EXPANSION OF THE GOLDEN APPLE SNAIL, *POMACEA CANALICULATA*, AND FEATURES OF ITS HABITAT

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ABSTRACT

The golden apple snail, Pomacea canaliculata (Lamarck), is a large freshwater snail native to tropical and subtropical South America. This snail is a serious rice pest in Southeast and East Asia because it damages young rice seedlings. In the early 1980s, the apple snail was widely raised as a human food in Japan. Within a few years, feral snails had spread to Kanto from Kyushu, where they were first recorded. By 2002, snails were found in 27 prefectures. Many potential snail habitats in Japan are still free of these snails, however. The snail can live in rivers, ponds, swamps, canals, and paddy fields. In summer, it is found in quiet waters with a high level of suspended matter and a high chemical oxygen demand. Near the northern boundary of its range, the snail can overwinter only in shallow canals with a high level of dissolved oxygen and a low pH. To restrict further expansion, it is most important to prevent, through education or regulation, transport of the snail to uninfected areas. Ecological information, such as the characteristics of suitable habitats and the movement of snails to new locations, is also needed so that we can predict and prevent its natural dispersal.

INTRODUCTION

Many alien species have been introduced from foreign countries to the Japanese freshwater system. According to the *Handbook of Alien Species in Japan* (Ecological Society of Japan, 2002), 43 species of fish, 15 species of mollusk, and 8 species of crustacean have established sustainable populations in Japanese freshwater. These alien species may adversely affect not only fisheries, agriculture, and human health but also the native ecosystem (e.g. Maezono and Miyashita 2003). To control the expansion of alien species and limit potential damage by them, countermeasures based on ecological information are indispensable.

The golden apple snail, *Pomacea canaliculata* (Lamarck), is a large freshwater snail native to tropical and subtropical South America. Since the 1980s, this snail has become a serious rice pest in most Southeast and East Asian countries, because it damages the young rice seedlings (Halwart 1994, Naylor 1996, Yusa and Wada 1999). There have been many scientific studies on the life history and behavior of the golden apple snail, the agricultural damage caused by the snail, and possible counter measures. However, ecological information from field studies of the snail is sparse. In particular, the relationship between environmental factors and the density and distribution of the snail have been poorly investigated (but see Ichinose *et al*. 2000, Martin *et al*. 2001). To predict and control snail populations, especially in areas where it is not native, it is very important to know the features of its habitat.

In this Bulletin, the ecology of the snail is explored: its life history and population growth, means of expansion, and features of its habitat. Environmental features of the overwintering habitat will also be examined, based on the results of field research on a northern population (Ito 2002). A snail control

Keywords: golden apple snail, habitat, invasive, Japan, overwinter, *Pomacoa canaliculata*, rice pest

strategy to prevent the expansion of the snail in Japan is then discussed. I am not concerned here with methods to reduce snail damage in Japanese paddy fields, because it has been already reviewed by many authors (e.g. Wada 1997, Yusa and Wada 1999).

INTRODUCTION OF THE GOLDEN APPLE SNAIL INTO JAPAN

The first introduction of the golden apple snail into Japan was in 1964, when it was imported as an aquarium pet by a private company in Kumamoto Prefecture. At that time, some snails emigrated into paddies and water canals near the company offices. Later, probably because the company was located in a cool mountainous region, this entire snail population died out (Hamada and Matsumoto 1985).

In the early 1980s, the culture of the apple snail for human food became fashionable in Japan. At that time, the apple snail was imported frequently from Taiwan and South America into Japan (Miyazaki 1985, Mochida 1991, Halwarat 1994). By 1983, it was being cultured at 495 sites in 35 prefectures throughout Japan (Hirai 1989). Because Japanese consumers did not like the taste of the snail, however, it lost its commercial value rapidly and remaining stocks were sometimes discarded (Hamada and Matsumoto 1985). Around 1982, the pinkish or reddish egg masses of the snail were found in canals and paddies in Kumamoto Prefecture, Kyushu (Hamada and Matsumoto 1985). By 1985, feral snails had been reported in many prefectures of Kyushu, Shikoku and Honshu (Mochida 1991).

The area of paddy fields in which the golden apple snail was found increased until it reached a plateau in 1997 (Fig. 1). In 2002, the snails were found in 74,000 ha of paddy fields in 27 prefectures (Fig. 2). The area of snail damage also increased from the 1980s, and in 1999 the area of damage suddenly increased to 13,000 ha (Fig. 3). The reason for this sudden increase in unknown.

