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Environmental tolerance of invasive golden apple snails (*Pomacea canaliculata* (Lamarck, 1822)) and Thai native apple snails (*Pila scutata,* (Mousson, 1848))

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Abstract: The success of aquatic invasive species such as golden apple snails may be due to the fact that they are very adaptive and can live in wide range of environmental conditions. In contrast, native fauna such as Thai apple snails, which are less locally adaptive than exotic species, are gradually disappearing from their native ecosystems. This study investigated the environmental conditions in a habitat of golden apple snails (*Pomacea canaliculata*) and compared them with that of Thai native snails (*Pila scutata*). We also determined degrees of tolerance and growth rates between *P. canaliculata* and *P. scutata* raised in water of different qualities. The results revealed that in natural habitats of *P. canaliculata*, the water quality (dissolved oxygen (DO) 2.37 ± 0.04 mg l^{-1}, (biological oxygen demand (BOD_5) 10.40 ± 0.18 mg l^{-1}) was much poorer than that of *P. scutata* (DO 8.03 ± 0.01 mg l^{-1}, BOD_5 0.83 ± 0.01 mg l^{-1}). Furthermore, when the two types of snails were raised in water of different qualities in the laboratory (clean (DO7.79 $\pm$ 0.03 mg l^{-1}, BOD_5 1.15 ± 0.01 mg l^{-1}), moderately deteriorated (DO2.30 $\pm$ 0.07 mg l^{-1}, BOD_5 12.08 ± 9.80 mg l^{-1}) and deteriorated)DO 1.61 ± 0.03 mg l^{-1}, BOD_5 16.75 ± 6.51 mg l^{-1}), *P. canaliculata* consumed larger quantities of food than *P. scutata.* We observed no statistically significant difference between the growth rates of *P. canaliculata* and *P. scutata* in clean water. In contrast, in moderately deteriorated and deteriorated water, growth rates of *P. canaliculata* were significantly higher than those of *P. scutata*, thus implying that deteriorated water negatively influenced *P. scutata* whilst having no adverse effects on *P. canaliculata.* In addition, in deteriorated water, while *P. canaliculata* survived throughout the eight weeks of the experiment, all *P. scutata* had died by the end of week five. Our results show that *P. canaliculata* was more tolerant to different environmental conditions than *P. scutata*, therefore, making them a very successful invader.

Resumen: El éxito de las especies acuáticas invasoras, como los caracoles manzana dorados, puede deberse aque son muy adaptables y pueden vivir en una gama amplia de condiciones ambientales. Por el contrario, la fauna nativa como los caracoles manzana tailandeses, que son menos adaptables localmente que las especies exóticas, están desapareciendo gradualmente de sus ecosistemas nativos. Este estudio investigó las condiciones ambientales en un hábitat de los caracoles manzana dorados (*Pomacea canaliculata*) y las comparó con el de los caracoles tailandeses nativos (*Pila scutata*). También se determinaronlos grados de tolerancia y las tasas de crecimiento de *P. canaliculata* y *P. scutata* criados en agua de diferentes calidades. Los resultados mostraron que en los hábitats naturales de *P. canaliculata*, la calidad del agua (oxígeno disuelto [OD] 2.37 ± 0.04 mg l^{-1}, demanda biológica de

