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Detection and Eradication of Giant African Snail (*Achatina fulica* Bowdich) in Kerala

(Final report of the project KFRI 612/2011: July2011-June2014)

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Contents

List of Tables

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Abstract

The Giant African snail (*Achatina fulica*) is one of the top tropical invasive species. The International Union for Conservation of Nature has listed this species as one of the world's 100 most invasive species. The snail is a pest to agriculture and a menace in human habitation**.** In 2010, it was a major problem in Konni of Pathanamthitta district in Kerala. The problem was filed in Ombudsman Court and was handed over to KFRI for studying the issue. This project was undertaken in the above context to detect the snail infested sites in the state and to control the population.

Detection of snail infested sites was made possible through interactions facilitated by the media. Surveys were conducted to locate the snail infested places. A total of 110 infested sites were recorded from the state of Kerala for the period 2011-2014. For finding the potential distribution of the snail in the state, Maxent model was run using the presence localities. Ernakulam was most predicted while Idukki the least. Public and local governing bodies were alerted. Posters and notices were sent to the localities which fall under high and medium risk of infestation and also to places which were presently infested. Pathways for the spread of *A.fulica* were detected and measures were taken to control the spread by notifying the concerned authorities and giving awareness to the public. All technical support was given to the infested panchayats for the control of the snail. Suspected sources for spread of the snail *A.fulica* were alerted.

Screening for best molluscicides was done to find the one which is lethally active. Both chemical and plant extracts were tested. TDCS (Tobacco decoction Copper Sulphate) mixture was found to be efficient in killing the snail with least side effects. This mixture has been recommended for use all over Kerala and is now being practiced in many places. Association of this snail with the

native species was studied to check for predators or parasites. Major predators of the snail recorded are coming under the group aves and mammals. The impact caused by the snail *Achatina fulica* was assessed through a questionnaire survey. Data analysis were done to find the cost of control. It was found that the cost for control was higher for farmers with large size holdings and for small farmers cost was higher than their income.

1. Introduction

Biological invasion is considered to be a major threat to biodiversity, across the world, next only to habitat fragmentation. Most of the invasive species in its introduced range turns out to be pests owing to the absence population regulatory mechanisms. However, not all species arriving at a new location turn out to be invasive. The ‘Tens rule’ states that only 10% of introduced, non-captive species will become established in a host environment, and that only 10% of established invaders will become pests (Williamson, 1996). *Achatina fulica* (Bowdich) commonly known as giant African snail is such an invasive species which has spread into many countries outside its native range. Being native to east Africa (Kenya and Tanzania) its occurrence has been reported from Pacific regions, South and South East Asia (Cobbinah et al., 2008). *A.fulica* Bowdich is economically the most important land snail pest of the world. It belongs to Class Gastropoda of Phylum Mollusca. In all the reported regions it acquired a pest status and feeds on about 500 varieties of plants thereby causing economic loss to agricultural and other crops. Thus it has been listed as one among the world’s 100 worst invasive species. The first introduction of *A.fulica* outside its homeland was to Calcutta, India in 1847. W.H. Benson, a malacologist collected a living specimen from Mauritius and carried it to Calcutta during his round trip from Africa through Ceylon. The specimen was not released in Ceylon but presented as a gift to his friend in Calcutta. This living specimen was released in Chowringhie garden, Calcutta and later its population exploded and spread to neighbouring states (Srivastava 1992). Later on many introduction of it occurred to different regions by way of trade and transport unintentionally and intentionally as pets, for commercial use (escargot), for research purpose and as a part of fantasy (Robinson, 1999).

Figure 1: ***Achatina fulica***

Globally *A.fulica* has been introduced to 66 major countries. In India 12 states are infested with this snail namely- West Bengal, Orisssa, Bihar, Uttar Pradesh, Madhya Pradesh, Maharashtra, Assam, Rajasthan, Andhra Pradesh, Karnataka, Tamil Nadu and Kerala (Srivastava, 1992).

This snail was introduced to Kerala during 1955 through a researcher, (Malayala manorama, 1970) P.N. Rajakrishna Menon. He had collected a couple of snails from Singapore and bought to his home in Elappully of Palakkad district where he reared the snails to conduct studies on the reproductive biology. The specimens were cultured in a drum and when the population increased, he threw the snail into the wild.

During 1970's *A.fulica* was a major problem in Palakkad district and various measures were taken by the Government and people to manage this problem. From 2003 onwards intermittent appearances of the snail occurred in the districts, Palakkad, Kozhikode, Ernakulam and Pathanamthitta. By 2010 all the districts of Kerala except four (Thrissur, Kottayam, Idukki,Wayanad) were found to be infested. The scenario of snail infestation till 2014 was that it established satellite populations in several places while in some other places the already established population had collapsed. High reproductive capability, absence of natural enemies and favorable climatic conditions supplement the potential of the snail to become invasive.

Besides its nature as pest it's also a nuisance in human habitation. Hence the need for controlling it is now becoming an urge.

Scope of the study

Different control measures have been attempted in different places of which chemical control coupled with physical means have been found to be despite adverse effects. Biological control has been tested in many places by the introduction of the snails natural enemies like the gastropod *Euglandina rosea* (Davis and Butler, 1964), and a flatworm *Platydemus manokwari* (Raut and Barker, 2002), but these trials were unsuccessful and negatively affected the native fauna since the enemies introduced were not host specific. It may be noted that sometimes the eradication of a species may result in the release of some other species which are closely associated with it (Barbier, 2001). Thus, it becomes imperative to study the association of all species with this snail so that the interspecific relationships can be found out which will pave way for locating potential biocontrol agents and for preventing inadvertent release of any other species.

The rapid increase in expense in an area of an invasion leads to the dictum that it is best to eradicate early (Simberloff 1997a; Weiss 1999). It is hard to persuade large groups of people with diverse interests to support an eradication campaign the benefits of which may not be equal to all. Because eradication can be subverted by one or a few individuals, a government agency or interagency entity must be able to compel cooperation (Simberloff 2002b). Early detection of the species, creating awareness among the people, cooperation from Government and local people, and/ preventing the spread of the species, make eradication of a species possible.

Since the information on the distribution of the Giant African Snail is scanty, geographical modelling is considered to be the best way to explore the possible potential habitats of this species in Kerala. The conventional methods are extremely time-consuming and the alternatives like Ecological Niche Modelling methods offer reconstruction of the potential occurrence or distribution areas by combining the known presence records (which is very less compared to the total distribution) with GIS data which explains the whole study area.

Thus the objectives of the study were to:

1. Monitoring and detecting populations of Giant African Snail and their pathways of spread in Kerala
2. Launch and spearhead time bound eradication programme in collaboration with local self-governments
3. Sensitization of key government departments like Quarantine & Port so as to prevent further influx of snails into the State.

2. Review of literature

2.1 Biological invasion

A species can be deliberately brought into a country and released intentionally, or its release can occur as an unintentional byproduct of cultivation, commerce, tourism or travel. (Wilcove et al., 1998). Most ecosystem types have already been impacted to a greater or lesser extent by biological invasions-the introduction, establishment and spread of species outside their home range (Parker et al., 1999). The probability of both establishment and spread also depends on the way in which the environment is altered by human behavior, and the way that potential invasive species is introduced (Mack et al., 2000). The probability of establishment of an intentionally introduced species is higher than that of an unintentionally introduced species simply because intentionally introduced species has been selected for its ability to survive in the environment where it is introduced (Smith et al., 1999) and may be introduced repeatedly (Enserink, 1999). Most species, however, are brought to their new homes unintentionally in ballast water, packing material and cargo (Jenkins, 1996). Most creatures introduced into alien environments die without a trace, and some become valued crops or ornamentals. But some invasive species are pathogens, some are agricultural pests, and some become major threats to the ecosystems (Margolis, 2005). Not all species become easily established once translocated into a new area, but characteristics such as a rapid reproduction rate, high fecundity and generalist food and habitat requirements can increase the success of an introduced species (Cowie, 2000). Organisms that become invasive are also most likely to possess traits that facilitate their transport by humans, the ability to withstand the problems of transport, the capacity to tolerate varying environmental conditions, and the preference to thrive in human-disturbed areas (Suarez

&Tsutsui, 2008). The success of an introduced species in a new area can also be influenced by the genetic composition of its population. In many cases, introduced species are represented by a few individuals and the narrow genetic basis leads to a founder effect. After many generations, a population bottleneck ensues where genetic variation is considerably reduced and allele frequencies undergo massive shifts (Dlugosch & Parker, 2008). As a consequence, some beneficial adaptive traits that could otherwise improve the survival and fitness of the species in the new habitat may be lost (Kolbe *et al*., 2007). However, this low genetic variability as a result of founder effects and bottlenecking could be counteracted by multiple introductions from different source populations (Dlugosch & Parker, 2008).

The 'Tens rule' of thumb of biological invasions suggests that only 10% of introduced, non-captive species will become established in a host environment and that only 10% of established invaders will become pests (Williamson, 1996). Perrings (2005) studied the invasive species problems in terms of the properties of the stochastic processes they induce. It considers how mitigation and adaptation strategies may be modeled, and identifies the conditions in which each approach may be efficient and effective. Simberloff (2003) reported that study of the population biology of introduced species is needed to manage them but the success in eradication and control of introduced invasive relies on brute-force chemical and mechanical techniques, not on population biological research. Many successful eradication and management campaign rely on manual labors (Simberloff, 2003). Simberloff (2009) reviewed the cases of successful eradication and maintenance management. Eradication of giant African snail was achieved with such an input of 67,183 man-hours of effort and cooperation of residents in the infested region of Florida (Poucher, 1975).

2.2 *Achatina fulica*

Achatina fulica commonly called as giant African snail is one of the largest land snails in the world (Peterson 1957). It belongs to class Gastropoda of phylum Mollusca. It is native to coastal regions of East Africa (Kenya & Tanzania). The shell of the snail reaches a maximum length of 20cm and a maximum diameter of 12 cm. The conical and spiraled shell is predominantly brown with weak, dark banded markings across the spiral. Colouration is highly variable, depending on diet. The average weight of a mature snail reaches about 250 grams (Cobbinah et al., 2008).

2.2.1 Biology

Achatina fulica is a protandrous hermaphroditic land snail, although reciprocal mating occurs and both individuals lay eggs (Lange,W.H, 1950). It possess a complex reproductive organ containing a hermaphroditic gonad in which oocytes and spermatozoa are produced simultaneously in close proximity (Berry & Chan, 1968). Giant African snail in the wild lay eggs about two to three times per season (Cobbinah et al,. 2008). Increase in humidity and soil moisture is the biggest factors which trigger breeding. These snails hatch their eggs by depositing them in burrows made in the soil or inside manure heaps, under rocks or roots of trees especially during the rainy season (Ugwu et al., 2011). Snails burrow at least two to five centimeters deep into the soil to lay and incubate the eggs. Loose soils with 20-40% organic content are reported to be better than compact soils with tendency to cake (Cobbinah et al., 2008). Optimum conditions for incubation and hatching of eggs are 24 to 28^{0}c and 15g of water per 100g of soil (Ebenso, 2006). Eggs are yellowish white and are laid in clutches of 10-400 eggs within 8-20 days of copulation. The number of eggs laid can vary depending on the age of the snail but can reach up to 1800 in a year in a tropical setting. If conditions become unfavourable, the snail can aestivate by burrowing underground and covering its shell opening with a calcareous membrane, called an epiphragm, until such time as the environment improves (Mead, 1979, Raut & Barker, 2002). Repeated layings may result from one copulation as sperm is stored in each snail. Upon hatching, the hatchlings consume their eggshells, remaining underground for 5-15 days and feeding on organic detritus. Juveniles with shell lengths of 5-30 mm cause the most damage to plants. The snails may reach sexual maturity in less than a year. Larger snails continue to feed on plant materials but feed increasingly on detritus as they age (Cobbinah et al., 2008). A typical *A. fulica* has a life span of 5-6 years, becoming sexually mature as early as five months (Mead, 1979, Raut and Barker, 2002).

2.2.2 *Achatina fulica* – A invasive snail

The species is a native of the coastal regions of East Africa (Kenya, Tanzania) and got spread by the 19^{th} century into Southern Ethiopia, Southern Somalia, and Northern Mozambique. During the same time, it was introduced, sometimes intentionally, into South East Asia, East Asia (Taiwan, Korea, and Japan), Australasia, the Pacific, the USA (now eradicated in various states), the Caribbean, Central America and South America (Brazil) (Cobbinah et al., 2008). The International Union for the Conservation of Nature (IUCN) describes the species one of the world's 100 most invasive pests.

2.2.3 History of invasion

The spread of *Achatina fulica* throughout the tropics is believed to be through human. The first introduction of *Achatina fulica* outside its native range was in India during 1847. W.H. Benson, a malacologist on his return journey from Mauritius to India took two live samples of *A. fulica* and just before leaving India presented it to his friend who released the snails in his garden at

Chowringie, near Asiatic Society's Museum in Calcutta (Naggs, 1997). These soon became established (Benson 1858) and, although the initial spread was slow (Blanford, 1868; Godwin-Austen, 1908) this snail was common in the garden of Calcutta and neighborhood (Annandale, 1907) and its range gradually extended through much of the Indian subcontinent. Current genetic studies indicate that all *A.fulica* now occurring throughout South Asia, Southeast Asia and the Pacific region are derived from one haplotype (Fontanilla et al., 2007) the source being a single pair of specimens released in a Calcutta garden in Chowringhee (Naggs,1997)

2.2.4 Introduction of *Achatina fulica*

Introduced species, also known as exotics, are those found outside their natural range due to human activity. *Achatina fulica* is a classic example of an accidentally introduced species (Primack, 2006). Globally this snail has been introduced to around 66 countries and in India 11 states are infested by this snail (Srivastava, 1992). The introduction of the snail *A.fulica* happened both intentionally and accidentally. Intentional introduction was as escargot (potential food item), pet, ornamental snail or as a source of 'baba de caracol' (snail mucus) (Correoso, 2006) while it was accidentally introduced by two main pathways: as 'un- invited' cargo through shipping and transportation industries (Robinson, 1999). One of the most important factors for the establishment and dispersion of *A.fulica* is human presence (De Winter, 1989). Another important factor that may condition *A.fulica* population dynamics is, growth rate, survival, fecundity and food preferences (Ahmed and Raut, 1991). Snail has been introduced to many places as escargot. Upatham et al., (1988) reported that the foot musculatures of *A.fulica* had crude protein and crude fat of 15.4g and 1.02g per 100g wet weight, respectively. Man has always been drawn to the Giant African Land Snail for reasons including its large size, supposed medicinal properties and its potential as a human or animal food source (Mead, 1979; Kliks & Palumbo, 1992; Raut & Barker, 2002). It is for these reasons that the species has been spreading globally primarily through human factors. The success of *A.fulica* as an introduced species can be attributed to several factors. First, the biology of *Achatina fulica* makes it eminently suitable for its survival success. The snail has a high fecundity, producing between 10 and 400 eggs per clutch and as many as 1800 eggs per year; they also become sexually mature between 5 and 8 months (Raut & Barker, 2002). Second, *Achatina fulica* possesses traits that facilitate its transport by humans. For instance, the snails can easily be transported in consigned cargoes, whether accidentally or on purpose, and survive the journey of several days with little adverse effect on the "hitchhikers." This was demonstrated by a tourist who came from Hawaii and inadvertently brought a live snail to the mainland USA over a period of ten days (Mead, 1979). During the periods of long distance travel, the snails are safe as they undergo aestivation (Mead, 1961). Furthermore, *A. fulica* has a wide tolerance for different environmental conditions despite being a tropical snail (Mead, 1979; Raut & Barker, 2002). Third, *Achatina fulica* is commonly introduced deliberately and is therefore transported in large numbers and properly cared for.