The northern boundary of the wild population of the snail is in the southern part of Ibaraki Prefecture (Wada 1997, Ito 2002), although wild snails were once recorded further north, in a river in Yamagata Prefecture (Wada 1997).

LIFE HISTORY AND POPULATION GROWTH OF THE GOLDEN APPLE SNAIL

Under laboratory conditions, the apple snail can survive for more than three years. It has one or two reproductive seasons in the course of its lifetime (Estebenet and Cazzaniga 1992). However, most of the snails in paddy fields live for only up to two years, and have only one reproductive season (Suzuki unpub.). Growth of the snails is influenced by temperature, population density and food availability (Kaneshima *et al.* 1987, Estebenet and Cazzaniga 1992, Tanaka *et al.* 1999, Estoy *et al.* 2002). In Okinawa Prefecture, the snail was found to reach sexual maturity when the

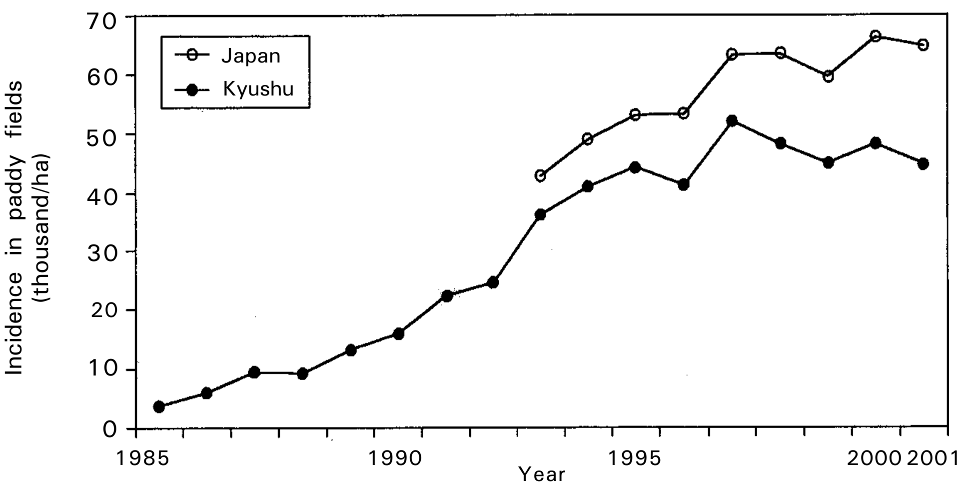

Fig. 1. Occurrence of the golden apple snail, *Pomacea canaliculata*, in Japanese paddy fields from 1985 to 2001

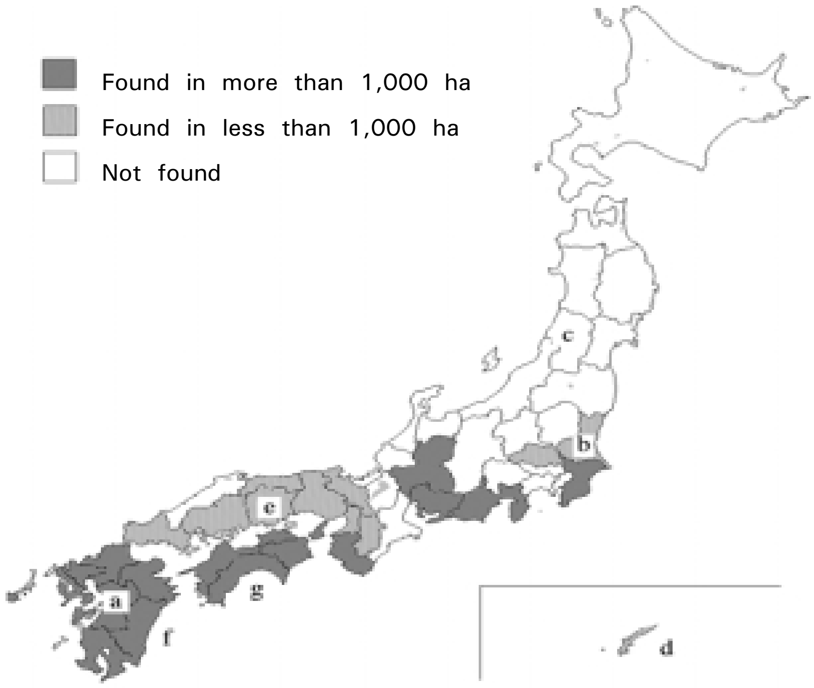

Fig. 2. Prefecture distribution of the golden apple snail, *Pomacea canaliculata*, in Japanese paddy fields, according to the report (2002) by the Plant Protection Department, MAFF, Japan. Data about Ibaraki Prefecture is based on Ito 2002. a; Kumamoto, b; Ibaraki, c; Yamagata, d; Okinawa, e; Okayama, f; Kyushu island, g; Shikoku island

