COMMUNITY STRUCTURE AND INFECTION CHARACTERISTICS OF METAZOAN PARASITES IN HOUSE GECKOS IN PENINSULAR MALAYSIA

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ABSTRACT

This study described the metazoan parasite community structure of house geckos from Peninsular Malaysia. Six hundred ninety-two geckos were collected from five gecko species (*Hemidactylus frenatus, H. platyurus, H. garnotii, Gekko monarchus* and *Gehyra mutilata*) from eight sites in December 2006 until September 2010. Total of 8094 parasites from nine species were identified. They are ectoparasitic mite (*Geckobia bataviensis*), pentastomid (*Raillietiella frenatus*), cestode (*Oochoristica javaensis*), trematodes (*Paradistomum geckonum, Postorchigenes ovatus*) and nematodes (*Thelandros* sp., *Spauligodon* sp., *Pharyngodon* sp., *Skrjabinodon* sp.). Host species, gender and size were analyzed in relations to parasite prevalence, intensity, abundance, and diversity to provide baseline data in studying the effects of parasite infection based on host species, gender and size, and overall parasite community structure. Results showed *H. frenatus* had the highest abundance and parasite diversity. However this parasite is not host specific as it had been found in non-gekkonid hosts About 60% of the gecko community comprised of *H. frenatus*, thus it is more available for infection. Host gender-biased susceptibility is apparent in blood-feeding parasites (*R. frenatus* and *G. bataviensis*) where infection in females is more prevalent ($p<0.05$). Females have higher parasite prevalence and diversity, but males have higher infection intensity, suggesting hormone involvement. Younger geckos (>4 cm of SVL) have low parasite load which may be caused by diet restriction due to gape limitation, less interaction with the environment and other geckos, reducing chance for infection. Infection increased when the gecko grows into reproductive size (4-6 cm of SVL) as the diversity and abundance of its diet, and interaction with the environment, increases. However as it grows older (<6 cm of SVL), infection decreased as it invests more energy on immune system which then controls parasitic infection. Parasites that spread through autoinfection (nematodes) or direct transfer (mites) thrive in high density host community, evident in island habitats where parasite prevalence and intensity are higher. The northern region of Peninsular Malaysia had higher trematode prevalence and intensity while the central region had higher prevalence and intensity of nematodes, pentastomids, and mites. This suggested that northern region had higher diversity of intermediate hosts while the central region had a dense host community and a higher abundance of pests such as cockroaches. The parasite community structure showed a negative correlation between abundance and numerical density and this can be explained by 1. gecko infection increases, then decreases with age as energy expenditure changes according to priorities at different phases of life, 2. bigger geckos can accommodate higher diversity and abundance of parasites, 3. species richness is not affected by host size as parasites are not age or size specific, only highly opportunistic. *R. frenatus* is euryxenous and had been recorded accidentally infecting humans. Other parasites from this study are stenoxenous, however parasites such as the oxyurid nematodes may be capable of accidentally infecting hosts apart from geckos as they spread through autoinfection. Therefore the potential of gecko parasites becoming zoonotic exists. More research into the distribution patterns and the parasites' ecology are needed to gauge their potential.

ABSTRAK

Kajian ini menerangkan komuniti parasit metazoa cicak rumah dari Semenanjung Malaysia. Enam ratus sembilan puluh dua ekor cicak dari lima spesies (*Hemidactylus frenatus, H. platyurus, H. garnotii, Gekko monarchus* dan *Gehyra mutilata*) dari lapan kawasan pensampelan ditangkap dari Disember 2006 sehingga September 2010. Sejumlah 8094 ekor parasit dari sembilan spesies dikenalpasti. Ini termasuklah tungau ektoparasit (*Geckobia bataviensis*), pentastomida (*Raillietiella frenatus*), cestoda (*Oochoristica javaensis*), trematoda (*Paradistomum geckonum, Postorchigenes ovatus*) dan nematoda (*Thelandros* sp., *Spauligodon* sp., *Pharyngodon* sp., *Skrjabinodon* sp.). Spesies, jantina dan saiz cicak perumah dianalisa untuk melihat hubungkait antara ‘prevalence’, intensiti, kelimpahan, dan kepelbagaian parasit sebagai maklumat asas untuk mengkaji kesan spesis, jantina dan saiz perumah terhadap jangkitan, dan keseluruhan struktur komuniti parasit. Keputusan menunjukkan cicak *H. frenatus* mempunyai kelimpahan dan kepelbagaian parasit tertinggi. Walaubagaimanapun ia bukan perumah spesifik kerana parasit tersebut pernah dijumpai dalam hos selain cicak. Populasi *H.frenatus* membentuk 60% daripada komuniti cicak, meningkatkan peluang jangkitan dalam cicak ini berbanding spesis lain. Kecenderungan parasit menjangkiti perumah berdasarkan jantina perumah diperhatikan di dalam jangkitan parasit penghisap darah seperti *R. frenatus* dan *G. bataviensis* di mana jangkitan parasit ini lebih prevalen di dalam cicak betina ($p<0.05$). Jangkitan dan kepelbagaian parasit lebih prevalen di dalam cicak betina, tetapi cicak jantan mempunyai intensiti jangkitan lebih tinggi, menunjukkan penglibatan hormon. Cicak muda (SVL >4 cm) mempunyai beban parasit rendah yang mungkin disebabkan oleh 1, kekangan bukaan mulut menyebabkan kepelbagaian diet terhad, dan 2. kurang interaksi

dengan persekitaran dan dengan cicak lain, mengurangkan peluang jangkitan. Jangkitan parasit meningkat apabila cicak memasuki fasa pembiakan (4-6 cm) kerana kepelbagaian dan kelimpahan diet meningkat, dan cicak mula berinterasi dengan persekitaran dan dengan cicak lain. Apabila cicak membesar (<6 cm), jangkitan semakin berkurangan kerana penggunaan tenaga cicak beralih dari pembiakan kepada perkembangan sistem imun yang akan mengawal jangkitan parasit. Parasit yang tersebar melalui 'autoinfection' (nematoda) atau pemindahan langsung (tungau) berkembang di dalam komuniti perumah dengan kepadatan tinggi, dan ini jelas dalam habitat pulau di mana prevalen and intensiti parasit adalah lebih tinggi. Kawasan utara Semenanjung Malaysia mempunyai prevalen trematoda yang tinggi manakala kawasan tengah pula mempunyai prevalen dan intensiti nematoda, pentastomida dan tungau yang tinggi. Ini menunjukkan kawasan utara mempunyai kepelbagaian perumah perantara yang tinggi, manakala kawasan tengah mempunyai kelimpahan haiwan perosak seperti lipas dan komuniti perumah dengan kepadatan tinggi. Komuniti parasit menunjukkan korelasi negatif antara kelimpahan dan kepadatan numerik dan ini boleh dijelaskan melalui 1. jangkitan parasit cicak meningkat, dan kemudian berkurangan berkadaran dengan usia cicak kerana penggunaan tenaga berubah mengikut kepentingan pada fasa hidup berlainan. 2. cicak bersaiz besar boleh menampung kepelbagaian dan kelimpahan parasit yang lebih tinggi. 3. kekayaan spesis tidak bergantung kepada saiz perumah kerana parasit bersifat oportunistik dan tidak menjangkiti perumah berdasarkan umur atau saiz. *R. frenatus* adalah parasit 'euryxenous' dan pernah menjangkiti manusia secara tidak sengaja. Parasit lain dari kajian ini adalah parasit 'stenoxenous'. Walaubagaimanapun parasit seperti nematod oxyurida mampu menjangkiti perumah selain cicak kerana ia tersebar melalui 'autoinfection'. Potensi parasit cicak untuk

menjadi zoonotik sentiasa ada, dan kajian terhadap pola taburan dan ekosistem parasit untuk melihat potensi parasit tersebut perlu dijalankan.

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SVL : Snout-vent-length

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CHAPTER 1: INTRODUCTION

Parasite infection requires numerous factors in order to be considered successful. There are two types of parasites, one with direct life cycles (do not require intermediate hosts) and parasites with indirect life cycles (require intermediate hosts). For parasites with indirect life cycles, they must be able to find intermediate hosts, which in turn must be able to reach the final hosts in order to complete the life cycle. Rationally, a parasite that is less discriminatory (generalists) in choosing its intermediate or final host is deemed to be more successful than a parasite species that requires very specific intermediate or final hosts (specialists). However this is sometimes not the case in the natural environment.

In the parasite context, a generalist species is a parasite that can utilize multiple species as its final host. These species of parasites do not discriminate their hosts, as long as their life cycle is completed. Bursey and Brooks (2011) showed that reptilian nematodes are capable of infecting more than one host species. Chances are these nematode species share intermediate hosts with similar lifestyles, i.e. the intermediate hosts perform coprophagial behavior therefore share the same infection route because of the same behavior characteristic. The pentastomid species *Raillietilla frenatus* has been found in hosts ranging from toads, to lizards to even some species of colubrid snakes (Barton & Riley, 2004; Barton, 2007, 2015; Kelehear *et al.*, 2012, 2013, 2014, 2015). Raillietiellids' known intermediate host is the cockroach (Lavoipierre & Lavoipierre, 1965), and the cockroaches although in the menus of frogs and toads, are not a part of a snake's diet. Therefore this particular species of pentastomid must have taken up intermediate hosts which are not its usual hosts, or infect the snakes accidentally and found the snakes to be a viable final host. Generalists can also act as pioneer species as they can thrive in various sometimes unfavorable conditions. Specialist parasites on the other hand are very particular about their intermediate host and their final host. Ending up in the wrong intermediate host or final host will result in the life cycle terminating prematurely, not being able to produce viable offspring and jeopardizing the survival of its species.

The patterns of species richness of parasites are less well documented compared to free-living organisms. The reasons that may explain as to why some species support high or low parasite richness are not completely resolved. Most reptile parasites are well-documented to being generalists, able to infect various types of hosts, in certain cases, even mammals and birds. Being generalists, the reptile parasitofauna however is not as rich as compared to the mammals. Their unique lifestyle is the main focus of this study, a foray into how the parasites behave in a natural environment, and the impact they have on their hosts and their community as a whole.

1.1 Geckos as hosts

Geckos are the most conspicuous group of reptiles, not only because that they live in close association with human habitation, but also due to their highly unique morphology. These animals have distinctive morphological characteristics; large heads with bulging, lidless eyes, exquisitely-shaped pupils, and of course, the digit specialization or scansors that allows them to stick on almost every surface. The scansors consist of expanded, flattened surfaces with fine projections called setae, each in turn branching into hundreds of bristles terminating in fine endplates (Cox *et al.*, 1998).

Geckos are sought after especially in traditional Chinese medicine, for example '*ge jie ding chuan wan'* are pills with dried gecko to relieve asthma (Gong *et al.*, 1998). They are disliked because of their commensalistic habits of eating human food. Commensal geckos are often considered a pest (Csurhes & Markula, 2009) and their habit of making human habitation their home has been a source of irritation to many. However, these geckos play a very important role in controlling insect pests, especially cockroaches and mosquitoes, resulting in a household free of disease vectors.

House geckos live in close contact to humans play a crucial role as a parasite reservoir. Geckos are host to a plethora of ecto- and endoparasites, each with a potential to cross host species given the right condition. Previous literature highlighted reptile parasites known to cross the species barrier and infect humans, for example, *Linguatula serrata* (Maleky, 2001), *Borrelia burgdorferi*, a bacterium species that causes Lyme disease can be found in ticks on lizards (Földvári *et al.*, 2009), and sparganosis in humans (Wiwanitkit, 2005). However not much is known of the behavior of these parasites in their host's population and their potential to cross species barrier and infect humans. Some accidental infections have been reported, for example *Raillietiella* sp. caused localized inflammation and intestinal infection in humans (Adeoye & Ogunbanwo, 2007). One particular species from this genus of cephalobaenid pentastome, *Raillietiella frenatus* has been documented in animals other than lizards; infecting toads (Kelehear *et al.*, 2012), geckos (Ali, 1983; Riley *et al.*, 1991; Goldberg & Bursey, 2010; Barton, 2007), skinks (Riley *et al.*, 1991), iguanas (Almeida *et al.*, 2008), anoles (Barton & Riley, 2004) and snakes (Goldberg *et al.*, 2005). Reports of human infection with *Raillietiella* species (Tappe *et al.*, 2016); ingestion of live lizards for therapeutic reasons in south-east Asia was linked to subcutaneous pentastomid infection called "creeping disease" was tentatively attributed to *Raillietiella hemidactyli*

(Dollfus & Canet, 1954; Drabick, 1987). Human infection is transmitted through accidental ingestion of the eggs (Nash, 2005). Handling fecal contaminated water, dishes, and other equipment may also result in accidental transmission.

Developments in Lyme disease research show that ticks that utilize lizards as an agent have reduced case of infection and act as a zooprophylactic agent (Tijsse-Klasen *et al.*, 2010)**.** The western fence lizard *Sceloporus occidentalis* appears to be immune to infection of *B. burgdorferi* after being exposed to infected ticks (Lane *et al.*, 2006). Infection in ticks also cleared after biting the lizards suggesting *S. occidentalis* typically destroys *B. burgdorferi* spirochetes present in tissues of attached ticks and feeding ticks nymphs, therefore reducing probability of transmission of these bacteria to humans or other animals.

Not only parasites of reptiles are of medical and economic importance to humans but the knowledge on reptile parasitofauna is crucial in arming ourselves against reptile-borne zoonoses. Among the major cause of new zoonotic agents emerging in human population is increased contact between humans and wildlife. In this ever-changing, fast-paced world, human-wildlife conflict is unavoidable as humans encroach into wilderness or movements of wild animals into human habituated areas. Reducing health risks from zoonoses is not an easy task and often not straightforward. It requires proper management in order to control risks and consideration of the complexity of human-animal interaction with the environment.

1.2 Parasite species composition

The final and the intermediate hosts must co-occur within the same environment in order for the parasites to survive. Some parasites are endemic, for example the blood parasite of *Hoplodactylus duvaucelii*, a large gecko species from New Zealand (Barry *et al.*, 2011). Reptiles and amphibians are proven to be good colonizers, adapting to local environment and even the parasitic composition of the local fauna. Reptile and amphibian parasites also are successful generalists, able to interchange their hosts, adapting well to produce viable parasite eggs in order to continue its survival (Kelehear *et al.*, 2013).

The global dispersion of house geckos is widespread and assisted by human movement. For example the Spiny-Tailed Gecko (*Hemidactylus frenatus*) is highly cosmopolitan, aided by human travel on cargo ships (Lever, 2003; Newbery & Jones, 2007). It is considered an invasive species and a threat to local gecko fauna as it competes for food and habitat (Gallina-Tesaro *et al.*, 1999; Rodder *et al.*, 2008). It is also capable of getting infected with the parasite composition of local geckos (Hanley *et al.*, 1995a; Prenter *et al.*, 2004; Barton, 2007). Interactions with local gecko fauna may cause parasite transfer and while in most cases *H. frenatus* are able to adapt to the parasites; past studies have shown that local fauna did not fare as well as the *H. frenatus* (Prenter *et al.*, 2004).

1.3 Parasite community structure and its implications

Parasites alter community structures of their hosts. For example direct impacts of parasitism on intertidal ecosystem includes behavior modification of hosts such as burrowing ability or spatial distribution, which will then lead to changes of various features of the habitat and affects settlement success of other organisms in the ecosystem (Mouritsen & Poulin, 2002). Changes in host diversity and community structures have been linked to diseases (Johnson *et al.*, 2008). In order to understand the structure of a community, basic information on the available species and their abundance are required. Other complementary information such as body size, biomass and density of the species will assist to explain the community structure better. Parasite community is unique because of their dependency on their hosts unlike those observed in the free-living organisms. Host body size is one of the important criterion (Lo *et al.*, 1998; Roca *et al.*, 2009), followed by habitat and dietary component (Muñoz *et al.*, 2002; Roca *et al.*, 2005), and social behaviour (Sorci *et al.*, 1997). Aspects such as microhabitats, body sizes, and associations between species have also been considered (Holmes, 1973; Lotz & Font, 1985; Adamson & Noble, 1993; Rohde, 1994; Sorci *et al.*, 1997; Sasal *et al.*, 1999; George-Nascimento *et al.*, 2004). In addition, the habitat size (host weight or microhabitat area) may also affect the understanding of parasite communities in abundances and densities because, in general, a large habitat may have more resources than small habitats and may support more individuals and species.

1.4 Objectives and justification of research

1.4.1 Baseline ecological data and population characteristics of house gecko parasites.

This study is essential to form a baseline data about the community structure and infection patterns of parasites in geckosto help elucidate basic population dynamics of the parasites' community.

1.4.2 How host specificity affects infection behavior of the parasites

The study aims to elucidate host specificity affects the infection behavior of parasites in house geckos. Although host specificity is not synonymous with reptilian parasites, this study attempts to see whether host specificity or even some form of host preference occurs in the gecko community.

1.4.3 Gender-based infection in gecko parasites and its implications

The premise is males and reproductive females have a higher, more intense rate of infectiondue to compromised immunity. Males compromise immunity to develop secondary sexual characteristics to compete for mating rights,as highly evident in birds and mammals. In geckos, males and females have similar physical appearance however adult male geckos are generally bigger in size compared to adult femalesas males invest more energy to gain bigger body in order to compete for mating rights or to defend their territory. Reproductive females sacrifice immunity in exchange for egg production which requires vast amount of energy. This study aims to examine whether the same strategy is applied by female geckos.

1.4.4 Infection of parasites in different host sizes and its implications.

Prevalence and intensity of parasites usually increase with host body size and age, as the range of dietary component expands, hosts consume a more diverse food which exposes them to more infection. This study attempts to see how the size of the gecko host affects parasitic infection.

1.4.5 Community structure of gecko parasites in Malaysia

This study is designed to identify and analyze the community structure of parasites of the Malaysian house geckos, by focusing on parasite abundance, species richness, and density in relation to host body size.

CHAPTER 2: LITERATURE REVIEW

Previous works on reptile parasites broadly ranges from classical taxonomy (Ali & Riley, 1983; Barton & Riley, 2004; Barry *et al.*, 2011; Antinori *et al.*, 2013; Bertrand *et al.*, 2013), to ecological (Aho, 1990; Almeida *et al.*, 2003; Balmer *et al.*, 2009; Barton, 2007, 2015), to physiological studies (Girons, 1980; Belliure *et al.*, 2004). Reptilian parasitofauna is unique as vast majority of them are generalists and have a wide range of intermediate and final hosts. They also appear to tolerate a wider range of climates. Parasites such as *Raillietiella frenatus* have been found in different continents with different climates such as in south east Asia (Ali & Riley, 1983; Matsuo & Oku, 2002), Australia (Barton, 2007; Hoskin, 2011; Kelehear *et al.*, 2012), Africa and the Caribbean (Riley *et al.*, 1991, Rivera *et al.*, 2003), and South America (Anjos *et al.*, 2008; Kelehear *et al.*, 2015). Armed with the ability to infect a wide range of hosts, they infect local fauna, competing fiercely with naturally occurring parasites (Dobson, 1985; Hanley *et al.*, 1995a,b; Petren & Case, 1996; Balmer *et al.*, 2009; Johnson & Buller, 2011; Kelehear *et al.*, 2013).

2.1 Parasite diversity of the saurian group

Saurians host a rich diversity of parasites. High diversity of endoparasites shows a highly diverse dietary component, and shed light as to the size of the animal's home range. Information regarding parasites' intermediate host will help describe human impact on the particular habitat (e.g. cockroaches host a variety of reptilian parasites and it is also a pest in human habitation). High diversity of ectoparasites on the other hand may provide clues how the host population is distributed, and the interactions between members of the same species or other host species with similar ectoparasites composition.

2.1.1 Nematodes

Most nematode species infecting geckos are from the family Oxyuridae. Oxyurid nematodes are more common in the colons of turtles and lizards but are rarely considered as pathogenic, although in large numbers they can cause impaction, leading to anorexia in the hosts (Wilson & Carpenter, 1996; Bouamer & Morand, 2002). They have a direct life cycle (ingestion of fertilized eggs although in some cases transmission of eggs may occur via fomites) therefore do not require an intermediate host (Anderson, 2000; Grear & Hudson, 2011). Examples of common oxyurids infecting lizards especially geckos are *Skrjabinodon* sp. (Vicente *et al.*, 2000; Goldberg *et al.*, 2011; Yildirimhan *et al.*, 2011; Jones, 2013), *Pharyngodon* sp. (Amer & Bursey, 2008; Bursey *et al.*, 2008; Goldberg *et al.*, 2011), *Spauligodon* sp. (Hering-Hagenbeck & Boomker, 2000; Goldberg *et al.*, 2011), *Thelandros* sp. (Goldberg *et al.*, 2003), *Physaloperoides* sp. (Goldberg *et al.*, 2011).

Bursey and Goldberg (2000) described a nematode, *Hedruris henlayi* from *Hemidactylus garnotii* from Cook Islands, Oceania. *Hemidactylus garnotii* is commonly found in Malaysia but there is no information on its parasitofauna (see Table 2). Information on the parasitofauna of such a widely distributed host species will provide information on distribution of geckos; even shed light on the host-parasite evolutionary path.

Another well dispersed genus is *Spauligodon*. Jiménez-Ruiz *et al.*, (2003) described *Spauligodon garcioprietoi* in the lacertid *Cnemidophorus* spp from Southern Mexico. Another study featured *Spauligodon aloisei* from *Podacris sicula*, lacertid from Italy (Casanova *et al.*, 2003). Ramallo *et al.*, 2002) described *Spauligodon loboi* from *Liolaemus*, an iguanid lizard, from Argentina. Another *Spauligodon* species, *Spauligodon zweifeli*, was found in the mourning gecko, *Lepidodactylus novaeguineae* from Papua New Guinea (Bursey *et al.*, 2005). Bursey and Goldberg (1996b) described *Spauligodon hemidactylus* from *Hemidactylus frenatus*, a gecko species with worldwide distribution. *H. frenatus* have adapted so well in new colonies to the point that they have a potential of affecting native species by introducing their infection to the local fauna (Galina-Tessaro *et al.*, 1999). *H. frenatus* is widely distributed due to human activities (Hardy & McDiarmid, 1969; Stebbins, 1985). Studying gecko parasitofauna will provide vital clues on its evolution and migration path, which enables us to trace back to its origin.

The biology of some gecko nematodes have also been studied. Hering-Hagenbeck & Boomker (2000) described a new species of nematode found in the peritoneal wall of the gecko *Pachydactylus turneri*. In addition, they also studied its developmental stages by reinfecting the nematode in its intermediate host, *Phlebotomus duboscqi* (Diptera : Psychodidae). Studies of parasite developmental stages are beneficial to determine infection patterns and the factors affecting infection. This is essential, especially in the management and control of zoonotic diseases.

2.1.2 Trematodes

Reptilian trematodes also infect various reptile groups. Scholz and Ditrich (1991) highlighted this phenomenon in a study carried out in Laos. They found *Paradistomum geckonum*, a common trematode of geckos (such as *Hemidactylus frenatus* and *H. platyurus*) parasitising a skink species, *Mabuya multifasciata* (Scincidae). *Paradistomum parvissimum* was recorded from a variety of hosts from the saurian group, such as *Ameiva ameiva* (teiid), *Hemidactylus mabouia* (gekkonid), *Iguana iguana* (iguanid), *Liolaemus lutzae* (agamid), *Mabuya macrorhyncha* (scincid), *M. agilis* (scincid), *Tropidurus torquatus* (gekkonid) and *Tupinambis teguixin* (teiid) (Ávila and Silva, 2010). Ability to infect hosts of different families is possibly due to the hosts sharing similar dietary components.

Allopharynx macallisteri (Trematoda: Plagiorchiidae) was first described from the small intestines of the gecko *Lepidodactylus lugubris* from Guam, Micronesia (Dailey *et al.*, 1998). Since then it was found in other gekkonid species such as *Cyrtodactylus louisiadensis*, *Gekko vittatus* and *Lepidodactylus lugubris* from Papua New Guinea (Bursey *et al.*, 2005; 2010). Another species of trematode is *Postorchigenes* spp. found in the intestines of *Hemidactylus frenatus*, *H. platyurus*, *Gehyra mutilata*, and *Gekko gecko* from Indonesia (Kennedy *et al.*, 1987a); *G. gekko, H. frenatus* and *H. platyurus* from Laos (Scholz and Ditrich, 1991); *H. frenatus* from Thailand (Wongsawad *et al.*, 1998); *Chamaeleo chamaeleon* from Egypt (Morsy *et al.*, 2012). One species of this genus, *P. gymnesicus* was discovered in a rodent *Eliomys quercinus gymnesicus* (Rodentia) from Menorca, Balearic islands in Spain (Más-Coma *et al.*, 1981). A common reptile species, *P. ovatus* was found bat species *Pipistrellus abramus* in China (Qu & Gong, 1994). This shows that this parasite is not restricted to the lizards only, but also insectivorous mammals.

2.1.3 Cestodes

Linstowiid cestodes consist of 12 genera with 3 occuring in reptiles as adults (Conn, 1985; Beveridge, 1994) and nine genera reported in mammals (Chandler & Melvin, 1951; Hickman, 1954; Okafor, 1988; Beveridge, 1994). *Oochoristica* cestodes have been found in various lizard groups (Loewen, 1940; Malhotra, 1984; Bursey & Goldberg, 1996; Yildirimhan *et al.*, 2011; Mašová *et al.*, 2012; Norval *et al.*, 2014).

Oochoristica maccoyi is exclusively found in lizard was documented from an anolis lizard, *Anolis gingivinus* from Anguilla, Lesser Antilles. (Bursey & Goldberg, 1996a) , *Oochoristica javaensis* from *Gehyra mutilata* and *Hemidactylus frenatus* from the Philippines (Goldberg *et al.*, 2005), both geckos are commonly found in Malaysia. *Oochoristica tuberculata* was found in the Ocellated Lizard, *Lacerta lepida* from Turkey (Yildirimhan *et al.*, 2011) while *Oochoristica javaensis* was recorded from *Phelsuma grandis* in Hawaii (Goldberg *et al.*, 2008).

2.1.4 Pentastomids

The majority of studies on pentastomids on taxonomy (Ali *et al.*, 1981, 1982a, 1982b, 1982c, 1983, 1984a, 1984b, 1985), the biology of pentastomids (Riley, 1986), and the life cycle studies (Lavoipierre & Lavoipierre, 1965; Bosch, 1986) are among important pioneer works. One particular genus, *Raillietiella* (Pentastomida:

Cephalobaenida) is the most commonly found pentatomid in lizards. A common parasite of reptiles and amphibians, it has been described from various hosts such as toads (Barton & Riley, 2004; Kelehear *et al.*, 2015), lizards (Lim & Yong, 1977; Krishnasamy *et al.*, 1985; Almeida *et al.*, 2008; Anjos *et al.*, 2008; Barton, 2007; Kelehear *et al.*, 2012; Riley *et al.*, 1991; Sousa *et al.*, 2014), snakes (Almeida *et al.*, 2003; Kelehear *et al.*, 2014) and vultures (Riley *et al.*, 2003).

2.1.5 Ectoparasites – Ticks and mites

Ectoparasitic mites infest lizards indiscriminately; evident from previous works documenting how mites are not specific to a particular host (Lawrence, 1936; Diong & Ho, 2001; Sri Prawasti, 2011; Bertrand *et al.*, 2013; Paredes-León *et al.*, 2013; Sri Prawasti *et al.*, 2013). The most common gecko ectoparasites are the pterygosomatid mites (Bochkov & Mironov, 2000; Haitlinger, 2004; Bertrand *et al.*, 2013; Sri Prawasti *et al.*, 2013). Adults are sessile in adulthood; therefore they have a short timeframe to reach their host during their larva stage. The lizards have develop adaptations in order to cope with ectoparasites infestation such as developing 'mite pockets' in order to minimize the effects of parasitism by having the mites congregate in the pockets instead (Loveridge, 1926; Bauer *et al.*, 1990; Bertrand, 2002). Mites are an important vector to blood parasites (Amo *et al.*, 2005).