A young boy returning from Hawaii in 1966 brought two or three individuals of the giant African snail (*Achatina fulica*) to Miami (Mead 1979) and it took ten years for the eradication with an expenditure of $700,000. In a survey of distribution of *Achatina fulica* carried out in July 1998 to December 1998 it was observed that *Achatina fulica* had migrated into four districts of Eastern Uttarpradesh, i.e. Gorakhpur, Deoria, Kushinagar and Maharajganj (Rao and Singh, 2002). Budha and Naggs (2008) reported the status of *A.fulica* in Nepal. Borrero et al., 2009 reported the introduction of snail *A.fulica* into Andes and its potential distribution in South America. Albuquerque et al., (2008) studied the distribution of *A.fulica* in an area of recent introduction, and identification of its habitat and food preferences in Brazil. *A. fulica* has often been associated with human disturbed areas such as agricultural lands and gardens, though they have also been found in primary and secondary forests in Hawaii, the Bonin Islands, India, Southeast Asia and New Caledonia (Raut & Barker, 2002). *Achatina fulica* is usually introduced consciously and is therefore transported in great numbers and properly cared for, which then increases the chance of its survival (Fontanilla, 2010). In Brazil, *Achatina fulica* was introduced in 1988, perhaps from Indonesia; it was an alternative source of meat. These snails were then distributed for commercial purpose and they have grown them. As a result, Brazil is now experiencing a dangerous stage of the invasion that is characterised by large individuals that are prevalent in urban areas, mostly in gardens (Thiengo *et al*., 2007).

Other purposeful introductions include those in Borneo where duck farmers used the snail as food, those in Nepal where the snails were introduced in local gardens and honoured for its spiritual significance (Budha & Naggs, 2008). Before and after the Second World War in the Indo-Pacific, the Japanese soldiers and merchants used the snail as food and sometimes as pets (Kliks & Palumbo, 1992; Civeyrel & Simberloff, 1996).

2.2.5 *Achatina fulica* in Kerala

The introduction of *Achatina fulica* to Kerala was in 1955 in Elappully panchayath of Palakkad district. The introduction was for research purpose and later on their release led to a small population in Palakkad (Malayala manorama, 1970). In Ernakulam district the snail was first reported in 2007 in Koovapadam in west Kochi (The Hindu, Oct 2010). The Hindu (Sep 19, 2007) reported the occurrence of it in Palluruthy and Mattanchery of Ernakulam district and its feeding on neem leaves, flowers, coconut leaves and papaya. The first report of snail from

Konni, Pathanamthitta was during 2006 from Chinamukku area. Later on it spread to other wards (10, 12, 15 and 16) of Konni panchayath, Cherimukku and Valanchuzhy area of Pramadam panchayath and Iravan area of Aruvappulam panchayath (Malayala manorama, Nov 2009). The occurrence of snail has been sited from areas like Kannur (The Hindu, Aug 2011), Muzhuppilangadu (Malayala Manorama, January 2011) Parassinikadavu, S.N. Park (Malayala Manorama, Aug 2011) and Vallakkadavu, Melarannoor and Vanchiyoor of Trivandrum district (The Hindu, June 2010).

2.2.6 *Achatina fulica* as a pest

The giant African land snail *Achatina fulica* (Bowdich, 1822) is a macrophytophagous and a generalist feeder. In part because of its polyphagous diet, it has become recognized as one of the world's most damaging pests and is listed in the Global Invasive Species Database (http://www.issgorg/ database/welcome/) among "One hundred of the world's worst invasive alien species" (Lowe *et al*., 2000). In addition to the 500 plant species that *A. fulica* is known to eat, the snail will also consume decaying and rotting vegetation, dung, garbage, wet paper and cardboard, dead animals, and crushed (*i.e*., already dead) snails of its own kind (Srivastava, 1992). In addition, this snail is known as a vector of at least two human disease agents: the rat lung-worm *Parastrongylus* (=*Angiostrongylus*) *cantonensis* and a gram negative bacterium, *Aeromonas hydrophila*, which causes a wide range of symptoms (Mead 1956, 1961, Wallace and Rosen 1969, Dean *et al.* 1970, Mead and Palcy 1992). The snail promotes substantial ecological and economic impacts in areas where it has been introduced (Raut and Barker, 2002). The snail is mainly a vegetarian and has been identified as a major agricultural pest (Cowie, 2000). There is recent evidence that it can also act as a snail predator (Meyer et al., 2008). It is one of the most destructive pests, causing large damages to farms, commercial plantations and domestic gardens (Mead, 1995). Reddy and Sreedharan (2006) conducted a survey and identify the areas affected by the giant snails and its damage to coffee and other subsidiary crops in Arakuvalley zone, Andra Pradesh. The species causes considerable economic damage to a wide variety of commercial crops. In most parts of the world, the amount of damage is greatest during the establishment phase when the individuals are usually very large and their populations immense. This is followed by a stable population phase, and then finally a period of decline (Cobbinah et al., 2008).

2.3 Association with other species with particular reference to predators and parasites

Barbier (2001) investigated how an invader interacts with native species in a model. He states that any interaction between invader and the resident may result in interspecific competition, diffusion or combination of these two effects which can lead to economic losses if the resident is economically valuable.

The main parasites of giant African snail are parasitic Protozoa, Cestodes, Trematodes, Nematodes and flies. Parasitic flies are from family Sciomyzidae. *Sciomyza dorsata* reported from Denmark might prove useful in the control of *A.fulica*. However, Davis et al., (1961) reported no danger of *S.dorsata* to the snail *A.fulica*. Seventy seven species of nematodes have been found associated with land snails; out of these, 55 have some vertebrate host also. So far only two species namely *Anafilaroide rostratus* and *Angiostrongylus cantonensis* have been identified from *A.fulica* (Mead, 1979). If man eats uncooked snails containing infected larvae of *Angiostrongylus cantonensis*, the larvae will migrate to his meninges and brain causing eosinophillic meningoencephalitis and brain damage (Malak and Cheng, 1974). Two outbreak of eosinophilic meningitis caused by *A.cantonensis* infection occurred in Kaobsiung, Taiwan during 1998 and 1999 (Tsai et al., 2001a and Tsai et al., 2001b). A detailed study of the 17 patients affected by meningitis was conducted by Tsai et al., in 2003. Grewal et al., (2003) studied the various types of association between nematodes and mollusks and their evolutionary trends. Molluscs are significant as hosts for Metastrongyloids (as intermediate host) and Rhabditis (as defensive host). Also molluscs act as a paratenic host (an organism that serves to transfer a larval stage or stages of a parasite from one host to another) for nematode parasites of vertebrates. *A.fulica* is already reported as an intermediate host of *A.cantonensis* and *Oslerus ostratus* (Grewal et al., 2003). Brockelman (1978) studied the effect of parasitism and stress on the protein concentration of hemolymph using the nematode *A.cantonensis* in *A.fulica*. *A.cantonensis* obtains nutrients during its development from first stage to third stage larvae, from its snail host (Lee, 1965). But the infection of even 2000 larvae does not cause noticeable physiologic damage to the host. Normal hemolymph protein concentration did not show any reduction when the snail were infected with third stage larvae but repeated bleeding shows a significant decrease in protein. Survey done by Deng et al in 2012 revealed a wide distribution of *A.cantonensis* and its intermediate hosts *Pomacea canaliculata* and *A.fulica* in Guadgdong Province, China. Neuhauss et al., 2007 reported that the giant African snail occurring in southern Brazil is not a permissive host for both *Angiostrongylus costaricensis* and *A.cantonensis* and does not represent a significant risk for transmission of these parasites. In infected snails the normal level of hemolymph glucose and reducing sugar dropped with a significant difference after one week of infection but later on the snails adapt themselves to the parasitic infection and will retain the normal range (Brockelman and Sithithavorn, 1980). The presence of nematode, *Rhabditis* sp. in the alimentary tracts of snail *A.fulica* was reported by Seehabutr (2005). This is not a dangerous parasite but other nematodes of Rhabditidae such as *Phasmarhabditis hermaphrodita* was a lethal parasite of slugs and was used in biological control (Grewal and Grewal, 2003). In Ceylon there was an incidence of the disease in the population of the *A.fulica* and was suspected to be caused by spirochete, protozoan, yeast or fungus and phorid flies (*Spinophora* sp.) was considered to be the possible mechanical or even cyclical vectors (Srivastava, 1992). The interaction between populations of *E.rosea* and *A.fulica* and a disease agent was studied by Gerlach (2001) and made a model which suggests that apparent reductions in *A.fulica* numbers following *E.rosea* introduction are the result of a combination of predation and disease effects. Rapid crashes of *A.fulica* population in the absence of introduced predators are suggested to be the result of epidemics of a disease caused by the bacterium *Aeromonas hydrophila* (Mead, 1979).

Srivastava and Srivastava, (1967) reported a millipede of orthomorpha sp. to be in association with *A.fulica* at Port Blair in the South Andamans. This predatory millipede attack the snail when they were resting on the soil surface but never found attacking the actively moving snails. Wallace and Shiels (2009) describe the predation of black rat *Rattus rattus* on the snail *A.fulica* (100%) and *E.rosea* (80%) and they hypothesize that reduction or eradication of *R.rattus* populations may cause an ecological release of some non indigenous snail species where these groups coexist.

Raut and Ghose (1979b) reported tree pie (*Dendrocitta vagabunda*) and the crow pheasant (*Centropus sinensis*) as natural enemies of *A.fulica*. These birds predate snails only during day time and as they are restricted only to few days in a year, they are not effective in reducing snail population (Raut and Ghose, 1979b). Common ducks feed on the eggs and juvenile of *Achatina* up to 3cm shell-size. Certain farmers and others keep the ducks to keep a check on the eggs and juveniles (Srivastava, P.D., 1992)

The bandicoot rat (*Bandicota indica*) has been reported as an effective predator of the giant African snail as it can locate the active as well as aestivating snails (Raut and Ghose, 1979b). Srivastava (1992) listed wild pig as a predator of *A.fulica*. Mead (1961) states that omnivorousness of domestic pigs "suggests correctly" that they would feed upon snails near habitations. The mongoose, *Herpestes mungo* is reported to feed on the giant African snail in Ceylon.

2.4 Predators as biocontrol agents

The use of biological controls has proved disastrous for native gastropods (Civeyrel and Simberloff, 1996; Griffiths et al., 1993). Although *Achatina* spp. is consumed by native predators there is little evidence they can control established populations (Raut and Barker, 2002).

As a part of biological control various natural enemies have been imported to many places. In Hawaii, enemies of *A.fulica* including *Gonaxis kibweziensis* (E.A.Smith), *Edentulina affinis* (C.R. Boettger), *Gonaxis quadrilateralis* (Preston), *E.rosea* (Ferrussac), *Tefflus zanzibaricus alluaudi* Sternberg were introduced under quarantine conditions (Davis and Butler, 1964). Decline in the population of *A.fulica* in the former areas of abundance in Oahu coincides with the tremendous increase in *Gonaxis quadrilateralis* (Davis and Krauss, 1964). Throughout much of the introduced range of *A.fulica*, the carnivorous snail *E.rosea* has been introduced in biological control programmes (Mead, 1961). This however did not reduce *A.fulica* populations (Cowie, 2001), but instead helped to the decline of many tree snail species (Clarke et al., 1984). In 1963, Mead reported a turbellarian flatworm, *Geoplana septemlineata* Hymn feeding on *A.fulica*.

Demographic analysis of the shell to determine the role of introduced predators on the biological control of this mollusk was studied by Nishida and Napompeth (1975). They found that young life stages were missing indicating age predation by *Gonaxis* spp. and *E.rosea*. Small snails were more vulnerable to predation by *E.rosea* and *Oxychilus alliarius*. Differences in size among prey can influence the predatory behavior of *E.rosea* (Meyer and Cowie, 2010).

Insects also play a role as predators of mollusc. A carabid *T.zanzibaricus alluaudi* was found to feed on *Achatina* in Mombasa, East Africa (Williams, 1951) and the first release of it was made in Kaneohe, Oahu on June 3, 1952 followed by 1954, 1957 and 1958. There is evidence that some carabid beetles naturally prey upon pest slugs (Symondson, 1996). Bequaert (1925) classified the dipterans associated with mollusks to three ethological types, viz., scavangers, ectoparasites and parasitoids. He also described a new dipterous parasite of the snail from Brazil. Amongst the non-snail predators, the main predators used against the giant African snail are the beetles especially the Indian glow worm *Lamprophorus tenebrosus* and hermit crabs of the genus *Caoenobita* (Srivastava, 1992). *L.tenebrosus*, a voracious feeder on the Giant African Snail in Ceylon and parts of India, has recently been introduced into other countries to combat this snail. The highest population of *L.tenebrosus* encountered was in certain cocoa plantations where *A.fulica* was fairly abundant. The soil in these areas was sandy loam, eutrophic and with higher moisture content (Bess, 1955). *L.tenebrosus* and *A.fulica* are more or less active throughout the year in the area where there is a better distribution of rainfall (Hutson and Austin, 1924). At night when there was sufficient moisture for the larvae and snails to be active, larvae were seen crawling around over the litter, by which they come in contact with snails their food. Often 2 or more larvae were found during the daytime partially inside of a shell of *A.fulica*. However, in localities where there is a prolonged dry season both *A.fulica* and *L.tenebrosus* remain inactive during drought (Bess, 1955). The terrestrial flatworm *P.manokwari* is an indiscriminate snail predator used against *A.fulica* (Bowd) (Raut and Barker, 2002). Iwai et al., (2010) studied the prey-tracking behavior in the invasive terrestrial planarian *P.manokwari* and found that the predator follows snail mucus trials on chemical cues. The use of pathogens, parasites and invertebrate predators against *A.fulica* and other Achatinidae has been summarized by Raut and Barker (2002).

Attempts to eradicate the snail from islands have been successful with incipient populations. Native island predators may act as an effective control agent for the snail. Reintroduction of endemic Telfair's skink *Leiolopisma telfairii* into the nature reserve island of lle aux Aigrette, Mauritius during 2006-2007 suggested being an important causal factor behind the decline of the snail population of *A.fulica* in the island.

2.5 Management

Eradication is often a stepchild in the field of introduced species management (Simberloff 2002a, 2002b, 2002c). Maintenance options are typically seen as mechanical, chemical, and biological control, plus ecosystem management (Simberloff 2002a). However, many animal invaders have been successfully eradicated (Simberloff 2002b). Eradication from smaller continental areas is fairly common, such as the elimination of the giant African snail (*Achatina fulica*) from a region of south Florida (Mead 1979) and part of Queensland, Australia (Colman 1978). The rapid increase in expense of an area of invasion increases leads to the strategy that it is best to eradicate early (Simberloff 1997a; Weiss 1999). It is hard to persuade large groups of people with diverse interests to support an eradication campaign whose benefits are not equal to all.

Because eradication can be subverted by one or a few individuals, a government agency or interagency entity must be able to compel cooperation (Simberloff 2002b).

Physical, biological and chemical strategies have been used to eradicate and manage *A.fulica* populations (Raut and Barker, 2002). Weber (1954) describes various control method of giant African snail.

Physical control strategies rely on the collection and destruction of snail and their eggs from infested sites (Raut and Barker, 2002). Attempts to eradicate *Achatina* spp. by physical removal have been of limited success (Raut and Barker, 2002). Shah (1992) recommends that snails be collected and destroyed during aestivation between January and April when they hide under hedges and debris.

While using new products as a pesticide, it is important to understand the behavioral responses of the animals in order to optimize the timing and techniques of application (Stenceth, 1989). A large number of toxicants have been used against *A.fulica*. Sodium chloride, the common salt is effective against *A.fulica* at high concentration and the mortality is caused only due to dessication of mucus from the snail body (Rao and Singh, 2002). Established infestations of *A.fulica* in Florida have been eradicated with a total of 128 tons of arsenate-metaldehyde bait (Poucher, 1975). Among the synthetic molluscicides, Snail Kill (metaldehyde) and cypermethrin were potent, whereas spraying of phorate and carbaryl is not effective upto 3% against *A.fulica* (Rao and Singh, 2002). Application of copper sulphate seemed to be a popular method of control of the snail (Mead, 1961). Kakoty and Das (1988) in a lab study found that copper sulphate caused 100% mortality of *A.fulica* after one week of treatment. Copper ricinoleate, when used in large dilutions and forming stable emulsions with the water, possesses a pronounced molluscicide action. The usage of copper ricinoleate as a molluscicide is recommended, due to its easy preparation, low cost, insolubility in water, with a formation of emulsions of very small particles and tendency to form thin layers of vegetation, active not only in the emulsion but also after depositing (Goncalves and Soares, 1955).