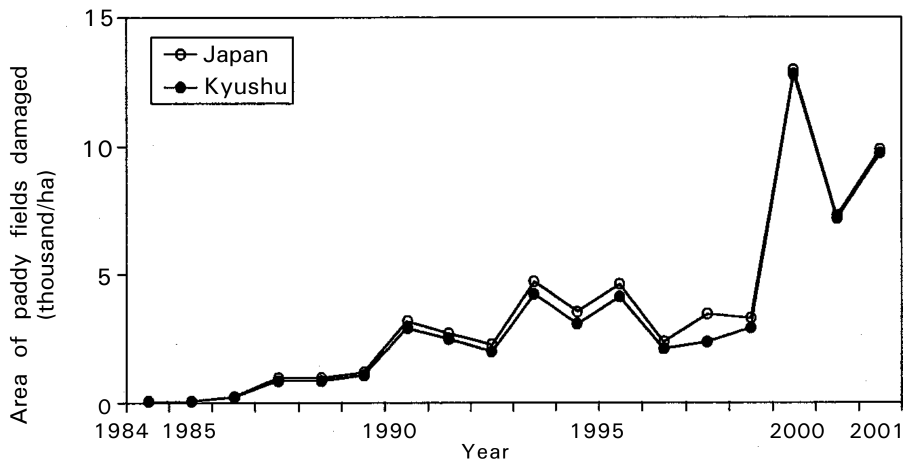

Fig. 3. Area of paddy fields in Japan damaged by the apple snail, *Pomacea canaliculata*, from 1984 to 2001

shell was about 30 mm high (Kaneshima *et al.* 1986). Under favorable conditions, the female takes 50 to 70 days to mature and start ovipositing (Kiyota and Sogawa 1996). However, most newly hatched juveniles in paddy fields do not seem to reach their mature size within a single year (Ozawa and Makino 1989, Syobu 1996).

The golden apple snail has separate sexes (Andrews 1964, Kaneshima *et al.* 1986). From June to November, the females deposit reddish egg masses above the water (Suzuki and Fukuda 1988). The fecundity of the snail is also strongly influenced by population density and the availability of food (Albrecht *et al.* 1999, Tanaka *et al.* 1999, Estoy *et al.*

2002). Egg production per female per breeding season varies from 400 to 3500, depending on the snail density in the paddy field (Tanaka *et al*. 1999). Growth and reproduction of the snail strongly depends on snail density. Thus, a low-density population shows a high population growth (Tanaka *et al*. 1999). Therefore, reduction in snail density by any method cannot suppress the density of the snail in subsequent generations.

MEANS OF EXPANSION

How did the golden apple snail become established and expand in Japan? Only a few research papers on the expansion process of the golden apple snail in Japan have been published (e.g. Hamada and Matsumoto 1985). Therefore, it is not clear whether human transport or natural snail movement is the main process by which the snail expands its range. However, the rapid dispersal of the snail in the early 1980s was predominantly caused by human transport, because after it was introduced it became actively traded throughout Japan (Hamada and Matsumoto 1985, Miyazaki 1985). According to one newspaper account in 1984 several tons of golden apple snails were conveyed every week from Okayama Prefecture to Chubu District in the central part of Japan (Miyazaki 1985). Within a few years, the feral snail had spread to Kanto from Kyushu, where it was first recorded. It is difficult to explain this rapid spread of the snail by natural movement alone. Snails carried around the country probably escaped from time to time, and established local populations.

Moreover, some farmers began to release apple snails into their fields as a biological control agent for weeds (Okuma *et al.* 1994a, Ichinose and Yoshida 2001). The expansion of the snail's range may thus have been promoted by human transport, whether intentional or accidental (e.g. in soil contaminated with the snail).