Ho and Ambu (1986) conducted a survey on ticks found on snakes and varanid lizards in Malaysia. One tick species found was theixodid tick *Aponomma lucasi*. In a South American and Caribbean study, mites found were *Geckobia leonilae* from *Phyllodactylus lanei rupius*; *G.guyanensis* and *G.manaensis* from *Platydactylus*; *G.*

cayennensis from *Phyllodactylus* sp.; *G.tarentolae* from *Tarentola americana*, and *Geckobia hemidactyli* from *Hemidactylus mabouia* (Rivera *et al.*, 2003).

Larvae and nymphs of the tick (*Ixodes pacificus*) have been found to infect the fence lizard, *Sceloporus occidentalis*. The tick is of medical significance as a vector for Lyme disease spirochaete bacterium, *Borrelia burgdorferi* (Schall *et al.*, 2000). Mites, including *Geckobiella* spp., also infect fence lizards and are vectors of the coccidian blood parasite, *Schellackia occidentalis*.

Rivera *et al.* (2003) recorded pterygosomatid mite *Geckobia hemidactyli* infesting various gecko species, including two Asian gecko species, *Hemidactylus frenatus* and *Hemidactylus mercatorius*. Bochkov and Mironov (2000) described two new species of *Geckobia*, from a lacertid and a eublepharid lizard that, exclusively parasitize geckos (Lawrence, 1936).

2.2 Parasite community structure

Parasite community presents a unique association due to their dependency on their hosts. One of the variables, the host's body size, is agreed by various previous works (Roca *et al.*, 2009; Lo *et al.*, 1998) among the important criterion, followed by habitat and dietary component (Roca *et al.*, 2005; Muñoz *et al.*, 2002), and social behaviour (Sorci *et al.*, 1997). Other aspects such as microhabitats, body sizes, and associations between species have also been considered (e.g., Holmes, 1973; Lotz & Font, 1985; Adamson & Noble, 1993; Rohde, 1994; Sorci *et al.*, 1997; Sasal *et al.*, 1999; George-Nascimento *et al.*, 2002). In addition, the habitat size (host weight or microhabitat area) may also affect the understanding of parasite communities in abundances and densities because, in general, a large habitat may have more resources and may support more individuals and species.

2.3 Conclusion

Most gecko parasites are not host specific. Some can infect across the saurian groups, stenoxenous parasites such as *Paradistomum parvissimum* (recorded from teiids, gekkonids, iguanids, agamids, and scincids) (Ávila & Silva, 2010), or euryxenous such as *Raillietiella frenatus*, recorded from gekkonids (Barton, 2015), toads (Barton & Riley, 2004), snakes (Kelehear *et al.*, 2014) and vultures (Riley *et al.*, 2003). This shows there is some potential of these parasites becoming zoonotic. However there is little known about the parasitofauna and the community structure of the Malaysian gecko metazoan parasites and should be addressed as these information are crucial in future disease management.

CHAPTER 3: PARASITE INFECTION SUCCESS – EFFECTS OF HOST SPECIES

3.1 Introduction

3.1.1 Gecko Host Diversity and Identification

Geckos are the most diverse genus of lizards with 1,492 species (source: The Reptile Database www.reptile-database.org). This number continues to grow as more species are being discovered every day. In Malaysia there are about 96 species of geckos (Appendix B), and can be found from highly disturbed, human-managed areas, to undisturbed, primary forests. Some gecko species, for example *Hemidactylus frenatus*, or the Spiny-Tailed Gecko, are cosmopolitan and spread throughout the world by hitch hiking on cargo ships. Geckos are originally from the Old World region, migrating from Asia to the African continent (Vidal & Hedges, 2004). Due to their high adaptability, these animals are able to colonize new habitats successfully, competing with native fauna for food and space. (Galina-Tessaro *et al.*, 1999).

The most common house gecko species in Malaysia are from the genera *Gehyra*, *Gekko* and *Hemidactylus*. *Gehyra* or Four-clawed Geckos are named after the inner-digit on all four feet lacks a claw. They are also known as web-clawed geckos or dtellas. *Gehyra* species have toepads and powerful claws. Their eyes are relatively large with vertical pupils, and they have very loose skin. Worldwide, around 40 species have been described, with five recorded species in Malaysia (see Appendix B). Many are found in or nearby human habitation.

Hemidactylus geckos are the most common house geckos. It has adapted to human habitations, although some species are true forest dwellers. These geckos are found in all the tropical regions, extending into the subtropical parts of Africa and Europe. Some species like *Hemidactylus frenatus* and *H. garnotii* have been introduced to various parts of the world through human activities. One hundred and thirty-seven species have been described; with five species recorded in Malaysia (see Appendix B). The dorsal scales of the *Hemidactylus* geckos are either uniform or heterogenous. Their pupils are vertical. Fingers and toes are free (webless); each toe has a slender distal clawed joint. Underneath the fingers and toes, they have two rows of lamellae in a pattern resembling a leaf.

The *Gekko* genus consists of large individuals, with more than 50 species described globally. About 30 species have been reported in Southeast Asia. Geckos of this genus can reach sizes with length up to 35 cm (*Gekko gecko*). They have robust bodies with large eyes and vertical pupils. Some *Gekko* species can make loud calls audible from great distances.

3.1.2 Parasite Identification.

3.1.1.1 Nematodes

Nematode identification can be arduous as there are many characteristics that must be taken into consideration in differentiating between the species. It is crucial to become familiar with basic nematode morphology before attempting to identify it as there are many aspects that must be deliberated. For the purpose of a broad and generic identification, these six observations are helpful; overall body type, lip/mouth region, oesophageal region, tail region, reproductive structures, and position of the nematode when in a relaxed state. To further differentiate the nematodes into higher levels of identification, more in-depth observation and measurements of the characteristics must be performed. Listed below are crucial diagnostic characteristics that will enable identification.

a) The body length, width and shape (i.e. cylindrical, tapering at the end, kidney-shaped, lemon-shaped etc.), and its position after death (straight, arctuate, spiral, etc.)

b) Cuticle thickness, striations, annulation (both transverse and longitudinal), punctuation and ornamentation.

c) Cuticular modification (ridges, spines, scales, alae).

d) The shape and the degree of separation from the body of the cephalic region are used in species differentiation.

e) Intestines, prerectum, rectum and anus morphology.

f) Female reproductive system (can be classified as either didelphic, monodelphic, pseudomonodelphic, prodelphic, opisthodelphic, monoprodelphic and mono-opisthodelphic); observe the shape and location of the vulva, the presence/absence of lateral vulval membranes and epiptygma, and the shape and size of spermatheca and its position in respect to the genital branch (axial or offset).

g) In male reproductive system, observe the size and shape of the spicules, gubernaculum and the spermatozoa.

h) Tail length and shape.

i) Observations of juvenile characteristics such as tail shape, and the shape and arrangement of spines.

3.1.1.2 Trematodes

A basic trematode morphology consists of a dorsoventrally flattened body, bilateral symmetry and a definite anterior end. Trematodes are leaf-shaped, possess an oral sucker around the mouth and a ventral sucker or acetabulum that is used to adhere to host tissue. They have a well-developed alimentary canal with a muscular pharynx and oesophagus. The intestine is usually a branched tube; the main branches may end blindly or open into an excretory vesicle. Trematodes are hermaphrodites, with both male and female reproductive organs in the same individual. The male organs consists of two testes with accessory glands and ducts leading into a cirrus which extends into the common genital atrium. The female organs consists of a single ovary with a seminal receptacle and vitellaria or yolk glands that connect to the oviduct as it expands into an ootype.

3.1.1.3 Cestodes

Adult cestodes are flattened, elongated and consist of segments known as proglottids. The body is divided into a scolex (bears organs of attachment), neck (region of segment proliferation) and a chain of proglottids (strobila). The scolex is characterized by its attachment organs. These organs consist of a rostellum, bothria, or acetabula. A rostellum is a retractable, conelike structure located on the anterior end of the scolex. In some species, the rostellum has hooks. Bothria are long, narrow, muscular grooves that are characteristic of the pseudophyllidean cestodes. Acetabula or suckers are characteristics of cyclophyllidean cestodes. The segments of proglottids near the neck are immature. As the strobila elongates, the segments become mature. Those that are more posterior are gravid, meaning the uteri are full of eggs.

3.1.1.4 Pentastomids

Pentastomid identification uses body shape, hook morphology, annulus number and the position of the female gonophore to distinguish broad, generic identification (Riley, 1986). Considerable emphasis has been placed on the rigid parts of the anatomy such as hooks and copulatory spicules, as these are less susceptible to artifacts (Riley and Self, 1979, 1980, 1981, 1982; Ali *et al.*, 1981, 1982a,b,c,, 1983, 1984a,b, 1985). Female pentastomids provide better identification as males tend to be short-lived, however in raillietiellids, males become important in specific diagnosis (Ali *et al.*, 1985).

The pentastomid body wall is thin and elastic, therefore fixation greatly affect its shape, the details of the cephalotorax, ventral aspect, and the lateral aspect, Live pentastomids are fragile, even the slightest puncture will cause deflation and contraction, which will affect annulus counts. Therefore preservation must be done carefully with 70% alcohol as it has been proven to produce the most consistent results (Riley, 1986). The number of abdominal annuli is frequently used as an important diagnostic character especially in certain porocephalids where differences are marked, but this characteristic is not rigidly determined. In large raillietiellids, variations are evident (Ali *et al.*, 1982a,b,c; 1984a,b). The annulus also can be too close and overlapping, further reducing its diagnostic value. A few factors must be taken into account, such as incomplete annuli, interannular distances, and protocols for the counting procedure in order for annulus counts to be of value.

Hook dimensions is a more reliable diagnostic tool to differentiate between porocephalids and cephalobaenids. Gross hook morphology and hook size has been used extensively as the hooks are tough and heavily sclerotized, therefore unaffected by fixation. They are also easily removed for measurement. Hook size increases with each moult, and this causes problems in determining which the fully-matured adult stage is in order to obtain the correct measurements. However this does not affect the males as they have copulatory spicules.

3.1.1.5 Ectoparasites – Ticks and Mites

Geckobia mites are described as having a dorsal scutum, short eyes, mouth parts almost wholly exposed on the anterio-dorsal surface of the body, and coxae armed with spurs. Very little is known about mite transmission within the host population. They are motile in the larval stage, but once they reach adulthood, they become sessile and will stay at the same place on the host’s body unless forcibly removed or transferred to another host during fights or mating between the hosts.

Mite identification was performed by studying identifying characteristics, the palpal, idiosomal and leg setation follows Granjeans's nomenclature (Grandjean, 1939; 1944: 1946) as implemented for Pterygosomatidae by Bochkov and O’Connor (2006), Bochkov *et al.* (2006) and Paredes-León *et al.* (2013).

3.1.3 Basic life cycles of gecko parasites – possibility of zoonotic potential.

Oxyurid nematodes have a direct life cycle (Anderson, 2000), therefore they do not require an intermediate host. Transmission does occur via fomites sometimes, but generally it is through fecal ingestion. Autoinfection is how a reptile maintains the nematodes, and a dense host population facilitates transmission. Ectoparasitic mites of the genus *Geckobia* have a direct life cycle where transmission is from gecko to gecko (Bauer *et al.*, 1990). Adult mites are sessile; therefore they have a small window during the early larva stage to infest their gecko hosts. Both of these parasites, albeit having different mode of living, share one factor in their transmission. Their transmissions are closely dependant on the density of the host population they parasitize. The higher the density of a host population is, the easier the transmission of parasites.

Trematodes have a complex life cycle, requiring two invertebrates as intermediate hosts in order to complete its life cycle. The first intermediate host is usually a freshwater mollusc, followed by a second intermediate host which is usually an insect. A life cycle study of the gecko trematode (*Paradistomum geckonum*) used a terrestrial gastropod (*Lamellaxis gracilis*) as the first intermediate host while the second intermediate host was unnecessary as the larvae from the gastropod was fed directly to the geckos (Kennedy *et al.*, 1987a).

Depending on the families, cestodes may have a simple or complex life cycle. Most lizard cestodes have a simple life cycle, requiring only one intermediate host. Among suitable intermediate hosts for linstowiid cestodes are tenebrionids (*Cestrinus punctatissimus*), cockroach *Platyzosteria melanaria*, the dermestid *Anthrenocerus* *australis* and the carabs *Mecyclothorax ambiguous*, *Promecoderus gibbosus*, and *Homothes guttifer* (Hickman, 1963). The intermediate hosts consumed fecal matter infected with the oncospheres of the cestodes. The oncosphere then enters the hemocoel where it develops into cysticercoids, which after a certain amount of time (21 days in the case of *Oochoristica vacuolata*), it will become a fully developed larva (Hickman, 1963). Lizards consumed the infected intermediate hosts, where the larva then continues its life cycle. Gravid proglottids are passed through fecal matter and the cycle repeats itself.

Pentastomids can have a simple or a complex life cycle, depending on its final host. Gecko pentastomids usually require one invertebrate intermediate host in order to complete its life cycle (Ali & Riley, 1983). The cycle started when eggs are expelled from an infected reptile, and these eggs are ingested by coprophagial insects such cockroaches (Lavoipierre & Lavoipierre, 1965). The eggs then hatched inside the gut of the insect (cockroach) and underwent two moults to become an infective third stage larva. After ingestion of a cockroach by a reptile, the larvae then burrows into the stomach to the lungs and undergoes further moults and finally matures into adulthood. Copulation is a once-in-a-lifetime event, when both males and females are of the same size.

Life cycle studies may provide hints to the possibility of parasites becoming zoonotic. There are records of pentastomid *Raillietiella* infecting humans (Dollfuss & Canet, 1954; Tappe *et al.*, 2016). The nematode *Thelandros* is also speculated to be capable of infecting humans due to its similar morphology to human parasites and for sharing its habitat with humans (Ameh & Ajayi, 2005). And as oxyurid nematodes have similar life cycle (autoinfection), there is the possibility of accidental infection in humans, especially to those with weak immune system. Pterygosomatid mites have been reported to spread blood-borne parasites (Walter & Shaw, 2002) albeit to other reptiles, however the possibility of accidental zoonotic infection exists.

Table 3.1 Examples of Known Intermediate Hosts.

Parasite	Potential Intermediate Hosts	Known Intermediate Hosts	Authors
Pentastomid	Cockroach, beetles	*Periplaneta americana*	Jeffrey *et al.*, 1985
		P.australasiae	
		Supella longipalpa	
		Neostylopyga rhombifolia	
		Lupparia notulata,	
		Blattela germanica	
		Pycnoscelus surinamensis	
Nematode	Insects	*Cotinus nitida* (Coleoptera)	Stewart & Kent (1963)
		Phlebotomus dubosqi (Diptera: Psychodidae)	Hering-Hagenbeck *et al.*,2000)
		Ephemera strigata (Ephemeroptera)	Hirasawa *et al.*,(2004)
		*Cephalotes atratus (*Hymenoptera)	Hughes *et al.*, 2008
Cestode	Insects, copepod	*Lasius niger* *Tapinoma sessile* (Formicidae)	Padgett & Boyce (2005)
		Cestrinus punctatissimus (Coleoptera) *Platyzosteria melanaria* (Blattodea), *Anthrenocerus australis, Mecyclothorax ambiguous, Promecoderus gibbosus*, *Homothes guttifer* (Coleoptera)	Hickman, 1963
Trematode	Molluscs, insects	*Trithemis annulata, Crocothemis erythraea, Anax imperator*, *A. parthenope* (Odonata)	Macy (1964)

3.1.4 Host specificity in gecko parasites

For most parasites, their hosts must be very specific, or their life cycle will reach an untimely end. These specialists face tremendous challenges in order to ensure their species survival; however they maximize their chances, developing specialized adaptations in order to ensure host colonization. For generalists however, this problem is minimized as the parasites are able to occupy a range of hosts, provided they fulfill certain criteria required by the parasites (i.e. hosts belonged to the same family ie *Skrjabinodon* sp. only infecting the saurids; same mode of living or habitat ie coprophagial behavior in insects such as flies, cockroaches and coprophagic beetles (Graczyk *et al.*, 2005; Huber *et al.*, 2007)**.** Previous literatures have shown that the parasite species obtained are not host-specific. Some parasite species may even use amphibians or snakes as its final host and still manage to produce viable eggs in order to continue its existence, as in the case of the pentastomid *Raillietilla frenatus*. It has been found in toads (Kelehear *et al.*, 2013), skinks (Riley *et al.*, 1991), iguanas (Almeida *et al.*, 2008), anoles (Barton & Riley, 2004) and snakes (Goldberg *et al.*, 2005).

Table 3.2 Examples of host diversity in reptilian parasites.

Parasite Species	Known Hosts	Authors
Geckobia bataviensis	*Hemidactylus frenatus* (Gekkonidae)	Csurhes & Markula, 2009
Paradistomum geckonum	*Hemidactylus platyurus* and *H. frenatus* (Gekkonidae)	Scholz & Ditrich, 1991
	Gehyra mutilata (Gekkonidae)	Matsuo & Oku, 2002 Scholz & Ditrich, 1991
	Mabuia multifasciata (Scincidae)	
Postorchigenes ovatum	*Pipistrellus abramus* (Mammal)	Qu & Gong, 1994
	Hemidactylus flaviviridus (Gekkonidae)	Chakravorty & Manna, 1982
	H. platyurus (Gekkonidae)	Matsuo & Oku, 2002
	H. frenatus (Gekkonidae)	Goldberg & Bursey, 2001
Oochoristica javaensis	*Gehyra mutilata* and *Hemidactylus frenatus* (Gekkonidae)	Goldberg *et al.*, 2005a
	Sphenomorphus jobiensis (Scincidae)	Goldberg *et al.*, 2005b
Skrjabinodon sp.	*Oedura robusta* (Gekkonidae)	Jones, 2013
	Hoplodactylus maculates (Gekkonidae)	Bursey & Goldberg, 1999b
	Nephrurus laevissimus (Gekkonidae)	
	N. levis	Vicente *et al.*, 2002
	N. vertebralis	
	Mabuya dorsivittata (Scincidae)	Hering-Hagenbeck & Boomker, 2000
	Hemidactylus mabouia (Gekkonidae)	
	Mabuya varia (Scincidae)	Bursey & Brooks, 2010
	M. striata	
	Gonatodes albogularis (Gekkonidae)	
Thelandros sp.	*Hemidactylus garnotii* (Gekkonidae)	Hallas *et al.*, 2005
	Egernia stokesii	Hering-Hagenbeck & Boomker, 2000
	Agama mossambica (Agamidae)	

Table 3.2, continued

Spauligodon sp.	*Hemidactylus mabouia* (Gekkonidae) *Mabuya quinguetaeniata* (Scincidae) *M. striata* *M. sulcata sulcata* *Pachydactylus bibronii* *P. turneri*	Hering-Hagenbeck & Boomker, 2000
	Phyllodactylus tuberculosus (Gekkonidae)	Bursey & Brooks, 2010
Pharyngodon sp.	*Agama culeata culeata* (Agamidae)	Hering-Hagenbeck & Boomker, 2000
	Gehyra oceanica (Gekkonidae)	Bursey & Goldberg, 1999
Raillietiella frenatus	*Hemidactylus frenatus* (Gekkonidae) *H. mabouia*	Ali *et al.*, 1981, 1983, 1984
	Rhinella marina (Bufonidae)	Anjos *et al.*, 2008 Kelehear, Brown and Shine, 2013
	Mabuya perrotetti (Scincidae)	Riley *et al.*, 1991 Almeida *et al.*, 2008
	iguanas	Barton & Riley, 2004
	anoles	Goldberg *et al.*, 2005
	snakes	
R. monarchus	*Gekko monarchus* (Gekkonidae)	Ali *et al.*, 1981, 1983, 1984
R. hemidactylii	*Hemidactylus frenatus* (Gekkonidae)	Ali *et al.*, 1981, 1983, 1984
R. gehyrae	*Gehyra mutilata* (Gekkonidae)	Ali *et al.*, 1981, 1983, 1984
	Mabuya homalocephala (Scincidae)	Pence & Canaris, 1973

With the exception of the parasites infecting snakes and birds, these parasites appear to be generalists within the saurid order, preferring hosts with similar dietary component (see Table 2). All the gecko species studied are carnivorous, although some were found with plant materials in their stomach content which may be due to accidental ingestion.

3.2 Methodology

3.2.1 Host Collection

The characteristics of the study sites are as follows; urban, suburban, rural, and forest habitats. Urban environment is defined as high density human population areas, with high rise buildings, state-of-the-art amenities, an advance transportation system, and vast housing areas. It is also defined by its role as a central place for a tributary area. Suburban areas are towns or unincorporated developed areas in close proximity to a city. This area is largely residential, are often dependent on the city for employment and support services; generally characterized by low-density development relative to the city. Rural environment includes small villages, scarce or completely devoid of big, concrete buildings. It is normally pertaining to the area outside larger and moderate-sized cities and surrounding population concentrations, generally characterized by farms, small towns, and unpopulated regions, and usually sparsely settled. Forest habitat ranges from small, secondary forests to pristine, primary forests. Sites were chosen from the northern region and the central region of Peninsular Malaysia (see Table 3.3, Figure 3.1).

Collections were carried out over a period of three years and ten months from the end of 2006 until September 2010. Eight study sites were chosen from Peninsular Malaysia [BERNAS Complex Rice mill in Megat Dewa, Kedah; kampung houses in

Kampung Maharaja, Kedah; housing estates in Jitra, Kedah; Langkawi island, Kedah; Pangkor island, Perak; Carey island, Selangor; Genting Highlands, Pahang; University Malaya].

Table 3.3 Gecko collection sites.

No.	Sites	Habitat Characteristics	GPS Coordinates
1.	Langkawi island, Kedah	Two thirds of the island is covered with mountainous forest, limestone hills and natural vegetation. Human activity revolves around fishing, paddy farming and nature tourism.	6.3500° N, 99.8000° E
2.	BERNAS Complex, Kedah	Rice mill surrounded by vast paddy fields, with sparse housings.	6.33333° N, 100.35° E
3.	Kampung Maharaja, Kedah	Small, traditional Malay village. Main human activity is paddy farming.	6.33333° N, 100.35° E
4.	Jitra, Kedah	Dense suburban residential areas.	6.2667° N, 100.4167° E
5.	Pangkor island, Perak	Hilly and forest-covered. Island environment similar to Langkawi. Human activity revolves around fishing and nature tourism.	4.2200° N, 100.5550° E
6.	Genting Highlands, Pahang	Residential areas. A cross of pristine, mountainous forest and human-impacted areas.	3.4237° N, 101.7934° E
7.	Carey island, Selangor	Palm oil plantation, refinery, on-site staff housings, Orang Asli settlements	2.8667° N, 101.3667° E
8.	University Malaya	City centre. Urban landscape with high rise buildings and bustling with human activity.	3.1208° N, 101.6564° E

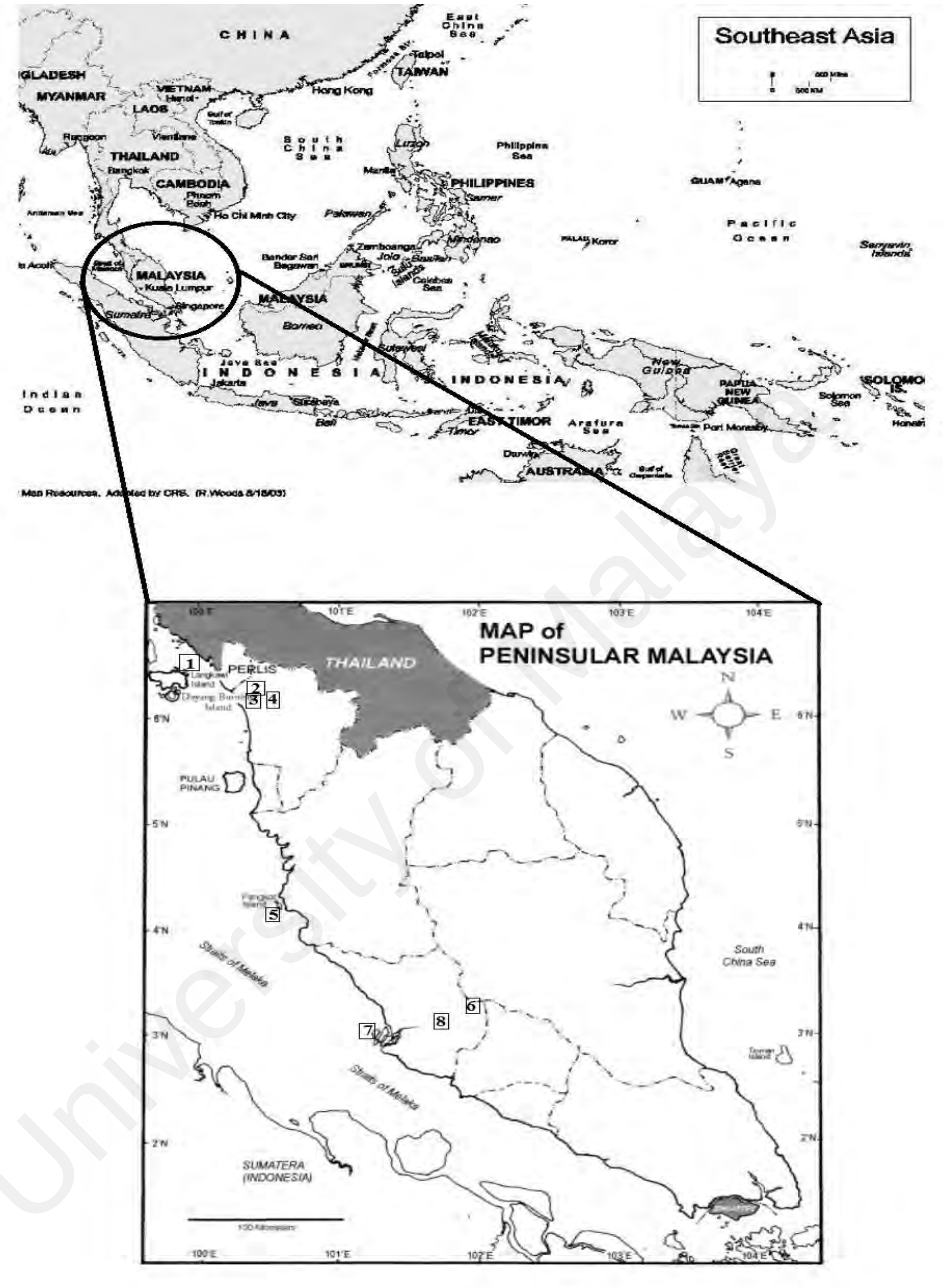

Figure 3.1 Map of Peninsular Malaysia showing the location of the eight sampling sites.

The house geckos were obtained either by using a sweep net, handpicked or by using traps. These methods inflict the least amount of stress to the animal. Live geckos are then kept in plastic aquariums. Identification was through basic morphological observations using the identification keys provided by Cox, *et al.*, (1998). Each gecko is necropsied by decapitation or in the case of larger geckos, by intraperitoneal injection of sodium pentobarbitol. The snout-vent length (SVL) of each gecko was taken for host size preference analysis.