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oxígeno [DBO_5] 10.40 ± 0.18 mg l^{-1}) fue mucho más pobre que la de *P. scutata* (DO 8.03 ± 0.01 mg l^{-1}, DBO_5 0.83 ± 0.01 mg l^{-1}). Además, cuando los dos tipos de caracoles fueron criados en agua de diferentes calidades en el laboratorio (limpia; DO7.79 ± 0.03 mg l^{-1}, DBO_5 1.15 ± 0.01 mg l^{-1}), moderadamente deteriorada (DO2.30 ± 0.07 mg l^{-1}, BO_5 12.08 ± 9.80 mg l^{-1}) y deteriorada (DO 1.61 ± 0.03 mg l^{-1}, DBO_5 16.75 ± 6.51 mg l^{-1}), *P. canaliculata* consumió cantidades mayoresde alimento que *P. scutata*. No hubo diferencias estadísticamente significativas entre las tasas de crecimiento de *P. canaliculata* y *P. scutata* en agua limpia. Por el contrario, en agua moderadamente deteriorada y deteriorada, las tasas de crecimiento de *P. canaliculata* fueron significativamente más altas que las de *P. scutata*, lo que implica que el agua deteriorada influyó negativamente sobre *P. scutata* pero que no tuvo efectos adversos sobre *P. canaliculata*. Además, mientras que *P. canaliculata* sobrevivió a lo largo de las ocho semanas del experimentoen agua deteriorada, todos los individuos de *P. scutata* había muerto a finales de la quinta semana. Los resultados muestran que *P. canaliculata* fue más tolerante a las diferentes condiciones ambientales que *P. scutata*, lo que hace de ella unaespecie invasora muy exitosa.

Resumo: O sucesso de espécies aquáticas invasoras, tais como os caracóis aruá pode ser devido ao fato de que eles são muito adaptáveis e podem viver numa gama ampla de condições ambientais. Em contraste, a fauna nativa, tal como a dos "caracóis maçã tailandeses", que são localmente menos adaptáveis do que as espécies exóticas, estão desaparecendo gradualmente dos seus ecossistemas nativos. Este estudo investigou as condições ambientais num habitat de caracóis aruá (*Pomacea canaliculata*) e comparou-as com as dos"caracóis maçã tailandeses" (*Pila scutata*). Determinámos também os graus de tolerância e as taxas de crescimento entre a *P. canaliculata* e a *P. scutata* criados em água com diferentes qualidades. Os resultados revelaram que em habitats naturais de *P. canaliculata*, a qualidade da água (oxigénio dissolvido (DO) 2,37 ± 0,04 mg l^{-1}, (carência bioquímica de oxigénio (DBO_5) 10,40 ± 0,18 mg l^{-1}) era muito mais pobre do que a de *P. scutata* (DO 8,03 ± 0,01 mg l^{-1}, DBO_5 0,83 ± 0,01 mg l^{-1}). Além disso, quando os dois tipos de caracóis foram colocados em laboratório,em água de diferentes qualidades (limpa (DO 7.79 ± 0,03 mg l^{-1}, DBO_5 1,15 ± 0,01 mg l^{-1}), moderadamente deteriorada (DO 2.30 ± 0.07 mg l^{-1}, DBO_5 12,08 ± 9,80 mg l^{-1}) e deteriorada (DO 1,61 ± 0,03 mg l^{-1}, DBO_5 16,75 ± 6.51 mg l^{-1}), a *P. canaliculata* consumiumaiores quantidades de alimentos do que a *P. scutata*. Observámos que não se verificaram diferenças estatisticamente significativas entre as taxas de crescimento de *P. canaliculata* e *P. scutata* em água limpa. Em contraste, em água moderadamente deteriorada e deteriorada, as taxas de crescimento de *P. canaliculata* foram significativamente maiores do que as de *P. scutata*, implicando, assim, que a deterioração da água influenciou negativamente a *P. scutata* enquanto não teve efeitos adversos sobre a *P. canaliculata*. Além disso, na água deteriorada, enquanto a *P. canaliculata* sobreviveu ao longo das oito semanas de experiência, todos os *P. scutata* tinham morrido até o final daquintasemana. Os nossos resultados mostram que *P. canaliculata* foi mais tolerante às diferentes condições ambientais do que a *P. scutata*, que se torna, por isso, um invasor muito bem sucedido.

Key words: Apple snail, golden apple snail, invasive species, Thailand,water quality, wetland.

