Proceedings of the National Symposium on Invasive Alien Species (IAS 2008), (Ranwala S. M. W., ed), Sri Lanka Association for the Advancement of Science

Habitat characteristics and population parameters of invasive alien golden apple snail, *Pomacea diffusa* in Western province, Sri Lanka

G. D. T. Perera and U. P. K. Epa

Department of Zoology

University of Kelaniya, Dalugama, Kelaniya

Abstract

Golden apple snail, *Pomacea diffusa* has been introduced to Sri Lanka by ornamental fish industry in 1980s. They became popular among ornamental fish hobbyists due to their varying colors, mainly the brownish red, brown and bright golden yellow and their scavenging feeding habit. However, later they became a burden to the aquarists when they were overpopulated and the ultimate result was to release them into natural environment. At the initial stages this practice was restricted to Colombo and suburbs and later such events were recorded in Kaluthara, Kandy, Ratnapura, Gampaha, Matara and Galle. This highlights the possibility of spreading of snails in to other areas in the country in future. The present study investigates the habitat characteristics and some population parameters of *P. diffusa* in the western province, Sri Lanka.

Overall average density of snails ranged from 42 to 164 m^{-2}. Percentage occurrence of length classes of 0-1, 1-2, 2-3, 3-4 cm were 20, 40, 17 and 23 %, respectively. Length-height relationship of snails was, length = 1.16 height + 0.0027; $R^2 = 0.98$ and length - weight relationship was curvilinear with the equation of, weight = 0.36 $lenght^{2.79}$; $R^2 = 0.97$.

Water temperature, pH, dissolved oxygen (DO), conductivity, biological oxygen demand (BOD_5), total suspended solids (TSS), soil organic matter (SOM), and water level of theri environment ranged from 26.8 ^{0}C – 32.8 ^{0}C, 6.3 - 7.3, 1.1 - 1.8 mg/l, 280.0 - 516.6 μS/cm, 0.5 - 1.0 mg/l, 0.03 - 0.07 mg/l, 5.9 – 14.1% and 29.4 cm - 46.8 cm, respectively in the snail habitats. There was a significant relationship ($p<0.05$) between the number of freshly laid egg masses and the rainfall of the area. Similarly number of egg- masses and height to the highest egg- mass from the water level was positively correlated ($p<0.05$) with the snail abundance. Snail abundance was inversely related ($p<0.05$) to water temperature, water level of the habitat, and SOM. Water pH, DO, TSS and BOD_5 did not show a correlation ($p> 0.05$) with snail abundance. High rainfall could have a positive effect on spread and distribution of snails and high water temperature, high water level and high SOM in the habitat may affect distribution of golden apple snails in Sri Lanka.

Key words: *Pomacea diffusa*, Invasive, Snail, Rainfall, Population

Introduction

During the past decades intentional or accidental introductions of alien species have severely affected the native species composition in many countries (Rainbow, 1998) and these introductions of species have been identified as the second greatest threat to biodiversity after the habitat loss (Clout, 1995; Barney *et al.*, 2005). These exotic or alien species are deliberately introduced as food sources, as pest controllers, as raw materials, etc, in almost all the sectors including agriculture, tourism, forestry, fisheries, pet trade, horticultural industry and many other industries worldwide (Williamson, 1996; Davis and Thompson, 2000; Daehler, 2000; Kolar and Lodge, 2001; McNeely, 2002). However, accidental introduction of species is considered as the major factor that has contributed to the introduction of invasive species in the world. These species may be beneficial in one region while detrimental in some other area.

Invasive alien species have been caused extinction of native species, especially in 'islands' (Clout, 1995). Sri Lanka being an island there is a growing concern to control invasive species and attempts have already being made to identify invasive biota in Sri Lanka and to generate public awareness (Ekanayake and Rathnayake, 1996; Gunawardana 1996; Bossard 1997; Bambaradeniya *et al.*, 1998; Kumara *et al.*, 1999; Marambe *et al.*, 2003; Epa, 2006).