3.2.2 Parasites Collection

The body cavity of the gecko was opened by a longitudinal incision from vent to throat. Various organs were removed into separate petri dishes and bathed in saline solution to prevent desiccation while keeping the parasites alive. The organs removed were the lungs, liver, gallbladder, stomach, small intestines, and large intestines. The endoparasites were removed and specifically preserved according to the methods most suitable to the parasite group (see Table 3.4). Ectoparasites on the skin and digital pads were also collected and preserved for further identification. Parasites were collected and preserved using specific techniques suitable to each group as elaborated in Table 3.4.

Identification was done according to the respective groups of the parasites (see Table 3.4). The pentastomids were bathed in saline and examined under a dissecting scope. The nematodes were fixed fresh in glycerin before being examined using light microscopy. The cestodes were also stained and examined under a light microscope. The trematodes were stained and examined using light microscopy. The ectoparasites were examined under the dissecting microscope.

Table 3.4 Methods of collecting, preserving and examining various groups of parasites.

Group	Collection and Preservation
Pentastomida	Worms were collected and relaxed in saline before being kept in 70% ethanol. Eggs were mounted in Hoyer's medium. Larvae were released from mature eggs by exerting gentle pressure on the cover slip of the slide mounted specimens. Hooks were dissected from chosen specimens and trimmed off of excess muscle before being mounted in Hoyer's medium and measured.
Nematoda	Worms were bathed in warm 85% ethanol to straighten the worms. The worms were then cleared in lactophenol, or a mixture of ethanol and glycerin. Worms were then examined using light microscope.
Cestoda	Worms were bathed in hot *AFA and kept in AFA for a day before changing to 85% ethanol for keeping. For examination purpose, the worm was dehydrated in graded alcohol, cleared in xylene, and mounted in balsam before examined using light microscopy. *AFA = 85% ethanol, 10% formalin, and 5% glacial acetic acid
Trematoda	Worms were mounted on glass slides and the slide was flooded with AFA. The slides were left flooded with AFA for a few hours to flatten the worms for easy examination. The worms were then kept in AFA for a few days before transferring to 85% ethanol. For examination, worms were dehydrated in graded alcohol, stained in 10% Alum carmine, destained in 0.1% hydrochloric acid, rinsed in distilled water, dehydrated in alcohol again, cleared in Xylol, and mounted in Canada balsam.
Ectoparasites	Any ectoparasites (i.e. mites and ticks) were kept in 70% ethanol along with the carcasses. The parasites were examined using a dissecting microscope.

Gecko carcasses were tagged and kept in 10% formalin. Geckos with ectoparasites were kept in 70% ethanol as stated in Table 3.4. A piece of the geckos' tissue and some parasites were preserved in 80-95% ethanol for future molecular study.

Representatives of each parasite species were stained and examined under light microscope. Identification of helminths was based on the morphological characteristics of the worms in their respective groups and identified according to Bochkov and Mironov (2000) for mites, Ali *et al.* (1981;1983; 1984; 1985) for pentastomids, Bursey *et al.* (1999; 1999b; 2005), Vicente *et al.* (2000; 2002), Hering-Hagenbeck and Boomker (2000), Bouamer and Morand (2002), and Amer and Bursey (2008) for nematodes, Hickman (1954) and Kennedy *et al.* (1982) for cestodes, and Killick and Beverley-Burton (1982), Kennedy *et al.* (1987a), and Morsy *et al.* (2012) for trematodes.

3.2.3 Statistical Analyses

Prevalence, mean intensity and mean abundance were calculated as described in Margolis *et al.* (1982). Basic population dispersion test, the Coefficient of Dispersion was applied to the parasitofauna from the host population and the study sites. The sample mean, x, is defined as 'the sum of all measurements in the sample divided by the number of measurements in the sample (Zar, 1984). Chi Square Test was applied to investigate differing success rate of infection in different host species. Diversity indices were used to calculate the complexity and measure the health of an ecosystem. Simpson's Index of Diversity, Ds, calculates the probability that two organisms sampled from a community belonged to different species. Shannon-Weiner Diversity Index, H' belongs to a subset of indices that maintain that diversity can be measured much like the information contained in a code or a message. It assumes that all species are represented in a sample and that the samples were obtained randomly. Actual diversity was also compared using a measure called Evenness. As with H’, evenness assumes that all species are represented within the sample.

3.3 Results

Six hundred and ninety-two house geckos belonging to five species were collected and examined for parasitic infection. These geckos were commonly found in Peninsular Malaysia namely *Hemidactylus frenatus* (421 geckos)*, H. platyurus* (150 geckos)*, H. garnotii* (41 geckos)*, Gekko monarchus* (40 geckos) and *Gehyra mutilata* (40 geckos) (Figure 3.2).

Nine parasites species were collected and identified (Table 3.5) belonging to five main groups; namely pentastomid (one species), trematodes (two species), nematodes (four species), cestode (one species), and pterygosomatid mite (one species). Table 3.6 shows the co-existence of parasites of geckos. The pentastomid (*Raillietiella frenatus*), and nematodes (*Thelandros* sp and *Spauligodon* sp.) co-exists with other parasite species. The nematodes (*Pharyngodon* sp. and *Skrjabinodon* sp.), and the cestode (*Oochoristica javaensis*), compete for space as they occupy the same niche. The trematodes *Paradistomum geckonum* and *Postorchigenes ovatus*, and the ectoparasitic mite *Geckobia bataviensis*, are not able to co-exist with the nematode *Pharyngodon* sp

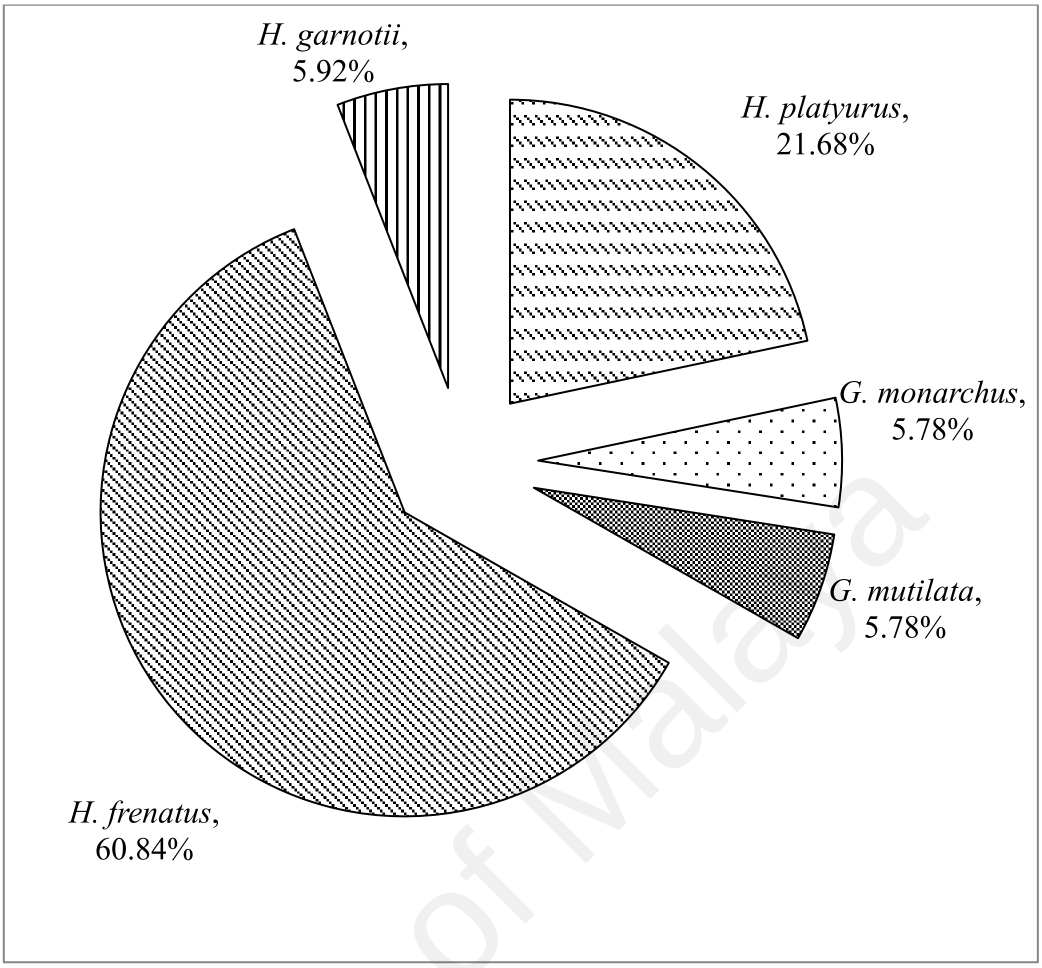

Figure 3.2: Composition of gecko species obtained from eight sampling sites in Peninsular Malaysia.

Table 3.5 Parasite Species Extracted from the Gecko Hosts.

Site	Endoparasites			Ectoparasite
	Lungs	Gallbladder	Alimentary canal	On skin, in-between digital pads
Parasite	Family Raillietiellidae Sambon, 1922	Family Dicrocoeliidae Odhner, 1910	Family Lecithodendriidae Lühe, 1901	Family Pterygosomatidae Oudemans, 1910
	Genus *Raillietiella* *Raillietiella frenatus* Ali, Riley and Self, 1981	Genus *Paradistomum* *Paradistomum geckonum* Bhalerao, 1929	Genus *Postorchigenes* *Postorchigenes ovatus* Tubangui, 1928	Genus *Geckobia* Mégnin, 1878 *Geckobia bataviensis* Vitzthum, 1926
			Family Linstowiidae Fuhrmann, 1932 Genus *Oochoristica* *Oochoristica javaensis* Kennedy *et al.*, 1982	
			Family Pharyngodonidae Travassos, 1920 *Thelandros* sp. *Spauligodon* sp. *Pharyngodon* sp. *Skrjabinodon* sp.	

Table 3.6 Parasites Co-existing in/on the Gecko Host Community.

	R. frenatus	*Thelandros* sp.	*Spauligodon* sp.	*Pharyngodon* sp.	*Skrjabinodon* sp.	*O. javaensis*	*P. geckonum*	*P. ovatus*	*G. bataviensis*
R. frenatus	■	+	+	+	+	+	+	+	+
Thelandros sp.	+	■	+	+	+	+	+	+	+
Spauligodon sp.	+	+	■	+	+	+	+	+	+
Pharyngodon sp.	+	+	+	■	-	+	-	-	-
Skrjabinodon sp.	+	+	+	-	■	-	+	+	+
O. javaensis	+	+	+	+	-	■	+	+	+
P. geckonum	+	+	+	-	+	+	■	+	+
P.ovatus	+	+	+	-	+	+	+	■	+
G.bataviensis	+	+	+	-	+	+	+	+	■

\+ Species A co-exist with Species B

\- Species A do not co-exist with Species B

3.3.1 Parasite infection in different host species

Five species of geckos were studied. These are *Hemidactylus frenatus, H. garnotii, H. platyurus, Gehyra mutilata,* and *Gekko monarchus*. Nine species of ecto- and endoparasites were found infecting/infesting the gecko hosts. These are ectoparasitic mite (i.e. *Geckobia javaensis*) and eight endoparasites. All endoparasites were classified as pentastomid (i.e. *Raillietiella frenatus*), cestodes (i.e. *Oochoristica javaensis*), trematodes (i.e. *Paradistomum geckonum* and *Postorchigenes ovatus*) and nematodes (i.e. *Thelandros* sp., *Spauligodon* sp., *Pharyngodon* sp., and *Skrjabinodon* sp.).

Table 3.7 highlighted parasite species found in their respective hosts. The geckos *Hemidactylus frenatus* and *H. platyurus* were infected with all nine parasite species. *Gehyra mutilata*, *Gekko monarchus* and *H. garnotii* harboured eight species.

Table 3.7 Parasite Species Found in/on the Gecko Hosts.

	Hemidactylus frenatus	***H. platyurus***	***H. garnoti***	***Gekko monarchus***	***Gehyra mutilata***
R. frenatus	+	+	+	+	+
Thelandros sp.	+	+	+	+	+
Spauligodon sp.	+	+	+	+	+
Pharyngodon sp.	+	+	+	+	+
Skrjabinodon sp.	+	+	-	+	-
O. javaensis	+	+	+	-	+
P. geckonum	+	+	+	+	+
P. ovatus	+	+	+	+	+
G. bataviensis	+	+	+	+	+

The highest parasite prevalence in house gecko population was the intestinal nematode species, *Thelandros* sp. in *H. platyurus* with a prevalence of 70% (Table 3.8). Prevalence of this nematode in other gecko species was relatively high compared to other parasites (*G. monarchus* = 17.5%; *G. mutilata* = 37.5%, *H. frenatus* = 22.09%; *H. garnoti* = 26.83%). Three other nematode species, one trematode and one cestode species was found in the same niche. The nematode infected all five species of house geckos studied, to increase its chances to complete its life cycle successfully.

Geckobia bataviensis is an ectoparasitic mite of the the skin and in-between the digital pads. It was also the second most prevalent parasite species inhabiting the geckos. The highest prevalence was recorded in the *H. frenatus* population, with a prevalence of 43.47%, followed by *H. garnotii* with a prevalence of 34.15%. Prevalence of this mite in the other gecko host species were low compared to other parasites (*G. monarchus* = 5%; *G. mutilata* = 5%, *H. platyurus* = 5.33%).

The highest mean intensity was recorded by the trematode *P. ovatus* in the gecko *H. garnotii* with a value of 35 ± 0.12 (range 1-137). Compared to mean intensity of the same parasite in other geckos (*H. platyurus* = 7.65; *G. monarchus* = 3; *G. mutilata* = 6.33; *H. frenatus* = 16), infection of *P. ovatus* in *H. garnotii* was significantly intense ($P < 0.05$). Mean intensity of this particular trematode in geckos other than *H. garnotii* was almost similar if not slightly higher as the mean intensity of other gut helminthes such as the nematodes and cestode.

Infection of *Skrjabinodon* sp. in *H. frenatus* had recorded the lowest prevalence, with 0.75%. This nematode species inhabits the intestines of the gecko host. Apart from this, there were three other species of nematodes from different genera found in the intestines of the geckos. All are common oxyurid nematodes infecting frogs, saurians and snakes.

Table 3.8 Prevalence, Mean Intensity and Mean Abundance of Parasites According to Host Species.

Host	Parasite	Prevalence (%)	Mean Intensity	Mean Abundance
Hemidactylus frenatus	*Raillietiella frenatus*	22.09	3.1(±0.22)	0.68 (±0.133)
	Thelandros sp.	32.78	3.67(±0.32)	1.21(±0.34)
	Spauligodon sp.	9.264	2.95(±0.09)	0.2732(±0.14)
	Pharyngodon sp.	33.49	5.38(±0.33)	1.8(±0.05)
	Skrjabinodon sp.	0.713	2.67(±0.0007)	0.02(±0.006)
	Oochoristica javaensis	2.613	1.73(±0.02)	0.05(±0.05)
	Paradistomum geckonum	12.11	4.78(±0.12)	0.58(±0.32)
	Postorchigenes ovatus	18.05	16(±0.18)	2.89(±1.4)
	Geckobia bataviensis	43.47	11.4(±0.43)	4.95(±0.7)
H. platyurus	*Raillietiella frenatus*	18	1.7(±0.18)	0.31(±0.08)
	Thelandros sp.	70	2.63(±0.7)	1.84(±0.17)
	Spauligodon sp.	8	2.25(±0.08)	0.18(±0.08)
	Pharyngodon sp.	8.667	2.38(±0.09)	0.21(±0.06)
	Skrjabinodon sp.	1.333	6.5(±0.01)	0.09(±0.03)
	Oochoristica javaensis	6.667	1.1(±0.67)	0.07(±0.03)
	Paradistomum geckonum	28	4.76(±0.28)	1.33(±0.44)

Table 3.8, continued

	Postorchigenes ovatus	11.33	7.65(±0.11)	0.87(±0.49)
	Geckobia bataviensis	5.333	2.5(±0.05)	0.13(±0.09)
H. garnoti	*Raillietiella frenatus*	17.07	4.29(±0.17)	0.73(±0.67)
	Thelandros sp.	26.83	2.45(±0.26)	0.66(±0.46)
	Spauligodon sp.	0	0	0
	Pharyngodon sp.	29.27	5.75(±0.29)	1.68(±0.42)
	Skrjabinodon sp.	0	0	0
	Oochoristica javaensis	0	0	0
	Paradistomum geckonum	7.317	5.67(±0.07)	0.41 (±0.5)
	Postorchigenes ovatus	12.2	35(±0.01)	4.27(±16.32)
	Geckobia bataviensis	34.15	9.36(±0.34)	3.2(±1.03)
Gehyra mutilata	*Raillietiella frenatus*	40	1.38(±0.4)	0.55(±0.18)
	Thelandros sp.	37.5	3.07(±0.37)	1.15(±0.52)
	Spauligodon sp.	2.5	2(±0.03)	0.05(±0.1)
	Pharyngodon sp.	27.5	6.36(±0.3)	1.75(±0.5)
	Skrjabinodon sp.	0	0	0
	Oochoristica javaensis	2.5	1(±0.02)	0.03(±)
	Paradistomum geckonum	10	2.25(±0.1)	0.23(±0.28)

Table 3.8, continued

	Postorchigenes ovatus	15	6.33(±0.02)	0.95(±1.56)
	Geckobia bataviensis	5	5.5(±0.05)	0.28(±0.27)
Gekko monarchus	*Raillietiella frenatus*	41.38	2.42(±0.4)	0.73(±0.26)
	Thelandros sp.	17.5	4.43(±0.18)	0.775(±0.38)
	Spauligodon sp.	7.5	2(±0.08)	0.15(±0.09)
	Pharyngodon sp.	5	2.5(±0.05)	0.13(±0.14)
	Skrjabinodon sp.	15	11.8(±0.15)	1.78(±1.6)
	Oochoristica javaensis	0	0	0
	Paradistomum geckonum	7.5	3(±0.08)	0.23(±0.17)
	Postorchigenes ovatus	5	3(±0.05)	0.15(±0.25)
	Geckobia bataviensis	5	14.5(±0.05)	0.73(±0.27)

From the study, seven parasite species were observed to display significant success in terms of higher prevalence in different host species (Table 3.9). Only two species did not show any significant difference in infection success in different host species i.e. the pentastomid (*Raillietiella frenatus*) and nematode (*Spauligodon* sp.). Both parasites infected the different gecko species without discrimination.

The nematode groups were among the most prevalent parasite groups in the gecko population. *Thelandros* sp. showed a significant ($p<0.05$) (Table 3.9) successful infection in *H. platyurus*, which had a prevalence of 75.5% (see Table 3.8). Both *Pharyngodon* sp. and *Skrjabinodon* sp. also showed a significant success in infecting *H. frenatus* and *G. monarchus* respectively.

Despite displaying high intensity, trematodes did not show high prevalence as nematodes (Table 3.9) The gallbladder trematode (*Paradistomum geckonum*) most successfully infected *H. platyurus* while the gut trematode (*Postorchigenes ovatus*) was successful in infecting *H. frenatus*.

The sole cestode species obtained from this study infected all gecko species equally. However the number of hosts infected with cestodes was very low and limited to younger or smaller geckos. Therefore discretion must be observed when evaluating the cestode infection.

Table 3.9 Parasite infection success in different host species (Parasite prevalence) (p=0.05).

Parasite species	**x^2**	**P**
Raillietiella frenatus	1.81	0.7703
**Thelandros* sp.	47.8	<0.0001
Spauligodon sp.	8.313	0.08
**Pharyngodon* sp.	36. 1	<0.0001
**Skrjabinodon* sp.	34.2	<0.0001
**Oochoristica javaensis*	24.7	<0.0001
**Paradistomum geckonum*	24.7	<0.0001
**Postorchigenes ovatus*	9.6	0.0477
**Geckobia bataviensis*	76.6	<0.0001

* Prevalence is significantly higher in particular host species.

3.3.2 Parasite dispersion pattern in the gecko host

Parasites inhabiting *H. frenatus* exhibited clustering and over dispersion patterns. In the lungs, the distribution of parasites is over dispersed, evident in the dispersions of *R. frenatus* with a CD of 4.22. In the gut environment, the distribution of parasites were slightly aggregated and over dispersed, with the exception of *P. ovatus*, which is the most aggregated and over dispersed parasite in the gut of *H. frenatus* (CD= 29.846). The gallbladder which is home to *P. geckonum*, housed an aggregated and over dispersed population of the trematode (CD= 9.416). *H. frenatus* harboured over dispersed populations of ten species of parasites, a feat considering the other two *Hemidactylus* gecko species only harboured five over dispersed parasite populations, while both *G .mutilata* and *G. monarchus* harboured five and four over dispersed populations respectively.

The gut parasites showed uniform and under dispersed to slightly aggregated and over dispersed distribution patterns, with the exception of the trematode (*P. ovatus*). This population are aggregated and over dispersed in all gecko species except in *G. monarchus*, where only one specimen was infected with *P. ovatus*. The nematodes also exhibited aggregated and over dispersed distribution patterns, with *Skrjabinodon* sp. being the most over dispersed in *G. monarchus* (CD= 22.25). The cestodes (*O. javaensis*) has the lowest over dispersion compared to other gut parasites.

The ectoparasites, *G. bataviensis* is largely aggregated and over dispersed in all gecko species except *G. mutilata*, where the population is uniform and under dispersed (CD= 0.09).

Table 3.10 Coefficient of Dispersion (CD) of Parasites in Gecko Hosts

	CD				
	H. frenatus	*H. platyurus*	*H. garnotii*	*G. monarchus*	*G. mutilata*
R. frenatus	4.22	1.16	5.19	1.83	0.79
Thelandros sp.	4.7603	0.6018	0.6815	0.6667	0.6739
Spauligodon sp.	2.6586	1.7879	-	-	-
Pharyngodon sp.	4.4815	1.7849	3.7984	1.8	4.7229
Skrjabinodon sp.	1.625	-	-	22.25	-
O. javaensis	1.2842	0.0909	-	-	1
P. geckonum	9.416	9.6182	1.7143	0.4444	1.5
P. ovatus	29.846	0.3636	87.5065	-	13.8889
G. bataviensis	11.9541	5.9429	5.4028	15.2069	0.0909

* Coefficient of Dispersion (CD) ≈ 1 ; the population is random and evenly dispersed

\> 1 ; the population is clustered and over dispersed

< 1 ; the population is uniform and under dispersed

3.3.3 Diversity and evenness of parasite community in the gecko host.

Table 3.11 showed how the host species fare as habitats for the parasites. *G. monarchus* had the highest diversity of parasites compared to the otherswith an H’ value of 1.7111 despite not being the dominant gecko species. The most dominant gecko host species was *G. mutilata* with a Simpson’s index of dominance of 0.9108 compared to *G. monarchus*’ 0.7769. *G. monarchus* had a higher diversity of parasite species compared to *G. mutilata*, but *G mutilata* was the more dominant species as a host to the parasites. The most evenly distributed parasite population was observed in the gecko host *H. platyurus* (E= 0.761). *H. frenatus*, on the other hand had a distribution that is the least even, with an evenness value of 0.6553. This suggested that some parasite species infecting *H. frenatus* exist in high abundance, namely three species with the highest mean abundance; *P. ovatus* (Mean abundance = 3.0835), *G. bataviensis* (Mean abundance = 5.281) and *Pharyngodon* sp. (Mean abundance = 1.92) (Table 3.8).

Among the house gecko species, *H. frenatus* had the lowest H’ (H’ 1.6 1) and also the lowest evenness value (E= 0.6604). Distribution of parasite’s populations found in the *H. frenatus* was less even, and this was contributed by the hugh abundance of *P. ovatus* (Mean abundance = 3.0835) and *G. bataviensis* (Mean abundance = 5.281). Both species recorded the highest abundance of parasites population in the *H. frenatus* (Table 3.8). However the Simpson’s index of dominance value for this gecko species was higher than most house geckos with a value of 0.753 highlighting *H. frenatus* as the more favorable as a host species.

Table 3.11 Diversity and Evenness of Parasite Community in Different Gecko Species.

Host Species	Total number of parasite species	Indices value		
		Ds	H'	E
H. frenatus	9	0.752	1.6283	0.6553
H. platyurus	9	0.759	1.672	0.761
H. garnotii	8	0.8193	1.5152	0.7787
G. monarchus	8	0.7769	1.7111	0.7431
G. mutilata	8	0.9108	1.6457	0.6623

3.4 Discussion

Raillietiella frenatus was the only pentastomid parasite species found inhabiting the lungs of the geckos. This confirmed previous observations of this pentastomid species in similar house gecko species in Malaysia (Ali *et al.*, 1981; Ali & Riley, 1983). Only one species of cestode was recovered, *Oochoristica javaensis*, residing in the small intestines of geckos. With the exception of *Gekko monarchus*, *O. javaensis* was found in all house gecko species studied. This cestode genus is generally found in lizards (Yildirimhan *et al.*, 2011; Mašová *et al.*, 2012; Norval *et al.*, 2014) but can occasionally be found in mammals (Hickman, 1954; Okafor, 1988). Two species of trematodes were obtained from this study; *Paradistomum geckonum* was found occupying the gallbladder while *Postorchigenes ovatus* colonizes the small intestines of all gecko species studied, which confirms earlier observations (Chakravorty & Manna, 1982; Killick *et al.*, 1982; Kennedy *et al.*, 1987a; Morsy *et al.*, 2012). Both trematode species infect all gecko species except *Gekko monarchus*.

Three nematode species parasitized all five gecko species and was confirmed by previous observations (Vicente *et al.*, 2000; Goldberg *et al.*, 2001; Matsuo & Oku, 2002; Goldberg *et al.*, 2005b; Amer & Bursey, 2008; Goldberg *et al.*, 2011). These nematodes also infect other saurians groups such as skinks (Goldberg *et al.*, 2005a). One species of nematode, *Skrjabinodon* sp. infected all but one gecko species, *Hemidactylus garnotii*.

Only one species of ectoparasitic mite was found parasitizing the house geckos. *Geckobia bataviensis* is a common gecko mite (Sri Prawasti, 2011; Sri Prawasti *et al.*, 2013). The mite infested all gecko species except *Gekko monarchus*.

Certain parasite species were capable of coexisting with other species in the same niche (see Table 3.6). This behaviour was clearly observed in the intestines of the geckos, where nematodes, trematodes and cestodes were found inhabiting the same niche at the same time. In the gut, the cestode played an important role in regulating the population of trematodes and nematodes. Although they did occasionally able to co-exist, but the abundance of trematodes and nematodes were greatly reduced when a cestode parasitize the gut. This may be due to the tissue damage caused by the attachment organs of the cestodes, reducing suitability of the niche to other parasite species.

3.4.1 **Parasite infection success in different host species**

Some reptile parasites are capable of using birds (Riley *et al.*, 2003) and mammals (Tiendrebeigo *et al.*, 1982) as definitive hosts. This showed some parasites' affinity towards a certain gecko species. Possible explanations for this observation Include i)being generalists, these parasites are opportunists, and may latch on suitable hosts once the intermediate host in consumed. The *Raillietilla* pentastomids are known to infect a variety of hosts including frogs (Barton & Riley, 2004), lizards (Riley *et al.*, 1991), snakes (Almeida *et al.*, 2003), birds (Riley et al, 2003) and mammals (Dollfus & Canet, 1954). This particular trait is the key to success for these parasites in acquiring hosts to continue their life cycles.