Introduction

Golden apple snail (*Pomacea canaliculata*) is a well-known invasive pest worldwide that was first introduced to Thailand from South America around 1984 (Keawjam & Upatham 1990). The main purposes of introduction were for a protein source for local consumption and as a regional export industry similar to other Asian countries such as Taiwan (Joshi & Sebastian 2006). The golden apple snails were also popular in the aquarium industry since they possess a beautiful appearance and a golden shell color. In aquariums, golden apple snails also helped control the growth of benthic algae and eliminated left over food (Thaewnon-ngiw *et al.* 2004). However, uses of *P. canaliculata* in the commercial food and aquarium industries, particularly in Thailand were not successful and thus leading to the spread of *P. canaliculata* into natural habitats across the country by both deliberate release and accidental introduction (Sri-aroon *et al.* 2007).

Nowadays, *P. canaliculata* and its pink eggs laid above water level are present and abundant in almost all types of aquatic habitats, particularly in Thailand. In contrast, indigenous snails, especially *Pila scutata*, have rarely been found in natural waters (Lauhachinda *et al.* 1988). It is questionable whether or not the absence of *P. scutata* is caused by the presence of *P. canaliculata* or by the deterioration of natural habitats making them unsuitable for *P. scutata* but suitable for *P. canaliculata*. The successful establishment and swift spread of golden apple snails outside their native range may be a result of the snails being well adapted to and having tenacious ability to colonize new and diverse habitats (Matthias 1994; Shan *et al.* 2011). In Thailand and Lao PDR, for example, *P. canaliculata* has appeared to survive even in polluted waters or in eutrophic conditions (Carlsson *et al.* 2004). In addition, a study in Japan shows that deteriorated water in the paddies did not have a detrimental effect on the snail growth and reproduction of *P. canaliculata* (Tanaka *et al.* 1999). In Hong Kong, it was found that water of high total phosphate and alkalinity was characteristic of sites inhabited by *P. canaliculata* (Kwong *et al.* 2008). In contrast, populations of Thai native apple snails, such as *P. scutata* (family Ampullariidae, the same family as *P. canaliculata*), have declined at a worrying rate in natural habitats and this could be linked to the fact that native snail species (*P. scutata*) may be less adapted and less tolerant to changing environmental conditions than a non-indigenous species (*P. canaliculata*). Therefore, environmental characteristics may or may not affect the colonization of apple snails both native and invasive species (Ito 2002; Kwong *et al.* 2008; Prasad 2012).

Little is known about the degrees of tolerance between *P. canaliculata* and *P. scutata* in different water quality habitats since most studies of *P. canaliculata* have focused on their direct effects on aquatic plants (Fang *et al.* 2010). Therefore, the main objectives of this study were to investigate the water quality between natural habitats of *P. canaliculata* and *P. scutata* and to determine the environmental tolerance between invasive golden apple snails (*P. canaliculata*) and Thai apple snails (*P. scutata*) that were raised in clean, moderately polluted and polluted water. The results will lead to an understanding of the ecology and specific traits of the two species that enable them to survive/not survive in nature and to highlight the effects of natural habitat deterioration that may not only cause the reduction of native species but also promoting the thriving invasion of alien species.

Materials and methods

Environmental characteristics of habitats of P. canaliculata and P. scutata

Pomacea canaliculata is widely distributed in Bangkok, Thailand. A natural habitat of *P. canaliculata* is the canals at Kasetsart University, Bangkok (13.847747″ N 100.57084″ E) whereas a natural habitat of *P. scutata* is canals in a palm oil plantation in Plaiwassub - district, Kanchanadit district, Surat Thani province (9° 09′ 56″ N 99° 28′ 16″ E), southern Thailand (Fig. 1). A habitat of *P. scutata* represents clear water state dominated by macrophytes and a habitat of *P. canaliculata* is a turbid phase dominated by phytoplankton. Sampling sites chosen were based on the presence of both snail species and sampling sites were quite homogenous in chemical characteristics. Five sampling stations were established in each of these two habitats and the criteria chosen to analyze the water quality parameters are based on Ito (2002), Carlsson & Lancoursiere (2005), Kwong *et al.* (2008) and Fang *et al.* (2010). The water quality parameters investigated in situ during May 2012 were: temperature (°C), transparency (cm) using a Secchi disc, conductivity (µS cm^{-1}), total dissolved solid (TDS; mg l^{-1}), pH and dissolved oxygen (DO; mg l^{-1}) using a multi-meter (Consort C933). Three liters of water were taken from each sampling station for further analysis in the laboratory of the Department of Environmental Technology and Management, Faculty of Environment, Kasetsart University. The physicochemical parameters measured were: total suspended solid (TSS; mg l^{-1}), total nitrogen (TN; mg l^{-1}) using ion chromatography (IC) nitrate method, nitrate nitrogen (NO_3-N; mg l^{-1}) using IC nitrate method, ammonium nitrogen (NH_4-N; mg l^{-1}) using Nessler's reagent, total phosphorus (TP; mg l^{-1}) using (soluble reactive phosphorus) SRP test tube method, soluble reactive phosphorus (SRP; mg l^{-1}) using SRP test tube method, chlorophyll a (mg l^{-1}) using acetone