Freshwater gastropod members in family Ampullariidae, which are commonly named as apple snails have an impressive track record as invasive species (Timothy *et al.,* 2007). Species belong to three genera, *Pila, Pomacea* and *Marisa* have a tenacious ability to survive and spread rapidly in the freshwater habitats into which they have introduced (Cowie, 1995). *Pomacea* spp. are naturally occurring in tropical and subtropical habitats in Africa, South and Central America and Asia (Cazzaniga, 2006; Cowie *et al.*, 2006). However introduction of one of the golden apple snail species, *P. canaliculata*, also known as channelled apple snail, in to many parts of the Asia has caused severe economic damage to agricultural crops (Naylor, 1996). Presently, golden apple snails are considered as one of the rapidly spreading invasive species in Asia (Halwart, 1994; Naylor, 1996; Cowie *et al.*, 2006). The invasions of apple snails have been not only a threat to local agricultural economies (Halwart, 1994; Naylor, 1996) but also the structure and the functioning of wetlands as the snail consumes rice and naturally occurring aquatic plants (Carlsson, *et al.*; 2004), respectively.

There is only one species of apple snails (Familly: Ampullariidae) native to Sri Lanka and it is *Pila globosa.* It is inhabited in stagnant waters, paddy fields and slow flowing streams (Mordan *et al.*, 2003). The *Pomacea* species introduced to Sri Lanka was misidentified as *P.*

canaliculata by several authors (Gunawardena, 1996; Kumara *et al.,* 1999; Bambaradeniya *et al.,* 2001). Recently scientists have identified that the species found in Sri Lanka is not *P. canaliculata* but it is *P. diffusa* (Cowie *et al.,* 2002; Cowie *et al.*, 2006).

Pomacea. diffusa (Fig. 1) have been introduced to Sri Lanka by ornamental fish industry as a pet (Gunawardena, 1996; Kumara *et al.*, 1999; Mordan *et al.*, 2003; Epa, 2006). They became popular among ornamental fish hobbyists due to their colors mainly the brown, brownish red and bright golden yellow and due to their scavenging feeding habit on algae. Their population densities increased rapidly as their reproductive rate was very high. Since their introduction in 1980s they became a burden to the aquarists due to their prolific breeding. As a result aquarists released them into natural environment, which provided the most conducive habitat for golden apple snail. At the initial stage this practise was restricted to Colombo region but now these snails have been recorded in Kalutara, Kandy, Ratnapura, Gampaha, Matara and Galle (Mordan *et al.,* 2003). There is a possibility of spreading of GAS in to other areas in the country in future.

Although, *P. canaliculata* has been recognized as a serious rice pest in many parts of South East Asia (Naylor, 1996; Yusa and Wada, 1999, Cowie *et al.*, 2006) it has not been still recorded in Sri Lanka but can be a next 'harmful visitor' in near future. *P. canaliculata* has been extremely studied due to its threat to paddy cultivation. Because of its economic importance, different aspects of its biology (Cazzaniga, 2002; Candida *et al.*, 2006), genetics (Zenaida and Roberto, 2006), morphology and control practices (Stevens, 1999; Carlsson, 2006; Yusa, 2006; Wada, 2006) have been carried out. As *P. diffusa* is one of the closed related species of *P. canaliculata* (Cowie *et al.*, 2006), there can be adverse effect of *P. diffusa* on the natural and agricultural ecosystems of Sri Lanka.

Most of the ecological factors or habitat characteristics of *P. diffusa* have not been studied in Sri Lanka or elsewhere in Asia. In particular, the relationship between environmental factors and the density of the snails has been poorly investigated. As *P. diffusa* is spreading rapidly in natural environments in Sri Lanka, factors that affect their distribution and their population parameters should be investigated. Management of an alien species could only be successful against a background of clear understanding of the ecology of that particular species.