The effect of plant-derived molluscicides in snail control has been extensively reviewed (Kloss and MoCullough, 1982). Spraying of *Azadirachta indica* oil is not effective against *A.fulica* but spraying of *Cedrus deodara* oil, *Allium sativum* bulb powder and *Nerium indicum* bark is effective of which the toxic effect of *C.deodara* oil is more pronounced (Rao and Singh, 2002). *C.deodara* oil, *A.sativum* bulb powder and *Nerium indicum* bark are potent molluscicides and the active moieties responsible for molluscicidal activity are oleandrin in *N.indicum* and allicin in *A.sativum* (Singh and Singh, 1995; Singh and Singh, 1998). These active moieties caused snail death due to inhibition of acetyl cholinesterase, lactic dehydrogenase and phosphatase activity in the nervous tissue (Singh and Singh, 2000). Ebenso (2003) reported that neem seed oil extract has no effect on the control of snails while the crude extract of bark, root and leaf of neem at 500 and 700 mg/kg produced mortality. Extracts of the fruits of *T.peruviana* has activity against *A.fulica* (Anderson, 1993). One way to tackle the problem of *Achatina* is to control the reproduction of these snails. It is found that plant derived molluscicides *A.indica* oil, *C.deodara* oil, *A.sativum* bulb powder and *N.indicum* bark powder significantly reduced fecundity, egg viability and survival of *A.fulica* (Rao and Singh, 2000). Prasad et al., (2004) studied the use of natural repellents to keep away *A.fulica* in an ecofriendly manner. *Annona glabra* followed by *A.muricata*, *A.reticulata* and *A.squamosa* repelled the snails from entering to nursey bed in Andaman Island.

2.6 Prediction modelling

Climate in combination with environmental factors has been much used to explain main vegetation patterns around the world. The quantification of such species-environment relationship represent the core of predictive geographical modeling in ecology (Guisan & Zimmermman 2000). The ecological niche models (ENM) are models which reconstruct the potential distribution by combining the known occurrence records (field surveys and other means) with the GIS coverage that summarize the background information of a particular area. Lawton claims that to predict the population dynamics of particular species in particular habitats requires study of that species and that habitat. Williamson (1999) found that the only acceptable predictor other than propagule pressure was whether a species had invaded before. Colautti et al (2006) found that propagule pressure was a significant predictor of both invasiveness and invasibility and propagule biases may confound current paradigms in invasion ecology. They stated that propagule pressure serve as the basis of a null model for studies of biological invasions when inferring process from patterns of invasions. Philips et al., (2006) introduced the use of maximum entropy method (Maxent) for modeling species geographic distribution with presence-only data and compared it with the commonly used presence-only modeling method, the Genetic Algorithm for Rules-Set-Prediction (GARP). Vaclavik and Meentemeyer (2009) evaluated the impact of presence-only, true-absence and pseudo-absence data on model accuracy using an extensive dataset on the distribution of the invasive forest pathogen *Phytophthora ramorum* in California and suggested true absence data as a critical ingredient not only for accurate calibration but also for ecologically meaningful assessment of ISDMs (Invasive species distribution modeling). Margolis et al (2005) analyzed the political process likely to govern the formation of tariffs so justified using a straightforward incorporation of an invasive species externality into Grossman and Helpman's (GH) well- known political economy model. Mehta et al., (2007) analyzed the trade-offs between detection and subsequent control costs using a stochastic dynamic model for a single invasive species. By this model optimal constant detection strategy is analyzed.

The geographical knowledge emerges from spatial thinking and reasoning is essential for finding out the space 'where the things are' and to make decisions to solve the problems (Golledge, 2002). The spatially explicit thinking thus evolved and opened up new vistas of integrated science and enhanced the understanding of the physical environments and its relations with humans. The information on species distribution pattern is one of the most crucial part of the systematic conservation planning and management of biodiversity (Margules and Pressey, 2000).

3. Materials and methods

3.1 Study area

Our study area was limited to the entire state of Kerala. The state lying between the latitude $8^{0}15'$N & $12^{0}50'$N and longitude $74^{0}50'$E & $77^{0}30'$E experience humid equatorial tropical climate receiving abundant rainfall mainly during the time of South west monsoon(July-September) and North east monsoon (October-November). Monsoon rainfall progresses from the south to north and there is characteristic differences in the rainfall between southern and northern part of the state as the Western Ghats create a barrier across the path of South west monsoon. Palaghat gap in the Kerala- Tamil Nadu border is one of the intercept in the Western Ghats and receive very less mean annual rainfall. Snail infestation in Kerala is mainly concentrated in the coastal regions and one exception of it is the Palakkad district which is made of plains with midland and highland areas. The soil type of Kerala is mostly of laterite type. This soil cannot retain moisture but in plains as they consist of heavy clay and loamy soil they retain moisture like in the case of Palakkad.

3.2 Methodology

3.2.1 Methodology in general

Achatina fulica, an invasive snail is a menace to human habitats in Kerala since 1970. The project aims to locate the snail *A.fulica* infested sites in Kerala, develop a control method and also sensitize the key Government departments and public about the issue and providing them the technical support needed in the eradication programmes. Extensive surveys have been carried out all over Kerala to identify the snail infested sites and also to detect the pathways of spread.

During the survey the infested localities were marked using GPS and the coordinates recorded were mapped. Using the details of occurrence, the potential distribution of the snail *Achatina fulica* in Kerala was predicted using Maxent modeling. Diverse management strategies were practiced by the people in Kerala in managing this invasive snail. Knowledge of the public about the snail was gathered and the control strategies practiced by them were evaluated to find the efficiency and applicability. Besides, various other molluscicides including chemicals, plant extracts and organic insecticide were tested for suitability. During the survey conducted associated species of *A.fulica* were recorded and monitored for the specific relationship among them. Detailed studies were conducted on the predators and parasites of the snail and the fluctuations in their population. Since public participation and involvement of Governing bodies determine the success of eradication programmes, they were sensitized by publishing notices, posters and brochures. Awareness classes were also taken to the public based on the request of governing bodies. The snail being an agriculture pest the economic impact caused by the snail was assessed by estimating the cost of eradication and comparing it with the annual income.

3.2.2 Tracing the history

To begin with we trace the history of introduction of *A.fulica* into Kerala. Archives from Mathrubhumi and Malayala manorama newspapers were collected. We communicated with the family of P.N.Rajakrishna menon (lived in Elappully Panchayat of Palakkad District), who introduce the snail *A.fulica* to Kerala. Information was also collected from one of his classmate Dr.Kesava Nair also. Strategies undertaken by the government authorities for the control of snail during that period were checked from the archives.

Figure 2: Snail reports

ഒച്ചുശല്യം ഖജാനയ്ക്കും

പാലക്കാട്ട് ഒരു ആഫ്റിക്കൻ നുഴഞ്ഞുകേററം

— സ്വന്തം ലേഖകൻ —

പാലക്കാട്ട് പട്ടണത്തിൽ ആഫ്രിക്കൻ ഒച്ചിന്റെ കടന്നാക്രമണം വൻതോതിൽ ആരംഭിച്ചിരിക്കുന്നു. വ്യൂഹം വ്യൂഹമായി അവൻ പടവെട്ടിപ്പിടിക്കാൻ തുടങ്ങിയിട്ടുണ്ട്. പച്ചിലത്തലപ്പുകളാണ് സമരവേദി

മച്ചൂടം മുടിക്കുന്ന ഒച്ചുകൾക്കെതിരേ.....

(ഒന്നാം പേജിൽനിന്ന്)

ആഫ്റിക്കൻ ഒച്ച്- നമ്മുടെകാർഷിക വിളകൾക്ക് ഒരു ഭീഷണി! പക്ഷേ....

--ഡോ. കെ. ഒ. ജോൺ

3.2.3 Detection of *Achatina fulica* infested regions

For locating infested regions of *Achatina fulica* in Kerala, a news inserting public assistance was given in the media. As a result, 310 responses were received from different parts of Kerala. Based on the calls recorded, a survey was conducted by visiting those places. Most of the places visited affirmed the presence of snail, while some reports pertained to native snail. From all the

A.fulica infested places GPS coordinates were received and live specimens of the snail collected. Collected live specimens were reared in our lab to monitor the status of each population. Field were conducted for the three successive years (2010 October -2013 December) and GPS coordinates were recorded.

3.2.4 Predicting potential distribution of snail *Achatina fulica*

From the field surveys conducted for the period 2010-2012, a total of 92 unique snail infested points were recorded from ten districts of Kerala. The geocoordinates were imported into GIS platform to map the presence localities. The presence only Environmental Niche Model or species distribution model (Franklin, 2009) Maximum Entropy modeling (Maxent) were chosen to predict the potential distribution of the Giant African Snail in Kerala. Maxent has its origin in the statistical mechanics and is a general purpose method which makes predictions from incomplete information. The probability distribution of maximum entropy (closest to the uniform), subject to a set of constraints that represent the incomplete information about the target distribution (Phillips *et al.* 2006). Maxent has shown to produce competitive results compared to other general purpose models in predicting potential geographical distribution of a species (Elith *et al*. 2006).

The recent Maxent version 3.3.3a (http://www.cs.princeton.edu/~schapire/maxent/) was used to run the models. In the program, 500 iterations were ran with a convergence threshold of 0.00001 and a maximum of 10,000 background points and algorithm parameters were set to auto features (Phillips and Dudik, 2008). Only the random test percentage in the settings was turned to 25% and all other parameters were set at default settings. The model quality is tested using a receiver operating characteristic (ROC) analysis, which has been widely used for model evaluation, and is part of the Maxent output. The ROC generates a single measure of model performance: area under the curve (AUC). Maxent generates predictions in the form of real numbers between 0 and 100 representing the cumulative probability of occurrence. The cumulative output format is chosen and the values were imported into ArcGIS as integer grids for further analysis and comparison. Maxent computes response curves showing how the model predictions of habitat suitability depend on the environmental variables. It helps in identifying the values of the most important environmental variables corresponding to the most suitable habitat conditions.

The background or environmental data consists of seven bioclimatic and three topographic variables (Table 1) available in the datasets WorldClim and SRTM. All the raster coverages were resampled to a resolution of 30 arc seconds (approximately one square kilometer pixels). All the layers are masked to the political boundary of Kerala. 92 unique distribution localities were used in the modeling with a test percentage of 20% (23 points out of 92 set apart before modeling).The predicted model is significant as revealed by the high ROC values (0.950 for training and 0.911 for testing)

Table 1: Environment variables used for modeling

	Variable
1	Slope
2	Maximum Temperature of Warmest Month
3	Mean Diurnal Range
4	Precipitation of Driest Month
5	Elevation
6	Minimum Temperature of Coldest Month
7	Annual Precipitation
8	Annual Mean Temperature
9	Aspect
10	Precipitation of Wettest Month

3.2.5 Detection of the pathways of spread

Spread of invasive species occurs mainly by trade and transport. It can be happen both deliberately and accidentally. Surveys were conducted to find out the pathways for the spread of *Achatina fulica*. Nearby areas of snail infested places were checked to find out the presence of small scale industries, depots, timber mills, gardens etc., from where chances of introduction of snail through importing of materials is high. Information from local people was also gathered. Suspected sources were also visited to check the presence of snail.

3.3 Management of invasive snail *Achatina fulica*

3.3.1 Screening of control methods

From the survey conducted, information was collected from the people on the method they followed. Table 2 provides the list of control measures applied by the people. These methods were tested to check their efficiency. Among the methods listed we tested for metaldehyde and TDCS in lab and field. Metaldehyde was tested in Kannur and TDCS was tested in Konni of Pathanamthitta. Granules of metaldehyde were placed in the gaps of the compound walls in the snail infested area. Day-night observations were taken. For TDCS, different concentrations were prepared and sprayed on the collected snail.

Table 2: Control methods practiced by the people

Sl.No	Method adopted	Place where the method is followed
1	Salt	In all places as a common method
2	Salt and lime	Choondi(Ernakulam)
3	Salt and Bleeching powder	Nemmara(Palakkad) Muhamma(Alappuzha)
4	Furidan mixed with toddy	Nemmara(Palakkad)
5	TDCS(TobaccoDecoction-Copper Sulphate mixture)	Konni(Pathanamthitta)
6	Throwing snail to water bodies	Chirarmangalam(Malappuram) Madhilmukku(Trivandrum)

		Azhiyur(Calicut)
7	Throwing snail on hard surfaces	Nenmara(Palakkad)
8	Handpicking and putting in salt solution	Pallavoor(Palakkad)
9	Beating snail with sticks	Elappulli(Palakkad)
10	Collect and packed in sacs and dumped in vacant places	Pariyapuram(Malappuram)
11	Metaldehyde	Konni(Pathanamthitta)

Experiments were conducted in the lab to find the better molluscicides. Both chemicals and plant extracts were tested. Materials checked are given in the table 3:

Table 3: Materials tested for molluscicidal activity

Sl.No	Chemicals	Plant Extracts	Organic Insecticide
1	TDCS	*Diploclisia glaucescens*	Econeem
2	Cupric ricinoleate	*Cocculus laurifolius*	
3	Iron phosphate	*Allium sativum*	
4	Actara	*Cerebra odollum*	
5	Metaldehyde	*Thevetia peruviana*	

Cupric ricinoleate

Two hundred gram of potassium hydroxide was dissolved in 2 litres distilled water. Added one litre of *Ricinus* oil to it, and placed it in a water bath till it is entirely dissolved in water. Kept it for 24 hours and the soap obtained was dissolved in 5 litres of water. 400 gm copper sulphate was dissolved in 2 litres distilled water and the solution was poured into 5 litre potassium soap solution. The greenish viscous mass setdown was separated by decanting and successively washed with 42° Baume heated alcohol until the alcohol comes out colourless.

Iron phosphate

Diet was prepared with one of the ingredient as iron phosphate. Different concentrations of iron phosphate were tried as shown in the table 4.

Table 4: Experiment with iron phosphate in diet

Experiment No:		**Ingredients**					
		Cattle feed (g)	**Beer waste (g)**	**Maida (g)**	**Iron phosphate (g)**	**Water (ml)**	**Agar (g)**
1	A	40	-	-	.4 (.2)	225	2
	B	40	-	-	.8 (.4)	225	4
	C	40	-	-	2 (.8)	225	4
2	A	-	30	-	.3 (.1)	225	4
	B	-	30	-	.6 (.3)	225	4
	C	-	30	-	1.5 (.7)	225	4
3	A	-	-	30	.3 (.1)	225	4
	B	-	-	30	.6 (.3)	225	4
	C	-	-	30	1.5 (.7)	225	4
4	A	-	-	40	7.5 (3)	250	4
	B	-	-	40	12.5 (5)	250	4
	C	-	-	40	20 (8)	250	4

Figures in paranthesis represent respective percentage values

Actara

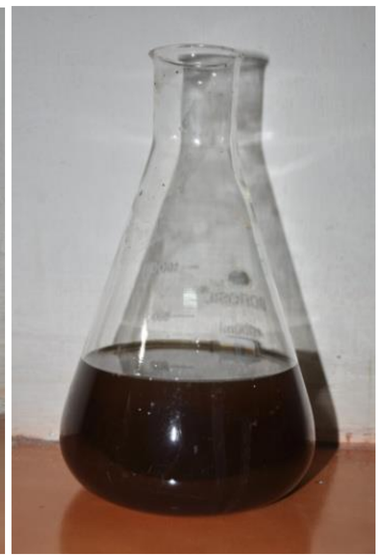
Solutions of actara were prepared in different concentrations by dissolving 1g, 5g and 10g actara in 1 litre water. Four replicate samples of snail with five individuals each were taken and three of it sprayed with solutions (1g, 5g and 10g) and the fourth was maintained as control. Observations were taken for one month.

TDCS

TDCS is a mixture of tobacco and copper sulphate. Lethal concentration of this molluscicide was tested by varying the concentration of the mixture. Different concentrations of TDCS was prepared by mixing 25g tobacco with varying concentrations of copper sulphate (20g, 40g, 60g and 80g) in 2 litre water. Snails were collected from the field and five groups were made with ten individuals in each group. The prepared solutions were sprayed and one group was kept as control.