The results showed that different parasite species with the exception of *Spauligodon* sp. and *P. ovatus* may have employed certain strategies in order to reach its final hosts. The five species of house geckos inhabited the same niche and share similar dietary component (see Table 3.1). These geckos have many overlaps in terms of habitats and niche, allowing the parasites equal chance to infect any of the gecko species. The higher success rate of infection in certain gecko species is possibly contributed by the distribution within the gecko community. *Hemidactylus* genus is a widespread genus. Their ability to withstand harsh conditions enable them to colonize different habitats, even effectively out-competing natural fauna for resources and space in certain cases (Goldberg *et al.*, 1998; Barton, 2007; Newberry & Jones, 2007; Hoskin, 2011). The gecko *Hemidactylus frenatus* for example is able to take in new parasite infections from local fauna in a new environment with very little harm done to its physical well-being (Hanley *et al.*, 1995a).

Hemidactylus frenatus make a large proportion of the gecko community studied (Figure 3.2). *H. frenatus* appears to adapt to its surroundings and is able to utilize resources better compared to the other four gecko species. However, the low success rate of infection showed *H. frenatus* is not the most sought after host in most cases. Parasitism is a limiting factor to a host population; a parasite can have many adverse effects on its host; such as limiting the host's ability to function normally, altering host's behavior to manipulate the host to orientate itself in ways that will enable successful dissemination of the parasites' eggs/larvae, or make the host susceptible to predators.

3.4.1.1 Carrying capacity

Carrying capacity is the maximum population that can be supported by the environment (Bush, 2000). In the case of parasitism, the resources are in the forms of nutrients derived from the host and sites of infection in/on the host. The ability to harbor optimal number of parasites varies between gecko species. Two species of parasite were significantly abundant in their hosts. These were *P. geckonum* on *H. platyurus* and *Skrjabinodon* sp. in *G. monarchus*. Although most of the parasites showed higher success in infecting certain hosts, not all the hosts can tolerate a high parasite load. The ability to tolerate high parasite load or having a high carrying capacity is possibly utilized by *H. frenatus* in order to successfully compete with the other geckos. Infection in *H. frenatus* is more abundant compared to other gecko species (Hanley *et al.*, 1995; Kelehear *et al.*, 2013).

Parasites exhibit typical aggregated and usually over dispersed pattern of distribution. Different species of geckos may have different limiting factors that control their ability to bear high parasitic load. Physiological factor such as the size is a possible limiting factor, especially in the case of ectoparasites. It is possible the geckos experience reduction of ectoparasite infection during ecdysis. Another probable factor contributing to the success or failure of parasitic infection is immunological. There are countless evidence how the host develops immunological strategies against parasites, such as reproductive hormones affecting mites infection in bats (Christe *et al.*, 1998), immunological differences between the sexes may increase parasitism in male hosts (Klein, 2004) and regulation of the immune response to cestode infection by progesterone (Vargas-Villavicencio *et al.*, 2005).

3.4.1.2 High diversity of parasite species

H. frenatus harboured nine parasite species. Having a high diversity of parasites is a smart strategy, as interspecific competition amongst the parasites keeps their numbers in check, thus inhibiting symptoms or illness from affecting the gecko (Barton, 2007; 2015; Goldberg *et al.*, 2005b; Mahagedara & Rajakaruna, 2015). Competition is evident in the case of the endoparasites, especially those sharing the same niche, such as the parasites found in the alimentary canal.

R. frenatus is the only species found in the lungs of the geckos. From previous literature, *R. frenatus* have been found in animals other than saurians, such as toads (Kelehear *et al.*, 2012), skinks (Riley *et al.*, 1991), iguanas (Almeida *et al.*, 2008), anoles (Barton & Riley, 2004) and snakes (Kelehear *et al.*, 2014). The parasite is a very successful generalist species, infecting various groups of reptiles and amphibians, and not limited to only saurians. This mechanism employed ensures the survival of its species. With such diverse final hosts, the pentastomid certainly make use of various intermediate hosts as well and not limited to insects as is often the case (Lavoipierre & Lavoipierre, 1965; Lim & Yong, 1977; Bosch, 1986).

A different scenario is observed in the gut, where four species of nematodes, one species of cestodes and one species of trematode are found. The nematodes (*Thelandros* sp. and *Spauligodon* sp.) and the trematode (*P. ovatus*) can co-exist with all gut parasite species. *Pharyngodon* sp. is capable of co-existing with almost all of the gut parasites, except *Skrjabinodon* sp. The nematode species is an oxyurid; most of its members are commensals or less pathogenic to its hosts (Rataj *et al.*, 2011).

3.4.1.3 High diversity of diet component

H. frenatus does not discriminate when it comes to diet (Tyler, 1961; Tkaczenko *et al.*, 2014). From previous works, it has been established that most reptilian parasites do not discriminate when it comes to finding their intermediate hosts, which allow a wider range of infection sources. In the case of the gecko endoparasites i.e. cestodes and trematodes, one uniting factor is that the parasites expel their eggs through fecal matter, therefore the prime candidate for intermediate hosts are insects such as cockroaches and beetles that share the same habitat range as the gecko and show coprophagial behavior. Foraging range increases with age as the gecko is less susceptible to predation, and less hindered by gape limitation.

3.4.1.4 Physiological/Immunological factors

Physiological factor such as having a comparatively more fragile skin affects a gecko's ability to obtain/retain ectoparasitic infection more effectively. *G. mutilata* is known for fragile skin that tears easily at the slightest provocation compared to the other four geckos species studied, which can lead to ectoparasites loss. This is a possible factor as to why the mite population on this gecko species is low. The current study does not involve an immunology component; however it is possible that immunological factors contribute to infection bias (Christe *et al.*, 1998; 2000; Klein, 2004; Morales-Montor & Hall, 2007; Roberts *et al.*, 2004). The four species of nematodes obtained from this study are from the family Oxyuridae, which is known for having direct life cycles (Anya, 1966). Autoinfection further increases indiscriminate infection in the gecko population, as transmission can occur by fecal ingestion or via fomites.

3.5 Conclusion

House geckos are hosts to a diverse group of generalist, mostly stenoxenous (with the exception of *R. frenatus*, which is euryxenous) parasites from various different groups, occupying different niches. Competition for niches is stiff, as clearly observed amongst the pentastomids occupying the lungs. The gut is the most diverse niche, hosting six species of parasites (one cestode, one trematode and four species of nematodes).

Most reptile parasites are generalists and are less picky about host species as long as the host is within the reptile group or family. Living in such close association with humans, geckos pose a risk of zoonotic transmission, or act as a reservoir host. Different gecko species also may have differences in dietary composition, a potential preferred prey exclusive to the gecko species that may explain the parasites' affinity. Immune system may also contribute to the observation; it is possible that the different gecko species have different levels of immunity (Zimmerman *et al.*, 2010). Certain species might invest more energy on other areas such as sexual characteristics, faster growth rate etc, at the expense of its immune system.

Invader species have characteristics that allow them to become successful in new territory. Gecko species such as *G. monarchus* travels in between different types of habitats and can easily introduce what appears to be a harmless, wild infection, into the urban environment where it may pose a risk to humans and livestock. The *Hemidactylus* genus, especially *H. frenatus* demonstrated this fact; the gecko species is able to tolerate a diverse parasitofauna better than other gecko species of different genera. *H. frenatus* is an aggressive competitor, out-competing other gecko species in terms of territory, food acquisition and parasitic infection. The gecko shares these similar traits with other successful invader species such as rats and monkeys. Both rats and monkeys are widely distributed, thanks to human activities; rats and geckos travelled across the globe by hitch-hiking on ships or cargo. The geckos especially *H. frenatus* is becoming a popular choice for a pet due to its ability to adapt quickly to its surrounding and the fact that it requires minimal care. The increased interaction between the geckos and humans may affect the dynamics of the geckos' parasites, possible allowing introduction of parasites in new hosts or reemergence of old parasites (Atehmengo & Nnagbo, 2014; Kublin *et al.*, 2003; Mackey *et al.*, 2014).

Forest fringe or ecotone species such as *Gekko monarchus* is similar to the long-tailed macaque *(Macaca fascicularis*). Both are found in the forest, in human habitation and the transitional habitats between the two. Ecotone species is capable of introducing infections into human environment. So far diseases involving wild reptiles infecting humans are restricted to contacts mostly through exotic pets industry; cases of salmonellosis in young children, old people or people who are immunocompromised (Grant & Olsen, 1999). The risk of *G. monarchus* introducing a new infection that is potentially dangerous to humans and livestock is low, however it is important to remain vigilant as an ecotone species is capable of doing so.

CHAPTER 4: PARASITE INFECTION SUCCESS - EFFECTS OF HOST GENDER AND SIZE

4.1 Introduction

The general belief that a parasite does not discriminate while infecting its host is arguable as differing success rate of infection in male or female hosts is often observed throughout the animal kingdom (Morales-Montor *et al.*, 2004; Morales-Montor & Hall, 2007). This is true in some groups of animals, as previous investigations have clearly shown some form of gender-based host selection, commonly found in higher vertebrates (birds and mammals) (Klein, 2004; Morand *et al.*, 2004). The effects of the host's gender on parasite infection intensity have been also documented in lizards (Schall *et al.*, 2000; Amo *et al.*, 2005).

Immunocompetence is the general capacity of an organism to build up an immune response against pathogens and parasites (Schmid-Hempel, 2003). Klein (2004) discussed that male host selection is more common in humans and mammals, especially for protozoans, nematodes, trematodes and ectoparasites. Hamilton and Zuk (1982) presented a controversial theory implying that parasitism affects host mating, proposing that male secondary sexual characteristics, such as bright plumage coloration in birds (Doucet & Montgomerie, 2003), plumage coloration, comb color and size in red jungle fowl (Zuk *et al.*, 1990) play a major role in attracting mates, but reduce their ability to resist parasitic infections. Testosterone has been speculated to play a role in increased parasitism by direct suppression of the immune response, or by altering energy usage, stimulating the male host to make frequent and lengthy movements such as foraging, thus increasing the exposure time of the male host to parasites (Hughes &

Randolph, 2001; Belliure *et al.*, 2004). In most higher vertebrates, parasites exhibit male host preference and this is likely due to higher mobility and lower immunocompetence of male hosts compared to females (Khokhlova *et al.*, 2009).

Behaviours that increase the likelihood of becoming infested by parasites has been documented. For instance, aggression between males for mating opportunities, decreased male grooming rate during the mating season (Mooring & Hart, 1995) and spatial aggregation within members of one sex (Zuk & McKean 1996). The flea rodent, *Xenopsylla ramesis* also exhibits a male-biased parasitism; fleas that feed on male *Meriones crassus* (gerbilline rodent, Subfamily Gerbillinae) are satiated faster and produce significantly more eggs (Khokhlova *et al.*, 2009). All the previous investigations of male host selection in higher vertebrates proposed that males spend more energy on expressing secondary male sexual characteristics at the expense of reduced immunocompetency in order to attract mates.

Female host selection in relation to parasitism although exist in nature, is less common compared to male host selection. Female-biased parasitism has been shown in certain species of birds and small mammals. *Acomys russatus* exhibited a female-biased parasitism, in which seasonality played a role (Krasnov *et al.*, 2005). Female estrogen is believed to encourage the parasites' growth and development in the hosts (Morales-Montor *et al.*, 2002). Testosterone injections reduced the resistance of the rodents *Myodes glareolus* and *Apodemus sylvaticus* to parasitism of the tick *Ixodes ricinus* (Hughes & Randolph, 2001).

Rolff and Siva-Jothy (2002) proposed that differences in immunocompetence between males and females are due to the higher investment of females in immunity, and on producing and/or caring for their young. Females have lower predation rate due to their inconspicuous physical characteristics and a higher immunocompetency, which enable them to withstand parasitic infection. Sex-specific behavior may affect the exposure time to parasites with one sex being more susceptible than the other (Krasnov *et al.*, 2005).

Host size as a determining factor in parasiteinfection is widely documented, most involving ectoparasites (Christe *et al.*, 2007) or blood parasites (Lumpkin *et al.*, 2014). Ectoparasites especially ticks have host size preference, although this may be confused by the fact that male lizards are larger than females (Lumbad *et al.*, 2011). High intensity infection of ectoparasitic ticks has been known to affect the hosts' population dynamics, behaviour, and the reproductive success (Duffy, 1983; Main & Bull, 2000). The parasitic isopod (*Hemioniscus balani*) showed size-selective parasitism in the barnacle, *Chthamalus fissus* (Blower & Roughgarden, 1988).

Some parasites prefer smaller or younger hosts, as juvenile hosts may have an underdeveloped immune system which will allow easy infection. However the size of the host could also be the physical manifestation of the infection. Heavy infections of parasites have been known to cause weight loss, thus affecting the overall appearance and size of the host (Dezfuli *et al.*, 2011). Cestodes are known to cause serious damage in most of its hosts including humans (Budke *et al.*, 2009).

4.2 Methodology

4.2.1 Basic Parasitological Parameters

Assessment of parasite composition in the house gecko population was performed using basic statistical analysis. Parasite distribution within the host population was determined the behavior and ecoparasitology of the gecko's endoparasitofauna. Basic parasitological parameters such as prevalence, intensity, mean intensity, abundance, and mean abundance were taken into account since these were key markers to determine level of infection within the community. Prevalence, mean intensity and mean abundance were calculated as described in Margolis *et al.* (1982).

Prevalence = (Number of infected hosts / number of hosts examined) x 100

Mean Intensity = Number of parasites / total of infected hosts

Mean Abundance = Intensity / total number of hosts examined

4.2.2 Parasite Dispersion Pattern – Coefficient of Dispersion

Basic population dispersion test, the Coefficient of Dispersion was applied to the parasitofauna from the host population and the study sites. The sample mean, x, is defined as 'the sum of all measurements in the sample divided by the number of measurements in the sample (Zar, 1984). The variance, S^2, of a population mean is a measure of mathematical variability within the population. These two parameters are important to determine which of the three types of hypothetical population dispersion (i.e. either random, underdispersed and overdispersed) the organism displays. In a population with a random distribution, the variance (S^2) is not significantly different from the mean (x); therefore variance ≈ mean. When the variance/mean ratio is bigger than $S^2 \approx x$ ($S^2 >> x$), the population is overdispersed. However if the variance/mean ratio is less than $S^2 \approx x$ (S^2 x), the population is underdispersed.

$$\text{Coefficient of Dispersion, CD} = \frac{\text{Variance, } S^2}{\text{Mean, } x}$$

CD ≈ 1 ; the population is random and evenly dispersed

> 1 ; the population is clustered and overdispersed

< 1 ; the population is uniform and underdispersed

4.2.3 Chi Square Test

Chi Square Test was applied to investigate differing parasites successful infection in different host genders and sizes. This is done in order to show a different quantitative method in complement of various diversity indices used, which will be further discussed later. The chi square analysis is straightforward and complemented the results obtained from the diversity indices.

4.2.4 Diversity Indices

Diversity indices were used to calculate the complexity and measure the health of an ecosystem. Greater variety of species allows for more species interactions, hence greater system stability, which indicates good environmental condition. A community is said to have high species diversity if many nearly equally abundant species are present. If a community has only a few species or only a few species are very abundant, the species diversity is considered low.

Simpson's Index of Diversity, Ds, calculates the probability that two organisms sampled from a community belonging to different species. The more even the abundance of individuals across species, the higher the probability that the two individuals sampled are belong to different species. The index ranges from 0 to 1; 1 being the perfect evenness (all species present in equal numbers)

$$Ds = \sum \frac{ni(ni-1)}{N(N-1)}$$

n_i = total of individuals from species $_i$

N = total of all individuals

Shannon-Weiner Diversity Index, H' belongs to a subset of indices that maintain that diversity can be measured much like the information contained in a code or a message. It assumes that all species are represented in a sample and that the sample was obtained randomly:

$$H' = -\sum_{i=1} p_i log p_i$$

p = proportion of individuals found in the $_i$th species

The Shannon index is affected by both the number of species and their equitability, or evenness. A greater number of species and a more even distribution both increase diversity as measured by H'. The maximum diversity (H_{max}) of a sample is found when all species are equally abundant.

$H_{max} = \ln S$

S = Number of species

Actual diversity was compared by using a measure called Evenness. The evenness of the sample is obtained from the formula

Evenness, E H'/ H_{max}

By definition, E is constrained between 0 and 1. As with H', evenness assumes that all species are represented within the sample.

4.3 Results

Six hundred and ninety-two house geckos belonging to five different species (*Hemidactylus frenatus, H. platyurus, H. garnotii, Gekko monarchus* and *Gehyra mutilata*) from eight sites on the west coast of Peninsular Malaysia were examined from December 2006 to September 2010. A total of 8094 parasites belong to nine species were identified. These are one ectoparasitic mite (*Geckobia bataviensis*), one pentastomid species (*Raillietiella frenatus*), one cestode species (*Oochoristica javaensis*), two trematode species (*Paradistomum geckonum* and *Postorchigenes ovatus*) and four species of nematodes (*Thelandros* sp., *Spauligodon* sp., *Pharyngodon* sp., and *Skrjabinodon* sp.). The prevalence of parasites in the house gecko population is 84.1% with a mean intensity of 8.65±0.8 (range 1-125) and a mean abundance of 7.27.

4.3.1 Parasite infection in different host genders.

Both female *H. frenatus* and *H. platyurus* geckos showed significantly higher susceptibility to infection of parasites as both hosts harboured the highest number of parasite species with nine species each (Table 4.1). The ectoparasitic mite *G. bataviensis* was the most prevalent parasite in the *H. frenatus* population (43%) while the gut nematode species *Thelandros* sp. was the most prevalent parasite in the *H. platyurus* population, with a prevalence of 70.5%. Not only this was the highest prevalence recorded in *H. platyurus*, it was also the highest prevalence of any parasite recorded in all gecko species, regardless of the gender of the host. The lowest prevalence of parasite in *H. frenatus* and *H. platyurus* was recorded by another gut nematode, *Skrjabinodon* sp. with a value of 0.81% and 0.82% respectively. This showed that competition between the nematodes to stay prevalent in the gecko population do exists, and *Thelandros* sp. appeared to have an advantage over *Skrjabinodon* sp. in maintaining its numbers in the female gecko population. In the male population of *H. frenatus* and *H. platyurus*, a total of seven species of parasites were found (Table 4.1). The mite *G. bataviensis* was the most prevalent parasite in *H. frenatus* (48.9%) while in *H. platyurus*, the gut nematode, *Thelandros* sp. was the most prevalent species (67.9%). The prevalence of both parasites in male and female gecko populations of *H. frenatus* and *H. platyurus* were almost similar, suggesting these parasites are equally successful in infecting both genders. The lowest prevalence of parasite in the male gecko population belonged to two parasites in *H. frenatus*; the gut nematode *Spauligodon* sp. (2.12%) and the gut trematode *P. ovatus* (2.12%); while *Spauligodon* sp was recorded as least prevalence in *H. platyurus* (3.57%). *Thelandros* sp. was a better competitor against *Skrjabinodon*, another gut parasite in the male geckos, similar to the observation of infection rate in female gecko population.

With the exception of *G. monarchus*, all the gecko population showed intense infection of *P. ovatus* in one or both host genders. *H. platyurus* recorded intense infection of the gut trematode, *P. ovatus* in both genders; male geckos had a mean intensity of 8.5 ± 0.07 (range 1 - 9), while the female geckos with 10.83 ± 0.09 (range 1 - 30). Female host preference was evident in *H. frenatus*, with intensity of 15.49 ± 0.21 (range 1 - 9) while in male host, the intensity is only 5 ± 0.02 (range 1 - 91). Only in *G. mutilata*, the males had a higher intensity of infection compared to the female geckos. Intensity in male is 15.5 ± 0.2 (range 2 - 29) compared to females, which is 6.3 ± 0.2 (range 3 - 11). Female geckos had a higher range of intensity than male geckos, although intensity of infection was almost similar between the two populations. The lowest mean intensity recorded for both gecko species was also for the same parasite, *O. javaensis* with 1.7273 ± 0.02 (range 1 - 2) in female *H. frenatus* and 1.125 ± 0.06 (range 1 - 2) in female *H. platyurus*. In male geckos, the lowest intensity of parasite in male *H. frenatus* was *Spauligodon* sp. with 1 ± 0.02 (range 1 - 12) and *O. javaensis* in male *H. platyurus* with the mean intensity of 1 ± 0.07 (range 0 - 1).

In *G. mutilata*, the female geckos hosted more parasite species, with eight species (Table 4.1) compared to only six species in the males. The highest prevalences of parasites in both male and female populations were from three different groups; in the females, the pentastomid *R. frenatus* and the nematode *Thelandros* sp. were most prevalent, with 40%, while in the males the nematode *Pharyngodon* sp. and the trematode *P. geckonum* were prevalent with also 40% prevalence. The lowest prevalence in both male and female populations was recorded by *O. javaensis*, the single cestode species obtained from the study, with 3.33% in female population and 10% in male population.

Females had the highest intensity of the nematode *Pharyngodon* sp. with 6.7 ± 0.23 (range 1 - 6) while in the male geckos, *P. ovatus* had the highest intensity with 15.5 ± 0.2 (range 1 - 29). Both parasites inhabited the gut of the gecko, and it will be interesting to speculate why one gender was more heavily infested with one species of parasite even though the geckos are of the same species. Parasites with lowest intensity for both male and female geckos was the cestode *O. javaensis* with 1 ± 0.03 (range 0 - 3) in females while the male geckos *O. javaensis* had a mean intensity of 1 ± 0.1 (range 0 - 1).

In *G. monarchus,* female population hosted a higher number of parasites species with eight species (Table 4.1), compared to only four species in the male population. Different groups of parasites were prevalent in both male and female populations. Unlike in the *H. platyurus*; *R. frenatus* was the most prevalent parasite in female geckos with 35.3% while in the male geckos, the gut trematode *P. ovatus* was the most prevalent, with 33.3%. The lowest prevalence of parasite in female gecko population belonged to *Pharyngodon* sp., with a prevalence of 2.9%. In the male population on the other hand, three species showed low prevalence, *Spauligodon* sp., *Pharyngodon* sp. and *Skrjabinodon* sp., each with 16.67% prevalence. So far, prevalence-wise, the female and male geckos' populations were very different. A lot of intergroup competition between the parasite species was more important compared to competition within the same group as observed in the *H. platyurus* population.

Comparing intensity between the two populations, the female population was heavily infested with the ectoparasite *G. bataviensis* with a mean intensity of 14.5 ± 0.06 (range 4 - 25) while in the male population, the highest intensity was recorded by the nematode *Skrjabinodon* sp. with a mean intensity of 9 ± 0.17 (range 0 - 9). Both populations had different high intensity of parasites, with the ectoparasites thriving better on the female geckos and the nematode *Skrjabinodon* sp. on the male geckos. The lowest intensity of parasite infecting the female geckos was *Pharyngodon* sp. with 1 ± 0.03 (range 0 - 1) while in the males, *Spauligodon* had the lowest mean intensity with 2 ± 0.17 (range 0 - 2).

H. garnotii was the only species of all-female, parthenogenic gecko species studied. This species offers a unique take on the whole host gender preference argument as a unisexual gecko, how well does it fare against the dioecious gecko species as a host? For starters, it hosted eight species of parasites (Table 4.1). The highest prevalence of parasite was recorded by *G. bataviensis* with 34.15%, while the lowest prevalence was of *Spauligodon* sp. with 2.4%. *H. garnotii* had an intense infection of the gut trematode *P. ovatus* with a mean intensity of 26 ± 0.17 (range 1 - 137), the highest value of mean intensity in any gender of the gecko population. The range was astounding, as a small gecko can host a staggering 137 mites at one time. The lowest intensities of parasites recorded in this gecko were seen in *Spauligodon* sp. with 1 ± 0.02 (range 0 - 1) and *O. javaensis* with 1 ± 0.07 (range 0 - 1).

Table 4.1 Prevalence, Mean Intensity and Mean Abundance of Parasites According to Host Gender.

Host Species	Host Gender	Parasite Sp.	Prevalence	Mean Intensity	Mean Abundance
H. frenatus	F	*R. frenatus*	22.7	3.09(±0.23)	0.7 (±0.09)
		Thelandros sp.	34.5	3.71 (±0.34)	1.28(±0.16)
		Spauligodon sp.	10.2	3(±0.1)	0.3 (±0.07)
		Pharyngodon sp.	32.4	5.35(±0.32)	1.73(±0.2)
		Skrjabinodon sp.	0.8	2.67(±0.8)	0.0214(±0.01)
		O. javaensis	2.9	1.73(±0.03)	0.0508(±0.02)
		P. geckonum	13.6	4.78(±0.14)	0.6524(±0.18)
		P. ovatus	21.1	15.49(±0.21)	3.2727(±0.56)
		G. bataviensis	43	11.09(±0.43)	4.7754(±0.4)
	M	*R. frenatus*	17	3.13(±0.17)	0.5319(±0.24)
		Thelandros sp.	19.2	3(±0.19)	0.5745(±0.22)
		Spauligodon sp.	2.1	1(±0.02)	0.0213(±0.02)
		Pharyngodon sp.	42.5	5.6(±0.43)	2.383(±0.64)
		Skrjabinodon sp.	0	0	0
		O. javaensis	0	0	0
		P. geckonum	17.021	3.75(±0.17)	0.6383(±0.11)
		P. ovatus	0	0	0
		G. bataviensis	48.936	13.04(±0.49)	6.383(±1.64)
H. platyurus	F	*R. frenatus*	14.754	1.94(±0.14)	0.2869(±0.08)
		Thelandros sp.	70.492	2.74(±0.7)	1.9344(±0.15)
		Spauligodon sp.	9.0164	2.36(±0.09)	0.2131(±0.08)
		Pharyngodon sp.	9.0164	2.45(±0.09)	0.2213(±0.08)

Table 4.1, continued.