Methodology

Four streams in Kanuwana, Tudella, Wewelduwa and Dalugama in the Western Province, Sri Lanka where *P. diffusa* was found were selected as sampling sites. All the selected streams were less than 3 m in width and were shady and shallow with muddy bottoms. Each sampling site was visited once a month from July 2006 to December 2006. Field sampling was carried out from 9.00 a.m. to 2.30 p.m. in each field working day.

The water temperature of each site was measured using the standard glass mercury thermometer. Water pH (pH meter, Model WTW-Ph-315i), dissolved Oxygen (DO meter, Model WTW-OXI- 315i), conductivity (mini-conductivity meter, Model 17250) and salinity (Refractrometer, Model ATAGO S-28) were measured *in situ.* The water transparency was measured using a Secchi disk. Water depth of each study stream was measured using the meter ruler at three sampling areas and the average water level was calculated. Total soluble solids in water (TSS) and soil organic matter (SOM) were measured according to AOAC (1990). Monthly rainfall data for the study period were gathered from the Meteorological Department of Sri Lanka.

Live specimens of *P. diffusa* were collected by dragging a hand net (diameter 25cm, mesh size 1mm) over a $1m^2$ area. They were collected in polythene bags and brought to the laboratory for further studies. At each study site, $400cm^2$ quadrate was thrown away randomly and the *Pomacea* snails in five attempts were counted and average was calculated per one m^2 as snail density.

Length, weight and height of 797 snails were measured. Before taking the measurements live snails were kept without disturbances for two hours to released excess water in their palial chamber. Then their wet weight was taken using the electrical balance (Model OHAUS/ China). Their length (L) and height (H) was measured using a vernier calliper as in Figure 2. All the measurements were taken site wisely. Considering their length values they were grouped into 5 classes as small (0 – 1 cm), young (1 – 2 cm), mature (2 – 3 cm) and adult (3 – 4 cm) and counts were taken. Then the snails brought to the laboratory were killed to avoid the unnecessary accidental introduction to the university premises by adding formalin.

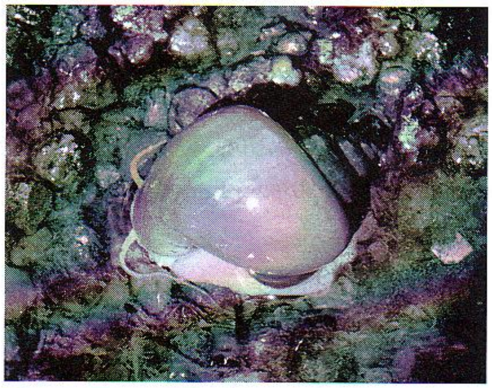


Figure 1. *Pomacea diffusa* in a shallow stream

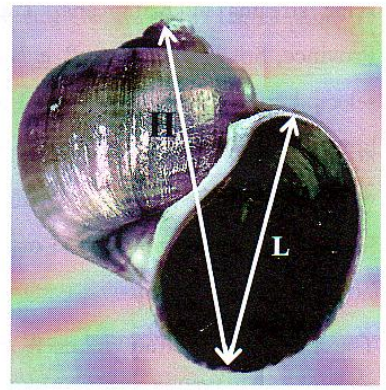


Figure 2: The length (L) and height (H) measurements of *Pomacea* sp.

Number of undamaged, freshly laid egg masses in one m^2 area was counted and the colours of the egg-masses were used to identify the freshly laid egg-masses. Newly laid egg-masses are bright pinkish-red in colour, which fades to light pinkish and then grayish before hatching (Teo, 2004). Only bright pinkish-red egg-masses were counted. The height to the highest newly laid egg-mass from the water surface was measured using the meter ruler to monitor the aerial mobility of the female snails during oviposition.

Predators of apple snails and egg masses were visually observed during the sampling period. Cast net (mesh size 3.5cm) and hand net (Mesh size 5mm) were used to sample co-occurring fish in the selected habitats.