Figure 3: Experiment with TDCS Solution

Copper Sulphate solution



Tobacco Decoction

TDCS (Tobacco Decoction Copper Sulphate)

Effect on spraying TDCS

Metaldehyde

Metaldehyde is a molluscicidal bait. This bait was first lab tested by placing some granules of it in a plane surface at a distance of 100cm from the snails (6 individual snails) to be tested. The snails were attracted towards the bait and body contact on the bait made some irritations for the snail. Among the six snails, four snails fed on some amount of granules while the two didn't take it all. The snails were kept in separate containers and checked for mortality.

Metaldehyde was field tested in Kannur. Metaldehyde granules were placed in crevices of the compound walls of the snail infested area in the morning time. The experiment was conducted in August during the rainy days. The snails were found to be active during morning time too.

Plant Extracts

Aqueous extracts of *Diploclisia glaucescens* (leaf and stem), *Cocculus laurifolius* (leaf and stem), *Thevetia peruviana* (fruit and leaf), *Allium sativum* (bulb) and C*erebra* odollum (fruit) were tested for molluscicidal activity. 25g of the plant material in 250 ml water was used for preparing aqueous extract using Soxhlet apparatus. The extracts obtained were sprayed on snail.

Econeem

Econeem is a neem based product. Dilutions of it were tried on snail *Achatina fulica*. Previous literatures show that application of econeem on snail makes them to stop feeding within 3 days. Four adult snails were taken in different glass cages A, B, C and D. Econeem was prepared in three different concentrations (1g, 5g and 10g in 1-litre water). Keeping one as control the extract was sprayed on other three snails. Equally weighed (2.5g) food of papaya leaf was provided all the snail to the experimental and control for a week and then weight of leftover leaves were taken. The experiment was set for six days consecutively. Dish containing water was also placed in the glass cages. Observations were taken and noted the leaf weight. Weight of leaf remaining was taken at the end of each day.

Table 5: Experiment with econeem

SL.NO	CONTAINER	LEAF WEIGHT (in gm)					
		1st day	2nd day	3rd day	4th day	5th day	6th day
1	A	1	1.5	0.9	0.3	1.4	0.7
2	B	0.5	2.7	1.1	2.0	1.8	1.5
3	C	1.8	0.5	0.7	1.2	0.9	2.1
4	D	0.8	0.6	1.0	1.6	1.1	0.4

Observation during second day showed the leaves in the container B was soaked in water placed in the container. The increase in leaf weight might be the result of soaking.

The snail's feeding activity were observed daily for one month.

3.3.2 Experiment for finding the best bait

A choice test was done in the field to find the best bait. The various food sources used in the test were cabbage, maida balls, papaya fruit and leaves, vegetable mix and mashed cabbage with beer. Snails were collected from the field and placed in the centre of the field. Baits to be tested were placed at equi distant from the centrally placed snails. After a gap of one hour, snails collected near each bait were counted.

Figure 4: Experiment conducted at Konni, Pathanamthitta to find best bait

Snail placed at the centre

Bait placed at equi distant from the snail

3.3.3 Study on the associated species

Surveys were conducted to find the species associated with this snail *A.fulica.* The associated species were recorded and the types of interaction between them studied. The associated species are classified into predators and niche sharing species based on the type of interaction they have. Predators include pig (*Sus scrofa*), crow pheasant (*Centropus sinensis*), ducks (*Anas* sp.), Peacock (*Pavo cristatus*), glow worm (*Lamprigera* sp.), rodents and snakes. Niche sharing species included slugs, snails and millipedes. Crow pheasants and wild boar plays an important role in reduction of *A.fulica* population in some parts of Kerala

3.4 Involving public and governing bodies in management of invasive species

Public participation and involvement of concerned government authorities are needed for the management of the invasive species. People also should be aware of the issue to limit the spread. In view of this situation awareness programmes were conducted in the infested panchayats. Posters and notices were sent to the people of infested places and to the concerned panchayats/

municipalities /corporations. Posters were also sent to institutions in places prone to infestation according to the prediction model. Control measures were suggested in all the infested places and assist them in the eradication programmes by giving them all technical support. Participation of the public and involvement of government officials were monitored to know how decision making go on in managing an invasive species.

Figure 5: Posters and notices circulated among public and Govt.institutions

3.5 Economic impact assessment

Achatina fulica is a pest in agriculture. It is a macro phytophagous and feeds on 500 plant species. Due to its voracious feeding it can damage the crops very easily. In a house they can be seen on the inner wall of wells, outlet of pipes or nearby, in bathrooms, kitchen, wash area and in the kitchen gardens and is a nuisance to people. Besides causing damages to crops it also cause damages to the buildings and compound walls by feeding on the cementing materials. By all the reasons the creature is a menace in human habitations. The species being a hermaphrodite laying 100-500 eggs in a single clutch, can explode their population if no control measures are applied. So the people are managing this snail mostly using chemicals.

Socio economic impact of *Achatina fulica* infestation was examined mainly in the aspect of crop damage and the cost of control. To determine the social and economic impact caused by this snail *A.fulica* in the infested places a pilot survey was conducted. Based on this a questionnaire was developed and send to the people of infested places. Of the 120 questionnaires send 66 people were responded and the uncompleted questionnaires were filled over phone contact. The average size of a household was 4.6 persons with a total population of 307 from 66 households. Among them farming was the major occupation for 12% of respondents while the rest had another source of income from government salary, labour wages, business, etc., in addition to farming. The annual average household income was estimated as Rs 55,740.

These 66 respondents were classified into small farmers (above 1 hectare), marginal farmers (below 1 hectare), homestead cultivators and respondents with no crop land. Of the 66 respondents 5% were small holders, 33% were marginal holders and 26% had homestead cultivation (Table 6). 36% of the respondents had no crop lands. The crops cultivated by the households are pineapple, guava, paddy, areca nut, beans, passion fruit, brinjal, yam, ginger, turmeric, jackfruit, rubber, pepper, papaya, ornamental plants, mango, cabbage, tapioca, colocasia, melon, spinach, chilly, cucumber, pea, coconut, banana, cauliflower, tomato, anthurium and orkids. The snail caused damage to all the plants except pineapple, guava, arecanut and passion fruit. Except paddy and pineapple most of the crops were cultivated in all categories of holders.

Table 6: Size of holdings and number of respondents

Sl.No	Size of holdings	Number of respondents
1	No crop land	24 (36)
2	Homestead cultivation	18 (26)
3	Marginal holders (up to 1 ha)	21 (33)
4	Small holders (1-2ha)	3 (5)
Total		66

Figures in parenthesis represent respective percentage values

In the case of respondents with no crop lands only the cost for control, time spend for control of the snail and annual income were considered to compare the cost and income due to snail infestation. While in the case of others (marginal farmers, small farmers and homestead cultivators), the cost of cultivation, cost of control, labour charge and time spent for control were taken as the cost and compared with the annual income of the respondents. Average of the cost in each classification was compared with the average of income in the respective classification.

Figure 6: Plants affected by *Achatina fulica*

Papaya

Coconut


Colocasia


Paddy


Musa


Tapioca

4. Results and discussion

4.1 *Achatina fulica* infested regions in Kerala

From the survey conducted for the period of 2010-2014 total 110 snail infested points were recorded from ten districts of Kerala and one infested point from Mahe (Table 7).

Table 7: Snail infested sites recorded during 2010-2014

S.N	District	Place name	Pan/Mun/Corp	Latitude	Longitude
1	Kasargode	Manjeswaram	Manjeswaram (P)	12° 43' 41.69"	74° 53' 1.11"
2	Kasargode	Neeleswaram	Neeleswaram (M)	12° 14' 57"	75° 7' 51"
3	Kasargode	Badiyadka	Badiyadka	12° 35' 36.76"	75° 4' 23.53"
4	Kannur	Kambil	Kolacherry (P)	11^0 58’ 00.8”	75^0 23’ 48.4”
5	Kannur	Parassinikadavu	Taliparambu (M)	11^0 59’ 19”	75^0 23’ 18”
6	Kannur	Parassinikadavu	Taliparambu (M)	11^0 59’ 18”	75^0 23’ 0”
7	Kannur	Darmasala	Taliparambu (M)	11° 59' 18.82"	75° 23' 12.69"
8	Kannur	Kannur	Kannur (M)	11^0 52’ 13”	75^0 21’ 35.8”
9	Kannur	Muzhippilangadu	Muzhippilangadu (P)	11^0 47’ 42”	75^0 27’ 10”
10	Kannur	Kulam Bazar	Muzhippilangadu (P)	11° 47' 37.39"	75° 27' 11.41"
11	Kannur	Madam	Muzhippilangadu (P)	11° 47' 45.2"	75° 27' 7.8"
12	Kannur	Railway Station	Thalassery (M)	11^0 45’ 15.2”	75^0 29’ 30.1”
13	Kannur	Thalassery	Thalassery (M)	11^0 45’ 20.7”	75^0 29’ 49.9”
14	Kannur	Chettamkunnu	Thalassery (M)	11^0 45’ 28.4”	75^0 29’ 7.7”
15	Kannur	Chonadam	Eranjholy (P)	11° 45' 46.91"	75° 30' 50.01"
16	Kannur	Edakkad	Muzhippilangadu (P)	11° 48' 21.8"	75° 26' 38.2"
17	Mahe	Azhikkal	New Mahe (P)	11° 42' 25.99"	75° 31' 48.79"
18	Calicut	Azhiyoor	Azhiyoor (P)	11° 41' 28.72"	75° 32' 16.12"
19	Calicut	Koroth road	Azhiyoor (P)	11° 41' 22.1"	75° 33' 23.9”
20	Calicut	Chakkittappara	Chakkittappara (P)	11° 33' 35.4"	75° 47' 57.4”
21	Malappuram	Pariyapuram	Tanur (P)	11^0 01’ 06.1”	75^0 51’ 46.5”
22	Malappuram	Chiramangalam	Parappanangadi (P)	11^0 01’ 30.1”	75^0 51’ 34.9”
23	Ernakulam	Palluruthi nada	Cochin ©	9^0 55’ 32.2”	76^0 16’ 18.8”
24	Ernakulam	Kacheripadi	Cochin ©	9^0 54’ 52.0”	76^0 16’ 34.0”
25	Ernakulam	Kacheripadi	Cochin ©	9^0 54’ 40.8”	76^0 16’ 38.9”
26	Ernakulam	Palluruthi	Cochin ©	9^0 55’ 32.5”	76^0 16’ 22.1”
27	Ernakulam	Palluruthi market	Cochin ©	9^0 55’ 12.3”	76^0 16’ 21.2”
28	Ernakulam	Palluruthi	Cochin ©	9^0 55’ 14.2”	76^0 16’ 28.2”
29	Ernakulam	Thopumpadi	Cochin ©	9^0 56’ 04.0”	76^0 15’ 29.3”
30	Ernakulam	Thopumpadi	Cochin ©	9^0 56’ 07.5”	76^0 15’ 31.3”
31	Ernakulam	Mattanchery	Cochin ©	9^0 57’ 16.1”	76^0 14’ 58.2”
32	Ernakulam	Willington Island	Cochin ©	9^0 56’ 30.1”	76^0 16’ 12.2”
33	Ernakulam	Choondi	Poothrukka (P)	9^0 57’ 58.6”	76^0 26’ 22.7”
34	Ernakulam	Choondi	Poothrukka (P)	9^0 58’ 01.3”	76^0 26’ 31.3”

35	Ernakulam	Kinginimattom	Poothrukka (P)	9^{0} 57’ 41.8”	76^{0} 28’ 05.8”
36	Ernakulam	Manalimukku	Edathala (P)	10^{0} 03’ 34.1”	76^{0} 21’ 57.1”
37	Alappuzha	Cherthala	Cherthala (M)	9^{0} 39’ 41.0”	76^{0} 19’ 49.5”
38	Alappuzha	Aroor	Aroor (P)	9^{0} 52’ 52.3”	76^{0} 18’ 16.6”
39	Alappuzha	Aryakkara	Muhamma (P)	9^{0} 36’ 33.7”	76^{0} 21’ 27.63”
40	Pathanamthitta	Konni	Konni (P)	9^{0} 13’20.47”	76^{0} 50’ 46.7”
41	Pathanamthitta	Konni	Konni (P)	9° 13' 58.29"	76° 50' 53.62"
42	Pathanamthitta	Vettoor	Pramadom (P)	9^{0} 15’ 00.1”	76^{0} 49’ 33.3”
43	Pathanamthitta	Ramanchira	Kulanada (P)	9^{0} 14’ 49.5”	76^{0} 42’ 29.1”
44	Pathanamthitta	Cheneerkkara	Cheneerkkara (P)	9^{0} 14’ 41.6”	76^{0} 44’ 08.3”
45	Kollam	Karavaloor	Karavaloor (P)	8^{0} 58’ 39.8”	76^{0} 54’ 41.7”
46	Trivandrum	Valiyathura	Trivandrum ©	8^{0} 27’ 49.9”	76^{0} 55’ 54.7”
47	Trivandrum	Valiyathura	Trivandrum ©	8^{0} 27’ 50.8”	76^{0} 55’ 34.4”
48	Trivandrum	Valiyathura	Trivandrum ©	8^{0} 27’ 54.1”	76^{0} 55’ 33.9”
49	Trivandrum	Shangumugam	Trivandrum ©	8^{0} 29’ 01.7”	76^{0} 54’ 44.9”
50	Trivandrum	Vettukaud	Trivandrum ©	8^{0} 29’ 37.3”	76^{0} 54’ 12.6”
51	Trivandrum	Kochuveli	Trivandrum ©	8^{0} 30’ 39.3”	76^{0} 53’ 47.6”
52	Trivandrum	Karikkakam	Trivandrum ©	8^{0} 30’ 27.2”	76^{0} 54’ 08.1”
53	Trivandrum	Karikkakam	Trivandrum ©	8^{0} 29’ 39.7”	76^{0} 54’ 41.6”
54	Trivandrum	Paalkulangara	Trivandrum ©	8^{0} 29’ 21.3”	76^{0} 55’ 42.7”
55	Trivandrum	Paruthipara	Trivandrum ©	8^{0} 31’ 58.2”	76^{0} 56’ 38.7”
56	Trivandrum	Bakery junction	Trivandrum ©	8^{0} 29’ 59.5”	76^{0} 57’ 10.8”
57	Trivandrum	TVM central	Trivandrum ©	8^{0} 30’ 22.0”	76^{0} 56’ 54.7”
58	Trivandrum	Vanchiyoor	Trivandrum ©	8^{0} 29’ 37.2”	76^{0} 56’ 26.6”
59	Trivandrum	Akkulam	Trivandrum ©	8^{0} 31’ 20.3”	76^{0} 55’ 01.5”
60	Trivandrum	Near to CESS	Trivandrum ©	8^{0} 31’ 20.2”	76^{0} 54’ 40.9”
61	Trivandrum	Near to CDS	Trivandrum ©	8^{0} 31’ 46.4”	76^{0} 55’ 15.1”
62	Trivandrum	Kesavadasapuram	Trivandrum ©	8^{0} 31’ 42.45”	76^{0} 56’ 21.77”
63	Trivandrum	Manakkkad, Thotta	Trivandrum ©	8^{0} 28’ 12.1”	76^{0} 56’ 51.1”
64	Palakkad	Pazhaya gramam	Nenmara (P)	10^{0} 35’ 20.2”	76^{0} 35’ 42.1”
65	Palakkad	Nenmara	Nenmara (P)	10^{0} 35’ 14.9”	76^{0} 35’ 45.4”
66	Palakkad	Pallavoor	Pallassana (P)	10^{0} 37’ 45.5”	76^{0} 36’ 44.8”
67	Palakkad	Kizhakkethara	Pallassana (P)	10^{0} 37’ 41.2”	76^{0} 37’ 08.5”
68	Palakkad	Vennakkkara	Palakkkad (M)	10^{0} 45’ 39.4”	76^{0} 38’ 25.8”
69	Palakkad	Kalleppulli	Palakkad (M)	10^{0} 47’ 36.1”	76^{0} 40’ 24.6”
70	Palakkad	Yakkara	Kannadi (P)	10^{0} 44’ 50.8”	76^{0} 39’ 04.4”
71	Palakkad	Kanjikode	Puthussery (P)	10^{0} 48’ 00.3”	76^{0} 45’ 17.9”
72	Palakkad	Kaavussery	Kaavussery (P)	10^{0} 39’ 08.4”	76^{0} 30’ 56.4”
73	Palakkad	Thenkurissi	Thenkurissi (P)	10^{0} 41’ 18.5”	76^{0} 37’ 17.2”
74	Palakkad	Vilayan chathanur	Thenkurissi (P)	10^{0} 41’ 39.2”	76^{0} 37’ 30.2”
75	Palakkad	Kayarankulam	Thenkurissi (P)	10^{0} 42’ 09.2”	76^{0} 38’ 06.6”
76	Palakkad	Thaayankavu	Thenkurissi (P)	10^{0} 41’ 56.7”	76^{0} 38’ 28.4”
77	Palakkad	Valiyaattukunnu	Thenkurissi (P)	10^{0} 41’ 19.8”	76^{0} 37’ 17.8”
78	Palakkad	Vaniyamparambu	Thenkurissi (P)	10^{0} 43’ 08.0”	76^{0} 38’ 13.9”
79	Palakkad	Idapparambu	Thenkurissi (P)	10^{0} 40’ 44.9”	76^{0} 36’ 32.9”
80	Palakkad	Vazhakode	Peruvembu (P)	10^{0} 41’ 50.4”	76^{0} 40’ 14.9”
81	Palakkad	Onaanthara	Peruvembu (P)	10^{0} 42’ 39.7”	76^{0} 39’ 35.7”