Fig. 1. Sampling locations (▲) of natural habitats of *P. canaliculata* in Bangkok and of *P. scutata* in Surat Thani province. (Map source : http//www.asiawaves.net).

extraction and biological oxygen demand (BOD_5; mg l^{-1}) based on standard methods for the examination of water and wastewater (APHA 1998).

Environmental tolerance of P. canaliculata and P. scutata

In this study, we tested our hypothesis of whether *P. canaliculata* and *P. scutata* could survive in clean, moderately deteriorated and deteriorated water specifically with respect to different dissolved oxygen and BOD conditions. A clean water sample was obtained from a tap (the water was chlorinated) linked to the reticulated water system of Kasetsart University (DO 7.79 ± 0.03 mg l^{-1}, BOD_5 1.15 ± 0.01 mg l^{-1}) whereas moderately deteriorated)DO 2.30 ± 0.07 mg l^{-1}, BOD_5 12.08 ± 9.80 mg l^{-1}) and deteriorated water samples)DO 1.61 ± 0.03 mg l^{-1}, BOD_5 16.75 ± 6.51 mg l^{-1}) were collected from natural water bodies at Kasetsart University, Thailand. Samples of *P. canaliculata* were collected at random from canals at Kasetsart University whereas *P. scutata* specimens were collected from its habitat in Plaiwas sub-district, Kanchanadit district, Surat Thani province, southern Thailand. We raised both snails until they produced eggs. Eggs of both snails were then incubated in separate containers at constant room temperature (approx. 30 degree Celsius) in a laboratory. After hatching, water spinach (*Ipomoea aquatic*) was used to feed both species before the snails were used in the experiments. Samples of *P. canaliculata* and *P. scutata* (each weighing approximately two grams) were maintained in aquaria for two weeks before the initiation of the experiments. Due to limited numbers of *P. scutata* in its natural habitat, one *P. canaliculata* and one *P. scutata* were raised separately in 1,000 ml plastic containers filled with 500 ml water at a constant room temperature in the indoor laboratory for eight weeks with three replicates for validity. Water level was maintained during rearing although water levels did not change much during the experiment. Prior to and during the experiment, growth rates (shell height, weight and width of all snails) were measured every week by a Vernier caliper. During the experiment, both species of snails were fed daily and sufficiently with water spinach (*Impomoea aquatica*) and the food consumption of each snail was recorded as well as the number of snails (*P. canaliculata* and *P. scutata*) that died during the experiment. Measurement of water quality before and after the experiment was also studied. Parameters measured were temperature (ºC), conductivity (µS cm^{-1}), total dissolved solid (TDS; mg l^{-1}), pH and dissolved oxygen (DO; mg l^{-1}), total suspended solid (TSS; mg l^{-1}), ammonium nitrogen (NH_4-N; mg l^{-1}), soluble reactive phosphorus (SRP; mg l^{-1}) and biological oxygen demand (BOD_5; mg l^{-1}) based on standard methods for the examination of water and wastewater (APHA 1998).