Length, weight and height data of snails were regressed to find out their relationships. Physico-chemical parameters, rainfall, number of egg masses and snail density of each site were statistically analyzed using one-way ANOVA to identify site wise differences. As site wise variations in physico-chemical parameters and biological parameters were not observed means of measured parameters of four sites were calculated and the relationships were enumerated using correlation for pooled data. The statistical package used for data analysis was Minitab for Windows (version11/14).

Results

Colour variation of snails

Smaller snails (>1cm) had a pale yellowish shell colour. Colour variation of snails larger than one cm varied from bright yellow, dark brownish black, brown, brownish red to orange.

Snail density

This study revealed dense permanent settlements of *P. diffusa* in the streams in the western province. The snail density ranged from 42 to 164 m^{-2}. Initially it was 140 m^{-2} in July but in September, 2006 it has reduced to 42 m^{-2}, reporting the minimum density. However, more than 100 snails m^{-2} was recorded throughout the study period except in September, 2006.

The size structure of the snail population (Fig. 3) was regular with the presence of all size classes during the study period. Average percentage occurrence of length classes of 0-1 (small), 1-2 (medium), 2-3 (mature), 3-4 (adult) cm were 20, 40, 17 and 23 %, respectively. Very low number of snails belongs to 0 – 1 cm length class was observed during October and November 2006 with the onset of heavy rains. Relatively the highest numbers of snails were belonging to the 1-2 cm length class.

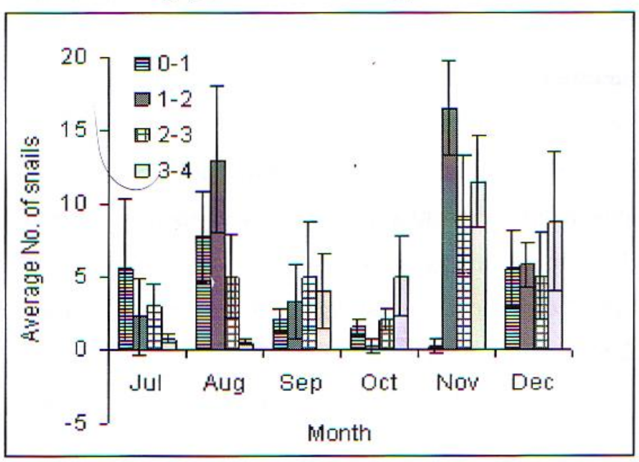


Figure 3. Mean ±Sd of different length classes of *P. diffusa* during the study period

The recorded highest length and height for *P. diffusa* were 4.01cm and 5.23cm, respectively. Length-height relationship of snails was, length = 1.16 height + 0.0027; R^2 = 0.98 (Fig. 4 (a)). The highest weight of snail recorded was 18.5g. Length - weight relationship was curvilinear with the equation of, weight = 0.36 $lenght^{2.79}$; R^2 = 0.97 (Figure 4(b)). Length – height and length- weight relationships of snails show the continuous growth of *P. diffusa* under the present environmental conditions in the Western province, Sri Lanka.