82	Palakkad	Maithri Nagar	Palakkad (M)	10^0 45’ 52.7”	76^0 38’ 54.5”
83	Palakkad	Chandranagar	Marutharode (P)	10^0 46’ 27.7”	76^0 48’ 52.8”
84	Palakkad	Perumkunam	Kuzhalmannam (P)	10^0 41’ 30.01”	76^0 36’ 45.79”
85	Palakkad	Thottakaadu thara	Koduvayur (P)	10^0 40’ 59.92”	76^0 39’ 40.28”
86	Palakkad	Karnaki nagar	Koduvayur (P)	10^0 40’ 53.8”	76^0 39’ 35.8”
87	Palakkad	Karuvanoor thara	Koduvayur (P)	10^0 41’ 24.0”	76^0 39’ 26.6”
89	Palakkad	Koduvayur	Koduvayur (P)	10^0 41’ 39.9”	76^0 39’ 32.9”
90	Palakkad	Ethanoor	Koduvayur (P)	10^0 40’ 59.0”	76^0 38’ 35.2”
91	Palakkad	Puthunagaram	Kollenkode (P)	10° 37' 5.41"	76° 41' 42.11"
92	Palakkad	Puthugramam	Kollenkode (P)	10^0 37’ 03.8”	76^0 41’ 43.3”
93	Palakkad	Nedumani	Kollenkode (P)	10^0 36’ 31.2”	76^0 42’ 49.8”
94	Palakkad	Achanamkode	Kollenkode (P)	10^0 36’ 21.2”	76^0 43’ 07.2”
95	Palakkad	Mannam	Vadavanoor (P)	10^0 38’ 12.3”	76^0 41’ 24.6”
96	Palakkad	Chittur	Chittur-Thathamangalam(M)	10^0 42’ 07.6”	76^0 44’ 16.0”
97	Palakkad	Chittur	Chittur-Thathamangalam(M)	10^0 42’ 17.8”	76^0 44’ 17.6”
98	Palakkad	Elappulli	Elappulli (P)	10^0 45’ 26.2”	76^0 44’ 33.5”
99	Palakkad	G.U.P.School	Elappulli (P)	10^0 45’ 27.0”	76^0 44’ 29.6”
100	Palakkad	Ambuja Nagar	Marutharoad P)	10^0 45’ 41.3”	76^0 42’ 19.7”
101	Palakkad	Kunnisseri	Erimayoor (P)	10^0 38’ 08.5”	76^0 35’ 57.4”
102	Palakkad	Medical	Kuzhalmannam (P)	10^0 44’ 27.2”	76^0 36’ 64.7”
103	Palakkad	Kannanore-thottupalam	Kuzhalmannam (P)	10^0 43’ 45.6”	76^0 36’ 34.1”
104	Palakkad	Anjumuri	Kuzhalmannam (P)	10^0 40’ 55.2”	76^0 34’ 44.4”
105	Palakkad	Kottarapadi	Kuzhalmannam (P)	10^0 42’ 42.2”	76^0 35’ 09.1”
106	Palakkad	Kulavanmukku	Kuzhalmannam (P)	10^0 42’ 32.1”	76^0 35’ 39.5”
107	Palakkad	Kulavanmukku	Kuzhalmannam (P)	10^0 42’ 45.0”	76^0 35’ 17.9”
108	Palakkad	Kalappetty	Kuzhalmannam (P)	10^0 42’ 13.7”	76^0 36’ 21.3”
109	Palakkad	Kalkulam	Kuthanur (P)	10^0 43’ 09.8”	76^0 33’ 55.5”
110	Palakkad	Kunnukaadu	Kuthanur (P)	10^0 42’ 43.9”	76^0 33’ 43.6”

High population of snail *Achatina fulica* is found in the districts of Trivandrum, Pathanamthitta, Ernakulam, Palakkad and Kannur. Palakkad district had a large number of snail infested sites; except these all other places were close to coastal areas.

4.2 Potential distribution of snail *Achatina fulica*

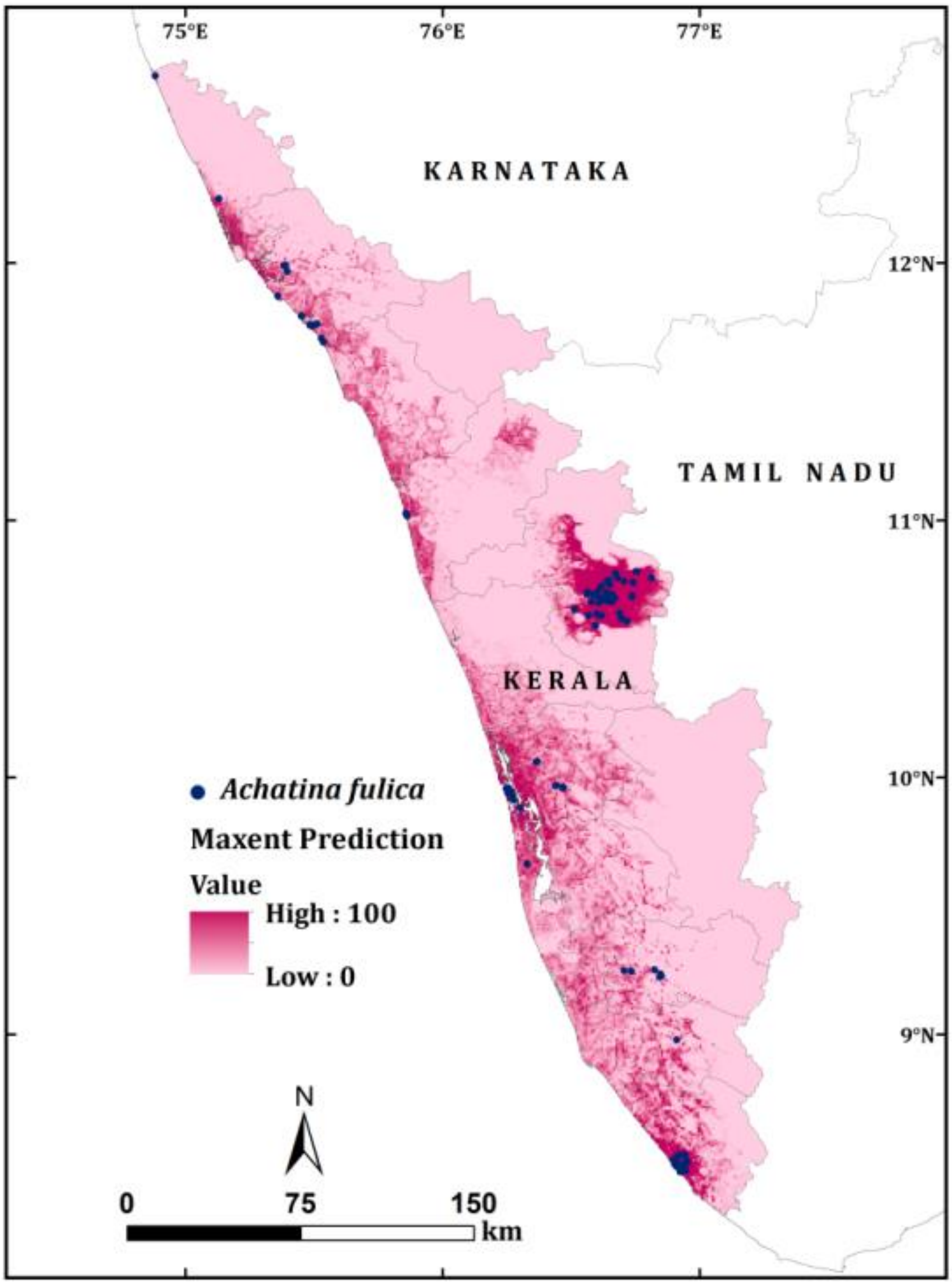
The potential distribution is apparently restricted to the coastal lowlands of Kerala, Palghat Gap and low elevation areas of Achenkovil-Thenmala Valley. District wise, Ernakulam district has the most potential areas of possible distribution. Idukki district, a mountainous highland is less predicted. Recently, a locality from the midlands of Kozhikode district (Chakkittapara) has been reported presence for the snail. The earlier recorded locality of the snail in the district is from the coastal area neighboring Mahe, a union territory of Pondicherry. Our model had earlier shown potential prediction for the now reported area.

Table 8: Variable contribution

Variable	Percent contribution	Permutation importance
Slope	33.6	22.4
Maximum Temperature of Warmest Month	31	13.6
Mean Diurnal Range	23.8	5.1
Precipitation of Driest Month	5.2	10.7
Elevation	2.7	18.3
Minimum Temperature of Coldest Month	1.4	5.5
Annual Precipitation	0.7	12.5
Annual Mean Temperature	0.7	0
Aspect	0.6	0.5
Precipitation of Wettest Month	0.4	11.4

The main bioclimatic variables (Table 8) that control the potential distribution of the snail are higher maximum temperature in the warmest month, lower mean diurnal temperature range i.e., the difference between the minimum and maximum temperature is less (warmer days!) and higher precipitation in the driest month. Also, high minimum temperature in the coldest month and low elevation influences the distribution of the snail. These are all the typical bioclimatic conditions that prevail in the lowland and in the river valleys in the midlands of Kerala – an ideal warm and humid tropic.

Figure 7: Map showing the potential distribution



4.3 Pathways of spread

The major pathways for the spread of Giant Africa Snail *A.fulica* in Kerala are found to be the timber depots through which timber from international trade reaches different localities and the timber mills through which snail can reach to rural areas. The other pathways found are sewage farm, hitchhiking in vehicles and collecting the snail for curiosity.

4.3.1 Sewage farm as a pathway:

Sewage farm in Valiyathura, Trivandrum is one of the major pathway for the spread of *A.fulica*. Here in 108 acres of land fodder grass cultivation was done using sewage effluents. These fodder grasses are being supplied to cattle farm of various places. This area of sewage farm where grasses are growing is infested by the snail *A.fulica*. There is a chance of spreading the snail through the grass fodder. Authorities of the sewage farm were informed to take necessary measures to control the snail and also to check the bunch of grasses before supply.

Control and prevention should be done at the point of spread. In the case of *Achatina fulica* single fertilized individual is capable of building up a population.

4.3.2 Timber depot as a pathway:

A huge timber depot situated in the Willington Island, Ernakulam and nearby areas is being infested by snail *A.fulica*. The timber depot was started in the year 2004. There timber was imported mainly from Malaysia, Burma, Nigeria, Algeria and Angola. Among these countries Malaysia, Burma and Nigeria are infested with *A.fulica*. Snail infestation in Willington Island traces back to the subsequent year of beginning of the timber depot here. This depot is suspected to be one of the major pathways for the introduction and spread of snail *A.fulica*. From the depot timber is supplying to various timber mills and the same way the snail spread.

Timber mill is the source for the introduction of snail in Bathiyadukka of Kasargode district also.

4.3.3 Hitch hiking in vehicles

There is a great chance for the snail *A.fulica* to be hitch hiked in vehicles. Vehicles parked in the snail infested area accidentally become a medium for the transportation of the snail from place to place. Incidents have been recorded from Konni and Omallur of Pathanamthitta District.

4.3.4 As a part of fantasy

The snail *A.fulica* is the largest terrestrial snail. Because of its large shell and big size people are keeping it as pet in many countries. In Kerala also, people are collecting one or two specimen of the snail to their homes where they become a problem later. Cheneerkkara panchayat and Omallur panchayat of Pathanmathitta got infested this way.

4.4 Management of snail *Achatina fulica*

4.4.1 Historical background of snail *Achatina fulica* in Kerala

4.4.1.1 First incidence of snail *Achatina fulica* infestation in Kerala

Infestation of the snail *Achatina fulica* in Kerala was first noticed during 1970's in Palakkad. It's entry to Kerala was suspected to be during 1955 through a researcher who brought two of the snail to Elapully panchayath of Palakkad district. Post effect of the research was the survival of the snail in the wild. Till 1970 there were no much impact due to this snail but thereafter it became a nuisance for the people at Elappully. To get rid from this snail, people contacted District Collector but he was not able to do take an appropriate action. The angry mob collected a packet of snail from Elappully and dumped them in Palakkad town. The snail thus got established in Palakkad town. Municipality decided to implement a snail eradication programme and they announced to give one paise per snail for collection and within 3 days they spent a sum of Rs.1928 for this. As this began to adversely affect the treasury, the Chairman decided to stop the package and suggested to employ Malaria eradication workers to destroy these snails. This issue though presented in the Parliament did not receive much attention but Kerala Government sensing the disaster caused by it decided to import predators of snail *Ublandy rosea* and *Gonoxis quadrilateralis* and planned to construct a separate centre for the rearing of this imported species. Unfortunately this didn't happen.

4.4.1.2 Pioneer introduction of *Achatina fulica* into Kerala

P.N. Rajakrishna Menon a resident of Elappully panchayath, Palakkad introduced the snail *Achatina fulica* in Palakkad. He was doing research in Annamalai University and for the purpose of his study on the reproductive biology of snail he bought a couple of snail from Singapore for 10 Indian rupees. He started to rear this snail in a drum in his home in Palakkad. The snails replicated inside the drum and increased to huge quantities. He with the help of his servants dumped these snails in an open space. Those snails which are thrown to wild survived and later infested the Palakkad town

4.4.1.3 Reappearance of *Achatina fulica* after a long gap

Snail *A.fulica* reappeared in Kerala from 2005 onwards after a long gap of 30 years. What happened to the snails in this 30 year gap is still a mystery. Whether the snails have been eradicated or whether they have been died because of some diseases is unknown. From 2005-2007 intermittent appearance of it occurred in places like Kozhikode, Palakkad, Ernakulam and Pathanamthitta. Table shows the infested region in Kerala till the period 2007.

Table 9: ***Achatina fulica*** **infested places from 2005-2007**

Sl.No	Year	Place	District
1	2005	Konni	Pathanamthitta
2	2006	Azhiyoor	Kozhikode
3	2006	Palakkad	Palakkad
4	2007	Palluruthi, Mattanchery, Koovapadam	Eranakulam

4.4.1.4 Collapse of snail *Achatina fulica* in some infested regions

Collapse of snail *A.fulica* was noticed in some infested places of Calicut, Palakkad and Ernakulam districts of Kerala and in Mahe. No snail or their shells were found in the area for 2-3 years. Recently in Mahe reinfestation of the snail was noticed in the collapsed region after 3 years. Density estimation of reinfested population found the occurrence of about 1587 snails in that site.

The collapse of *A.fulica* in Kerala occurred in places where no much management actions were practiced. How does the collapse happen? Do the snails' undergone aestivation for the last three years? Is it is a new infestation in the same place? Do the cases of other collapsed region will be same as Mahe? The science behind the collapse is a mystery.