		Skrjabinodon sp.	0.8197	4(±0.08)	0.0328(±0.03)
		O. javaensis	6.5574	1.125(±0.07)	0.0738(±0.03)
		P. geckonum	34.426	4.76(±0.34)	1.6393(±0.39)
		P. ovatus	9.8361	10.83(±0.09)	1.0656(±0.03)
		G. bataviensis	25	2.71(±0.25)	0.6786(±0.1)
	M	*R. frenatus*	32.14	1.44(±0.32)	0.4643(±0.12)
		Thelandros sp.	67.857	2.11(±0.68)	1.4286(±0.24)
		Spauligodon sp.	3.5714	1(±0.03)	0.0357(±0.03)
		Pharyngodon sp.	7.1429	2(±0.07)	0.1429(±0.1)
		Skrjabinodon sp.	0	0	0
		O. javaensis	7.1429	1(±0.07)	0.0714(±0.05)
		P. geckonum	0	0	0
		P. ovatus	7.1429	8.5(±0.07)	0.6071(±0.03)
		G. bataviensis	3.45	1(±0.03)	0.03(±0.03)
H. garnotii	F	*R. frenatus*	9.76	4.25(±0.1)	0.4146(±0.3)
		Thelandros sp.	26.829	2.45(±0.27)	0.6585(±0.2)
		Spauligodon sp.	2.439	1(±0.02)	0.0244(±0.02)
		Pharyngodon sp.	29.268	5.75(±0.29)	1.6829(±0.56)
		Skrjabinodon sp.	0	0	0
		O. javaensis	7.3171	1(±0.07)	0.0732(±0.04)
		P. geckonum	7.3171	5.67(±0.07)	0.4146(±0.36)
		P. ovatus	17.073	26(±0.17)	4.439(±3.07)
		G. bataviensis	34.146	9.36(±0.34)	3.1951(±0.95)
G. monarchus	F	*R. frenatus*	35.3	2.42(±0.35)	0.8529(±0.03)
		Thelandros sp.	20.588	4.43(±0.2)	0.9118(±0.33)
		Spauligodon sp.	5.8824	2(±0.6)	0.1176(±0.08)

Table 4.1, continued

		Pharyngodon sp.	2.9412	1(±0.02)	0.0294(±0.03)
		Skrjabinodon sp.	17.647	11.83(±0.17)	2.0882(±1.45)
		O. javaensis	0	0	0
		P. geckonum	8.8235	3(±0.08)	0.2647(±0.13)
		P. ovatus	5.8824	3(±0.6)	0.1765(±0.48)
		G. bataviensis	5.8824	14.5(±0.06)	0.8529(±0.74)
	M	*R. frenatus*	0	0	0
		Thelandros sp.	0	0	0
		Spauligodon sp.	16.667	2(±0.16)	0.3333(±0.4)
		Pharyngodon sp.	16.667	4(±0.17)	0.6667(±0.8)
		Skrjabinodon sp.	16.667	9(±0.17)	1.5(±1.8)
		O. javaensis	0	0	0
		P. geckonum	0	0	0
		P. ovatus	33.333	3(±0.33)	1(±0.8)
		G. bataviensis	0	0	0
G. mutilata	F	*R. frenatus*	40	1.33(±0.4)	0.5333(±0.14)
		Thelandros sp.	40	2.92(±0.4)	1.1667(±0.33)
		Spauligodon sp.	3.3333	2(±0.03)	0.0667(±0.07)
		Pharyngodon sp.	23.333	6.71(±0.23)	1.5667(±0.78)
		Skrjabinodon sp.	0	0	0
		O. javaensis	3.3333	1(±0.03)	0.0333(±0.1)
		P. geckonum	13.333	2.25(±0.13)	0.3(±0.39)
		P. ovatus	20	6.33(±0.2)	1.2667(±0.39)
		G. bataviensis	6.6667	5.5(±0.06)	0.3667(±0.26)
	M	*R. frenatus*	30	1.67(±0.3)	0.5(±0.34)

Table 4.1, continued

Thelandros sp.	30	3.67(±0.3)	1.1(±0.64)
Spauligodon sp.	0	0	0
Pharyngodon sp.	40	5.75(±0.4)	2.3(±1.27)
Skrjabinodon sp.	0	0	0
O. javaensis	10	1(±0.1)	0.1(±0.11)
P. geckonum	40	2.5(±0.4)	1(±0.22)
P. ovatus	20	15.5(±0.2)	3.1(±3.22)
G. bataviensis	0	0	0

Table 4.2 illustrated the effect of host gender on parasite infection success. In the gecko *H. frenatus*, significant success of infection rate in female host is observed in seven parasites (*R. frenatus*, *Thelandros* sp., *Spauligodon* sp., *Skrjabinodon* sp., *O. javaensis, P. ovatus* and *G. bataviensis*) whereas only one parasite species exhibited infection success in male host (*Pharyngodon* sp.) ($p < 0.05$) and *P. geckonum* showed similar infection success rates in *H. frenatus* and infect both genders equally. In *H. platyurus*; four parasite species exhibited a more successful infection in female hosts (*R. frenatus*, *Spauligodon* sp., *P. geckonum* and *G. bataviensis*) while the rest (*Thelandros* sp., *Pharyngodon* sp., *Skrjabinodon* sp., *O. javaensis* and *P. ovatus*) showed no significant differences in infection rates towards either sex ($p < 0.05$). In *G. monarchus*, four parasite species showed more successful infection in female hosts (*R. frenatus*, *Thelandros* sp., *P. geckonum* and *G. bataviensis*) while two parasite species showed more success in infecting male hosts (*Spauligodon* sp. and *Pharyngodon* sp.) ($p < 0.05$). *Skrjabinodon* sp. and *P. ovatus* did now show any differences in successful infection in both gender in *G. monarchus* and infected both genders indiscriminately. Four parasite species (*R. frenatus*, *Thelandros* sp., *Spauligodon* sp., and *G. bataviensis*) were more successful in female *G. mutilata*, while three parasite species (i.e. *Pharyngodon* sp., *O. javaensis* and *P. geckonum*) were more successful in male hosts ($p < 0.05$). Host gender appeared to affect patterns of infection, although the parasite species in question vary in different gecko host species. Parasites thrive better in female hosts compared to male hosts in gecko parasitism.

Table 4.2 Gender based parasite infection success rate in four species of house geckos.

Parasite Species	Host Species							
	H. frenatus		***H. platyurus***		***G.monarchus***		***G. mutilata***	
	x^2	**p**	**x^2**	**p**	**x^2**	**p**	**x^2**	**p**
R. frenatus	196.7*	<0.00001	17*	<0.00001	29*	<0.00001	5.76*	0.0164
Thelandros sp.	61.047*	<0.00001	1.7604	0.18458	116.26*	<0.00001	25.714*	<0.00001
Spauligodon sp.	18.757*	<0.00001	8.5895*	0.00338	31.654**	<0.00001	4.44*	0.03511
Pharyngodon sp.	26.706**	<0.00001	0.9861	0.3207	51.901**	<0.00001	71.637**	<0.00001
Skrjabinodon sp.	0.56	0.45426	0.58	0.44631	0.25	0.61708	-	-
O. javaensis	3.63	0.05675	0.1	0.75183	-	-	12.8**	0.00035
P. geckonum	3.05	0.08074	43.7*	<0.00001	23.9*	<0.00001	184**	<0.00001
P. ovatus	98*	<0.00001	2.03	0.15422	[t]	-	-	-
G. bataviensis	8.86*	<0.00001	123*	<0.00001	11.6*	0.00066	14.4*	0.00015

* Host gender affects parasite prevalence (P<0.05); more successful in female hosts

** Host gender affects parasite prevalence (P<0.05); more successful in malehosts

[t] The number of *P. ovatus* was equally distributed among male and female geckos.

Table 4.3 displayed the parasite diversity between host genders. Females had a higher diversity in all four species of dioecious geckos. However with the exception of *H. frenatus*, parasites were more evenly distributed in the male population of the other three gecko species (*H. platyurus*, *G. monarchus* and *G. mutilata*). Female geckos may had a higher diversity, but the male geckos had the more even parasite distribution.

The gecko, *H. garnotii* appeared to be an adept host to the parasites as well, on par with the dioecious geckos in a sense that it did had a high diversity of parasites with an H’ 1. 1 , a value higher than H’ in the population of female *G. monarchus*. Its parasite community also had an even distribution compared to the ones exhibited in both population of male and female *H. frenatus*, and the female geckos of *H. platyurus.*

Table 4.3 Diversity of parasite community in male and female geckos populations in eight locations in Peninsular Malaysia.

Host Species	Host Gender	Indices value			Total Species
		Ds	H'	E	
H. frenatus	Male	0.5819	1.1763	0.6045	7
	Female	0.7608	1.6506	0.7512	9
H. platyurus	Male	0.7504	1.5712	0.7556	8
	Female	0.7553	1.631	0.7423	9
H. garnotii	Female	0.7195	1.4458	0.6953	8
G. monarchus	Male	0.7238	1.2609	0.9095	4
	Female	0.7629	1.6347	0.7861	8
G. mutilata	Male	0.7444	1.4806	0.826	6
	Female	0.7937	1.7008	0.8179	8

4.3.2 Parasite infection in different host sizes

Infection of parasites were recorded from geckos with snout-vent-length (SVL) ranging from 3 cm to 7.9 cm. Figure 4.1 demonstrated the distribution across geckos of different lengths. Very few juveniles below the SVL of 4 cm were examined, and most were from the species *H. frenatus*. Infection of parasites in juveniles was low in abundance, but increases with age. The number of infection was highly concentrated in medium-sized geckos, with lengths ranging from 4 to 6 cm in snout-vent-length. Few factors are possible contributors to this observation. The number of infection decreases once the geckos crossed the 6 cm SVL.

Table 4.4 showed parasites recovered in geckos of differing lengths. Pentastomids species were rarely found in geckos with SVL less than four centimeters, with the exception of *H. platyurus*, while nematodes, trematodes, cestodes and the ectoparasitic mites were found regardless of the SVL range. The raillietiellids displayed size-selective infection, while other parasites did not appear to discriminate the gecko host size.

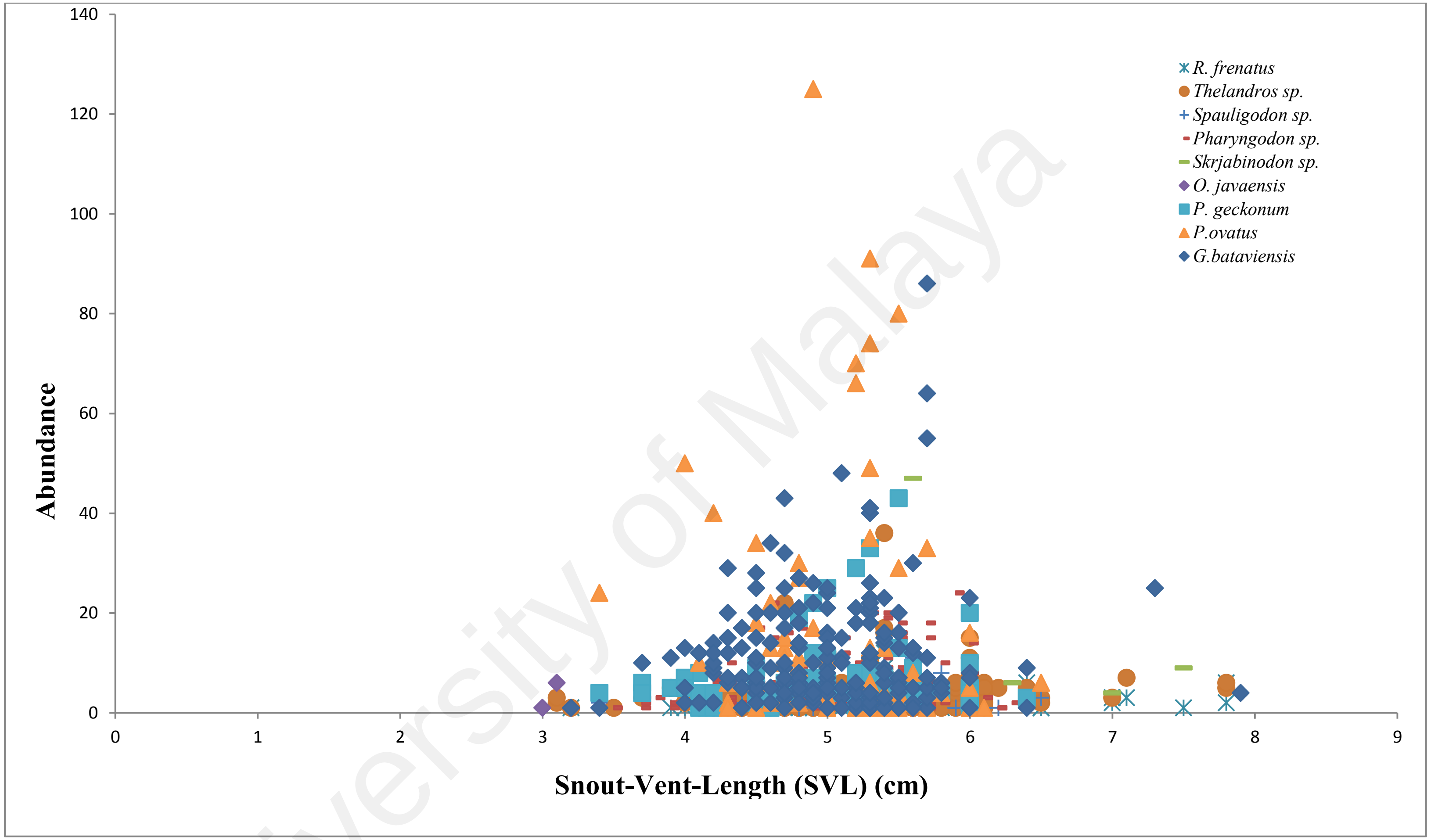

Figure 4.1 Abundance of parasites according to the snout-vent-length of the gecko hosts. The highest concentration of parasites are found in geckos with sizes ranging from 4 to 6 cm.

Table 4.4 Parasite Species Found in Different Host Lengths.

Parasite Species	Snout-Vent Length (SVL) (cm)														
	H. platyurus			*G. monarchus*			*G. mutilata*			*H. frenatus*			*H. garnotii*		
	<4	4-6	>6	<4	4-6	>6	<4	4-6	>6	<4	4-6	>6	<4	4-6	>6
R. frenatus	+	+	+	-	+	+	-	+	-	-	+	+	-	+	-
***Thelandros* sp.**	+	+	+	-	+	+	-	+	+	+	+	+	+	+	-
***Spauligodon* sp.**	+	+	+	-	+	+	-	+	-	+	+	+	-	+	-
***Pharyngodon* sp.**	-	+	-	-	+	-	-	-	-	+	+	+	-	+	-
***Skrjabinodon* sp.**	-	+	-	-	+	-	-	-	-	-	+	-	-	-	-
O. javaensis	+	+	-	-	-	-	-	+	-	+	+	-	-	+	-
P. geckonum	+	+	+	-	+	+	-	+	-	+	+	+	-	+	-
P. ovatus	+	+	+	-	+	-	-	+	-	+	+	+	-	+	-
G. bataviensis	+	+	+	-	-	+	-	+	-	+	+	+	-	+	-

Table 4.5 Prevalence, Mean Intensity and Mean Abundance According to the Host Length.

Host Species	Parasite Species	Host Size (Snout-Vent-Length) (cm)								
		<4			4--6			>6		
		Prevalence	Mean Intensity	Mean Abundance	Prevalence	Mean Intensity	Mean Abundance	Prevalence	Mean Intensity	Mean Abundance
H. frenatus	*R. frenatus*	0	0	0	22.76	3.11(±0.23)	0.71(±0.09)	33.33	2.75(±0.33)	0.92(±0.3)
	Thelandros sp.	11.76	2(±0.1)	0.24(±0.21)	34.78	3.57(±0.34)	1.24(±0.16)	50	2.67(±0.5)	1.33 (±0.55)
	Spauligodon sp.	5.882	2(±0.06)	0.12(±0.16)	7.417	3.66(±0.07)	0.27 (±0.07)	25	2.33(±0.25)	0.58 (±0.14)
	Pharyngodon sp.	41.18	2.86(±0.41)	1.18(±0.5)	32.99	5.65(±0.32)	1.87(±0.21)	41.67	2(±0.41)	0.83 (±0.43)
	Skrjabinodon sp.	0	0	0	0.767	2.67(±0.007)	0.02 (±0.01)	0	0	0
	O. javaensis	11.76	3.5(±0.11)	0.42(±0.47)	2.302	1.33(±0.02)	0.03 (±0.01)	2.5	2(±0.03)	0.05(±0.05)
	P. geckonum	5.882	3(±0.06)	0.18(±0.7)	14.32	4.75(±0.14)	0.68 (±0.18)	16.67	2.5(±0.17)	0.42(±0.57)
	P. ovatus	23.53	23.5(±0.25)	5.53(±4.2)	18.93	15.22(±0.19)	2.88(±0.57)	16.67	4.5(±0.17)	0.75(±0.19)
	G. bataviensis	41.18	6.71(±0.41)	2.76 (±1.44)	44.76	11.51(±0.44)	5.15 (±0.45)	16.67	12.5(±0.17)	2.08 (±0.76)
H. platyurus	*R. frenatus*	11.76	0.5(±0.11)	0.06(±0.1)	17.97	1.83(±0.18)	0.33(±0.08)	20	1(±0.2)	0.2(±0.16)
	Thelandros sp.	29.41	2.6(±0.29)	0.76 (±0.5)	75	2.56(±0.75)	1.92 (±0.14)	80	4.25(±0.8)	3.4(±0.4)
	Spauligodon sp.	0	0	0	8.594	2.36(±0.09)	0.2 (±0.09)	20	1(±0.2)	0.2(±0.05)
	Pharyngodon sp.	0	0	0	15.4	1.5(±0.15)	0.23(±0.17)	0	0	0(±0.16)
	Skrjabinodon sp.	0	0	0	0.781	4(±0.008)	0.03 (±0.03)	0	0	0
	O. javaensis	11.76	1(±0.11)	0.1176(±0.1)	7.813	1.3(±0.07)	0.1 (±0.2)	0	0	0(±0.1)
	P. geckonum	5.882	7(±0.05)	0.4118(±0.3)	34.38	4.57(±0.34)	1.57 (±0.04)	60	4.33(±0.6)	0
	P. ovatus	0	0	0	11.72	7.93(±0.12)	0.93(±0.03)	20	1(±0.2)	0.2(±0.09)
	G. bataviensis	5.882	1(±0.06)	0.0588(±0.08)	4.688	3(±0.05)	0.14 (±0.11)	20	1(±0.2)	0.2(±0.07)

Table 4.5, continued

H.garnoti	*R. frenatus*	0	0	0	10	4.25(±0.1)	0.43(±0.32)	0	0	0
	Thelandros sp.	0	0	0	27.5	2.45(±0.28)	0.68(±0.21)	0	0	0
	Spauligodon sp.	0	0	0	2.5	1(±0.03)	0.03(±0.03)	0	0	0
	Pharyngodon sp.	100	3(±1)	3	27.5	6(±0.28)	1.65(±0.58)	0	0	0
	Skrjabinodon sp.	0	0	0	0	0	0	0	0	0
	O. javaensis	0	0	0	7.5	1(±0.08)	0.08(±0.04)	0	0	0
	P. geckonum	0	0	0	7.5	5.67(±0.08)	0.43(±0.38)	0	0	0
	P. ovatus	0	0	0	17.5	26(±0.17)	4.55(±3.31)	0	0	0
	G. bataviensis	0	0	0	35	9.36(±0.35)	3.28(±1)	0	0	0
G. monarchus	*R. frenatus*	0	0	0	26.67	2(±0.27)	0.53 (±0.35)	31.8	2.57(±0.31)	0.81(±0.23)
	Thelandros sp.	0	0	0	20	3.33(±0.2)	0.67(±0.32)	19.05	5.25(±0.19)	1(±0.48)
	Spauligodon sp.	0	0	0	20	2(±0.2)	0.4(±0.23)	0	0	0
	Pharyngodon sp.	0	0	0	13.33	2.5(±0.13)	0.33 (±0.3)	0	0	0
	Skrjabinodon sp.	0	0	0	20	17.33(±0.2)	3.47(±3.35)	13.6	6.33(±0.13)	0.86(±0.5)
	O. javaensis	0	0	0	5.9	2	0.12(±0.09)	0	0	0
	P. geckonum	0	0	0	6.667	3(±0.07)	0.2(±0.4)	4.76	3(±0.05)	0.1429(±)
	P. ovatus	0	0	0	0	0	0	4.54	16(±0.05)	0.72(±0.72)
	G. bataviensis	0	0	0	0	0	0	9.52	14.5(±0.1)	1.38(±1.14)
G. mutilata	*R. frenatus*	0	0	0	38.46	1.4(±0.38)	0.5385(±0.15)	50	2	0.12(±0.09)
	Thelandros sp.	0	0	0	35.9	3.07(±0.36)	1.1026(±0.3)	0	0	0
	Spauligodon sp.	0	0	0	2.564	2(±0.03)	0.0513(±0.06)	0	0	0
	Pharyngodon sp.	0	0	0	28.21	6.36(±0.28)	1.7949(±0.73)	0	0	0
	Skrjabinodon sp.	0	0	0	0	0	0	0	0	0
	O. javaensis	0	0	0	5.89	2(±0.06)	0.12(±0.09)	0	0	0
	P. geckonum	0	0	0	20.51	2.38(±0.2)	0.4872(±0.31)	25	5(±0.25)	1.25(±1.25)
	P. ovatus	0	0	0	20.51	8.63(±0.2)	1.7692(±0.9)	0	0	0
	G. bataviensis	0	0	0	5.128	5.5(±0.05)	0.2821(±0.23)	0	0	0

Young geckos, due to their small size (house geckos with SVL < 4 cm), had limited dietary component because of gape limitation, however this did not affect the route of infection as the young geckos harbored the same species of parasites found in the medium-sized geckos (SVL 4 - 6 cm) and the adults (SVL > 6 cm) (Tables 4.4 and 4.5). Species composition of each group size differed greatly, which highlighted a few interesting information. Geckos with SVL below 4 cm did not harbor any pentastomids which inhabit the lungs of the geckos, with the exception of *R. frenatus* in *H. platyurus* (Prevalence= 11.6%). Infection was only seen in geckos with SVL of 4 cm and above, and prevalence of the pentastomids appeared to increase with the size of the gecko it infected. This was observed in *R. frenatus* in *H. platyurus* and *H. frenatus*.

The intensity of infection in the medium-sized geckos and the full grown adults also increased with the size of the gecko hosts. Full grown geckos harbored a higher intensity of infection (Table 4.5). Abundance of the pentastomids across the population was relatively low compared to other groups of parasites but the pattern was still the same. The bigger the geckos are, the higher the abundance.

Young geckos harboured only one to three species of nematodes (*Thelandros* sp. in *H. platyurus; Pharyngodon* sp. in *H. garnotii; Thelandros* sp., *Spauligodon* sp. and *Pharyngodon* sp. in *H. frenatus*), compared to three to four species in medium-sized geckos and full grown adults. Infection of *Skrjabinodon* sp. was only observed in geckos over 4 cm in SVL. Prevalence of *Thelandros* sp. in the geckos increased steadily into adulthood as exhibited in *H. platyurus*, *G. mutilata* and *H. frenatus*. Intensity of infection remained almost constant, with a slight increase in the infection of *Thelandros* sp. in *H. platyurus*.

Thelandros sp. appeared to be able to infect more hosts while maintaining the intensity of infection within them. The nematode *Spauligodon* sp. on the other hand exhibited a rather erratic infection pattern, as observed in *H. platyurus.* Prevalence decreased in the medium-sized geckos but shot up once the geckos grew longer than 6 cm in SVL. In *H. frenatus, Spauligodon* sp. prevalence was increased with size. However, *Pharyngodon* sp., which was only found in the medium-sized geckos and full grown adults, shows decreased prevalence, intensity and abundance as the geckos matures into adulthood.

An interesting infection behavior was observed in the cestode species, *Oochoristica javaensis*. Prevalence, intensity and abundance were highest in the young geckos (*H. platyurus* and *H. frenatus*). However these parameters decreased as the gecko hosts grew. This declining pattern of parasite infection in small size host was shared by another parasite, the trematode *Postorchigenes ovatus* (in *H. platyurus* and *H. frenatus*). Infection was most prevalent and intense in young geckos (SVL > 4 cm; Table 4.5).

Another trematode species, *Paradistomum geckonum*, parasitizes a very unique niche; the gallbladder. Prevalence of this parasite in the gecko population (*H. platyurus* and *H. frenatus*) increased as the geckos increased in size, but the intensity decreased as the geckos grew bigger. Abundance peaked in medium-sized geckos, but decreased again once they reached adulthood.

In the case of ectoparasites, both prevalence and abundance of the mite *Geckobia bataviensis* in the gecko host population peaked in the medium-sized geckos, but decreased in adults.

Most of the parasite species had the highest intensities in the medium-sized geckos. However, two parasite species (*O. javaensis* and *P. ovatus*) showed a decline in intensity as the geckos got bigger. This may be due to the acquired immune response acting as an impediment for the parasites as the host matures. The mite *G. bataviensis* infection intensified with size, suggesting the mites were more successful in hosts with bigger snout-vent-length.

In most parasites, there are visible signs of size-selective infection success. While the mites, pentastomids and the nematodes infected in high intensity in the medium geckos, the trematodes infection were more intense in the young geckos. For the mites, pentastomids and nematodes, size of the geckos may play a role in controlling the size of the parasites' population. As for the trematodes, immunological factor might be the reason the intensity of infection decreased with size.

The only species of unisexual, parthenogenic gecko studied harboured less diversity compared to other house geckos, with only eight species of parasites. With the exception of *Pharyngodon* sp., all parasites were recorded parasitised geckos with SVL >4cm. Only one juvenile was collected for *H. garnoti* species. However the pattern of infection is similar to the one exhibited in *H. platyurus*, infection intensified as the gecko grows. Most of the geckos collected are medium-sized geckos. The trematode *P. ovatus* had the highest intensity of infection in medium sized geckos.

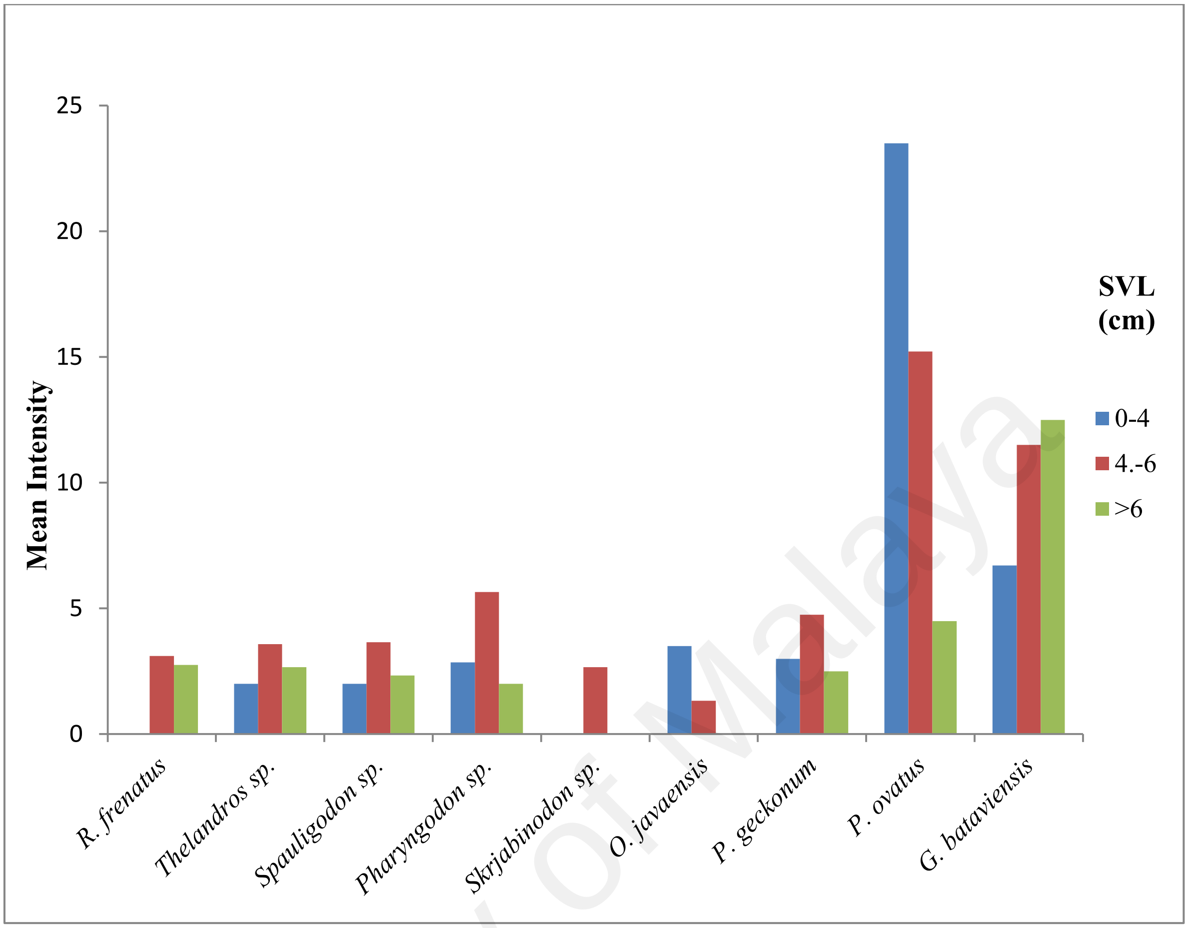

Figure 4.2 Mean Intensity of Parasites in *H. frenatus* According to SVL (cm).