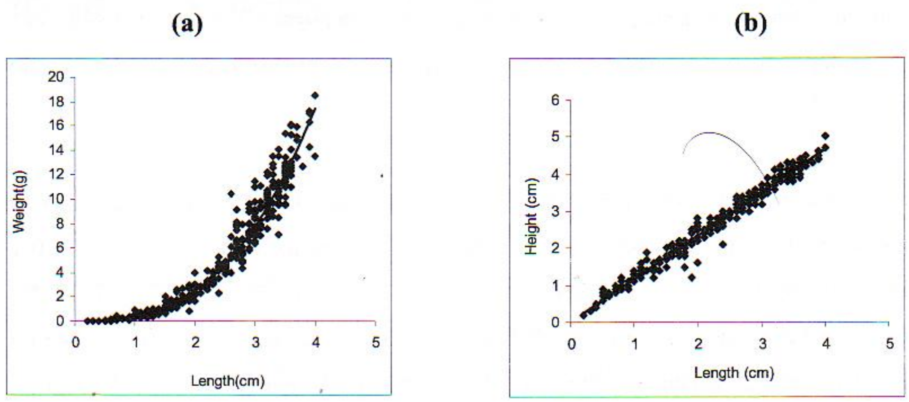


Figure 4. Length – Weight (a) and length – height (b) relationships of *P. diffusa*

Water quality parameters

Site specific variations in water quality parameters were not detected in the present study (Oneway ANOVA, p>0.05). However, the establishment success of snails was evidently facilitated by relatively favourable environmental conditions recorded in the study. Water temperature, pH, dissolved oxygen (DO), conductivity, biological oxygen demand (BOD_5), total suspended solids (TSS), soil organic matter (SOM), and water level ranged from 26.8 ^{0}C – 32.8 ^{0}C, 6.3 - 7.3, 1.1 - 1.8 mg/l, 280.0 - 516.6 μS/cm, 0.5 - 1.0 mg/l, 0.03 – 0.07 mg/l, 5.9 – 14.1 % and 29.4 cm - 46.8 cm, respectively in the snail habitats (Table 1).

Table 1. Mean ± SD of Water temperature, pH, dissolved oxygen (DO), conductivity, biological oxygen demand (BOD_5), total suspended solids (TSS), soil organic matter (SOM), and water level in snail habitats from July – December 2006.

MONTH	Temperature (°C)	pH	DO (mg/l)	Conductivity (µS/cm)	BOD_5 (mg/l)	TSS (mg/l)	SOM (%)	Water Level (cm)
July	29.7±0.8	7.3±.4	1.8±1.1	300.8±21.2	1.0±0.3	0.07±0.04	5.9±11.5	43.0±12.2
August	32.8±0.1	6.6±1.2	1.8±0.8	280.0±14.0	1.0±0.8	0.05±0.02	8.7±3.5	46.8±16.5
September	30.8±0.3	6.5±1.1	1.2±0.9	377.4±12.5	0.8±0.5	0.05±0.02	14.1±1.8	42.6±18.0
October	29.1±0.4	6.3±1.4	1.1±1.0	305.0±23.6	0.5±0.4	0.06±0.01	7.2±1.9	29.4±12.2
November	27.1±0.8	6.4±1.1	1.6±1.3	302.5±22.0	0.7±0.4	0.03±0.0	8.5±1.5	32.3±21.0
December	26.8±0.5	6.5±1.5	1.5±0.5	516.6±47.3	0.7±0.5	0.06±0.03	12.1±1.0	39.8±13.2

Egg masses

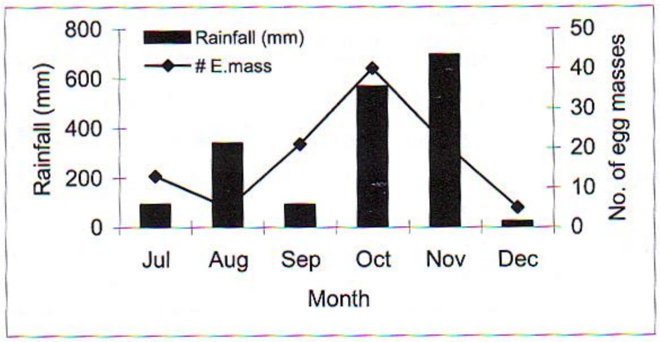
The conspicuous, aerial egg masses of *P. diffusa* were observed on concrete dykes, wooden stakes, discarded plastic cans, tree trunks, aquatic plants etc. Number of freshly laid egg masses varied from 5 – 40 m^2 in the sampling sites and fresh egg masses were observed in all the sampling days.