4.4.2 Control methods of *Achatina fulica*

Finding a good control strategy is needed in the management of an invasive species. In the case of the management of the snail *A.fulica*, TDCS solution was found to be very effective compared to the other chemicals or plant extracts tested. The experiment on cupric ricinoleate was not able to complete successfully. The use of other chemicals like actara and iron phosphate was not successful in killing the snail. Metaldehyde was effective but when field tested it was found harm other mollusks. Also impacts to other organisms were also reported. Plant extracts even though causing irritation are not lethally effective to this snail. Organic insecticide econeem is also not effective. Using common salt is the common method followed by most of the people as it is the easily available method and is very cheap. Salt is a good method for the control of snail but it can't be used in a large amount as it can alter the soil chemistry and also cause foul smell that arise from the dead snails killed.

The snail *A.fulica* is nocturnal. They are active from dusk to dawn. During day time, they will hide in the crevices of the wall or attached to the compound walls, inside the soil or in the vegetation. This is mainly to avoid the day temperature. During day time use of bait is not effective. So during day time physical along with chemical method is more reliable. Hand picking the snail and putting them in a salt solution or TDCS solution will be effective for the day time. The dead snails can be dumped into pits which should not be left uncovered as otherwise the empty shells may serve as breeding sites for mosquitoes as well as to avoid the bad smell.

As the snails are found to be active from dusk and it is the best time to use the bait. Among the bait, cabbage mixed with beer found to be most effective. Papaya and Cabbage alone can also be used as bait as they are giving good result in the field. During night time, snails will come out from their hiding place and they all will be on the ground. While placing bait we can attract the snails, can be killed by spraying TDCS solution and later dumped into pits covered.

Biological control is the best method for eradication of a species. From our study on the faunal association of *Achatina fulica* in Kerala recorded predators of the snail including mammals (*Sus scrofa, Rattus rattus, Bandicota indica, Herpestes edwardsii* and *Suncus murinus*), aves (*Centropus sinensis, Pavo cristatus, Anas* sp.), insects (lampyridae) and reptiles (viper). Most of the predators of snail *Achatina fulica* are generalist feeders. The feeding mode of each predator varies depending on the grasping mechanisms. *Sus scrofa* feed the snail as a whole along with its shell. Other mammalian predators and birds break the shell by hitting it on any hard surfaces and feed on the flesh. They leave the adult due to the inability in breaking hard shell. The only predator which feed the snail in all age group is lampyrids larvae. They crawl along the body of the snail and will bite on the exposed body parts. Numerical increase in the predator population was recorded mainly in the case of crow pheasants and lampyrids and constitutes a significant predation pressure on snail *Achatina fulica*. The role of predation by the mammalian predator *Sus scrofa* and avian predator *Centropis sinensis* greatly reduced the population of snail *Achatina fulica* in regions of Kerala including Ernakulam and Palakkad. The predatory lampyrid numerically respond to snail infestation but is unable to contain the pest populations.

Figure 8: Map showing the places where snail population reduced by crow pheasant

Figure 9: Map showing the places where snail population reduced by wild boar

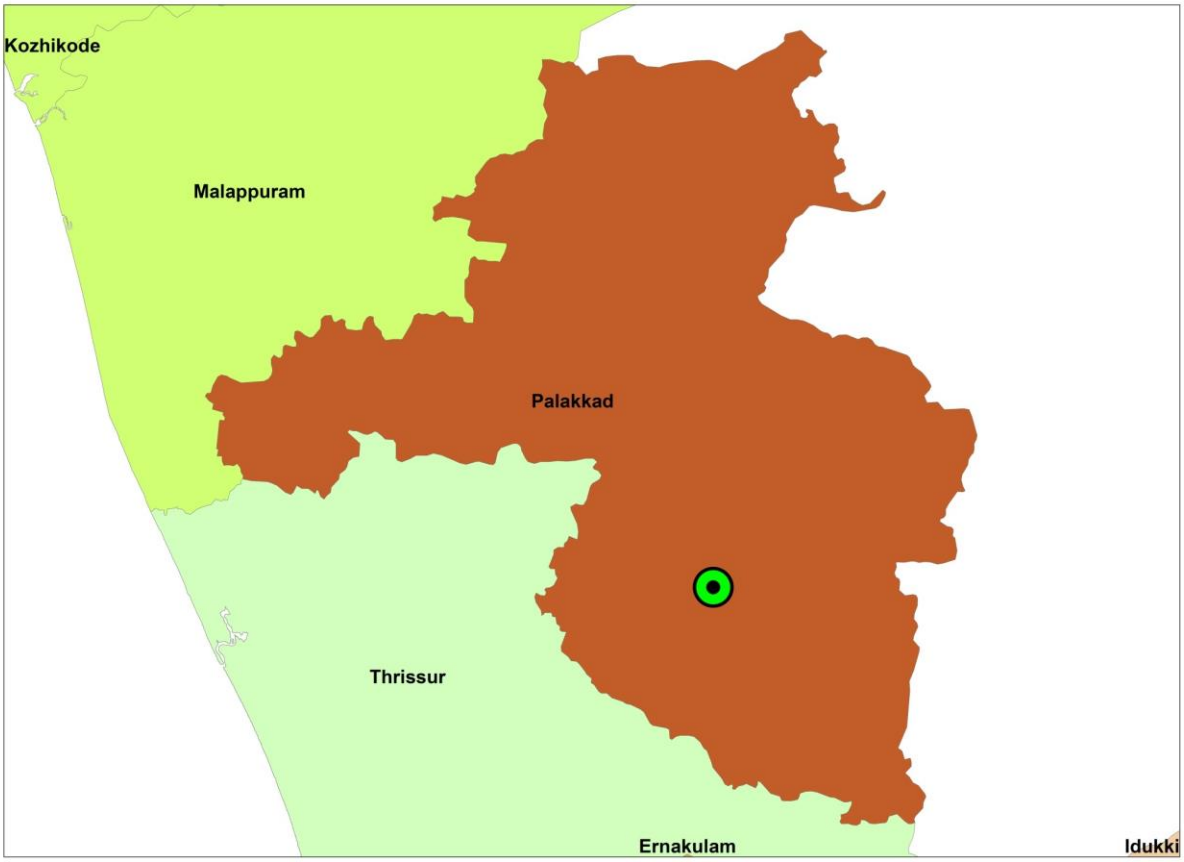


Figure 10: Snail predation by lampyrids

4.5 Public participation

Public participation is a continuous process of interaction between the organization responsible for decision making and the public. It involves awareness of the public about the status and implementation stage of an activity, measures promoting the full understanding by the public of the procedure of decision making used by an authority, collection of the concerned citizen's opinions, their attitude towards the project objectives and tasks. Public participation is an effective method for building public support. It can be achieved by consultation on key issues that directly affects public and inclusion of public values and ideas into the process. Education is the major tool to be used here as it promotes understanding of invasive species issues among public.

In the case of the management of the invasive snail *Achatina fulica* in Kerala, the public was informed and alerted by notifications in the newspaper, notices, booklets and posters. Knowledge on the snail *Achatina fulica*, its pest status, reason for introduction, the impact caused, need for the control and management strategies were shared among the public. Firsthand information from the public was taken to know the impact level caused by them and their ideas in managing this invasive species. Public meetings were conducted and awareness classes were provided on the management of invasive species. All the technical supports were provided for them in the eradication programme with the support of local governing bodies. The response from the general public was immense all through the period of study. It was interesting to note that the respondents to the news on the snail were mostly women. The field work which ensued indicated that at many places, men were not at all aware of the issue while women had called the helpline for assistance. This was due to the fact that women exclusively operate in the wet places in around the housing where the snails prefer to reside. There had been better coordinated efforts at places where women representatives in the local self-governments took up the issue.

The attitude of the people, the lifestyle of the people, society where they live also determine the response of the people in addressing a problem. It seems similar in the case of management of invasive species also. People living in rural areas responded better compared to those in urban areas. In rural areas people formed groups for day and night work in managing the snails.

4.6 Involvement of governing bodies

The responses of the local self-governing bodies including Panchayats/Municipalities/ Corporations, agriculture department, health centres were greatly appreciated in some places. Authorities took up action research in managing this invasive species by engaging labourers to control this snail and by providing the molluscicides to the public. MNREGS workers were engaged by some panchayats like Muzhippilangadu, Konni and Edathala for the management of this invasive snail. Kannur municipality also engaged municipal workers in the management programme and their efforts helped to eradicate the snail completely in a plot near to S.N. Park area. In Muzhippilangadu panchayat of Kannur district the authorities of the health centre are supplying the TDCS mixture to the people as per their need. The eradication programme was a success in the area near to Madathilkavu temple of Konni. The success of this eradication programme was due to the combined effort of the public and the Panchayat authorities. In urban areas, the authorities were not much interested in taking up the issue due to the lack of cooperation from the public. The response of local self-governments in snail infested sites of Kerala is given in Table 10. There were 32 reports from the rural areas and 9 from urban areas.

When the communication was send to all of them, there was better response from rural locations than the urban areas.

Table 10: Response of local self-governing bodies

Number of local-self governments	Rural	Urban
From which snail infestation was reported	32	9
To which information was sent	32	9
Responded	19 (59%)	3 (33%)
Which conducted awareness campaign	9 (28%)	1 (11%)
Which undertook eradication work	11(34%)	2 (22%)

4.7 Evaluation of eradication programme

Involvement of local people and concerned government authorities decides the efficiency of eradication programme. Also, in implementing the eradication programme better response was found in rural locations. Overall, only 31.7% of the local self-governments graduated to the level of undertaking eradication measures. However, the campaign could completely eradicate the snail populations in two sites and significant information was passed on to the general public which now uses the methods to keep their premises clear of snails.

Effective management of alien invasions needs action research supported by government and the general public. In this case, significant deficit on preparedness on the part of all stakeholders was evident. This includes lack of awareness on the problems posed by alien invasive species, the inability of the local self-governments to financially support eradication drives, lack of a single government agency to implement eradication programmes, inability to continue the eradication campaign for longer periods and the lack of co-operation among the general public in the urban areas. The only good and appreciable response were from the media which helped in taking up back and forth communication between the general public and researchers.

4.8 Socio economic impact of *Achatina fulica*

The snail *Achatina fulica* is a pest to agriculture and a menace to human habitation. Among the households selected snail infestation severity varies differently. 9% household's shows high level of infestation, 29% medium and 28% constituted low level of infestation (Table. 11).

Table 11: Level of infestation

Size of holdings	High	Medium	Low
No crop land	2 (8)	9 (38)	13 (54)
Homestead cultivation	2 (12)	7 (41)	8 (47)
Marginal holders (up to 1 ha)	4 (18)	11 (50)	7 (32)
Small holders (1ha-2ha)	1 (33)	2 (67)	0
Total	9	29	28

Figures in paranthesis represent respective percentage values

Various control measures are practiced by the holders. 80% of the holders are practicing chemical control while 12% were practicing integrated methods (physical and chemical methods combined). Only 2% of holders is practicing physical method. The physical method involves hand picking of the snail, hitting the snail with hard substances, throwing the snail on hard surfaces. Among the 80% of holders practicing chemical control 96% were of people with no crop land followed by those with homestead cultivations (82%). An integrated method of control is practiced more by marginal holders and small holders. Control measures practiced by the people reduce net income through increased labour costs or reduce the time available for other activities.

Table 12: Control methods practiced by the holders

Size of holdings	Physical	Chemical	Integrated
No crop land	1 (4)	23 (96)	0
Homestead cultivation	0	14 (82)	3 (18)
Marginal holders (up to 1 ha)	0	14 (64)	8 (36)
Small holders (1ha-2ha)	0	2 (67)	1 (33)
Total	1(2)	53 (80)	12 (18)

*Figures in parenthesis represent respective percentage values

Chemical methods have been used mostly by the holders of all category (Table 13). 76% of the holders used common salt to control the snail while only 6% used TDCS.A combination of these two methods was practiced by 9% of the holders. The method of using salt and lime were practiced by the rest 9% of the holders. For the control of snail in their cultivated area farmers are spending some amount of their income for buying the chemicals needed including salt, copper sulphate, tobacco and lime and labour charges.

Table 13: Chemical measures used by the holders

Size of holdings	**Salt**	**TDCS**	**Salt+TDCS**	**Salt+Lime**
No crop land	22 (92)	0	2 (8)	0
Homestead cultivation	13 (76)	2 (12)	1 (6)	1 (6)
Marginal holders (up to 1 ha)	14 (64)	1 (5)	3 (13)	4 (18)
Small holders (1ha-2ha)	1 (33)	1 (33)	0	1 (33)
Total	50 (76)	4 (6)	6(9)	6(9)

Figures in parenthesis represent respective percentage values

Among the holders, besides crop damage 26% have reported some health problem (Table 14) while 74% reported no such health issues due to snail in their habitation. 3% of the holders reported mental tension in seeing this snail, 5% reported leg injury due to the broken shell of this snail, 15% reported itching when contact with the body fluid of the snail, 2% reported mosquito breeding in the empty shells of the snail and 2% reported sickness in children due to the presence of snail.

Table 14: Self-reported health problem by the holders

Size of holdings	**Leg injury**	**Itching**	**Mosquito breeding**	**Mental tension**	**Sickness in children**	**No health problem**
No crop land	0	5 (21)	0	0	1 (4)	18 (75)
Homestead cultivation	1 (6)	1 (6)	0	2 (12)	0	13 (76)
Marginal holders (up to 1 ha)	1 (5)	4 (18)	0	0	0	17 (77)
Small holders (1ha-2ha)	1 (33)	0	1 (33)	0	0	1 (33)
Total	3 (5)	10 (15)	1 (2)	2 (3)	1(2)	49 (74)

Figures in parenthesis represent respective percentage values

The snail being nocturnal mostly people are applying the control in the night or in the morning (Table 15). Among the holders, 29% applied control measures in the night while 16% in the morning. 26% of holders do the control both in the night time and in the morning time while 29% do the control all the time when they see the snail.

Table 15: Time period of controlling the snail *Achatina fulica*

Size of holdings	Morning	Night	Morning+Night	All the time
No crop land	5 (21)	6 (25)	6 (25)	7 (29)
Homestead cultivation	4 (24)	3 (18)	4 (24)	6 (34)
Marginal holders (up to 1 ha)	2 (9)	9 (41)	6 (27)	5 (23)
Small holders (1ha-2ha)	0	1 (33)	1 (33)	1 (33)
Total	11 (16)	19 (29)	17 (26)	19 (29)

*Figures in parenthesis represent respective percentage values

The holders are spending some hours of their daily working time for the control of the snail (Table 16).

Table 16: Hours spent daily in controlling the snail

Size of holdings	Half an hour	1 hour	2 hours	3 hours	4 hours
No crop land	11 (46)	9 (37)	4 (17)	0	0
Homestead cultivation	5 (29)	6 (36)	5 (29)	1(6)	0
Marginal holders (up to 1 ha)	5 (23)	7 (32)	6 (27)	2 (9)	2 (9)
Small holders (1ha-2ha)	0	0	1 (33)	2 (67)	0
Total	21 (32)	22 (33)	16 (24)	5 (8)	2 (3)

*Figures in parenthesis represent respective percentage values

Here the time spent by the people in controlling the snail has been converted into rupees with related to the labourer charge. Farmers are doing the control in the whole rainy season from june (South west monsoon) till November (North east monsoon). By December the snail will undergo aestivation till May. During pre-monsoon rains, the snail may break their aestivation but only few will come out of their sleeping phase. So no much damage will be causing those periods. The total cost of the control includes the money spent for buying chemicals and the time spent in controlling theses snails. Total cost includes cost of control, cost of cultivation and labour charge.

