those seeking quick profits from marketing the snails for food, etc. In particular, in Southeast Asia, the impact of the spread of GAS on rice-growing areas that have not been infested so far must be clearly communicated to farmers in a series of comprehensive education campaigns with the support of agricultural managers (Huan and Joshi 2002). Only with public cooperation and public understanding can a potential disaster be averted. Indonesia, the Philippines, Vietnam, and some other Asian countries have already started these types of quarantine and related educational and awareness programs to overcome this problem (Ngoc 2002).

Knowledge Gaps and Future Needs

There have been many scientific studies on the life history and behavior of GAS, the agricultural damage it causes, and possible countermeasures. However, much additional work is required for developing sustainable management of GAS, as follows.

Ecological Aspects

Ecology. Field-level ecological information on GAS is sparse. In particular, the relationship between environmental factors and the density and distribution of the snails has been poorly investigated. To predict and control snail populations, especially in areas where GAS is not native, it is very important to know the features of their habitats, and how they behave or respond to changes in environmental conditions.

Taxonomy. There is a diversity of snails in different ecological systems. Taxonomic studies of species with respect to geographical origins and distribution of the *Pomacea canaliculata* group of species in South America and Asia are required to prevent future invasions into non-infested areas. In such taxonomic studies, both biochemical and molecular methods will enable differentiation of GAS species and identification of their habitats.