The golden apple snail potentially has a great ability to move a long distance within a water system. In a canal, the apple snail can move more than 100 m upstream or more than 500 m downstream in one week (Ozawa and Makino 1989). However, spread of the apple snail does not necessarily take place within the same water system. Ichinose and Yoshida (2001) suggested that the snail could not expand its range to the upper areas of a water system, because of the discontinuity between rice fields and the faster water flow upstream. Moreover, one local population (established about 20 years ago) at the northern boundary of the snail's range is restricted to an area of only 1.5 x 0.5 km in quiet water canals. Snails have not been observed outside this range for at least three years (Ito unpublished). Factors restricting the expansion of the snail within a water system are not fully understood.

FEATURES OF THE SNAIL HABITAT

Most descriptions of the habitat of the golden apple snail are qualitative. In its native area, the apple snail has been described as inhabiting mainly quiet stretches of water, such as lagoons, ponds and swamps (Scott 1957, Bachmann 1960). However, field research suggests that the snail is frequently found in streams in its native area (Martin *et al.* 2001). In Japan, the snail is found in a wide variety of habitats, including rivers, ponds, swamps, reservoirs, creeks, drainage canals and paddy fields (Hirai 1987).

So far, the main focus of research in Japan has been the effect of temperature variation on life-history traits such as growth, breeding and overwintering survival. For example, yearly fluctuations in temperature have a close relationship with the rate of successful hibernation in a dry paddy field (Syobu *et al.* 2001). However, quantitative descriptions of the snail habitat suggest that the abundance and distribution of the golden apple snail are determined by many environmental factors.

Ichinose *et al*. (2000) examined the relationship between the density of the snail population and the environment, based on a survey within a single agricultural water system (approximately 12 square kilometers). They found that the snail was concentrated in shallow-water habitats with a high chemical oxygen demand (COD), and that snail density was near zero where the water flow velocity was more than 50 cm/s (Ichinose *et al.* 2000). It should also be noted that in the northernmost part of their range in Japan, apple snails tend to concentrate in shallow (10-20 cm depth) canals (Ito unpublished).

Larger-scale surveys of golden apple snail habitats have been conducted in its native area. Martin *et al*. (2001) compared the