Table 17: Average cost and income of the holders

Size of holdings	Average cost (in Rs)	Average annual income(in Rs)
No crop land	10,343	59,332
Homestead cultivation	18,071	57,000
Marginal holders (up to 1 ha)	28,825	53,093
Small holders (1ha-2ha)	65,306	59,667

The average cost increases with the size of holdings. The average cost estimated for small holders is Rs 65,306 and for marginal holders it is Rs 28,825. For people doing homestead cultivation it decreased to Rs 18,071 while for those who are not doing any cultivation the cost estimated is Rs 10,343

5. Conclusions

Achatina fulica is an invasive snail that has acquired a pest status in many parts of the Kerala state. There are 110 snail infested sites in Kerala recorded from ten districts except Idukki, Kottayam, Thrissur and Wayanad. In all the infested sites the authorities and the public were contacted to share the information on this invasive snail and also on the management strategies. Mapping the potential distribution using Maxent modelling enabled us to know the areas which are prone to snail infestation. Ernakulam area was found to be most predicted while Idukki the least. Information on this snail was passed to the high and medium predicted areas based on the model to alert the people and local self-government for detection of this species. Pathways of the spread of this species were detected and the authorities were informed. Various control methods including chemical, herbal extracts, organic insecticide were tried and found TDCS (Tobacco Decoction Copper Sulphate) mixture to be effective. The information was passed to the public and governing bodies and are practicing now in most of the places. Information on the snail *A.fulica*, the impact caused, management measures and the things to be taken into care during the management programmes were made aware to public through awareness classes, posters, notices and brochures. For assisting the management programme bait were tested and cabbage mixed with beer found to be the best. Cabbage and papaya alone also give good result. Besides the control of snail population by human beings they were naturally controlled in some places by their predators. In Ernakulam and Palakkad district the snail population was found declined to a low level due to the predation by Crow pheasant and pigs. Eradication programmes were undertaken by governing bodies in some places and all the technical details were provided to them. However, the campaign could completely eradicate the snail populations in two sites and significant information have been passed on to the general public who now use the methods to keep their premises clear of snails. The response was more of rural areas compared to the urban and public participation played a crucial role in the management of invasive snail. Assessment of the economic impact of *Achatina fulica* found that the average cost increases with increasing size of the holdings. Average cost for marginal farmers, homestead cultivators and those with no croplands are less than their average income but for small farmers average cost is higher than their income.

6. References

Ahmed, M. and Raut, S.K., 1991. Influence of temperature on the growth of the pestiferous land snail *Achatina fulica* (Gastropoda: Achatinidae). *Walkerana*, 5(3): 33-62

Albauquerque, F.S., Peso-Aguiar, M.C. and Assuncao-Albuquerque, M.J.T., 2008. Distribution, feeding behavior and control strategies of the exotic land snail *Achatina fulica* (Gastropoda: Pulmonata) in the northeast of Brazil. *Braz.J.Biol*, 68(4): 837-842

Allen, J.A., 1983. The inheritance of a shell colour polymorphism in *Achatina fulica* Bowdich from East Africa. *Journal of Conchology*, 31:185-189.

Anderson, B., 1993. The Philippine snail disaster. *The Ecologist*, 23: 70-72.

Anderson, R.C., 2000. Nematode parasites of vertebrates: Their development and transmission. Wallingford, UK: CABI publishing

Annandale, N., 1907. The distribution in India of the African snail *Achatina fulica* Fer. Records of the Indian Museum, Calcutta, 1: 176-77

Barbier, E.B., 2001. A note on the economics of biological invasion. *Ecological Economics*, 39: 197-202.

Batabyal, A.A. and Nijkamp, P., 2007. The stochastic arrival of alien species and the number of and the damage from biological invasions. *Ecological Economics*, 62: 277-280

Benson, W.H., 1858. Note sur la transportation et la naturalization au Bengale de l' *Achatina fulica* de Lamarck. *Journal de Conchyliologie*, 1: 336-339

Bequaert, J., 1925. The arthropod enemies of mollusks, with description of a new dipterous parasite from Brazil. *The journal of Parasitology*, 11(4): 201-212

Berry,A.J. & Chan,L.C.,1968. Reproductive condition and tentacle extirpation in Malayan *Achatina fulica* (Pulmonata). *Australian Journal of Zoology*, 16:849-55

Bess, H.A., 1955. Ecological notes on *Lamprophorus tenebrosus* (Walker) (Coleoptera: Lampyridae), an enemy of the Giant African Snail. Proc Hawaiian Entomol, Soc 16(01): 24-29

Blanford, W.T., 1868. On the occurrence of *Diplommatina huttoni* and *Ennea bicolor* in the West Indies. Annals and Magazine of Natural History, 1: 110-112

Born, W., Rauschmaer, F. and Brauer, I., 2005. Economic evaluation of biological invasions-a survey. *Ecological Economics*, 55: 321-336

Borrero, F.J., Breure, A.S.H., Christensen, C.C., Correoso, M. and Avila, V.M., 2009. Into the Andes: three new introductions of *Lissachatina fulica* (Gastropoda, Achatinidae) and its potential distribution in South America. Tentacle, 17: 6-8

Botafogo Goncalves, N. and Rostan de Rohan Loureiro Soares, 1955. Molluscocide action of the cupric ricinoleate. *Memorias do Instituto Oswaldo Cruz*, 53(2,3 e 4): 404-409

Bowdich, T.E., 1822. Elements of Conchology, including the fossil genera and the animals. Part 1. Univalves. Printed by Smith, J., Paris, 132pp.

Brockelman, C.R. and Sithithavorn, P., 1980. Carbohydrate reserves and hemolymph sugars of the African giant snail, *Achatina fulica* in relation to parasitic infection and starvation. *Z.Parasitenkd*, 62: 285-291

Brockelman, C.R., 1978. Effects of parasitism and stress on Hemolymph protein of the African giant snail, *Achatina fulica*. *Z.Parasitenkd*, 57: 137-144

Budha, P.B. and Naggs, F., 2008. The giant African Snail *Lissachatina fulica* (Bowdich) in Nepal. Malacological Society of London, 50: 19-21

Cheng, T.C. and Alicata, J.E., 1965. On the modes of infection of *Achatina fulica* by the larvae of *Angiostrongylus cantonensis*. *Malacologia*, 2(2): 267-274

Civeyrel, L. and Simberloff, D., 1996. A tale of two snails: is the cure worse than the disease? *Biodiversity and Conservation*, 5: 1231-1252

Clarke, B.C., Murray, J.J. and Johnson, M.S., 1984. The extinction of endemic species by a program of biological control. *Pacific Science*, 38: 97-104

Cobbinah,J.R, Vink, A. and Onwuka, B., 2008. Snail farming: Production, Processing and Marketing. Agrodok 47. Agromisa foundation. Wageningen 1st ed. ISBN CTA 978-92-9081-398-9

Colautti, R.I., Grigorovich, I.A. and MacIsaac, H.J., 2006. Propagule pressure: a null model for biological invasions. *Biological invasions,* 8: 1023-1037

Colman, P.H., 1978. An invading giant. Wildl Aust 15(2):46–47

Copsey, J.A., Shelbourne, G., Grice, R., Goder, M., Buckland, S., Jhumka, Z., Nundlaul, V., Jones, C. and Cole, N., 2011. Possible control of introduced giant African land snails (Achatina spp.) by the reintroduced endemic skink *Leiolopisma telfairii*, lle aux Aigrettes, Mauritius. *Manag.Biolog.Invasions*, 2: 39-45

Correoso, M., 2006. Estrategia preliminar para evaluar y erradicar *Achatina fulica* (Gastropoda: Achatineaceae) en Ecuador. Boletin Técnico IASA, *Serie Zoológica,* 2: 45-52.

Costanza, R. and Farber, S., 2002. Introduction to the special issue on the dynamics and value of ecosystem services: integrating economic and ecological perspectives. *Ecological Economics*, 41(3): 367-373

Cowie, R.H., 2000. New records of alien land snails and slugs in the Hawaiian Islands.*Bishop Museum Occasional Papers*, 64: 51-53

Cowie, R.H., 2000. Non-indigenous land and freshwater molluscs in the islands of the Pacific: conservation impacts and threats. In: Invasive species in the Pacific-A technical review and draft regional strategy (ed.Sherley,G.),p.143-172. South pacific Regional Environmental Programme,Apia

Cowie, R.H., 2001. Can snails ever be effective and safe biocontrol agents? *International Journal of Pest Mangement*, 47: 23-40

Cutter, S.L., Golledge, R.G. and Graf, W.L., 2002. The big questions in geography. *The Professional Geographer* 54: 305-317.

Daniel Simberloff, 2003. Eradication—preventing invasions at the outset**.** *Weed Science*, 51(2):247-253

Davis, C.J. and Butler, G.D., 1964. Introduced enemies of the giant African snail *Achatina fulica* Bowdich, in Hawaii (Pulmonata: Achaitinidae). Proc, Hawaiian Ent. Soc., 18(3): 377-389

Davis, C.J. and Krauss, N.L.H., 1964. Recent introductions for biological control in Hawaii-IX. Proceedings Hawaiian Entomological Society, 18(3): 391-398

Davis, C.J., 1961b. *Proc.Hawaii.Entomol.Soc*., 17:329

De Winter, A.J., 1989. New records of *Achatina fulica* Bowdich from the Cote d'Ivoire. *Basteria*, 53: 71-72

Dean, W. W., A. R. Mead, and W. T. Northey., 1970. *Aeromonas liquefaciens* in the giant African snail, *Achatina fulica*. *Journal of Invertebrate Pathology* 16:346–351.

Deng, Z.H., Zhang, Q.M., Huang, S.Y. and Jones, J.L., 2012. First provincial survey of *Angiostrongylus cantonensis* in Guangdong Province, China. *Tropical Medicine and International Health*, 17:119-122

Dlugosch, K.M. and I.M. Parker., 2008. Founding events in species invasions: genetic variation, adaptive evolution, and the role of multiple introductions. *Molecular Ecology*, 17, 431-449.

Ebenso, I.E. 2006. A note on the effect of water on incubating eggs of edible tropical land snail limicolaria aurora. *Livestock research for rural development* 18 (10) 2006.

Ebenso, I.E., 2003. Molluscicidal effects of neem (*Azadirachta indica*) extracts on edible tropical land snails. *Pest Mang Sci*, 60: 178-182

Echikson, P., Layman, L.R., Fried, B. and Sherma, J., 1996. Uptake of copper by *Biomphalaria glabrata* (Gastropoda:Planorbidae) as determined by atomic absorption spectrophotometry. *Veliger*, 39: 89-90

Elith, J., Graham, C.H., et al. 2006. Novel methods improve prediction of species' distributions from occurrence data. *Ecography* 29: 129-151.

Enserink, M., 1999. Biological invaders sweep in. *Science*, 285: 1834-1836

Eubanks, M.D., 2001. Estimates of the direct and indirect effects of red imported fire ants on biological control in field crops. *Biological control*, 21: 35-43

Finoff, D., Shogren, J.F., Leung, B. and Lodge, D., 2007. Take a risk: preferring prevention over control of biological invaders. *Ecological Economics*, 62: 216-222

Fontanilla, I.K.C., 2010, *Achatina* (*Lissachatina*) *fulica* Bowdich: its molecular phylogeny, genetic variation in global populations, and its possible role in the spread of the rat lungworm *Angiostrongylus cantonensis* (CHEN), M.Sc. thesis, Nottingham University: 633pp.

Fontanilla, I.K.C., Hudelot, C., Naggs, F. and Wade, C.M., 2007. *Achatina fulica*: its molecular phylogeny and genetic variation in global populations. Abstracts. World Congress of Malacolgy, Antwerp, Belgium 15-20 July, 2007.Page 63

Franklin, J., 2009. Mapping species distributions. Cambridge University Press, Cambridge.

Gerlach, J., 2001. Predator, prey and pathogen interactions in introduced snail populations. *Animal conservation*, 4: 203-209

Godwin-Austen, H.H.,1908. Dispersal of land shells by the agency of man. Proceedings of Malacological Society of London, 8: 146-147.

Golledge, R.G., 2002. The nature of geographic knowledge. *Annals of the Association of American Geographers* 92: 1-14.

Grewal, P.S., Grewal, S.K., Tan, L. and Adams, B.J., 2003. Parasitism of Molluscs by Nemtodes: Types of Associations and Evolutionary Trends. *Journal of nematology*, 35(2): 146-156

Grewal, S.K. and Grewal, P.S., 2003. Effect of osmotic dessication on longevity and temperature tolerance of *Phasmarhabditis hermaphrodita* (nematode: Rhabditidae). *J.Parasitol*, 89(3): 434-438

Griffiths, O., Cook, A. and Wells, S.M., 1993. The diet of the introduced carnivorous snail *Euglandina rosea* in Mauritius and its implications for threatened island gastropod faunas. *Journal of Zoology*, 229: 79-89

Guisan,A & Zimmermman,M.E., 2000.Predictive habitat distribution models in ecology.*Ecological modelling*, 135: 147-186

Hijmans, R.J., Cameron, S.E., Parra, J.L., Jones, P.G. and Jarvis, A., 2005. Very high resolution interpolated climate surfaces for global land areas. *International Journal of Climatology*, 25: 1965-1978.

Hutson, J.C. and Austin, G.D., 1924. Notes on the habitats and life-history of the Indian glow-worm, an enemy of the African or Kalutara snail. *Bull.Dept.Agric*., 69: 1-15

Independent correspondent, 1970. Palakkad oru African nuzhanjukettam. Malayala manorama(Kozhikode), July.14: Editorial page.

Independent correspondent, 1970. Palakkad oru African nuzhanjukettam. Malayala manorama(Kozhikode), July.14: Editorial page.

Independent correspondent, 2009. African ochu:Kuttikalude padana report kaimaari. Malayala manorama (Pathanamthitta), November.17: Editorial page.

Independent correspondent, 2011. Ellam thinnu African ochu yathra thudarunnu. Malayala manorama (Kannur), August 12: Editorial page.

Independent correspondent, 2011. Muzhuppilangadine mulmunayil nirthi African ochukalude safari. Malayala manorama (Kannur), January 3: Editorial page.

Iwai, N., Sugiura, S. and Chiba, S., 2010. Prey-tracking behavior in the invasive terrestrial planarian *Platydemus manokwari* (Platyhelminthes, Tricladida). *Naturwissenschaften*, 97: 997-1002

Jayasinghe, U.L.B., Wannigama, G.P. and Macloed, J.K., 1993. Saponins of *Diploclisia glaucescens*. Natural Product Letters, 2(4): 249-253

Jenkins, P.T., 1996. Free trade and exotic species introductions. *Conservation biology*, 10(1): 300-302

Kakoty, N.N and Das, S.C., 1998. The giant African snail, *Achatina fulica* Bowditch a non-arthropod pest. Two and a Bud, 34: 33-35

Keane, R.M. and Crawley, M.J., 2002. Exotic plant invasions and the enemy release hypothesis. *Trends in Ecology and Evolution*, 17: 164-170

Kliks, M.M. and N.E. Palumbo., 1992. Eosinophilic meningitis beyond the Pacific Basin: the global dispersal of a peridomestic zoonosis caused by *Angiostrongylus cantonensis*, the nematode lungworm of rats. *Social Science & Medicine*, 34(2): 199-212.

Kloss, H. and MoCullough, F.S. 1982. Plant molluscicides. *Planta Medica*, 46: 195-209.

Kolbe, J.J., Glor, R.E., Schettino, L.R., Lara, A.C., Larson, A. and J.B. Losos., 2007. Multiple sources, admixture, and genetic variation in introduced *Anolis* lizard populations. *Conservation Biology*, 21(6): 1612-1625.

Lange,W.H., 1950. Life history and feeding habits of the giant African snail on Saipan. *Pacific science*, Vol 4:323-335

Lawton, J.H., 1999. Biodiversity and Ecosystem Processes: Theory, Achievements and Future Directions, the Biology of Biodiversity. Springer-Verlag, Tokyo, pp. 119 – 131

Lee, D., 1965. Physiology of nematodes. London: Oliver and Boyd

Lowe, S., Browne, M., Boudjelas, S. and De Poorter, M. 2000. 100 of the World's Worst Invasive Alien Species: a selection from the Global Invasive Species Database. Published by The Invasive Species Specialist Group (ISSG**)** a specialist group of the Species Survival Commission (SSC) of the World Conservation Union (IUCN), 12pp. Updated and reprinted version: November 2004.

Mack, R.N., Simberloff, D., Lonsdale, W.M., Evans, H., Clout, M. and Bazzaz, F.A., 2000. Biotic invasions: causes, epidemiology, global sequences and control. *Ecological applications*, 10(3): 689-710

Malek, E.A. and Cheng, T.C., 1974. Medicinal and economic malacology. Academic press. New York USA: 398pp

Margolis, M., Shogren, J.F. and Fisher, C., 2005. How trade politics affect invasive species control. *Ecological Economics*, 52: 305-313

Margules, C.R. and Pressey, R.L., 2000. Systematic conservation planning. *Nature,* 405**:** 243-253.