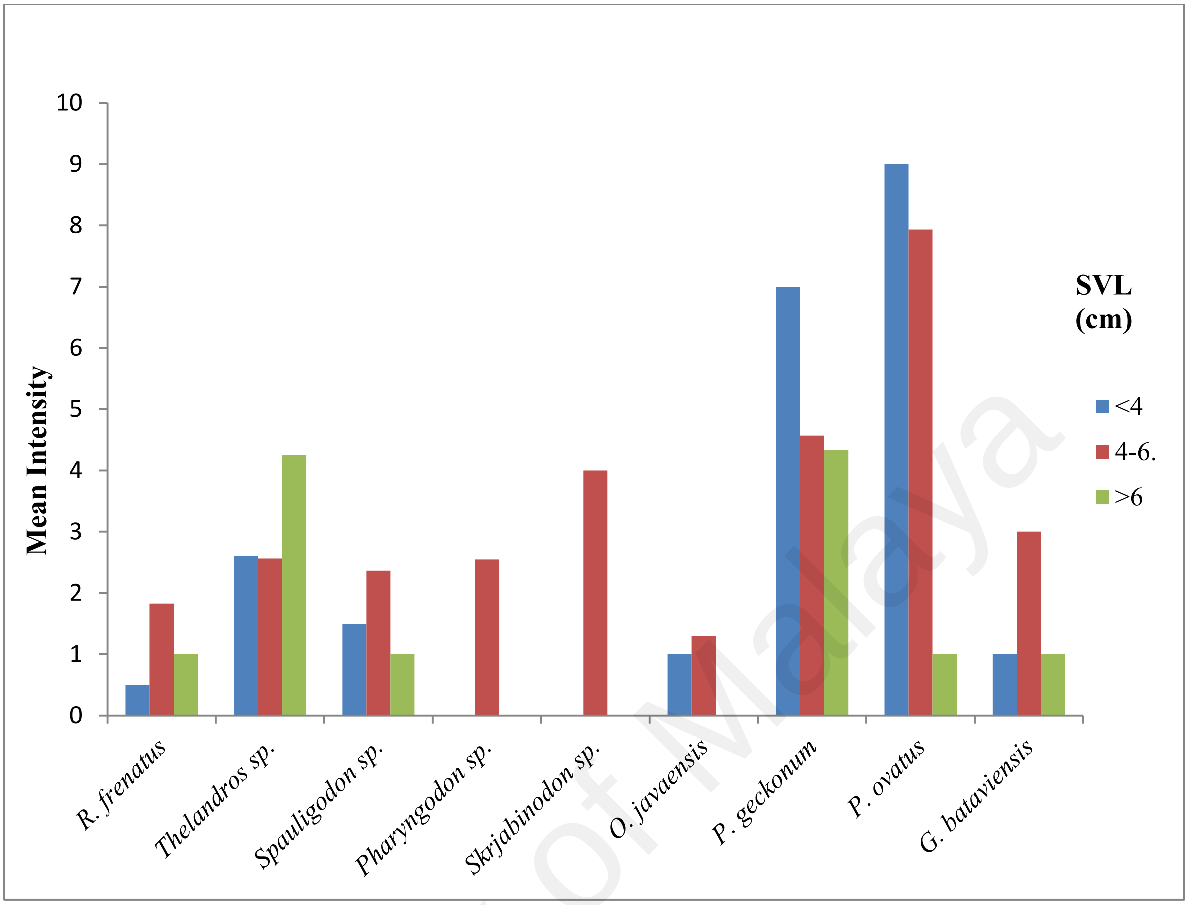

Figure 4.3 Mean intensity of parasites in *H. platyurus* according to SVL (cm).

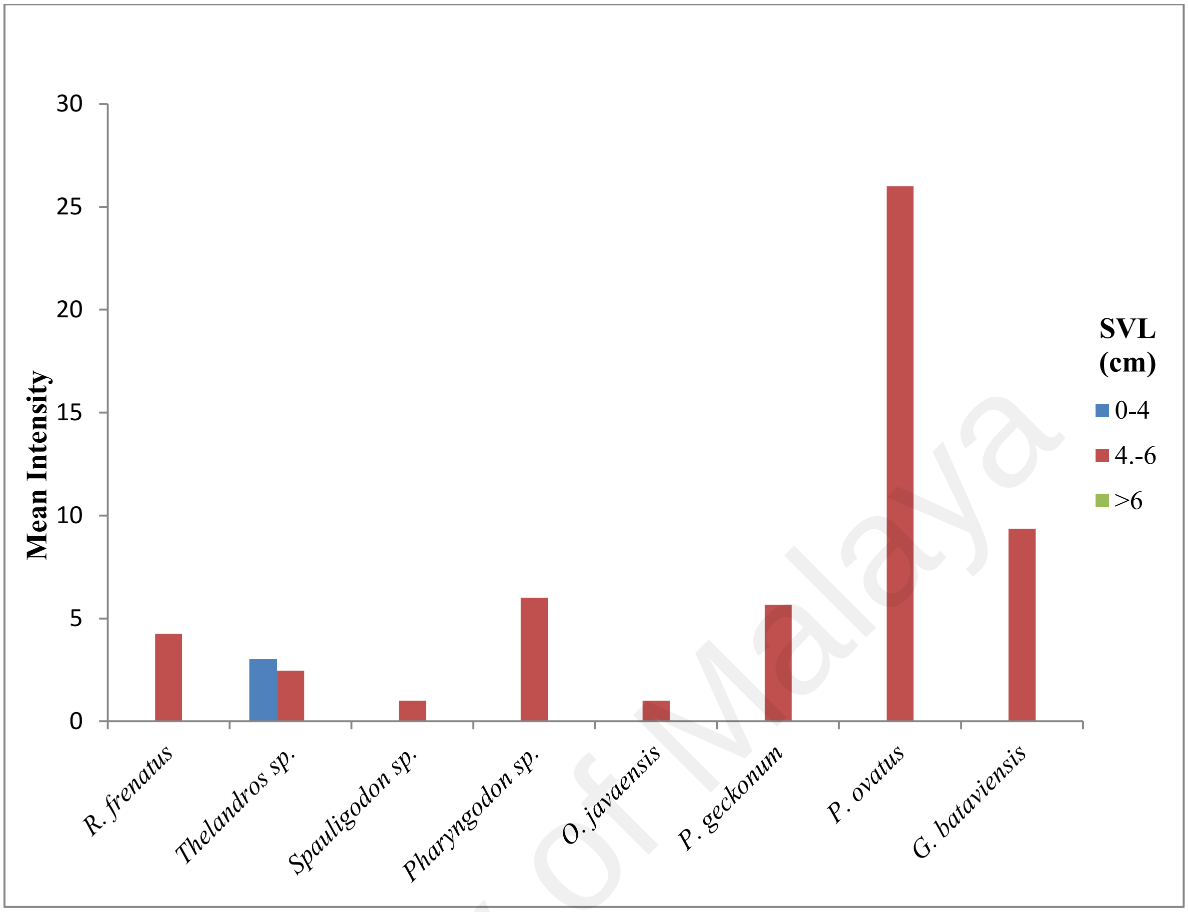

Figure 4.4 Mean Intensity of Parasites in *H. garnotii* According to SVL (cm).

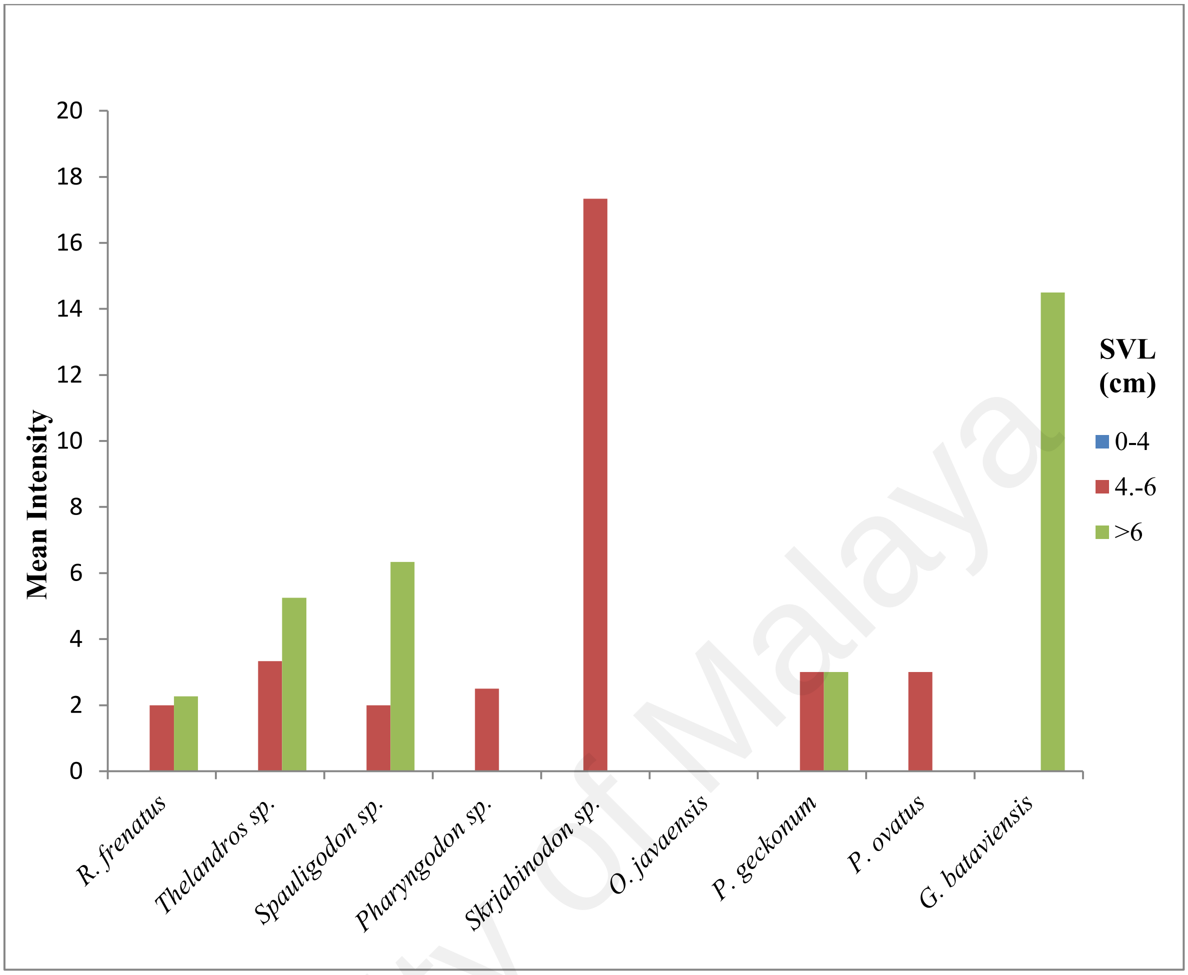

Figure 4.5 Mean Intensity of Parasites in *G. monarchus* According to SVL (cm).

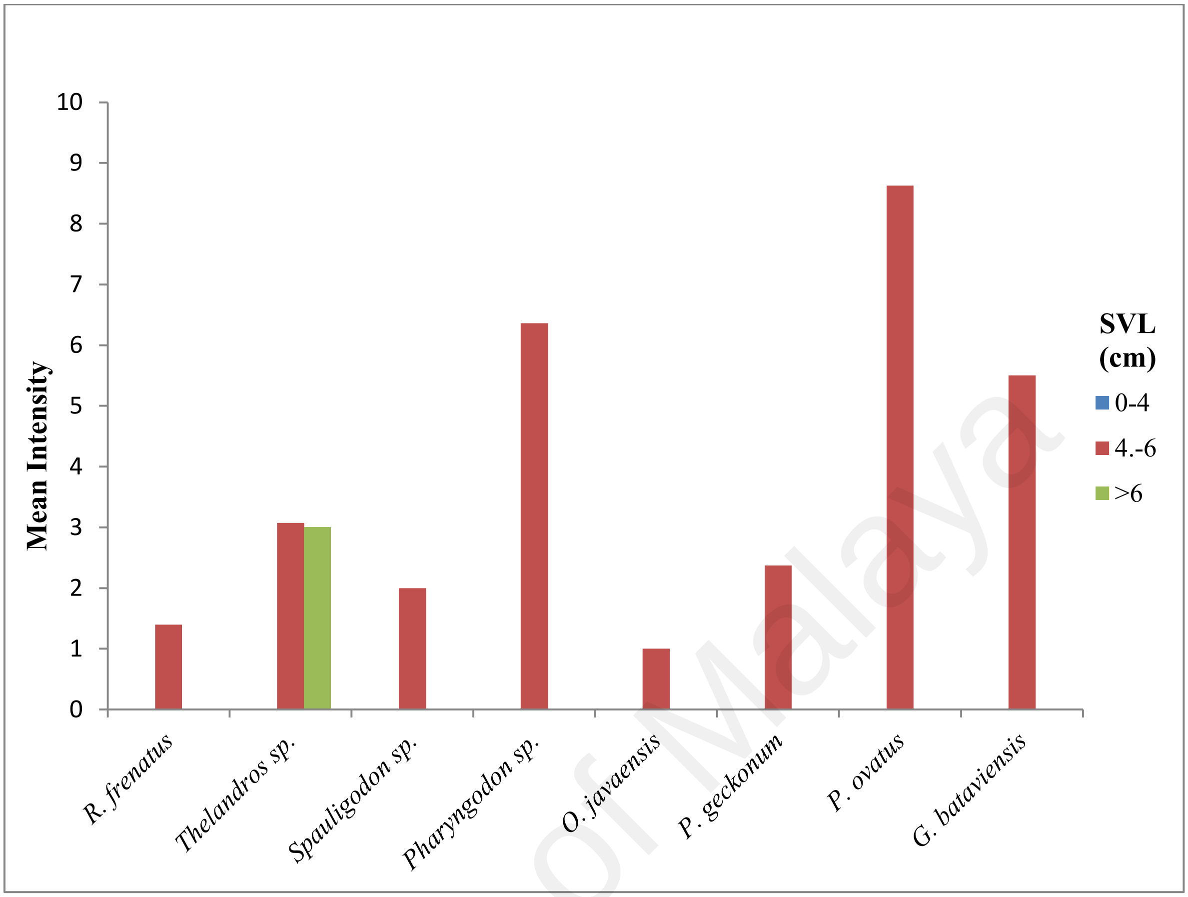

Figure 4.6 Mean Intensity of Parasites in *G. mutilata* According to SVL (cm).

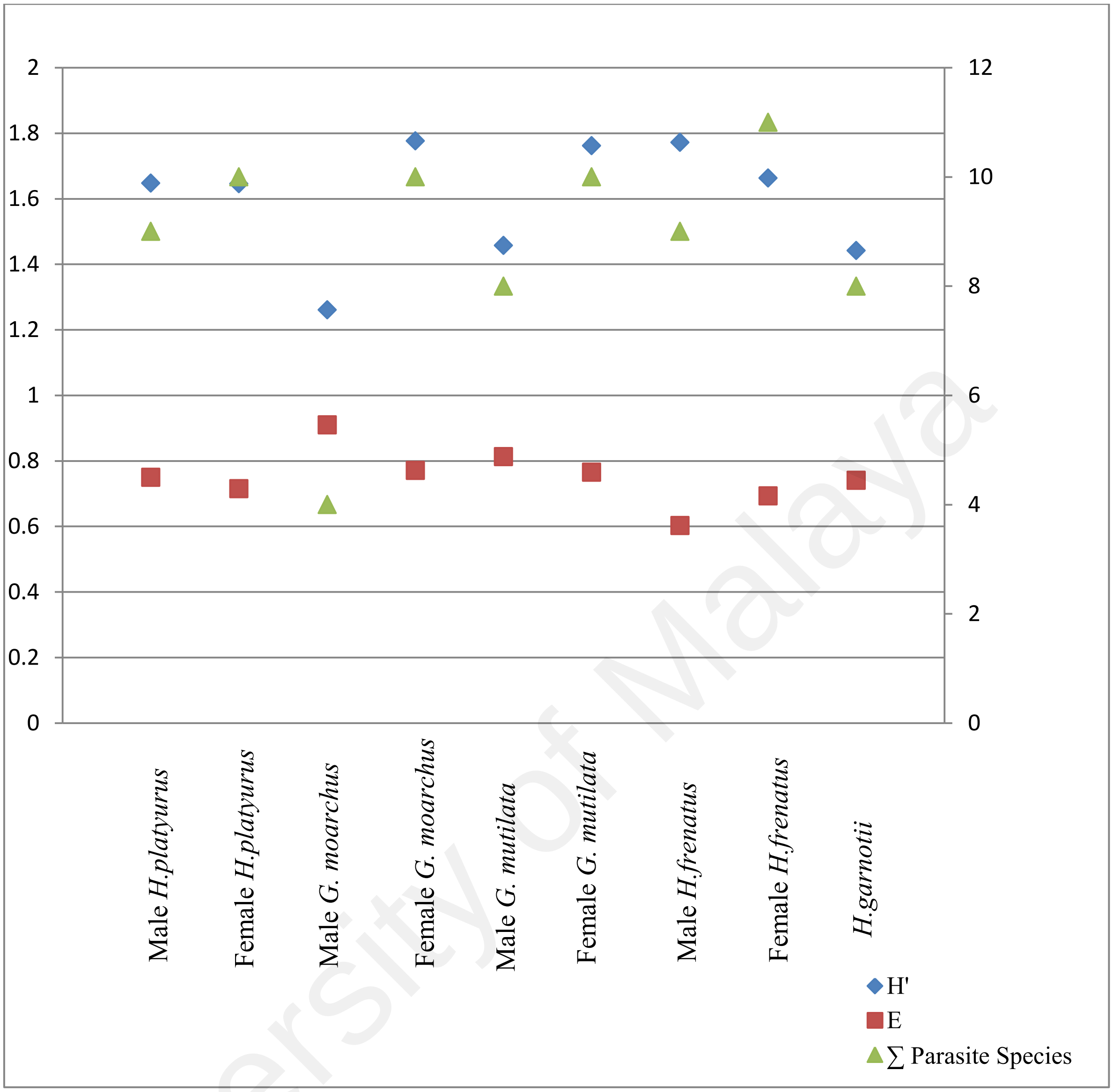

Figure 4.7 Relationship between diversity, evenness and total species in different gecko hosts. Female geckos harbour more parasite species; however both diversity and evenness indices of the parasites in the females are very similar to the males, indicating a higher intensity of infection in the males.

4.4 Discussion

4.4.1 Parasite infection success in different host genders

This study shows that gender-based infection does exist in nature, although it is more pronounced in mammals and birds than in reptiles (Addis, 1946). However there are instances showing clear evidence of gender-biased infection suceptibility in reptilian parasites as well (Lumbad *et al.*, 2011; Pollock *et al.*, 2012). There were significant differences in infection success in both genders within the same host species of geckos. There were also clear signs of competition for hosts in all of the geckos regardless of the genders. *H. platyurus, H. frenatus, G. mutilata* and *H. garnotii* showed similar infection traits among its parasites; male and female geckos usually had higher prevalence or mean intensity by similar parasites or parasites from the same group. Another trait was when the prevalence of a certain parasite in both genders were almost similar, the mean intensity will determine what sort of competition or strategy the parasite engage in order to reproduce successfully in its host, clearly is displayed in the infection of *G. bataviensis* in *H. frenatus*.

Both the pentastomid (*Raillietiella frenatus*) and the ectoparasitic mite (*Geckobia bataviensis*) showed more success in infecting female hosts in all gecko host species. Both parasites feed on blood, therefore their female host-centric infection success suggested some hormonal factors involvement. Female hormones had been proven to be influential in affecting parasites population (Addis, 1946; Morales-Montor *et al.*, 2004; Escobedo *et al.*, 2005; Duneau *et al.*, 2012). The gut nematode *Thelandros* sp. showed female host preference in three hosts (*H. frenatus, G. monarchus*, and *G. mutilata*) but not in *H. platyurus*. *Pharyngodon* sp. on the other hand preferred male hosts in three gecko species except *H. platyurus*. Most of the nematodes do not have strong preference to a specific gender in the different gecko species. However in the case of the cestode (*O. javaensis*), the observation may be due to very low abundance of the cestode in the gecko population.

Female geckos harbour more parasite species than the males, with an even distribution similar to the males. Although this does not confirm female host susceptibility, it does highlight the fact that intensity of infection is higher in male geckos, suggesting males invest more in other areas (such as secondary sexual characteristics in birds and mammals) besides immunity.

4.4.2 Parasite Preference for Host Size

Size does matter to the parasite when it comes to choosing a suitable host to reproduce. A host with a good, robust size in adulthood may offer better spatial benefits for the parasite to reproduce, but on the other hand, a bigger host might also means the host acquired better immunological response which will hinder the parasite's ability to reproduce.

The Tasty Chick Hypothesis (TCH) proposes that in a nest of bird hatchlings, parasites prefer to feed on the host with the poorest condition, usually the last-hatched chicks, simply because offspring reproductive value generally decreases with hatching rank (Christe *et al*. 1998). It is a form of an antiparasite strategy employed by avians as the poor body condition of the later-hatched chicks would impair parasite resistance and render them especially attractive to ectoparasites, protecting the older chicks, allowing them to grow into adulthood. However this is not true for all cases of avian parasitism. Valera *et al.*

(2004) showed that the parasite *Carnus hemapterus* prefers larger bee eaters (*Merops apiaster*) thus highlighting the fact that in some cases, ecological factors such as body size of the host trumps the state of the host's immunological response. The study examined whether gecko parasites survive better in hosts of different sizes, i.e. smaller hosts pose less immunological challenges, thus mimicking the Tasty Chick Hypothesis or apply the more ecological route and thrive better in bigger hosts to gain maximum spatial needs instead.

There are few pentastomids found in young geckos because of two reasons, 1. the young geckos have gape limitation, where the size of the prey is limited to the size of the gecko's gape, and 2. parasites such as pentastomids are limited by space, naturally a small gecko will have a small pair of lungs, thus limiting the pentastomids ability to reproduce. This renders the young geckos as an unsuitable host for the pentastomids. Pentastomid infection increases with size, until it reaches its peak during the reproductive phase of the geckos, then the abundance of infection dipped as the gecko grows older. As the gecko matures, the geckos' gape limitation decrease and can consume larger prey, also the pentastomids are no longer inhibited by the size of their niche, causing them to proliferate. With the geckos' immune system not fully developed during the reproductive phase, the pentastomids thrive at its best. However as the geckos grow older, energy invested in reproduction is now being diverted to improving and maintaining the immune system instead. This results in a drop of infection of parasites.

Apart from size, pentastomids also require coprophagial insects such as cockroaches as an intermediate host (Lavoipierre & Lavoipierre, 1965). Cockroaches are not an easy prey for a small gecko to obtain due to gape limitation, as a result restricting chances of infection. As geckos mature, their dietary component expands, and they also consume more varied diet. This increases the chance of infection, and with space no longer a hindrance in adult geckos, the parasites proliferated.

Nematodes are also limited by space; larger geckos are able to host a higher richness and abundance of nematodes. However the oxyurid nematodes in the geckos possibly have a direct life cycle similar to the rest of the members of the Oxyuridae family (Anderson, 2000) therefore autoinfection is the route of infection (Grear & Hudson, 2011). Living in a highly dense gecko population can also cause transfer of nematodes (transmission via fomites or ingestion of fecal matter). As the gecko matures and gains size and weight, the parasite's niche becomes bigger, allowing for proliferation of the nematodes in the gut. The cycle of autoinfection also increases the abundance of the nematodes (Anderson, 2000).

Young geckos are more susceptible to cestode infection. Very rarely cestodes are found in geckos with SVL larger than 4 cm. There are two possible explanations for this observation. Either young geckos are more susceptible because of their weak immune system, or cestode infection increases the mortality rate of the geckos. Considering how cestode infection can negatively impact the niche they occupy (Budke *et al.*, 2009; Dezfuli *et al.*, 2011), the geckos can easily succumb to the effects of infection (i.e. malnutrition) and die.

Trematode infection in young geckos was only observed in two gecko species, *Hemidactylus frenatus* and *H. platyurus*. Most trematodes have complicated life cycle, usually requiring two invertebrates as intermediate hosts (Cribb *et al.*, 2003). The young geckos have limited prey due to their small size, and consume less than an adult gecko, further decreasing opportunities for the trematode infection. This is an interesting observation when taken into account the gecko's physiology, the trematodes should be limited by space, yet it thrived better in the young geckos. However as the geckos mature, the prevalence, intensity and abundance decreases possibly due to the host's acquired immune response. Intensity of trematode infection increases with age, which implies immunology plays an important role in the infection. In older, bigger geckos, infection is more intense and this may be due to two possible explanations; bigger geckos offer bigger niche for the trematodes to occupy, or bigger geckos consume more diverse and abundant prey items, increasing their chances of infection. As with other groups of parasites, trematode infection decreased as the geckos grow older. The trematodes prefer to infect bigger hosts in order to maintain its prevalence in the host community, but as the gecko matures, the prolonged infection triggers an immunological response, causing a dip in intensity as the gecko matures.

Mite infection is more complex than endoparasite infection. Transmission is direct (gecko-to-gecko), and the mites have a small window to infect the hosts as it can only infect during its larval stage. (Bauer *et al.*, 1990). The young geckos are not yet sexually mature therefore contact with other geckos is limited to chance encounters. In order to obtain mite infection, it is possible the young geckos live in a dense population (i.e. island population where the gecko habitat is confined) where interaction with other geckos occur more frequently therefore facilitating mite transfer. As the geckos enter reproductive phase, more contacts with other geckos are made. This increases the chances of mite transfer between the geckos which explains the observation of increasing mite prevalence and intensity as the geckos mature. After a certain size/age, infection decreased drastically. Various reasons, both ecological and immunological, are possible contributors to this observation. As the gecko enters sexual maturity, the male geckos will engage in more aggressive behavior in order to gain mating rights (Sakata *et al.*, 2002), providing an outlet for parasite transfer or parasite loss. As the geckos grow into adulthood, the mite prevalence and abundance decreased, although intensity of infection remained constant.

Ecological factors play a more pivotal role in host selection for the parasites. Gecko parasites gravitated towards size-selective parasitism. At the end of the day, size matters for a parasite as a criterion in choosing its host, simply because bigger hosts have a higher carrying capacity. Immunological factors appear to be secondary and only appears to play a more important role when the geckos are older, suggesting that the parasites might have its own strategies in dealing with the hosts' immune response to the infection.

In order for a parasitic disease to start manifesting symptoms and pose a real threat to the host population, three main criteria must be met; conditions of the host, the parasite, and the environment (Kennedy, 1976). If one of these conditions spiral out of the norm, symptoms of diseases can manifest in the host. Information obtained regarding the life stages of a gecko when a parasite reaches its highest intensity and abundance, will enable us to glean what are the conditions required by the parasites in order to proliferate successfully. Certain parasites, for example the cestode (*Oochoristica javaensis*) favours younger geckos, and may have affected the geckos' mortality as larger, older geckos rarely harbour cestodes. No previous works have been done to study the tissue pathology of the geckos' intestinal tract infected by the cestodes, however studies involving other cestode species and their effects on the tissue hosts showed damages on the sites of attachment, flattened villi, and reduced or diminished absorption rate in the intestines (Parija, 1990).