Data were presented as the mean ± standard deviation. A t-test Excel 2010 was used to differentiate the water quality between habitats of *P. canaliculata* and *P. scutata* as well as to distinguish the growth rates and food consumption of both snails in water samples of different quality.

Table 1. Water quality analysis of natural habitats of *P. canaliculata* and *P. scutata* (n = 5).

Parameters	Results	
	Habitat of *P. canaliculata*	Habitat of *P. scutata*
pH	7.86 ± 0.19^a	7.2 ± 0.16^b
transparency (m)	0.50 ± 0.06^a	0.44 ± 0.11^a
water temperature (°C)	31.60 ± 0.90^a	28.80 ± 0.00^b
Conductivity (µS cm^{-1})	654.00 ± 11.94^a	304.00 ± 19.85^b
TSS (mg l^{-1})	0.01 ± 0.01^a	0.08 ± 0.06^a
TDS (mg l^{-1})	335.50 ± 23.76^a	160.80 ± 9.10^b
DO(mg l^{-1})	2.37 ± 0.19^a	8.03 ± 0.11^b
BOD_5 (mg l^{-1})	10.40 ± 0.42^a	0.83 ± 0.10^b
TN (mg l^{-1})	9.12 ± 0.88^a	1.94 ± 1.63^b
NH_4-N (mg l^{-1})	0.06 ± 0.01^a	0.56 ± 0.42^b
NO_3 - N(mg l^{-1})	0.02 ± 0.01^a	0.03 ± 0.03^a
TP (mg l^{-1})	0.87 ± 0.03^a	0.21 ± 0.07^a
SRP(mg l^{-1})	0.54 ± 0.01^a	0.09 ± 0.01^b
chlorophyll a (mg l^{-1})	0.23 ± 0.02^a	0.01 ± 0.01^b

Remark: Same superscript letters (^{a,a}) in a row indicate no differences among data and different superscript letters (^{a,b}) indicate significant differences among data at $P < 0.05$.

Results

Environmental characteristics of habitats of P. canaliculata and P. scutata

Environmental characteristics of the natural habitats of *P. canaliculata* and *P. scutata* are presented in Table 1. The results show that the environmental parameters differed remarkably among the two types of habitats. Overall, the habitat of *P. scutata* had better water quality by high DO (8.03 ± 0.11 mg l^{-1}), low nutrient concentrations and low BOD_5 (0.83 ± 0.10 mg l^{-1}). In contrast, the habitat of *P. canaliculata* had relatively low DO (2.37 ± 0.19 mg l^{-1}), high nutrient contents and high BOD_5 (10.40 ± 0.42 mg l^{-1}). In addition, statistical analysis indicated that most water quality parameters such as BOD_5, NH_4-N, NO_3-N, SRP and chlorophyll a were significantly different between the habitats of *P. canaliculata* and *P. scutata* at 95 % confidence level.

Environmental tolerance of P. canaliculata and P. scutata

This section shows the results of the two types of snails that were raised in different water quality samples (clean (DO 7.79 ± 0.03 mg l^{-1}, BOD_5 1.15 ± 0.01 mg l^{-1}), moderately deteriorated (DO 2.30 ± 0.07 mg l^{-1}, BOD_5 12.08 ± 9.80 mg l^{-1}) and deteriorated)DO 1.61 ± 0.03 mg l^{-1}, BOD_5 16.75 ± 6.51 mg l^{-1}). It was discovered that *P. canaliculata* consumed a greater amount of food than *P. scutata* in all types of water and this over all resulted in faster growth rates (weight, height and width) of *P. canaliculata* than of *P. scutata* (Table 2). It was also found that food consumption of both snails was overall greater when they were raised in clean water rather than in deteriorated water. The survival rates of *P. canaliculata* and *P. scutata* in clean water were not different since all snails survived the experiment. However, in moderately deteriorated and deteriorated water, the survival rate of *P. canaliculata* was markedly higher than that of *P. scutata.* It was also found that in deteriorated water, all *P. scutata* died by week five of the experiment whereas *P. canaliculata* individuals were still alive at the end of the study.