Mead, A. R. and L. Palcy., 1992. Two giant African land snail species spread to Martinique, French West Indies. *The Veliger* 35:74–77.

Mead, A. R. 1956. Disease in the Giant African snail *Achatina fulica* Bowdich. *Science*, 123:1130–1131.

Mead, A. R., 1961. The Giant African Snail: A Problem in Economic Malacology. University of Chicago Press, Chicago. 257 pp.

Mead, A.R., 1963. A flatworm predator of the giant African snail, *Achatina fulica* in Hawaii. Malacologia, 1(2): 305-309

Mead, A.R., 1979. *Economic malacology with particular reference toAchatinafulica*.In:Fretter, V. and J. Peake. (eds.) *Pulmonates, Vol. 2B.* Academic Press, London, 150 pp.

Mead, A.R., 1995. Anatomy, phylogeny and zoogeography in African land snail family Achatinidae. In proceedings of the 12th International Malacological Congress, Vigo, Spain.p.422-423

Mehta, S.V., Haight, R.G., Homans, F.R., Polasky, S. and Venette, R.C., 2007. Optimal detection and control strategies for invasive species management. *Ecological Economics*, 61: 237-245

Meyer, W.M., Hayes, K.A. and Mayer, A.L., 2008. Giant African snail, *Achatina fulica*, as a snail predator. *American Malacological Bulletin*, 24: 117-119

Meyer, W.M.III and Cowie, R.H., 2010. Feeding preferences of two predatory land snails introduced to Hawaii and their conservation implications. *Malacologia*, 53(1): 135-144

Mule, M.B., and Lomte, V.S., 1994. Effect of heavy metals (CuSO4 and HgCl2) on the oxygen-consumption of the freshwater snails Thiaratuberculata. *Journal of environmental biology*, 15: 263-268

Munda, G., 1996. Cost-benefit analysis in integrated environmental assessment: some methodological issues. *Ecological Economics*, 19: 157-168

Naggs, F., 1997. William Benson and the early study of land snails in British India and Ceylon. *Archives of Natural History*, 24: 37-88.

Nandakumar, T., 2010. Snail invasion sends people into a tizzy. The Hindu (Thiruvananthapuram), June.28: main page

Neuhauss, E., Fitarelli, M., Romanzini, J. and Teixeira, C.G., 2007. Low susceptibility of *Achatina fulica* from Brazil to infection with *Angiostrongylus costaricensis* and *A.cantonensis.* Mem Inst Oswaldo Cruz, Rio de Janeiro, 102(1): 49-52

Nishida, T. and Napompeth, B., 1975. Effect of age-specific predation on age distribution and survival of the giant African snail, *Achatina fulica*. Proc, Hawaiian Ent.Soc., 12(1): 119-123

Noran, A.M., Ahmad, R.A. and Zaid, I.M., 1995. Molluscicidal efficacy of *Azadirachta indica* A juss extract. *Malaysia J.Appl.Biol*, 24: 29-33

Nunes, P.A.L.D. and van den Berg, J.C.J.M., 2001. Economic evaluation of biodiversity: sense or nonsense? *Ecological Economics*, 39: 203-222

OECD 1996. Saving biological diversity: Economic incentives. Paris

Parker, I.M., Simberloff, D., Lonsdale, W.M., Goodell, K., Wonham, M., Williamson, M.H., Von Holl, B., Moyle, P.B., Byers, J.E. and Goldwasser, L., 1999. Impact: toward a framework for understanding the ecological effects of invaders. *Biological Invasions*, 1: 3-19

Perrings, C., 2005. Mitigation and adaptation strategies for the control of biological invasions. *Ecological economics*, 52: 315-325

Peterson,G.D., 1957. Studies on the control of the giant African snail on Guam. Hilgardia 26: 643-658

Philbrick, A.N., 1949.The Times (London) No.51477:5

Philips, S.J., Anderson R.P. and Schapire, R.E., 2006. Maximum entropy modeling of species geographic distributions. *Ecological modeling*, 190: 231-259.

Phillips, S.J. and Dudik, M., 2008. Modeling of species distributions with Maxent: new extensions and a comprehensive evaluation. *Ecography*, 31: 161-175.

Pimental, D., Lach, l., Zungia, R. and Morrison, D. 2000. Environmental and economic costs of non-indigenous species in the United states. *Bioscience*, 50: 53-65

Poucher, C. 1975. Eradication of the giant African snail in Florida. Florida state horticultural society: 523-524

Prasad, G.S., Singh, D.R., Senani S. and Medhi, R.P., 2004. Eco-friendly way to keep away pestiferous Giant African Snail, *Achatina fulica* Bowdich from nursery beds. *Current science*, 87: 1657-1659.

Primack, R.B., 2006 .Essentials of Conservation Biology, 4th edition.Sinauer Associates, Inc., USA. 585 pp.

Rao, I.G. and Singh, D.K., 2000. Effect of single and binary combinations of plant derived molluscicide on reproduction and survival of the snail *Achatina fulica*. *Archives of Environmental Contamination and Toxicology*, 39(4): 486-493

Rao, I.G. and Singh, D.K., 2002. Toxic effect of single and binary treatments of synthetic and plant derived molluscicides against *Achatina fulica*. *J. Appl.Toxicol*., 22: 211-215

Raut, S. K. and G.M. Barker., 2002. *Achatina fulica* Bowdich and other Achatinidae as pests in tropical agriculture. In: Barker, G.M. (ed.) *Molluscs as Crop Pests*, CAB International Publishing, Wallingford. pp. 55-114.

Raut, S.K. and Ghose, K.C., 1979b.*Bull.Ent*. 20:153-155

Reddy, A., Elizabeth, L.P. and Bernard, F., 2004. Effects of copper sulfate toxicity on cercariae and metacercariae of *echinostoma caproni* and *echinostoma trivolus* and as the survival of *Biomphalaria glabrata* snails. *Journal of Parasitology*, 90(6): 1332-1337

Reddy, K.B. and Sreedharan, K., 2006. Record of giant African snail, *Achatina fulica* Bowdich on coffee in Visakha Agency Areas, Andhra Pradesh. Planter's World: 17-19

Rees, W.J., 1950.Loris, 5(4):159-161

Robert H. Cowie, Robert T. Dillon, Jr., David G. Robinson, and James W. Smith. ,2009. Alien Non-Marine Snails and Slugs of Priority Quarantine Importance in the United States: A Preliminary Risk Assessment. American Malacological Bulletin, 27(1/2):113-132.

Robinson, D.G., 1999. Alien invasions: the effect of the global economy on non-marine gastropod introductions into the United States. *Malacologia*, 41: 413-438

Rochana Tangkoonboribun and Suriya Sassanarakkit, 2009. Molluscicide from tobacco waste. *Journal of Agricultural Science*, 1: 76-81

Schuder, I., Port, G. and Bennison, J., 2004. The behavioral response of slugs and snails to novel molluscicides, irritants and repellents. *Pest Manag Sci*, 60:1171-1177

Seehabutr, V., 2005. Nematodes in alimentary tracts of giant African snails (*Achatina fulica*) in Thailand. *Kamphaengsaen Acad.J.*, 3: 37-41

Shah, N.K., 1992. Management of the giant African snail. *Indian farming*, 41(11): 21

Shoeb, H.A., 1984. The molluscicidal properties of some agavaceae *Agave feruse*, *Agave angustifolia* and *Yucca aluifolia* as *Biomphalaria alexandrina* snails. *Vet Med J*, 32: 299-312

Simberloff, D. 1992. Conservation of pristine habitats and unintended effects of biological control. Pages 103–114 in W. C. Kauffman and J. E. Nechols, eds. Selection Criteria and Biological Consequences of Importing Natural Enemies. Baltimore, MD: Entomological Society of America.

Simberloff, D. 1997a. Eradication. Pages 221–228 in D. Simberloff, D. C. Schmitz, and T. C. Brown, eds. Strangers in Paradise. Impact and Management of Nonindigenous Species in Florida. Washington, DC: Island Press.

Simberloff, D. 1997b. Nonindigenous species—a global threat to biodiversity and stability. Pages 325–334 in P. Raven, ed. Nature and Human Society. The Quest for a Sustainable World. Washington, DC: National Research Council.

Simberloff, D. 2002a. Managing established populations of introduced species. Pages 269–278 in R. Claudi, O. Hendrickson, and H. Ottens, eds. Alien Invasive Species: A Threat to Canadian Biodiversity. Ottawa: Natural Resources Canada, Canadian Forest Service.

Simberloff, D. 2002b. Why not eradication? Pages 541–548 in D. J. Rapport, W. L. Lasley, D. E. Ralston, N. O. Nielsen, C. O. Qualset, and A. B. Damania, eds. Managing for Healthy Ecosystems. Boca Raton, FL: CRC/Lewis Press. Simberloff, D. 2002c. Today Tiritiri Matangi, tomorrow the world!—Are we aiming too low in invasives control? Pages 4–12 in D. Veitch and M. Clout, eds. Turning the Tide: Eradication of Invasive Species. Auckland: Invasive S

Simberloff, D., 2003. How much information on population biology is needed to manage introduced species? *Conservation biology*, 17(1): 83-92

Simberloff, D., 2009. We can eliminate invasions or live with them. Successful management projects. *Biol Invasions*, 11: 149-157

Singh, D.K. and Agarwal, R.A., 1983. In vivo and in vitro studies on synergism with anti cholinesterase pesticide in the snail *Lymnaea acuminate*. *Arch. Environ. Contam. Toxicol*, 12: 483-487

Singh, D.K. and Agarwal, R.A., 1983. Inhibition kinetics of certain organophosphorous and carbamate pesticides on acetylcholynesterase from the snail *Lymnaea acuminate*. Toxicol. Lett., 19: 313-319

Singh, K. and Singh, D.K., 2000. Toxicity to the snail *Lymnaea acuminate* of plant derived molluscicides in combination with synergists. *Pest Manag.Sci*, 56: 889-898

Singh, S. and Singh, D.K., 1998. Molluscicidal activity of *Nerium indicum* bark. *Braz.J.Med.Biol.Res*, 31: 951-954

Singh, V.K. and Singh, D.K., 1995. Characterization of allicin as a molluscicidal agent in *Allium sativum* (Garlic). *Biol. Agric. Hortic*, 12: 119-131

Smith, C.S., Lonsdale, W.M. and Fortune, J., 1999. When to ignore advice: invasion predictions and decision theory. *Biological Invasions*, 1: 89-96

South,F.W., 1926.Malayan Agric.Jour., 14 (7):231-241

Srivastava, P.D., 1992. Problem of Land Snail Pests in Agriculture: A Study of the Giant African Snail. Concept Publishing Company, New Delhi. 234 pp.

Srivastava,P.D. and Srivastava, Y.N., 1967. Orthomorpha sp. - a new predatory millipede on *Achatina fulica* in Andamans. *Experientia*, 23: ***776***-777

Stenceth, C., 1989. Instructions for pest control on ornamental plants in the greenhouse. *Gartneryrket*, 79: 19-22

Suarez, A.V. and N.D. Tsutsui., 2008. The evolutionary consequences of biological invasions. *Molecular Ecology*,17, 351-360.

Sudhi, K.S., 2007. West Kochi losses sleep over Giant African Snails. The Hindu (Kochi), September.19: main page

Sudhi, K.S., 2010. African snails keep phone lines busy. The Hindu (Kochi), October.31: main page

Sudhi, K.S., 2011. Snail conquer new territories in Kerala. The Hindu (Kochi), August.9: main page

Symondson, W.O.C., Erickson, M.C. and Liddell, J.E., 1996. Progress in the development of antibodies to detect predation on slugs in a review, plus new data on a monoclonal antibody against *Tandonia budapestensis,* in Slug and snail pests in agriculture. BCPC Symposium Proceedings No 66, BCPC, Farnham, Surrey, UK, pp 263–270.

Thiengo, S.C., Faraco, F.A., Salgado, N.C., Cowie, R.H. and Fernandez, M.A., 2007. Rapid spread of an invasive snail in south America: The giant African snail, *Achatina fulica* in Brazil. *Biol invasions,* 9:693-702

Tisdell, C.A., 1990. Economic impact of biological control of weeds and insects, 301-316. In Critical issues in biological control, Mackauer, M., Ehler, L.E. and Roland, J.(eds.) Intercept limited, Andover, Hants, UK

Tsai, H.C., Liu, Y.C., Kunin, C.M., Lai, P.H., Susan Lee, S.J., Chen, Y.S., Wann, S.R., Lin, H.H., Lin, W.R., Huang, C.K., Ger, L.P., Lin, H.H. and Yen, M.Y., 2003. Eosinophilic meningitis caused by *Angiostongylus cantonensis* associated with eating raw snails: correlation of brain magnetic resonance imaging scans with clinical findings. *Am J Trop. Med.Hyg*., 68(3): 281-285

Tsai, H.C., Liu, Y.C., Kunin, C.M., Susan Lee, S.J., Chen, Y.S., Lin, H.H., Tsai, T.H., Lin, W.R., Huang, C.K., Yen, M.Y. and Yen, C.M., 2001. Eosinophilic meningitis caused by *Angiostongylus cantonensis* : report of seventeen cases, 111: 109-114

Tsai, T.H., Liu, Y.C., Wann, S.R., Lin, W.R., Susan Lee, S.J., Lin, H.H., Chen, Y.S., Yen, M.Y. and Yen, C.M., 2001. An outbreak of meningitis caused by *Angiostongylus cantonensis* in Kaohsiung. *J Micro-bio Immunol Infect*, 34: 50-56

Ugwu,S.O.C, Ogbu,C.C and Amaechi, C.C.,(2011. Effect of soil type and soil depth on the reproductive performance of two species of giant African land snails in the humid tropics. *International journal of science and nature*, 2(2):176-182

Upatham, E.S., Kruatrachu, M. and Baidikul, V., 1988. Cultivation of the giant African snail, *Achatina fulica*. *J.Sci.Soc*. Thailand, 14: 25-40

Vaclavik, T. and Meentemeyer, R.K., 2009. Invasive species distribution modeling (Isdm): are absence data and dispersal constraints needed to predict actual distributions? *Ecological modeling*, 220: 3248-3258

Wallace M. Meyer III, Kenneth A. Hayes, Amanda L. Meyer, 2008. Giant African snail, *Achatina fulica*, as a snail predator**.** *American Malacological Bulletin*, 24(1):117-119

Wallace, G. D. and L. Rosen., 1969. Studies on eosinophilic meningitis. V. Molluscan hosts of *Angiostrongylus cantonensis* on Pacific islands. *Journal of Tropical Medicine and Hygiene*, 18:206–216.

Wallace, M.M.III and Shiels, A.B., 2009. Black rat (*Rattus rattus*) predation on nonindigenous snails in Hawaii: Complex management implications. *Pacific science*, 63(3): 339-347

Weber, W., 1954. Studies on the giant African snail. Proc, Hawaiian Ent.Soc., 10(1): 363-367

Weiss, J. 1999. Contingency planning for new and emerging weeds in Victoria. Plant Prot. Q. 14:112–114.

Wilcove, D.S., Rothstein, D., Dubow, J., Philips, A. and Losos, E., 1998. Quantifying threats to imperiled species in the United states. *Bioscience*, 48: 607-615

Williams, F. X., 1951. Life-history studies of East African *Achatina* snails. *Bull. Mus. Comp. Zool*., 105(3): 295-317

Williamson, M., 1996. Biological Invasions. Chapman and Hall, London, p.244

Williamson, M., 1999. Invasions. *Ecography*, 22: 5– 12.

Xu, H., Ding, H., Li, M., Qiang, S., Guo, J., Han, Z., Huang, Z., Sun, H., He, S., Wu, H. and Wan, F., 2006. The distribution and economic losses of alien species invasion to China. *Biological Invasion*, 8: 1495-1500

Xu, H.G. and Qiang, S., 2004. Inventory of Invasive Alien Species in China. China environmental sciences press, Beijing