There was a significant correlation ($p<0.05$) between the number of freshly laid egg masses and the rainfall of the area (Fig. 5(a)). The height to egg mass from the water level ranged from 5 – 52 cm. Snail density and height to the highest egg- mass from the water level and snail density and rainfall were positively correlated ($p<0.05$) (Figs. 5(b) & 4(c)).

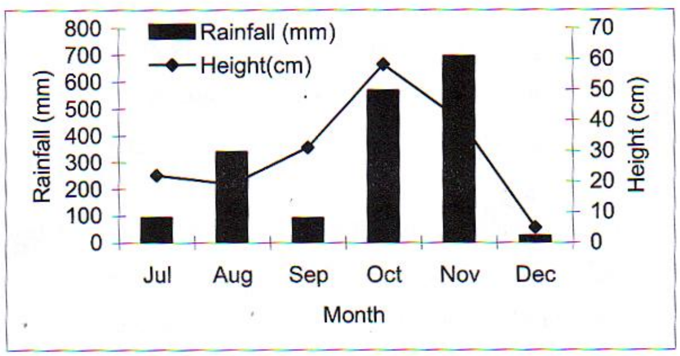
Snail abundance was inversely related ($p<0.05$) to water temperature ($p=0.04$), water level of the habitat ($p=0.04$), and SOM ($p=0.03$) (Figure 6).

Water pH, DO, TSS and BOD_5 did not show a significant correlation ($p> 0.05$) with snail abundance.

(a)



(b)



(c)

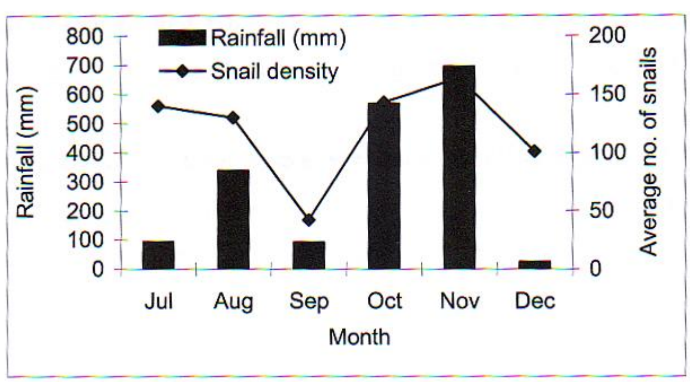


Figure 5. Change of number of egg masses (a), height to the highest egg mass (b) and number of snails (c) with the rainfall in *P. diffusa* habitats