P. canaliculata and *P. scutata* had caused significant changes in water qualities too. It was observed that water quality of *P. canaliculata* and *P. scutata* (in clean, moderately deteriorated and deteriorated conditions) prior to and at the end of experiment showed similar results (Table 3). Con-

Table 2. Comparison of food consumption, growth rates and survival of *P. canaliculata* and *P. scutata* in clean, moderately deteriorated and deteriorated water over eight weeks (n = 3).

Parameters	Types of water					
	Clean		Moderately deteriorated		Deteriorated	
	P. canaliculata	*P. scutata*	*P. canaliculata*	*P. scutata*	*P. canaliculata*	*P. scutata*
Food consumption (g(	6.84 ± 3.46[a]	4.26 ± 1.59[b]	9.14 ± 1.05[a]	3.20 ± 0.93[b]	2.76 ± 0.91[a]	0.57 ± 0.51[b]
Growth rates of snails						
Weight) g(	10.40 ± 3.37[a]	9.32 ± 1.21[a]	14.46 ± 2.25[a]	7.87 ± 1.26[b]	11.90 ± 2.62[a]	4.88 ± 4.06[b]
Width (cm(	4.38 ± 1.91[a]	3.27 ± 0.72[b]	4.03 ± 0.57[a]	2.98 ± 0.44[b]	3.59 ± 0.50[a]	1.69 ± 1.40[b]
Height (cm(	4.48 ± 1.91[a]	3.37 ± 0.72[b]	4.14 ± 0.57[a]	3.01 ± 0.50[b]	3.69 ± 0.50[a]	1.75 ± 1.45[b]
Survival (%(	100.00 ± 0.00	100.00 ± 0.00	100.00 ± 0.00	87.50 ± 17.25	83.33 ± 25.20	58.33 ± 49.60

Remark: Same superscript letters ([a,a]) in rows indicate no differences among data and different superscript letters ([a,b]) in rows indicate significant differences($P < 0.05$) among data.

centrations of nutrients (NH_4-N and SRP) decreased remarkably from the beginning to the end of the experiment. BOD substantially increased during the experiment whereas dissolved oxygen concentrations showed a decline down to nearly 0 mg l^{-1} towards the end of the study. Other parameters including temperature, pH and conductivity were relatively comparable from the beginning toward the end of the experiment.

Discussion

Environmental characteristics of habitats of P. canaliculata and P. scutata

Populations of *P. scutata* have declined especially in central Thailand (Lauhachinda *et al.* 1988) possibly due to habitat alteration and deterioration of water quality. In fact, *P. scutata* native snails tended to be present mostly in southern and northeastern Thailand (Thaewnonngiw *et al.* 2004). From direct observation, the canal where *P. scutata* populations were found in the southern province of Surat Thani had not been affected much by human activities as indicated by good water quality (Table 1). The studied canal was also dominated by aquatic vegetation such as *Impomoea aquatic* and was in a clear water state. Therefore, this study suggested that *P. scutata* may be a good indicator of typical pristine freshwater habitats. In contrast, the canal where *P. canaliculata* was present in high numbers was more disturbed and polluted. It was phytoplankton dominated and turbid phase with the absence of aquatic macrophytes. This is in agreement with Carlsson *et al.* (2004) discovering that a survey of natural wetlands in Thailand showed that high densities of *P. canaliculata* were associated with almost complete absence of aquatic plants, high nutrient concentrations, and high phytoplankton biomass. The study of Kwong *et al.* (2008) also revealed that water of high total phosphate and alkalinity was characteristic of sites inhabited by *P. canaliculata* in Hong Kong. Thus, it could be concluded that *P. canaliculata* is a good indicator of high nutrients and turbid water dominated by phytoplankton.