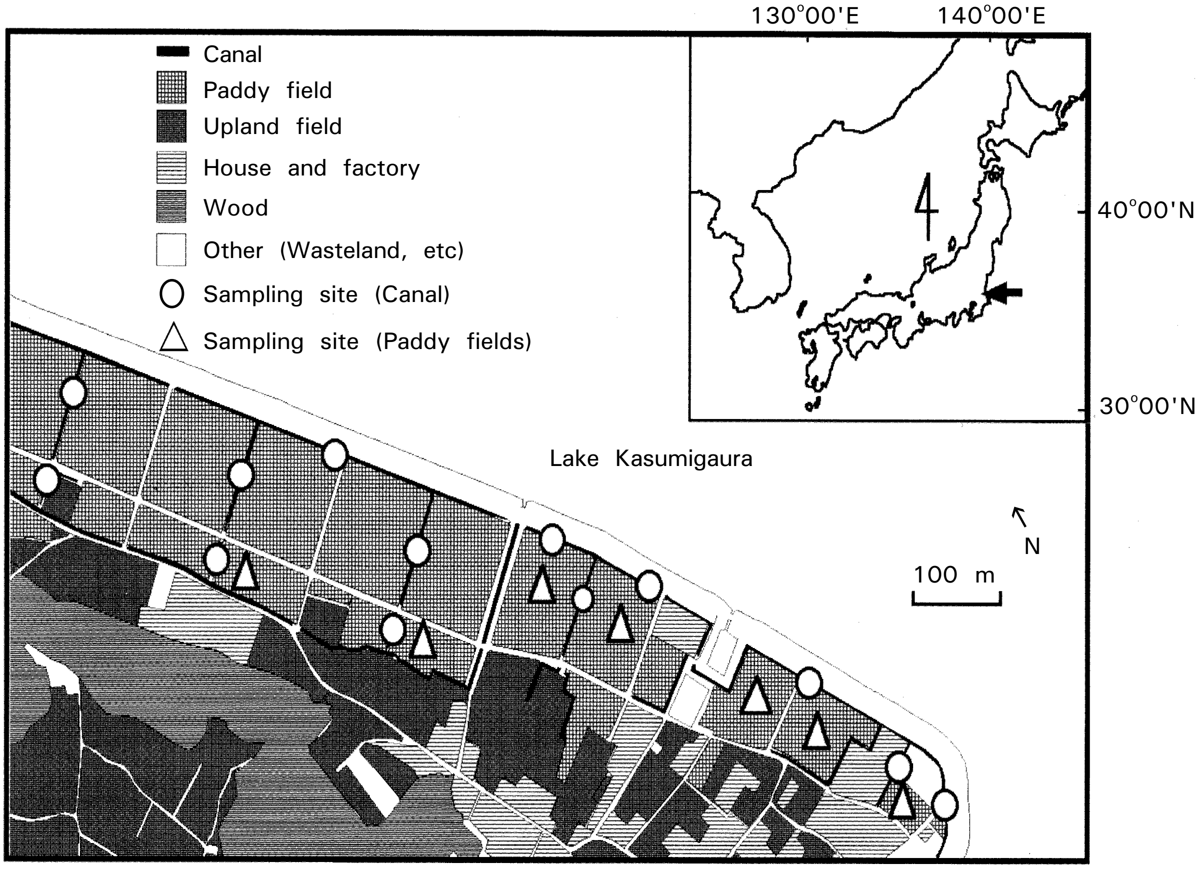

Fig. 4. Map showing the study site in the northernmost part of the snail's range in Japan

environments of sites inhabited by snails and those without snails in Buenos Aires Province, Argentina (an area of approximately 120,000 square kilometers). They found that the snail was not found in shallow water, but mostly inhabited water at a depth of 0.3-1.7 m. It also tended to be found in sites with low water velocity, a high content of suspended material, and a low ratio of sodium to potassium and magnesium ($Na^+/(K^++Mg^{2+})$) (Martin *et al.* 2001).

These field studies of the golden apple snail were conducted only in summer, and the winter habitat use pattern of the snail has not been fully examined. However, the distribution and habitat use pattern of the snail may change seasonally (see below).

FEATURES OF THE OVERWINTERING HABITAT

Because the golden apple snail is indigenous mainly to tropical and subtropical regions of South America, it is not tolerant of cold weather. The overwintering mortality of the snail in dry paddy fields ranges from 0% to 90%, depending on the region, winter temperature, and the characteristics of the habitat (Syobu 1996). Although various environmental factors influence freshwater benthic organisms such as snails (Giller and Malmqvist 1998), the effects of environmental variables, except temperature, on the overwintering success of the golden apple snail have not yet been investigated. To clarify the environmental factors affecting the overwintering success of the snail, a field survey was conducted on a population in the northernmost part of its range in Japan (Ito 2002). The habitat of this population consisted of drainage canals and paddy fields (Fig. 4).

Paddy fields in this area are dry from September to April, but there is water in the canals all year round. The results of the survey suggested that in the autumn, the snail was found in both paddy fields and canals, but that the snail overwintered successfully

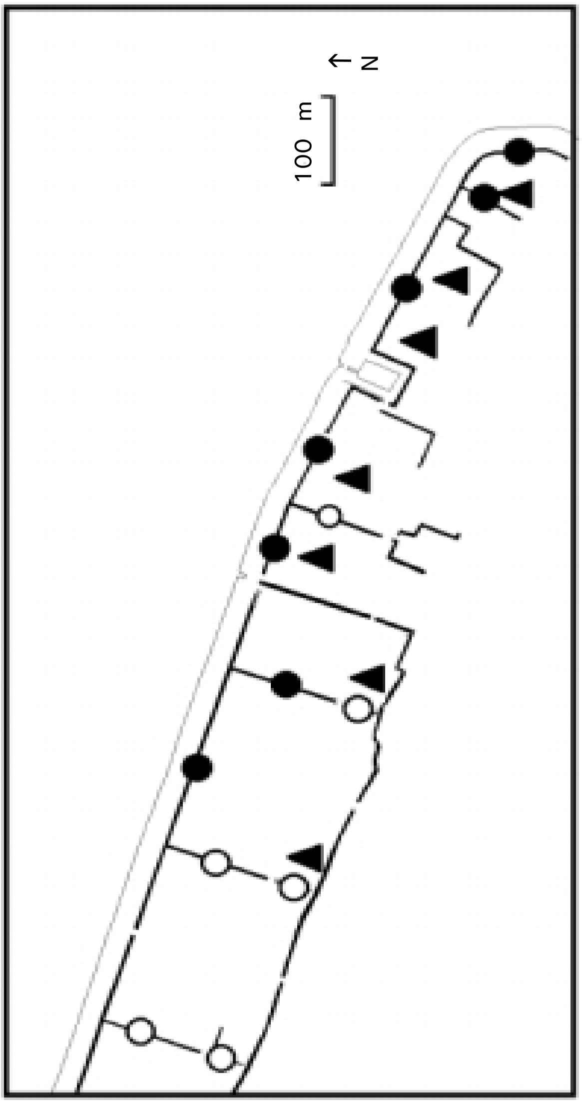

Fig. 5. Overwintering success of *Pomacea canaliculata* in an agricultural water system.
○; Successfully overwintered in canal, ●; failed to overwinter in canal, ▲; failed to overwinter in paddy field

only in some of the canals. All snails in dry paddy fields died during the winter (Fig. 5).