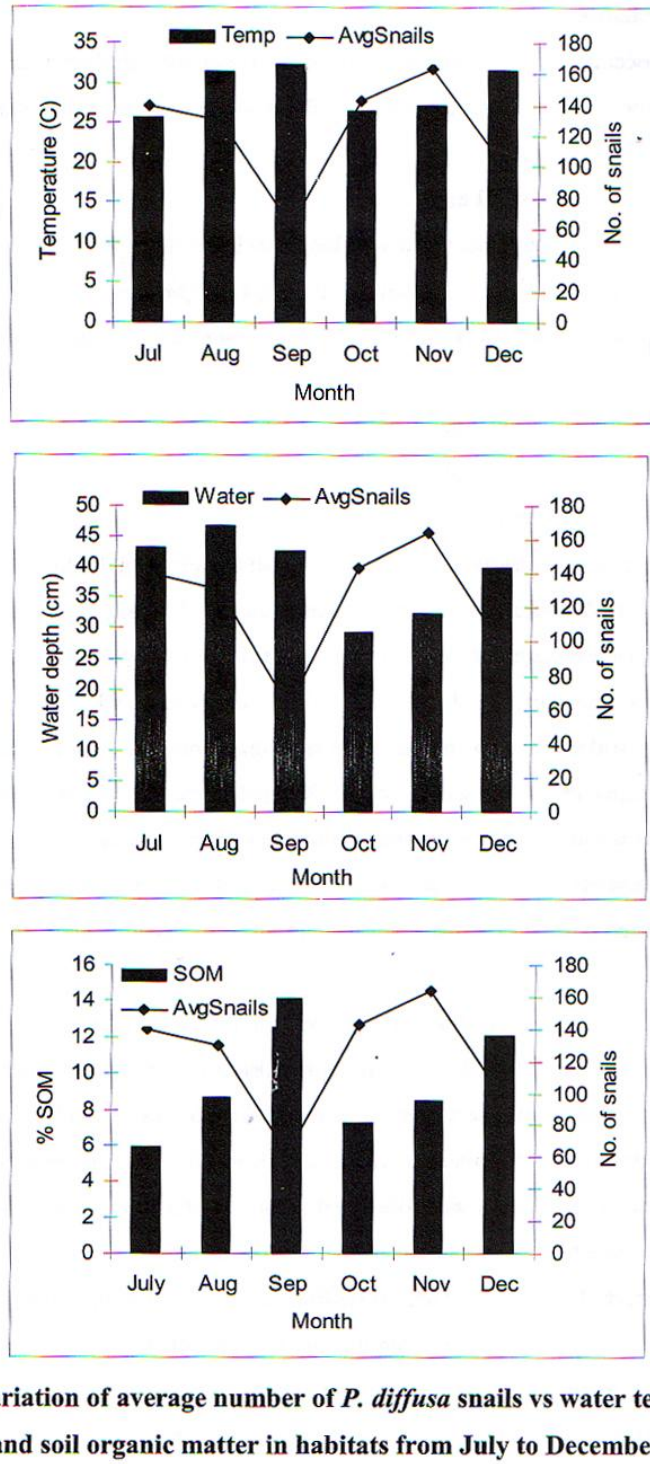


Figure 6. Variation of average number of *P. diffusa* snails vs water temperature, water level and soil organic matter in habitats from July to December 2006

Co-occurring fish species

The only co-occurring fish species observed was *Poecilia reticulata* (Guppy), which is another alien species, and it was recorded in all the sites except in Dalugama.

Predators of snails and snail eggs

Two predatory species were identified attacking two life stages of apple snails. Sri Lankan indigenous bird, Greater Coucal (Common Coucal) *Centropus sinensis* (Centropodidae) was observed feeding on large snails and an ant, *Tapinoma* spp. was observed damaging egg masses.

Discussion

Golden Apple Snails, *Pomacea* spp. are large fresh water snails native to tropical and subtropical South America (Kenji, 2003; Cazzaniga, 2006). Among the apple snails, *P. canaliculata* has been recognized as one of the most destructive pests in rice cultivation in Asian countries (Halwart, 1994; Naylor, 1996; Yusa and Wada, 1999; Kenji, 2003; Carlsson, 2006) and a threat to the structure and functioning of wetlands (Carlsson *et al.,* 2004) and included in to 'the world worst 100 invasive alien species'. The effect of *P. diffusa* which is a close relative of the serious rice pest *P. canaliculata* on natural and agricultural ecosystems has not been received much attention as this particular species has only been recorded as an invasive species in few countries including Sri Lanka.

A significant relationship was observed between the numbers of freshly laid egg masses, snail abundance and rainfall in the present study. Also the rainfall influences the height to the highest egg mass from the water level. According to these results there is a close relationship between snail behaviour and the rainfall and it is in conformity with Bronson (2002). Freshly laid egg masses were observed in all the sites during the study period and year round reproduction of apple snails also has been also observed in other tropical countries (Halwart, 1994; Lach *et al.*, 2002; Estebenet and Martin, 2002). Surface water level to freshly laid egg masses was significantly higher with higher snail abundance and this may be due to the high competition for oviposition sites. According to Estebenet and Martin (2002), these aerial egg-masses impose an additional cost to female. The female oviposition height recorded in the present study ranged from 5 – 52 cm but according to Marwoto (1988) oviposition usually takes place approximately 20 cm above the water level. During the heavy raining periods, with higher water levels some egg – masses were observed even in walls of near by houses, coconut tree trunks, etc. With the increasing water level, they may also have reached higher positions to lay eggs to avoid the damage caused to the eggs by the flood.

