

Effects of Global Warming on the Distribution of Overwintering *Pomacea canaliculata* (Gastropoda: Ampullariidae) in Korea

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The golden apple snail, *Pomacea canaliculata*, is a freshwater snail native to tropical and subtropical South America. The species was introduced into Korea as a human food source in 1983 and was first applied as a weed control agent for the paddy fields in 1992. As the snail is well known as an environmentally friendly biological control agent for weeds, the area of cultivation in which the golden apple snail is used for biological control has been enlarged substantially each year. Currently, the species is observed in open water courses. It is possible that the snail may overwinter in these open water courses and may become a serious pest, as is already the case in many Asian countries. In this study, we determined the status of the overwintering golden apple snail based on a literature survey and investigated the potential distribution area of the snail, as a result from global warming in Korea. The potential distribution area of the overwintering golden apple snail would be enlarged under the influence of global warming; ranging from 45.5% of South Korea's land area in the 2020s to 88.4% in the 2080s.

Key words : golden apple snail, *Pomacea canaliculata*, global warming, prediction, temperature increase

INTRODUCTION

The golden apple snail, *Pomacea canaliculata* (Gastropoda: Ampullariidae, Lamarck, 1822) is a freshwater snail native to tropical and subtropical South America. It was initially introduced into Asian countries as a protein source (Halwart, 1994; Wada, 1999). However, the golden apple snail has become a serious agricultural pest, especially in young rice, in Asian countries (Hirai, 1988; Hal-

wart, 1994; Lach *et al.*, 2000; Teo, 2001; Lee *et al.*, 2002) as a result of the escape of the snails into paddy fields. The first evidence that the golden apple snail feeds on rice was reported from Japan in 1984 (Hirai, 1989). As the area of distribution of the snail increased, the snail was observed in approximately 65,000 ha of paddy fields in Kyushu (Wada, 2004). For this reason, the Ministry of Agriculture, Forestry and Fisheries in Japan has designated the golden apple snail as an animal pest in the crop industry in the Plant

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Protection Act (Teo, 2001), and Taiwan has strictly prohibited the culture of the snail (Lee *et al.*, 2002). Furthermore, numerous instances of damage to rice in paddy fields due to the vigorous feeding of the golden apple snail have been reported in Japan, Philippine, Brazil, Taiwan, Columbia, Bolivia and Venezuela (Tanzo and Barroga, 1989; Lee *et al.*, 2002). The International Union for Conservation of Nature and Natural Resources (IUCN) has listed the golden apple snail as one of the 100 worst invaders worldwide (Bang and Cho, 2008).

The introduction of the golden apple snail in Korea is presumed to have occurred from Japan in 1981 (Rural Development Administration (RDA), 2004), and the snail was officially introduced in Asan, Chungcheongnam-do in Korea in 1983 as a human food source. The snail was applied as a weed control agent in paddy fields in 1992 (Lee *et al.*, 2002). As the snail has been well known as an environmentally friendly biological control agent for weeds (e.g., weed removal rate: 98.6%) (Moon *et al.*, 1997), the area of cultivation in which the golden apple snail is used has increased substantially each year (179 ha in farmland in 2000, 48,437 ha in farmland in 2007) (Lee *et al.*, 2002).

When the golden apple snail was first used for weed control in paddy fields, it was considered unable to overwinter in Korea because it originated from a tropical area. However, the overwintering of the golden apple snail was observed in southern areas of South Korea (e.g., Haenam and Gangjin) as a result of acclimation to Korean weather conditions (Hwang *et al.*, 2002; Lee *et al.*, 2002; Kim *et al.*, 2007). In addition, Lee *et al.* (2002) reported that golden apple snails that succeed in overwintering feed on young direct-seeded rice, resulting in serious problems in rice culture in Korea.

Temperature is one of the significant factors that determine the distribution of animal species in aquatic environments (Prosser and Heath, 1991). The distribution patterns of organisms are strongly related to maximum, minimum and mean temperatures, as well as to temperature fluctuations (Prosser and Heath, 1991). In addition, global warming influences the distribution and survival rate of intermediate hosts, causing changes in the maturation rate and the reproduction of parasites. For example, the golden apple snail represents a new suitable intermediate host for *Angiostrongylus cantonensis*, considered the primary cause of human eosinophilic meningitis

(Nishimura *et al.*, 1986). This development is possible because global warming provides opportunities for the snail, a stenothermal organism, to enlarge its potential habitat and colonize new habitats (Lv *et al.*, 2006). However, to our knowledge, there is no research on the future distribution of the golden apple snail under a global warming scenario, especially in Korea. In this study, therefore, we aimed to determine the current status of the overwintering golden apple snail and the potential changes in its distribution caused by global warming in Korea.

MATERIALS AND METHODS

1. Ecological data

Data on the distribution of the golden apple snail were obtained from the literature (Table 1) (Hwang *et al.*, 2001; Lee *et al.*, 2002; Kim *et al.*, 2007; Park, 2008; Seo *et al.*, 2010). The distribution of the snail was initially monitored in Iksan, Jangseong and Haenam in Jeollanam-do in 2000 (Hwang *et al.*, 2001), and the monitoring area was gradually enlarged in 2006 (total 75 sites) (Park, 2008). The samples reported in the literature were collected primarily in irrigation canals and ditches near paddy fields in conjunction with research on the use of the golden apple snail in environmentally friendly farming. Five to ten replicate samples were collected with a scoop net (30 cm in diameter) at each sampling site.

2. Temperature data

Surface air temperature data were obtained from the Korea Meteorological Administration (KMA, <http://www.kma.go.kr>). The output of the Hadley Centre climate model (HadGEM2-AO) was downscaled using HadGEM3-RA by the Korea Meteorological Research Institute (METRI) to produce a high-resolution (12.5 km) regional scenario based on the Representative Concentration Pathways 8.5 (RCP 8.5) scenario. The air temperature data were further downscaled to a 1 km scale to enhance the resolution of the regional scenario. The KMA provides monthly average air temperature data in a grid of 1 km × 1 km resolution for each year from 2010 to 2099. The water temperatures were calculated with a linear regression equation ($Water\ temperature = 2.56 + 0.71\ Air\ temperature$), following Morrill *et al.* (2005), who deriv-