Not only geckos have the possibility to introduce parasitic infection to humans and livestock, they may also act as barriers from more virulent and dangerous pathogens. A study by Giery and Ostfeld (2007) illustrated how ticks feeding on skinks experienced a reduction of their *Borrelia burgdorferi* infection, thus decreasing to the point of stopping the infection from reaching humans. *B. burgdorferi* causes Lyme disease, a painful affliction from ticks infected by the bacterium. The skink in question, *Eumeces fasciatus* may play an important role by acting as a dilution host, thus reducing vector infection prevalence and associated human risk of infection.

4.5 Conclusion

Female geckos are more susceptible to infection compared to males; chances are immunological factors play a bigger role compared to ecological. Both male and female geckos are physiologically similar, with the only difference being their sizes once they reached adulthood. Unlike in birds, where males invested more energy on colourful, brazen secondary characters to attract mates (van Oordt, 1931) , male geckos may invest their energy to increase their size since bigger geckos have more energy and have better possibility in securing mating rights, whereas gravid females spend more energy in producing egg (Hibbitts & Whiting, 2005). Investing more energy on developing secondary sexual characteristics and egg production may cost the hosts their immunity. Future studies on the immunological properties of the geckos would be highly beneficial, especially on how the hormones directly affect the infectionof parasites. It is probable the parasites harness the hormonal properties to control their infectionbehavior on the hosts.

More work needs to be done in order to complement the current study; especially regarding the immunological properties of the geckos and how it reacts to changes in the environment. Living in close quarters with humans, these geckos may act as an indicator to the environmental changes that might affect humans. Unlike frogs, the geckos are more adaptable to their environmental changes, hence their widespread distribution. However their parasitofauna composition will allow us to assess the health of the geckos' population, and also the health of its habitat as a whole.

CHAPTER 5: COMMUNITY STRUCTURE OF PARASITES OF MALAYSIAN HOUSE GECKOS FROM PENINSULAR MALAYSIA

5.1 Introduction

5.1.1 Parasite distribution – shaping the parasite community structure

Parasites face tremendous amount of challenges in order to fulfill their unique life cycles. Apart from obstacles faced while finding hosts, they also need to tackle issues regarding barriers posed by the environment: biotic and abiotic factors of not only their microhabitat in or on their hosts, but also the macrohabitat; the habitats of their hosts, as well. Factors such as temperature, rainfall, pH, altitude, distance from water body, etc are crucial in the distribution of the gecko hosts (Stabler *et al.*, 2012; Tlili *et al.*, 2014). Geckos are ectothermic, therefore they rely on their environment not only to regulate their body heat but also to perform locomotion, feeding, reproduction, etc., since these actions require the geckos to have a relatively elevated temperature (Girons, 1980). Naturally the highest concentration of gecko species is in the tropics, the closer a place is to the equator, the higher gecko populations are found.

Parasite composition is a useful tool in order to elucidate geographical information of their host. In case of host specific parasites, this information enables us to determine host origin. It is possible for parasites to be confined to certain geographical area; however various factors have caused parasites to become widely distributed. Humans have enabled parasites, via their hosts, to be dispersed in new places. Rats carrying bacteria causing bubonic plague were believed to travel to Europe from Asia in ships (Dobson, 2007).

Gecko distribution worldwide, with the exception of the house gecko species, does show a preference towards certain of habitat. Forest type geckos are very endemic to their preferred type of habitats, although there were some species that have no problem moving from forest to forest fringes or to human-habitated areas, such as the Banded Gecko (*Gekko monarchus* Gray, 1845). However geckos with widespread distribution such as *Hemidactylus frenatus*, invades various habitats, sometimes threatening the local species through competition for food and niche. There have been cases of invader species driving out the local gecko fauna through food competition and introduction of parasites that are detrimental to the local fauna (Barton, 2007; Barton, 2015; Kelehear *et al.*, 2012; Kelehear *et al.*, 2013; Kelehear *et al.*, 2015).

5.1.1.1 Parasite community structure

To understand the structure of a community, information on the available species and their abundance is crucial. Complementary information such as body size, biomass and density of the species provides a better overview of the community structure. Parasite community presents a unique challenge; their dependency on their hosts calls for different kinds of variables, unlike in the free-living species. One of the variables, the host's body size, is agreed by various studies as among the important criterion (Roca *et al.*, 2009; Lo *et al.*, 1998), followed by habitat and dietary component (Roca *et al.*, 2005; Muñoz *et al.*, 2002), and social behaviour (Sorci *et al.*, 1997). Aspects of parasites such as their microhabitats, body sizes, and associations between species have also been considered (e.g., Holmes, 1973; Lotz & Font, 1985; Adamson & Noble, 1993; Rohde, 1994; Sorci *et al.*, 1997; Sasal *et al.*, 1999; George-Nascimento *et al.*, 2004). In addition, the habitat size (host weight or microhabitat area) may also affect the understanding of parasite communities in abundances and densities because, in general, a large habitat may have more resources than small habitats and may support more individuals and species. The objective of this study is to identify and analyze the community structure of parasites of the Malaysian house geckos, and to assess the importance of parasite abundance, species richness, density and host body weight.

5.1.1.2 Abundance, species richness and parasite density

Reptilian parasitofauna is less diverse in terms of species richness compared to parasitofauna of groups such as the fishes and the birds (Dobson *et al*, 2008). Reptilians are carnivorous, with the exception of certain lizard species which are herbivorous or omnivorous (Carretero *et al.*, 2006). Reptiles such as smaller groups of lizards, i.e. geckos, skinks, agamids have a dietary component consisting of mostly insects whereas the larger group of lizards, the varanid lizards consume eggs, smaller reptiles, fish, birds, small mammals while some species eat fruits and vegetation, depending on their habitat. This shows that they have a diverse intermediate hosts, thus different channels of parasite infection.

Parasite composition is useful in elucidating geographical information of the host. In the case of host specific parasites, this information may enable us to determine host origin. It is possible for parasites to be confined to certain geographical area; however various factors have caused parasites to become more widely distributed. Human activity has enabled parasites, via their hosts, to be dispersed in new places. House geckos such as *H. frenatus* have a global distribution, carrying all its parasites throughout the world. This particular house gecko had introduced various parasite species to not only local gecko fauna, but also to frogs and toads (Barton & Riley, 2004; Kelehear *et al.*, 2012), snakes (Kelehear *et al.*, 2014) and vultures (Riley *et al.*, 2003). In Australia, geckos are a common sight and are considered as an invader species as it drives out local lizard fauna by competition or by introduction of its parasitofauna which may prove detrimental to the local lizards (Kelehear, *et al.*, 2013). This had resulted in similarity of parasites species diversity infecting various gecko species. Among species of parasites recently reported from *H. frenatus* are *Paradistomum* sp. (Platyhelminthes: Digenea: Dicrocoeliidae), *Oochoristica* sp. (Platyhelminthes: Cestoda: Linstowiidae), *Spauligodon hemidactylus* (Nematoda: Pharyngodonidae), *Maxvachonia* sp. (Nematoda: Cosmocercidae) (Goldberg *et al.*, 1998; Goldberg *et al.*, 2005; Barton, 2007; 2015). House geckos in South America also showed similar pattern of species richness and diversity as observed in Asia and Australia (Anjos *et al.*, 2005; Anjos *et al.*, 2008; Sousa *et al.*, 2014). Various studies in Indonesia have shown similarities with the current study, especially nematodes of the groups Pharyngodonidae and Cosmocercidae (Matsuo & Oku, 2002), trematodes from Dicrocoeliidae, pentastomid species (*Raillietilla frenatus*) (Sri Prawasti *et al.*, 2013), mites of the genus *Geckobia* (Sri Prawasti, 2011; Sri Prawasti *et al.*, 2013) and cestodes from the group Linstowiidae (Kennedy *et al.*, 1982; Kennedy *et al.*, 1987a,b; Killick *et al.*, 1982).

House geckos are highly dependent on humans; very few species are found in areas devoid of human impact although there are some species (such as *Gekko monarchus*) is capable of moving back and forth between urban and forested habitats. Geckos thrive best in man-made structures; the eggs are properly sheltered from the elements and predators, hidden in crevices and cracks on the building. Food is abundant, as human activity is a factor in insect population boom; urban environment attracts pests such as cockroaches, one of the main components of the diet of the house geckos.

5.2 Methodology

5.2.1 Host collection from different sites

Geckos were caught by hand and kept in plastic aquariums to minimize injuries and loss of ectoparasites. Each host individual was sexed and measurements of the SVL (snout-vent-length) were taken as a representation of the host body size. They were collected from eight study sites located throughout Peninsular Malaysia. These are BERNAS Complex, Kedah (rice mill); Kampung Maharaja, Kedah (small village); Carey island, Selangor (palm oil plantation),Genting Highlands, Pahang (residential areas); Institute of Biological Sciences, University Malaya, Kuala Lumpur (city centre), Jitra, Kedah (residential areas), Langkawi island, Kedah (villages) and Pangkor island, Perak (small town) (Table 3.3, Figure 3.1). Each sites represented a unique and diverse habitat for the gecko and this study intends to dissect each habitat and see is there any patterns of similarity emerges.

The study sites comprised of urban environment such as office buildings, suburban and rural areas such as housing estates, farming communities, fishing villages, rice mill, forest/forest fringes such as oil palm plantation and secondary forests. There are some forms of human activity in the sites chosen. The sites were divided into two major groups; the northern region (Langkawi, BERNAS Complex, Kampung Maharaja, Jitra, and Pangkor) and the central region (Genting highlands, Carey island, and University Malaya). The northern region consist of sites with similar characteristics; densely to sparsely populated small towns, small fishing villages, farming communities and secondary forests, whereas the central region consist of highly dense, urban to suburban communities (Table 3.3, Figure 3.1). Comparison between these two regions was made to see whether there are any differences in term of gecko diversity and parasitisation patterns.

5.2.2 Statistical Analyses

The parasitological descriptors of richness, abundance, and prevalence were calculated according to Bush *et al.* (1997). The Proportional Similarity Index (Czekanowski Index) is calculated (Bloom, 1981). Another parameter was included: the numerical density of the parasites (numerical abundance/ individual host size). Most parameters were transformed to log10 (x+1) to reduce the data biases (Zar, 1984). Pearson correlations were applied to relate the parasitological parameters with host body size. It is also applied for logarithmic transformed data to relate parasitological parameters with parasites and host body sizes. A significance level of 0.05 was used for all statistical analyses.

5.3 Results

5.3.1 Parasite species composition in different sites

A total of five species of house gecko were studied. These are *Hemidactylus frenatus, H. platyurus, H. garnotii, Gehyra mutilata* and *Gekko monarchus*. These geckos share the same habitat, i.e. human-impacted environment such as housing and office buildings. Although *G. monarchus* is known to travel back and forth between fringe habitat and human settlements, other house gecko species especially the *H. frenatus*, heavily occupy residential areas.

Langkawi island is situated north of Malaysia, and almost two-thirds of the island is covered in mountainous forest, limestone hills, and natural vegetation. It has among the highest total parasite species with eight species (*Raillietiella frenatus, Thelandros* sp., *Spauligodon* sp., *Pharyngodon* sp., *Oochoristica javaensis, Paradistomum geckonum, Postorchigenes ovatus* and *Geckobia bataviensis*) (Figure 5.1). Ectoparasites have the highest abundance of the total species composition, 22% consisting of a single species, *G. bataviensis*. Parasite abundance appears to be evenly distributed among the species, a stark contrast to another island environment, Carey island. *Pharyngodon* sp. (19%), *Spauligodon* sp. (18%), and *P. geckonum* (16%) are the other three species of parasites with higher abundance. The lowest abundance of parasites was recorded by *Oochoristica javaensis* (0.2%), a cestode species. Another gut parasite, *Paradistomum ovatus*, a species of trematode also had a low abundance compared to the nematodes (4.6%). The Langkawi endoparasitic fauna is dominated by the nematode group, which may offer some clues to the diversity of insects from this site. High abundance of ectoparasites on the other hand may suggest that the gecko population on the island exists in tight groups, where physical transfers of the mites are facilitated by the close proximity.

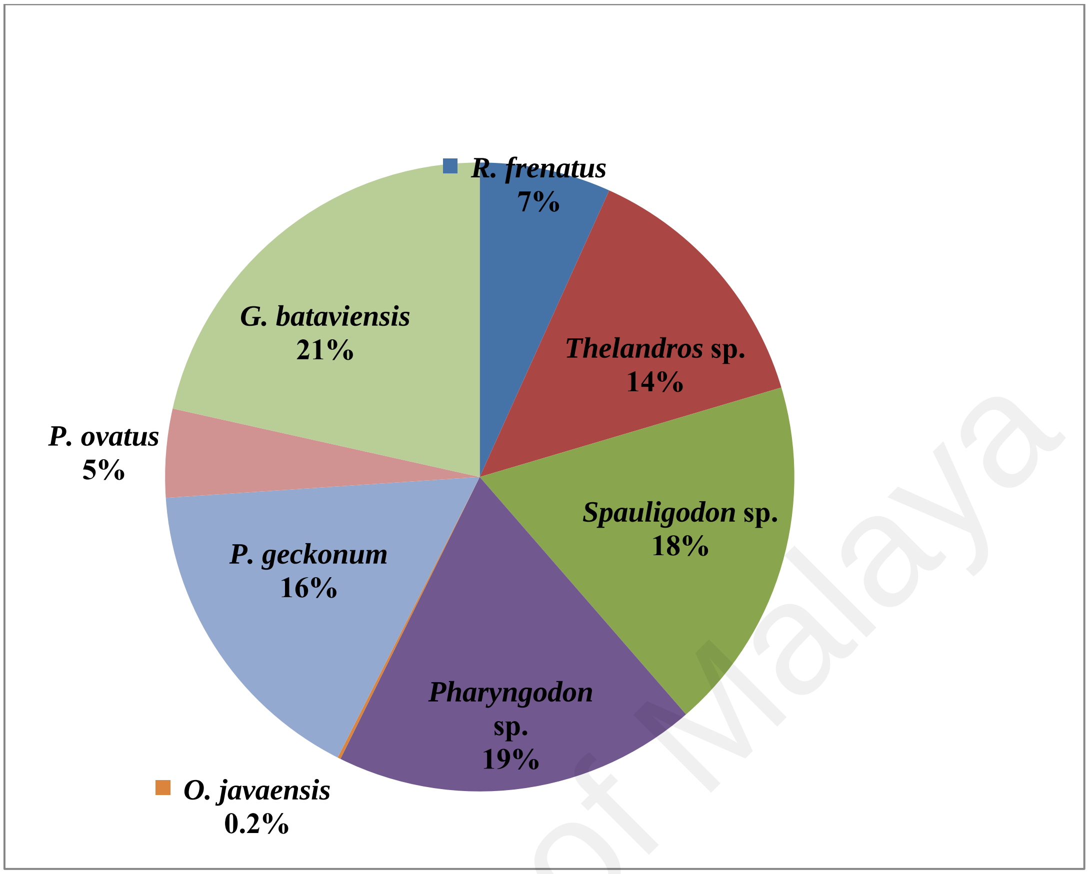

Figure 5.1 Parasite Composition of the Gecko Community in Langkawi island.

From the gecko population in BERNAS rice mill, the parasite composition consists of nine species. These are *Raillietiella frenatus, Paradistomum geckonum, Postorchigenes ovatus, Oochoristica javaensis, Thelandros* sp., *Spauligodon* sp., *Pharyngodon* sp., *Skrjabinodon* sp., and *Geckobia bataviensis*. The highest number of parasite species was recorded in this area compared to other study sites. Parasite species composition of this site is dominated by the trematode groups, with the intestinal trematode *Postorchigenes ovatus* forming more than half of the community (58% of total parasitofauna). Another species of trematode, *Paradistomum geckonum* also formed a considerable portion of the total parasitofauna (10%).

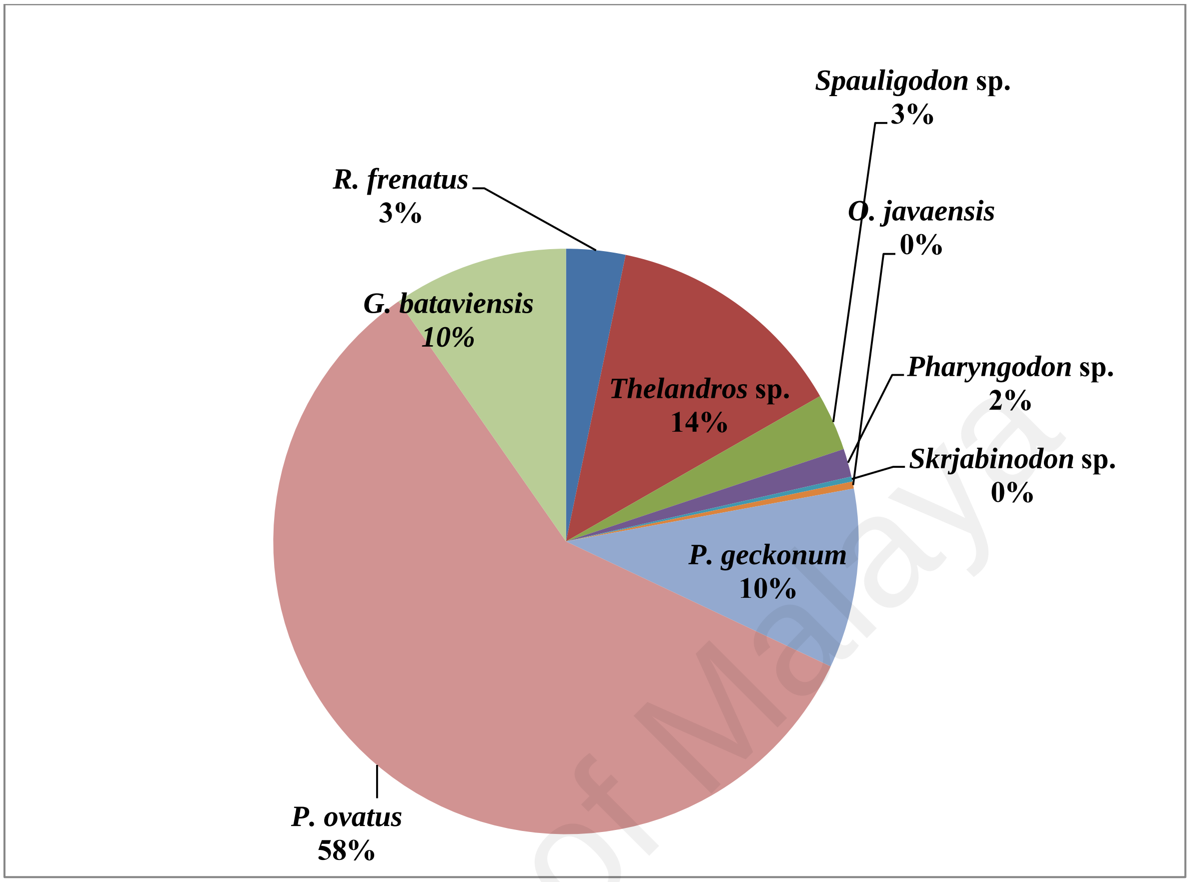

Figure 5.2 Parasite Composition of the Gecko Community in BERNAS Complex, Kedah.

The parasite composition of Kg. Maharaja consisted of eight parasite species. These are *Raillietiella frenatus, Thelandros* sp., *Spauligodon* sp., *Pharyngodon* sp., *Oochoristica javaensis*, *Paradistomum geckonum, Postorchigenes ovatus,* and *Geckobia bataviensis*. Although this site is near to the BERNAS Rice mill (Figure 5.2), the total species of parasites available is less than the first site. Parasite species composition of this site is dominated by the trematode groups, with the intestinal trematode *Postorchigenes ovatus* forming more than half of the community with 63% of total parasitofauna. The cestode *O.javaensis* is also the parasite with the lowest abundance in the sites' gecko population, with only 0.2%. The nematode species existed in considerably low abundance compared to *P. ovatus*, with *Thelandros* sp. making up the highest percentage (14%), followed by *Spauligodon* (3.7%) and *Pharyngodon* (1.4%).

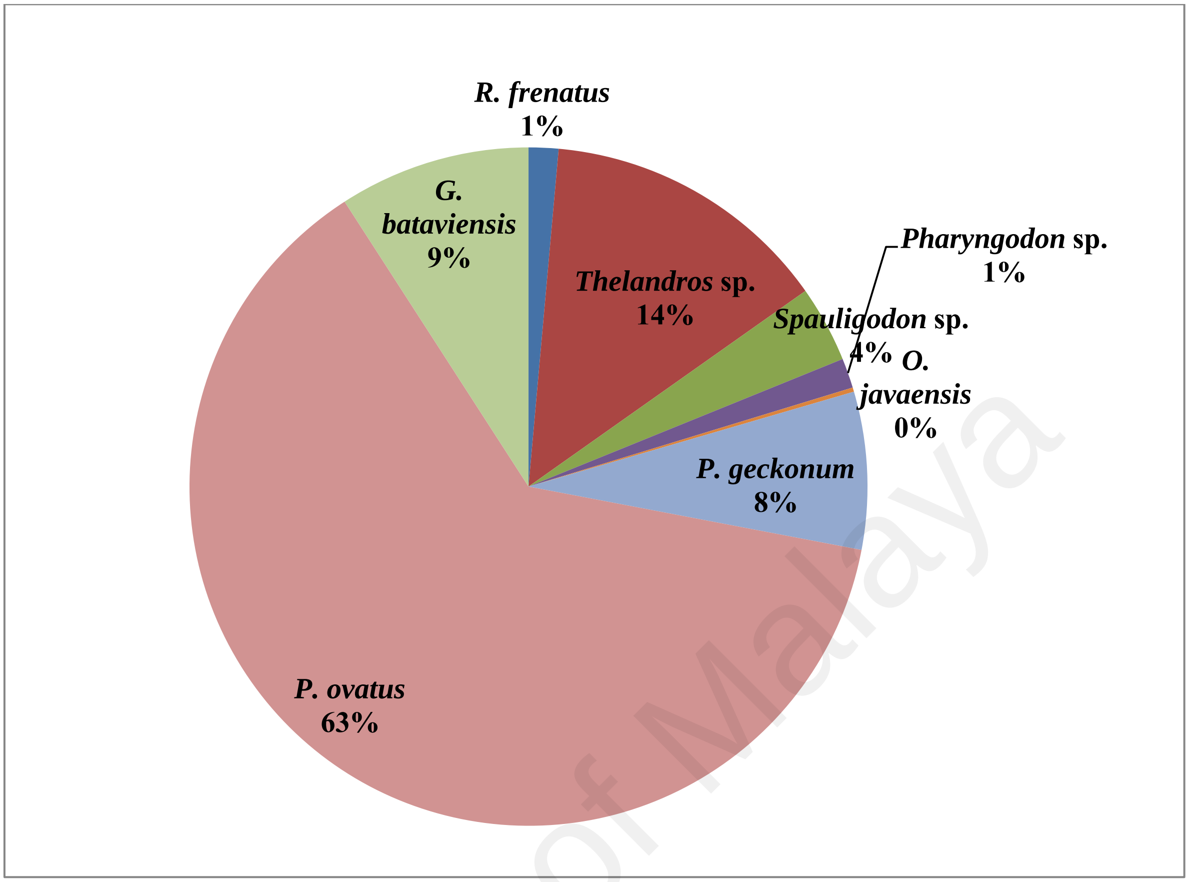

Figure 5.3 Parasite Composition of the Gecko Community in Kampung Maharaja, Kedah.

In the suburban Jitra gecko community, the parasite species composition comprises of six species; with one pentastomid species (*Raillitiella frenatus*), three species of nematodes (i.e. *Thelandros* sp., *Spauligodon* sp., and *Skrjabinodon* sp.) and two species of trematodes (i.e. *Paradistomum geckonum* and *Postorchigenes ovatus*). The parasite species that dominates the total species composition of geckos from Jitra is the nematode species *Thelandros* sp. (45%). This is followed by *Skrjabinodon* sp. with 23%. The gallbladder trematode *P. geckonum* made up the smallest percentage of total parasitofauna, with 2.3%.

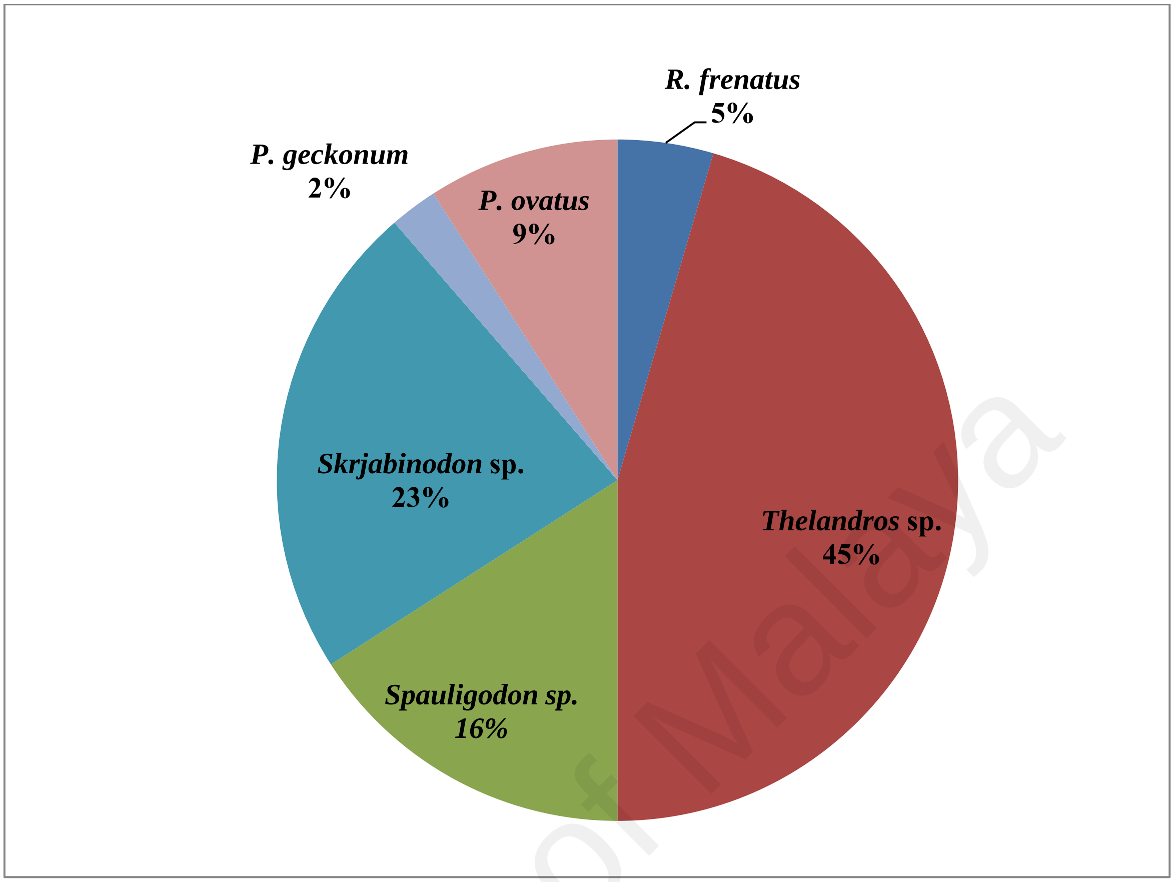

Figure 5.4 Parasite Composition of the Gecko Community in Jitra, Kedah.

Pangkor island hosts less gecko parasite species with only seven species. These are *Raillietiella frenatus, Thelandros* sp., *Spauligodon* sp., *Oochoristica javaensis, Paradistomum geckonum, Postorchigenes ovatus* and *Geckobia bataviensis*. *G. bataviensis* has the highest abundance of parasites with 57%. *Thelandros* sp. is the most abundant endoparasite with 23%. Pangkor island is more similar to Carey island (Figure 5.7) than Langkawi (Figure 5.1), with ectoparasites dominating the total parasitofauna. The parasite with the lowest abundance is the gut trematode *P. ovatus*, with only 0.3%.