The growth curves clearly revealed the continuous growth of snails under the prevailing environmental conditions of wet zone of Sri Lanka. Estebenet and Martin (2002) indicated that the growth of *Pomacea* was continuous and it was highly dependant on temperature. The temperature range recorded in the present study (26.8 ^{0}C – 32.8 ^{0}C) may not have any significant effect on the growth of the snails but higher temperature may have affected their behavior. Snails tend to hide under foliage to avoid harsh conditions and the low number of snails was recorded with higher water temperatures. The significant linear relationship between length with the height of the snails observed in the present study in conformity with Estebenet and Martin (2002) who indicated that under low temperature variations growth in length was continuous for *P. canaliculata.*

Dissolved Oxygen level as favourable for growth and activity of most aquatic organisms has been reported to be > 5 mg/l, if it is < 3 mg/l, it is reported to be stressful to most aquatic organisms and if it is less than 2 mg/l it may not support fish life (Martin *et al.*, 2001). The present study recorded a mean DO level (1.8 mg/l) which was comparatively low to support aquatic life and *P. diffusa* living in Sri Lankan waters were hard enough to tolerate this DO level.

These apple snails have been shown to spread very rapidly from one water body to another and via floods (Lach and Cowie, 1999; Schreiber *et al.*, 2003). During October and November months, the number of small snails recorded was comparatively low with onset of high rainfall. The reason could be that small snails would have been drifted away by the flood water. This shows the possibility to observe them throughout the country in near future in many locations as aquatic habitats in Sri Lanka are interconnected during rainy season. Not only that the apple snail can moves more than 100 m upstream or more than 500 m downstream in one week (Kenji, 2003).

According to Sin (2003) even low densities of *P. canaliculata* (2-5 snails/m^2) is enough to cause damage to rice. Alarmingly, the density of snails recorded in the present study ranged from 42 to 164 m^{-2}. The highest apple snail density recorded in ponds in southern Texas was only 36 m^{-2} (Cazzanga, 2006). The higher snail density recorded in the present study may be attributed to environmental factors and to the paucity of natural enemies in the habitats.

The only co-occurring fish species observed in the *P. diffusa* habitats was *Poecilia reticulata* (Guppy). This lack of other fish species may be due to either predation by native fish over snail eggs/ young stages or might be predation on the fish eggs and fingerlings by the snails. Predation of apple snails by fish and birds is well documented (Beltzer, 1985; Sykes, 1987). However, it is interesting to note that an indigenous bird in Sri Lanka has started to feed on this alien snail in wild habitats. Steven (1999) and Yusa (2001) showed that fire ants in genus *Solenopsis* are able to predate on apple snails and their eggs. However, this is the first observation of predation of an ant, *Tapinoma* spp. on apple snail egg masses in Sri Lanka and elsewhere.

Introduction of apple snail poses serious threats to aquatic eco systems through potential habitat modification and competition with native aquatic species (Cowie, 2000). *P. diffusa* may affect on biodiversity, agricultural crops, aquarium industry and aquatic plant industry in Sri Lanka and prevention of further spread and new introductions should be avoided. *Pomacea* spp. also eats small fish, snails (Cazzanga, 2002) and other aquatic organisms (Cazzanga, 2006). According to the results of the present study rainfall is the main factor that influence the breeding and abundance of *P. diffusa* in Sri Lankan waters. Therefore high rainfall could positively affect further distribution of snails. High water temperature, high water level and high SOM in the habitat may negatively effect the distribution of *P. diffusa* and further research on these aspects is warranted.

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