There was no statistically significant evidence that snail density or size before the winter began affected overwintering success in the canals. In other words, snail density in an overwintering site was not necessarily high before winter (Table 1). Hibernation sites in the canals were characterized by shallow water, a high level of dissolved oxygen (DO) and a low pH. Water temperature was not important (Table 2).

These results imply that the snail population in this area is supported by recruitment from those snails that successfully overwinter in suitable parts of the habitat, that is, in sections of canals which meet the above criteria. To effectively manage golden apple snails in this area, it is important to identify their overwintering habitat. However, it may be difficult to determine the locations of suitable overwintering sites before winter,

Table 1. Relationships between snail density and size and overwintering success of the golden apple snail in canals from a likelihood-ratio analysis of a univariate logistic regression model

Independent variable	X^2	df	*P*-value
Snail density	1.466	1	0.2260
Mean shell height	0.024	1	0.8757

Table 2. Relationships between various water characteristics and overwintering success of the golden apple snail in canals from a likelihood-ratio analysis of a univariate logistic regression model

Independent variable	X^2	df	*P*-value
Mean value of maximum water temperature from November to May	1.284	1	0.2572
Mean value of minimum water temperature from November to May	0.725	1	0.3946
Water velocity	0.049	1	0.8243
Depth	5.461	1	0.0195
DO	6.059	1	0.0138
pH	17.924	1	0.0001

because snail density in autumn does not predict wintering success in canals (Table 1).

CONCLUSION

Only recently have quantitative studies of environmental characteristics of the golden apple snail habitat been conducted. Therefore, there is still little information on the habitat of these snails (Ichinose *et al.* 2000, Martin *et al.* 2001). However, the available reports suggest that in the summer the snail is likely to inhabit quiet waters which contain a high level of suspended matter and a high COD (Ichinose *et al.* 2000, Martin *et al.* 2001). In Japan, measuring these environmental parameters in areas without snail populations might provide useful information on possible countermeasures for limiting the expansion of the snail's distribution. Previously, Baker (1998) predicted the potential range of the golden apple snail using climatic data (temperature, rainfall and humidity). More extensive research on snail distribution and habitat, however, is needed to precisely predict its expansion in specific localities. In addition, the habitat of the snail in seasons other than summer (especially winter) needs to be investigated further, because snail distribution may change seasonally (Ito 2002).

As mentioned above, the total area of paddy fields in Japan with golden apple snails seems to have reached a plateau in 1997 (Fig. 1). However, these data do not necessarily mean that the snail is no longer expanding its range. First, snails are found in areas other than paddy fields. The overwintering mortality of the snail is higher in dried paddy fields than in canals (Kiyota and Okuhara 1987, Kondo and Tanaka 1991, Ito 2002). This may suggest that paddy fields are not the most suitable habitat for this snail. However, in Japan, we have yearly fluctuation data only for paddy fields which are infested with snails.

The distribution of the snail in other habitats, such as ponds and rivers, is unknown.

Second, new occurrences of the snail are still being reported. For example, owing to its artificial introduction after 1998, a new sustainable population was established in an upper area of a water system which the snail had not previously seemed able to reach (Ichinose and Yoshida 2001). In Kasumigaura Lake, Ibaraki Prefecture, the golden apple snail was found at only one site in 1995, but it was found at five sites in 2002 (Asaza Project, personal communication). These results suggest that many potential snail habitats as yet lack snails.

Recently, some farmers have begun to treat the golden apple snail not as a rice pest, but as an "environmentally friendly" biological control agent for weeds. In fact, the golden apple snail is effective in controlling weeds (Okuma *et al*. 1994a, 1994b). However, it is almost impossible to prevent the emigration of the snail from one paddy field into those around it, while snail damage to young rice plants cannot be controlled if the paddy fields have an uneven surface and/or are poorly drained (Wada 1997, Yusa and Wada 1999). Moreover, the effect of the snail on the native Japanese ecosystem is not yet clear. Therefore, the introduction of the golden apple snail to uninfected paddies to control weeds should be stopped.