Environmental tolerance of P. canaliculata and P. scutata

Under suitable clean water condition, both *P. canaliculata* and *P. scutata* fed well but in contrast under unsuitable deteriorated environmental conditions, both *P. canaliculata* and *P. scutata* fed at a lower rate. It was also found that *P. canaliculata* tended to grow at faster rates than *P. scutata* in all water quality conditions. This was in agreement with Morrison & Hay (2011) who indicated that *P. canaliculata* tended to eat more, grow more, and had higher conversion efficiencies than the native *Pomacea paludosa* of the United States of America. Conner *et al.* (2008) also found that the invasive *P. insularum* grow better than native species and they can be up to four times heavier than the native *P. paludosa*. Furthermore, this study clearly showed that *P. canaliculata* was more tolerant to different environmental conditions than *P. scutata*, thus making the former species a successful invader. This is because in deteriorated water, *P. canaliculata* survived throughout the eight weeks of the experiment but in contrast all *P. scutata* had died by the end of week five of the study. Matthias (1994) revealed

Table 3. Comparison of water quality before and after the experiment of *P. canaliculata* (A) and *P. scutata* (B) in clean, moderately deteriorated and deterioratedover eight weeks (n = 3).

(A) *P. canaliculata*

Parameters	Clean		Moderately deteriorated		Deteriorated	
	Before	After	Before	After	Before	After
pH	7.23 ± 0.05[a]	6.02 ± 0.33[b]	7.77±0.21[a]	6.18 ± 0.22[b]	7.45 ± 0.18[a]	6.54 ± 0.11[b]
Temperatures (°C)	28.64 ± 0.53[a]	28.71 ± 0.81[a]	29.43 ± 1.16[a]	29.05 ± 0.73[a]	28.91 ± 0.93[a]	29.05 ± 0.69[a]
Conductivity (μS cm^{-1})	401.02 ± 4.01[a]	470.74 ± 24.84[b]	656.50 ± 11.72[a]	638.73 ± 72.87[a]	863.28 ± 25.51[a]	964.84 ± 40.84[b]
TSS (mg l^{-1})	0.02 ± 0.01[a]	1.62 ± 1.03[b]	0.14 ± 0.05[a]	0.28 ± 0.11[b]	0.16 ± 0.09[a]	0.26 ± 0.13[b]
TDS (mg l^{-1})	210.21 ± 4.02[a]	252.44 ± 24.84[b]	349.28 ± 10.62[a]	349.63 ± 31.91[a]	472.54 ± 4.93[a]	524.00 ± 32.73[b]
DO (mg l^{-1})	7.79 ± 0.18[a]	0.29 ± 0.34[b]	2.30 ± 0.26[a]	0.08 ± 0.01[b]	1.61 ± 0.16[a]	0.05 ± 0.01[b]
BOD_5 (mg l^{-1})	1.15 ± 0.09[a]	86.06 ± 8.51[b]	12.08 ± 3.13[a]	88.85 ± 7.05[b]	16.75 ± 2.55[a]	114.09 ± 26.07[b]
NH_4-N (mg l^{-1})	0.01 ± 0.01[a]	2.31 ± 0.66[b]	6.93 ± 0.78[a]	7.27 ± 0.59[b]	1.27 ± 0.18[a]	3.65 ± 0.59[b]
SRP (mg l^{-1})	0.001 ± 0.001[a]	1.56 ± 0.49[b]	0.80 ± 0.15[a]	1.88 ± 0.33[b]	1.15 ± 0.15[a]	1.65 ± 0.33[b]

(B) *P. scutata*

Parameters	Clean		Moderately deteriorated		Deteriorated	
	Before	After	Before	After	Before	After
pH	7.23 ± 0.05[a]	6.36 ± 0.40[b]	7.77 ± 0.21[a]	6.46 ± 0.30[b]	7.45 ± 0.18[a]	6.53 ± 0.23[b]
Temperatures (°C)	28.64 ± 0.53[a]	28.82 ± 0.76[a]	29.43 ± 1.16[a]	29.14 ± 0.75[a]	28.91 ± 0.93[a]	28.90 ± 0.76[a]
Conductivity (μS cm^{-1})	401.02 ± 4.01[a]	486.18 ± 30.47[b]	656.50 ± 11.72[a]	668.04 ± 32.68[a]	863.28 ± 25.51[a]	1,038.38 ± 69.21[b]
TSS (mg l^{-1})	0.02 ± 0.01[a]	0.92 ± 0.73[b]	0.14 ± 0.05[a]	0.33 ± 0.19[b]	0.16 ± 0.09[a]	0.30 ± 0.09[b]
TDS (mg l^{-1})	210.21 ± 4.02[a]	269.23 ± 20.39[b]	349.28 ± 10.62[a]	388.73 ± 28.19[b]	472.54 ± 4.93[a]	528.70 ± 11.27[b]
DO (mg l^{-1})	7.79 ± 0.18[a]	0.19 ± 0.06[b]	2.30 ± 0.26[a]	0.22 ± 0.10[b]	1.61 ± 0.16[a]	0.13 ± 0.19[b]
BOD_5 (mg l^{-1})	1.15 ± 0.09[a]	79.21 ± 1.63[b]	12.08 ± 3.13[a]	87.70 ± 5.87[b]	16.75 ± 2.55[a]	103.26 ± 16.52[b]
NH_4-N (mg l^{-1})	0.01 ± 0.01[a]	2.45 ± 0.41[b]	6.93 ± 0.78[a]	8.00 ± 1.05[b]	1.27 ± 0.18[a]	3.60 ± 0.59[b]
SRP (mg l^{-1})	0.001 ± 0.001[a]	1.51 ± 0.44[b]	0.80 ± 0.15[a]	1.86 ± 0.32[b]	1.15 ± 0.15[a]	1.77 ± 0.22[b]

that *Pomacea* snails are well adapted to life in alternating wetland and dryland since they have both gills and a lung-like breathing organ that can breathe in water and in air. Ichinose *et al.* (2000) also supported our finding that *P. canaliculata* abundance was positively correlated with COD, indicating that this snail has adapted to more polluted water. The adaptability of *P. canaliculata* is not confined to Southeast Asia but to any location with wetlands and a warm climate (Teo 2004). From the current study, it is worrying that deterioration of natural habitats in Thailand due to residential, agricultural and industrial expansion has had a strong adverse effect on the survival rate of and decreases the numbers of *P. scutata,* the native snail species.

Water quality in clean, moderately deteriorated and deteriorated conditions of both *P. canaliculata* and *P. scutata* changed remarkably throughout the experiment (Table 3). It can be stated that both *P. canaliculata* and *P. scutata* can lower water quality. This is consistent with Carlsson *et al.* (2004) and Carlsson & Lacoursière (2005) stating that golden apple snails can increase the nutrient concentrations of the water. *P. canaliculata* may lower water quality through waste excretion since the snails fed more food than *P. scutata.* However, it is uncertain whether waste excretion from *P. canaliculata* or left over food in containers of *P. scutata* has a strong effect on water quality or both. Further investigations are required to explain actual effects (waste or leftover food) on water quality. Certainly, a field experiment of Carlsson *et al.* (2004) showed that grazing of aquatic macrophytes by *P. canaliculata* can cause a change of water quality toward dominance of planktonic algae, potentially as a consequence of the release of nutrients from the snails (Fang *et al.* 2010).

In conclusion, this study clearly indicated that *P. canaliculata* was more tolerant and better adapted to a wider range of environmental conditions (clean, moderately deteriorated and deteriorated water) than native *P. scutata.* This crucial trait has led *P. canaliculata* to successfully establish and spread into a diverse range of habitats. In contrast, native *P. scutata* is less tolerant, especially in a deteriorated environment, thus making it worryingly vulnerable to a decrease in its population levels. It could be concluded that if environment quality continues to deteriorate as a result of anthropogenic impact, native organisms such as *P. scutata* may well face extinction. In parallel with these losses, poor water quality may, in contrast, facilitate the successful invasion of non-indigenous invasive species like *P. canaliculata.*

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