In view of the risks associated with the expansion of the snail's range, the countermeasures that have been undertaken against human transport of the snail do not seem sufficient. In 1984, Japan's Ministry of Agriculture, Forestry and Fisheries officially designated the golden apple snail a quarantine pest, and prohibited the introduction of this snail from foreign countries (Kiyota and Sogawa 1996). However, the introduction of the snail from infected to uninfected areas within Japan is not forbidden. Hence, farmers can legally release snails into their paddy fields.

In conclusion, if we are to restrict any further expansion of the golden apple snail's distribution area in Japan, it is important, through education and regulation, to prevent its transport to uninfected areas. Moreover, ecological information such as the characteristics of suitable habitats, and movement of the snail to new locations, is needed so that we can predict and prevent its natural dispersal.

REFERENCES

Albrecht, E.A., N.B. Carreno, and A. Castro-Vazques. 1999. A quantitative study of environmental factors influencing the seasonal onset of reproductive behaviour in the South American Apple-Snail Pomacea canaliculata (Gastropoda: Ampullariidae). *Journal of Molluscan Studies* 65: 241-250.

Andrews, E.B. 1964. The functional anatomy and histology of the reproductive system of some Pilid gastropod molluscs. *Proceedings of the Malacological Society of London* 36: 121-140.

Bachmann, A. 1960. Apuntes para una hidrobiologia argentina II. Ampullaria insularum Orb. y A. canaliculata Lam. (Moll. Prosobr. Ampullariidae). Observaciones biologicas y ecologicas. *First South American Congress of Zoology* 1: 19-26.

Baker, G.H. 1998. The golden apple snail, *Pomacea canaliculata* (Lamarck) (Mollusca: Ampullariidae), a potential invader of fresh water habitats in Australia. In: *Sixth Australasian Applied Entomological Research Conference, Vol. 2*. University of Queensland, Brisbane, Australia, pp. 21-26.

Ecological Society of Japan. 2002. *Handbook of Alien Species in Japan*, Chijinshokan, Tokyo, p. 408. (In Japanese).

Estebenet, A.L. and N.J. Cazzaniga. 1992. Growth and demography of *Pomacea canaliculata* (Gastropoda: Ampullariidae) under laboratory conditions. *Malacological Review* 25: 1-12.

Estoy, G.F., Y. Yusa, T. Wada, H. Sakurai, and K. Tsuchida. 2002. Size and age at first copulation and spawning of the apple snail, *Pomacea canaliculata* (Gastropoda: Ampullariidae). *Applied Entomology and Zoology* 37: 199-205.

Giller, P.S. and B. Malmqvist. 1998. *The Biology of Streams and Rivers*. Oxford University Press, New York.

Halwart, M. 1994. The golden apple snail *Pomacea canaliculata* in Asian rice farming systems: present impact and future threat. *International Journal of Pest Management* 40: 199-206.

Hamada, S. and T. Matsumoto. 1985. Apple snail in Kumamoto Prefecture. *Kyushu-no-kai* 24: 5-12. (In Japanese).

Hirai, Y. 1987. Ecology and control of the golden apple snail, *Pomacea canaliculata*. *Nougyou-oyobi-engei* 62: 612-616. (In Japanese).

Hirai, Y. 1989. Expanding occurrence and distribution of the apple snail, Pomacea canaliculata (LAMARK), in Japan. *Shokubutsu-boeki* 43: 498-501. (In Japanese).

Ichinose, K., T. Wada, Y. Yusa, and T. Kubota. 2002. Influence of habitat differences brought about by environmental changes on the densities of adults and eggs of *Pomacea canaliculata*. *Kyushu Plant Protection Research* 46: 78-84. (In Japanese with English summary).

Ichinose, K. and K. Yoshida. 2001. Distribution of apple snail, related to rice field distribution and water flow. *Kyushu Plant Protection Research* 47: 77-81. (In Japanese with English summary).

Ito, K. 2002. Environmental factors influencing overwintering success of the golden apple snail, *Pomacea canaliculata* (Gastropoda: Ampullariidae), in the northernmost population in Japan. *Applied Entomology and Zoology* 37: 655-661.

Kaneshuima, M., S. Yamauchi, and K. Higa. 1986. Sexual maturity of the apple snail, *Ampullarius insularus*. *Proceedings of the Association for Plant Protection of Kyushu* 32: 101-103. (In Japanese).

Kaneshima, M., S. Yamauchi, and T. Kurozumi. 1987. Effect of rearing temperature and density upon the growth of apple snail, *Pomacea canaliculata* (LAMARCK). *Proceedings of the Association for Plant Protection of Kyushu* 33: 110-112. (In Japanese).

Kiyota, H. and K. Okuhara. 1987. Overwintering ability of the apple snail, *Pomacea canaliculata*. *Proceedings of the Association for Plant Protection of Kyushu* 33: 102-105. (In Japanese).

Kiyota, H. and K. Sogawa. 1996. Ecology and management of the apple snail in Kyushu, Japan. *Proceedings of the International Workshop on the Pest Management Strategies in Asian Monsoon Agroecosystems* (Kumamoto 1995), pp. 187-195.

Kondo, A. and F. Tanaka. 1991. Seasonal prevalence and winter survival of the apple snail, *Pomacea canaliculata* LAMARCK in Okayama Prefecture. *Res. Bull. Okayama Agric. Exp. Sta.* 9: 39-42. (In Japanese).

Maezono, Y. and T. Miyashita. 2003. Community-level impacts induced by introduced largemouth bass and bluegill in farm ponds in Japan. *Biological Conservation* 109:111-121.

Martin, P.R., A.L. Estebenet, and N.J. Cazzaniga. 2001. Factors affecting the distribution of *Pomacea canaliculata* (Gastropoda: Ampullariidae) along its southernmost natural limit. *Malacologia* 43: 13-23.

Miyazaki, J. 1985. On Japanese name of Ampullarius insularus d'Orbigny. *Chiribotan* 6:28-29. (In Japanese).

Mochida, O. 1991. Spread of freshwater Pomacea snail (Pilidae, Mollusca) from Argentina to Asia. *Micronesia Supplement* 3: 51-62.

Naylor, R. 1996. Invasions in agriculture: assessing the cost of the golden apple snail in Asia. *AMBIO* 25: 443-448.

Okuma, M., Y. Fukushima, and K. Tanaka. 1994a. Feeding habitat of apple snail (Pomacea canaliculata) to paddy weeds and damage avoidance to rice seedlings. *Weed Research, Japan* 39: 109-113. (In Japanese with English summary).

Okuma, M., K. Tanaka, and S. Sudo. 1994b. Weed control method using apple snail (*Pomacea canaliculata*) in paddy fields. *Weed Research, Japan* 39: 114-119. (In Japanese with English summary).

Ozawa, A. and T. Makino. 1989. Biology of the apple snail, *Pomacea canaliculata* (Lamarck), and its control. *Shokubutsu-boeki* 43: 502-505. (In Japanese).

Scott, M.I.H. 1957. Estudio morfologica y taxonomica de los Ampullaridos de la Republica Argentina. *Rev. Mus. Argent. Cienc. Nat. (Zool.)* 3: 233-333.

Suzuki, M. and T. Fukuda. 1988. Seasonal occurrence of the apple snail, *Pomacea canaliculata* (LAMARCK). *Proceedings of the Kanto-Tosan Plant Protection Society* 35: 219-220. (In Japanese).

Syobu, S. 1996. Biology of apple snail, *Pomacea canaliculata* (LAMARK), and its control. *Shokubutsu-boeki* 50: 211-217. (In Japanese).

Syobu, S., H. Mikuriya, J. Yamaguchi, M. Matsuzaki, S. Zen, and T. Wada. 2001. Estimating the overwintering mortality of the apple snail, *Pomacea canaliculata* (Lamarck) (Gastropoda: Ampullariidae) in a paddy field of southern Japan using temperature data. *Japanese Journal of Applied Entomology and Zoology* 45: 203-207 (In Japanese with English summary).

Tanaka, K., T. Watanabe, H. Higuchi, K. Miyamoto, Y. Yusa, T. Kiyonaga, H. Kiyota, Y. Suzuki, and T. Wada. 1999. Density-dependent growth and reproduction of the apple snail, *Pomacea canaliculata*: A density manipulation experiment in a paddy field. *Researches on Population Ecology* 41: 253-262.

Wada, T. 1997. Introduction of the apple snail Pomacea canaliculata and its impact on rice agraiculture. In: *International Workshop on Biological Invasions of Ecosystem by Pests and Beneficial Organisms*, Yano E., K. Matsuno, M. Shiyomi and D.A. Andow (Eds.). Tsukuba, Japan, pp. 143-151.

Yusa, Y. and T. Wada. 1999. Impact of the introduction of apple snails and their control in Japan. *NAGA, The ICLARM Quarterly* 22: 9-13.