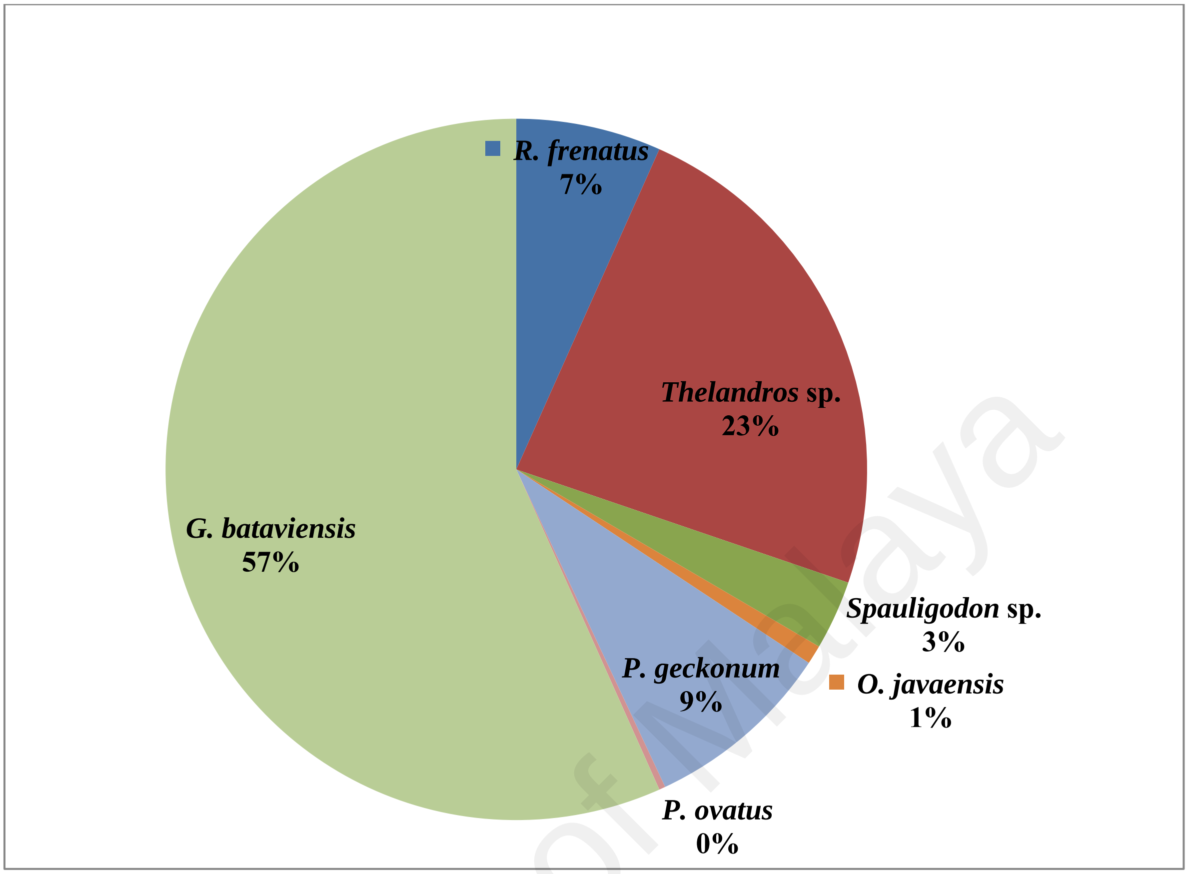

Figure 5.5 Parasite Composition of the Gecko Community in Pangkor island.

Only three species of parasites were collected from the gecko population in Genting Highlands; one species of lung pentastomid (*Raillietiella frenatus*), and two species of gut nematodes (i.e. *Pharyngodon* sp. and *Skrjabinodon* sp.). *Skrjabinodon* sp. dominated the species composition with 83.5%, while the other nematode species, *Pharyngodon* sp. only made up 1% of the total parasitofauna. This suggest the existence of intense competition between these two nematode species. *R. frenatus* made up 15.3% of the total parasitofauna. Vast differences in abundance of the parasites might be contributed by the availability of intermediate hosts of the parasites. No ectoparasites were found on these geckos.

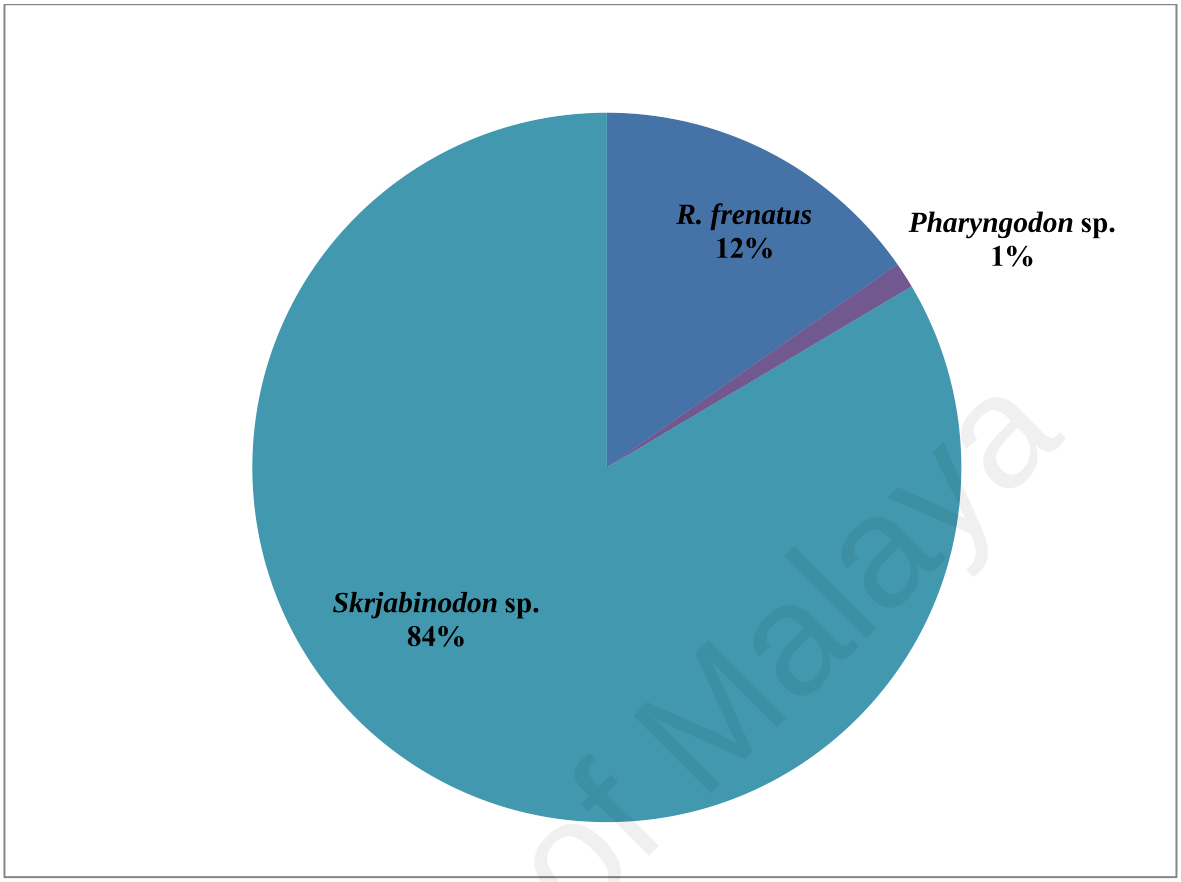

Figure 5.6 Parasite Composition of the Gecko Community in Genting Highlands, Pahang.

The Carey island parasite composition is comprised of all nine species of parasites (i.e. *Raillietiella frenatus, Paradistomum geckonum, Postorchigenes ovatus, Oochoristica javaensis, Thelandros* sp., *Spauligodon* sp., *Pharyngodon* sp., *Skrjabinodon* sp., and *Geckobia bataviensis*). The gecko mite species *Geckobia bataviensis* is the dominant parasite species of geckos in this site, forming 55% of the parasite composition. While most sites studied showed endoparasites dominating the species composition, it is interesting that the Carey island geckos are infested by ectoparasites more than geckos from other sites, rivalled only by the geckos from Pangkor island, Perak (Figure 5.5). The majority of parasites infecting these geckos are from the nematode group. This implies an abundance of potential intermediate hosts for the nematodes, especially from the group coleopterans. Trematodes were found in very low abundance in these geckos.

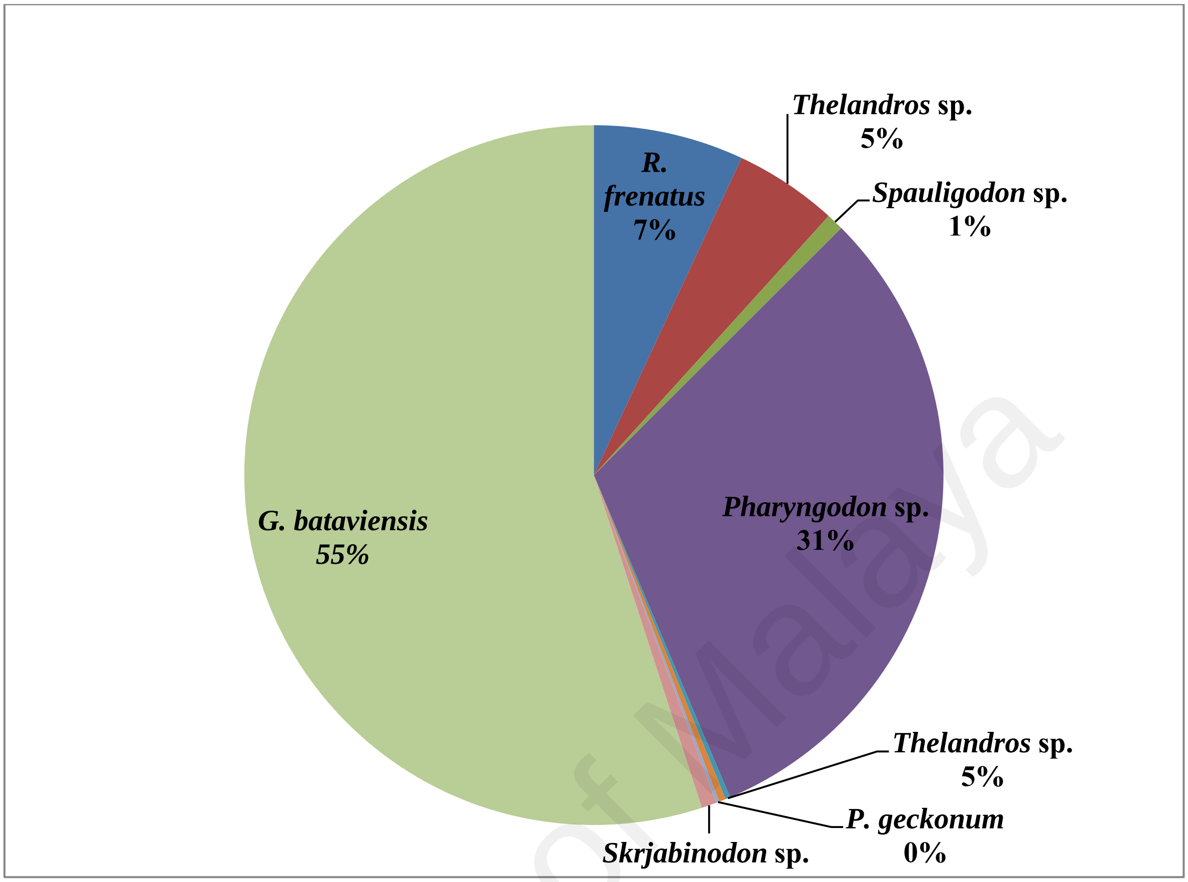

Figure 5.7 Parasite Composition of the Gecko Community in Carey Island, Selangor.

University Malaya harboured eight species of gecko parasites from all five groups; one pentastomid species (*Raillietilla frenatus*), three species of nematodes (*Thelandros* sp., *Spauligodon* sp. and *Pharyngodon* sp.), two species of trematodes (*Paradistomum geckonum* and *Postorchigenes ovatus*), one species of cestode (*Oochoristica javaensis*), and one species of mite (*Geckobia bataviensis*). The parasite species dominating the total parasitofauna composition is the nematode *Thelandros* sp. with 27%. The lowest abundance of parasite was recorded by another nematode species inhabiting the gut, *Spauligodon* with only 1.1%.

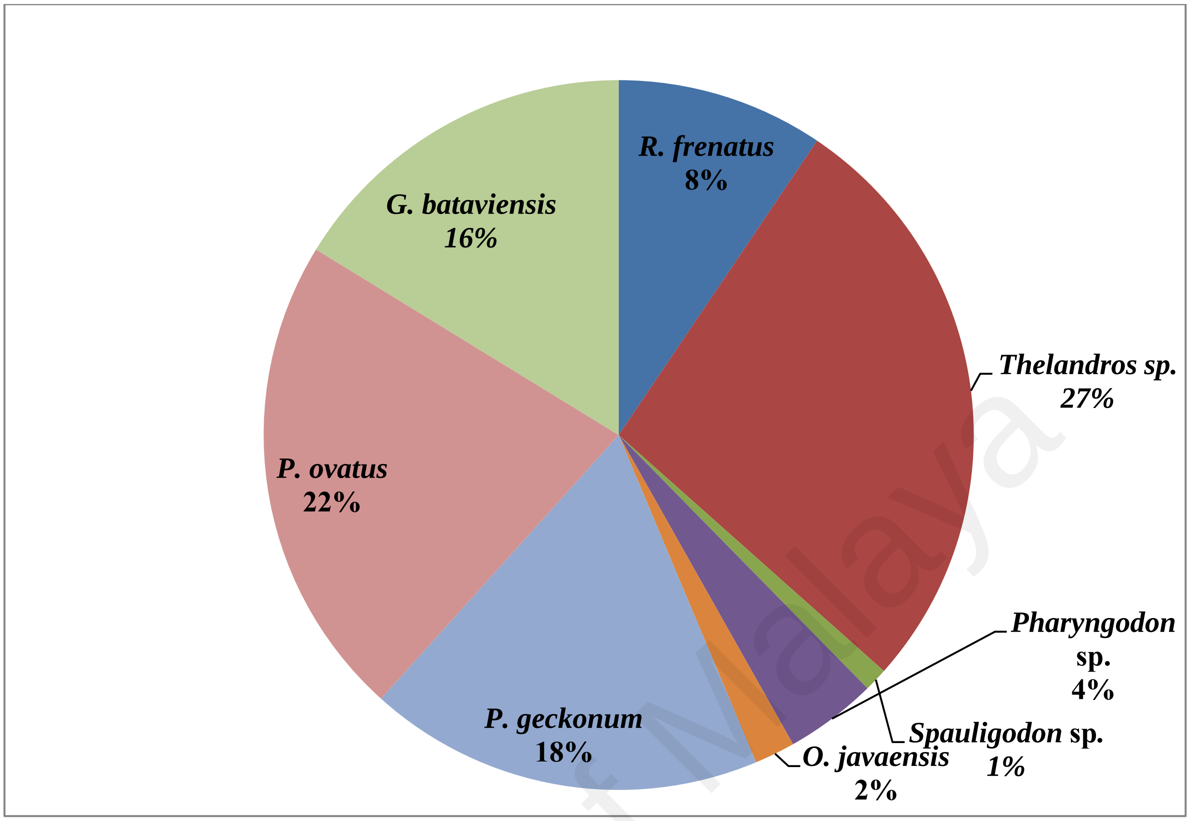

Figure 5.8 Parasite Composition of the Gecko Community in University Malaya, Kuala Lumpur.

Table 5.1 Diversity and Evenness of Eight Study Sites.

Study Sites	H'	E	Total Species	Ds
1) Langkawi, Kedah	0.4079	0.1961	8	0.0045
2) BERNAS Complex, Megat Dewa, Kedah	0.3234	0.1472	9	0.6213
3) Kampung House, Parit Maharaja, Kedah	0.2543	0.122	8	0.00017
*4) Jitra, Kedah	0.7697	0.4296	6	0.001
5) Pangkor island, Perak	0.3323	0.1708	7	0.0043
*6) Genting Highlands, Pahang	0.4898	0.4459	3	0.02
7) Carey Island, Selangor	0.6184	0.2815	9	0.005
8) ISB,UM,KL	0.4778	0.2298	8	0.009

*Disparity in sampling numbers from certain sites is due to possibilities such as increased availability of predators such as cats (Jitra) or dense vegetation (Genting Highlands). Therefore results will be discussed with these discretions in mind.

Diversity of parasites in the study sites is generally low (H' <1). Jitra, Kedah recorded the highest H' value with 0.7697. However it must be taken into account the low number of samples collected compared to other sites. Carey island has the second highest diversity of parasitofauna. With nine species of parasites collected from this site, it is only comparable to another site with also nine species, BERNAS rice mill. This later site, however had a much lower H' value with 0.323 . Both sites had a low evenness values (BERNAS rice mill = 0.1472; Carey Island = 0.2815), showing certain species asserting dominance in terms of abundance from the total parasitofauna load. More than half of total parasitofauna of BERNAS rice mill consist of the trematode *P. ovatus*. High density of some species from the total parasitofauna greatly affects the diversity; this is common in parasite community where each parasite have different life histories. Gecko parasites are limited by the size of their niche, therefore parasites with high fecundity have a higher chance of controlling the population of other parasites.

Gecko population with the most even parasite community are recorded in Jitra, Kedah (E= 0.4296) and Genting Highlands, Pahang (E= 0.4459). Both are nematode-rich sites, however due to low sample numbers from both sites, this observation may not be accurate and accurately represent the natural system. The rest of the sites also reported low E values, confirming that for each site, there are species dominating the total parasitofauna of the gecko population. Trematodes and nematodes are usually the parasites that are dominant; site BERNAS rice mill, Parit Maharaja, and University Malaya are trematode-rich. Total parasitofauna of BERNAS rice mill and Parit Maharaja are made up of more than 50% trematodes, while in University Malaya, trematodes made up 22%. These high percentages affect the diversity and evenness values of the three sites.

Ectoparasitic mites (*G. bataviensis*) are highest in three sites, i.e. Langkawi, Pangkor, and Carey Island. All these sites are island habitats, suggesting that the gecko population on the islands exist in small, tightly clustered which facilitate easy transfer of the mites. High abundance of mites affected the H’ and E values of both Langkawi and Pangkor, but not in Carey island. This latter site had a much higher diversity (H’ 0.618) compared to Langkawi island (H’ 0. 079) and Pangkor island (H’ 0.3323). It also has a more even distribution (E= 0.2815) compared to Langkawi (E= 1961) and Pangkor (E= 0.1708). Mainland habitats on the other hand had a much lower abundance of ectoparasites compared to the island gecko population, the highest percentage was 16% (University Malaya). This suggest that the gecko population are widespread compared to their island counterparts, which limited mite transfer during mating or fighting.

5.3.1.1 The Proportional Similarity Index (Czekanowski Index)

a. Results for eight sampling sites

The Proportional Similarity Index (Czekanowski Index) for the eight sites must be evaluated with discretion due to the uneven number of samples collected from each sites. Some sites have lower number of samples due to various reasons. Genting highlands appears to have a small and widely dispersed gecko population, therefore sampling size was small. Samples from Jitra, Kedah are low in numbers due to a large number of specimens dying en route to the lab for examination.

BERNAS rice mill and the small farming village of Kampung Parit Maharaja are in close proximity of each other (Figure 3.1), which accounts for the 94.6% of species composition similarity between the two. The similarity between both sites and the urban environment, University Malaya however exhibit an interesting dynamics between two very different types of environment. With a proportional index of 60.8%, the similarities between these sites are the top four species dominating each site (Figures 5.2, 5.3 and 5.8). While both the rural environments hosted a higher abundance of trematodes (*Postorchigenes ovatus*), the urban environment hosted a higher abundance of nematodes, specifically the *Thelandros* species (Figure 5.8). In the rural environment, the distribution of parasites across species is highly uneven with the main trematode species dominating more than 50% of total species composition (Figures 5.2 and 5.3) compared to the urban environment.

Another case of urban versus rural environment was observed between University Malaya and the fishing village of Pangkor island. Both sites are dominated by the nematode *Thelandros* sp., with almost similar species composition, 27% for the former and 23% for the latter. However Pangkor Island population recorded higher infection of ectoparasitic mites, which contributed to 57% of total parasite composition compared to only 16% University Malaya population (Figures 5.5 and 5.8).

The three island habitats showed little similarity to each other (Figure 5.9a). Langkawi island stood apart from the rest, its parasite composition differs from all sites. Pangkor island showed 68% similarity with Carey island. With the exception of University

Malaya population, both parasites population from Pangkor and Carey islands have very low similarity with the other mainland habitats.

Table 5.2 The Proportional Similarity Index (Czenakowski Index) for eight sampling sites.

Locality A	Locality B	Proportional Similarity
Langkawi, Kedah	BERNAS Complex, Megat Dewa, Kedah	24%
	Kampung House, Parit Maharaja, Kedah	23.3%
	Jitra, Kedah	30.6%
	Pekan Pangkor, Perak	21.4%
	Genting Highlands, Pahang	3.2%
	Carey Island, Selangor	20.2%
	ISB,UM,KL	24.5%
BERNAS Complex, Megat Dewa, Kedah	Kampung House, Parit Maharaja, Kedah	94.6%
	Jitra, Kedah	30.6%
	Pekan Pangkor, Perak	38.3%
	Genting Highlands, Pahang	4.7%
	Carey Island, Selangor	20.8%
	ISB,UM,KL	60.8%
Parit Maharaja, Kedah	Jitra, Kedah	29.8%
	Pekan Pangkor, Perak	35.1%
	Genting Highlands, Pahang	2.6%
	Carey Island, Selangor	18.2%
	ISB,UM,KL	56.2%
Jitra, Kedah	Pekan Pangkor, Perak	31.6%
	Genting Highlands, Pahang	25%
	Carey Island, Selangor	8.9%
	ISB,UM,KL	47.6%
Pangkor, Perak	Genting Highlands, Pahang	6.7%
	Carey Island, Selangor	68%
	ISB,UM,KL	57.4%
Genting Highlands, Pahang	Carey Island, Selangor	8.3%
	ISB,UM,KL	9.1%
Carey Island, Selangor	ISB,UM,KL	34.1%

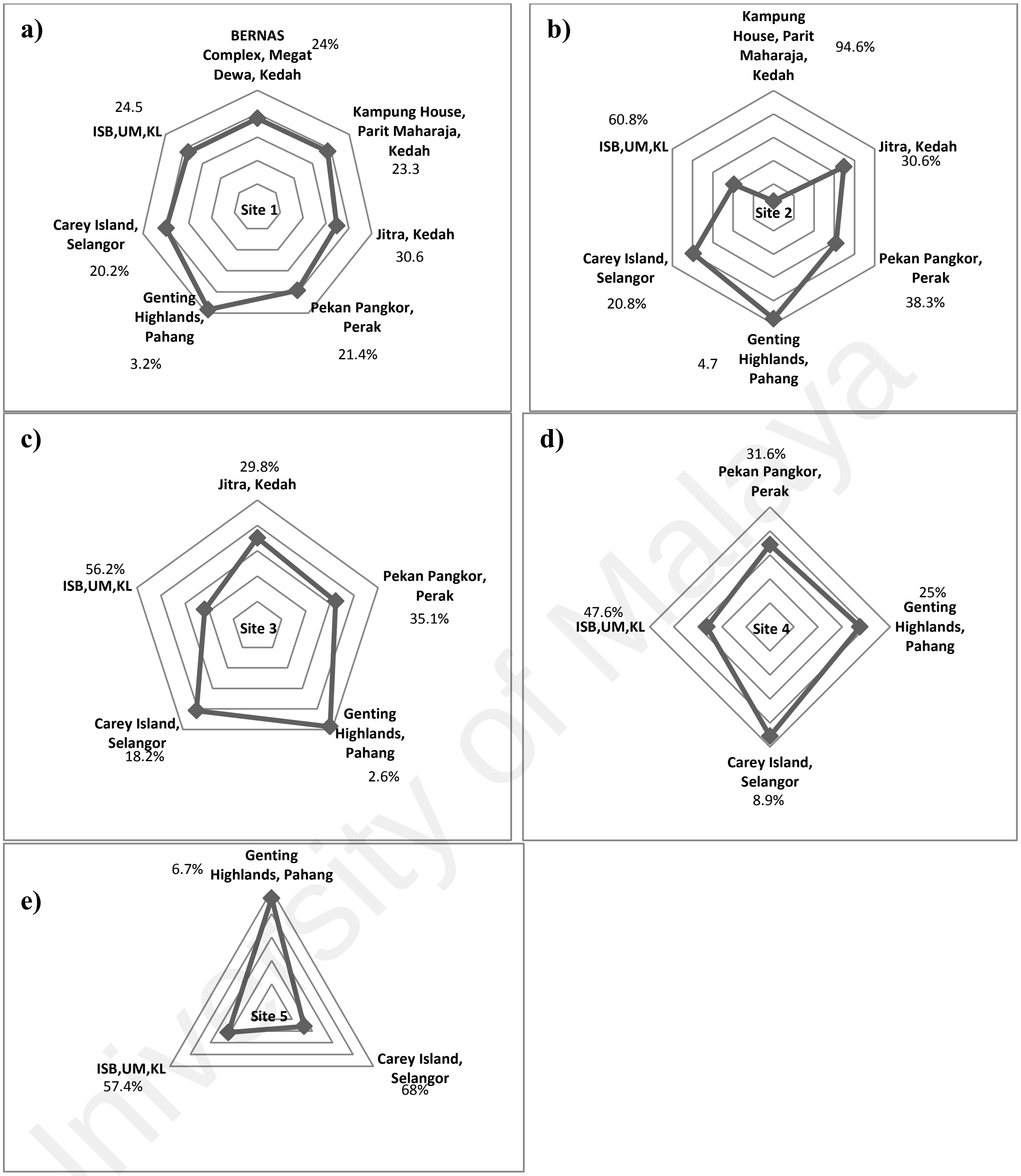

Figure 5.9 Proportional similarities (Czekanowski index) between different sampling sites. Figure (a) represented Langkawi island, Kedah as Site 1, (b) with BERNAS Complex, Kedah as Site 2, (c) with Kampung Maharaja, Kedah as Site 3, (d) with Jitra, Kedah as Site 4, (e) with Pangkor island, Perak as Site 5. Sites 6 (Genting highlands, Pahang), 7 (Carey island, Selangor) and 8 (University Malaya, KL) are represented in Table 2.

b. Results of the northern and central regions

Both regions showed 51.2% similarity in terms of species diversity and composition. Both regions have all the nine species of parasites found in the study (Figures 5.10 and 5.11), however both have different composition. The gecko parasitofauna from the northern region is dominated by trematodes (*Postorchigenes ovatus* – 42%; *Paradistomum geckonum* -10.6%) while the central region is dominated by the mite *Geckobia bataviensis* (42%). Nematode composition (with the exception of *Pharyngodon* sp.), do not differ much in both regions. However *Pharyngodon* sp. made up a higher percentage (22.14%) of the total composition in the central region compared to the northern region. Pentastomids made up a small portion of total parasitofauna in both regions, both recording percentages less than 10% (Northern 4.03%, central 7.91%). Ectoparasitic mites were found more on the geckos from the central region; mites made up 42% of total parasitofauna of the geckos.

Table 5.3 Czekanowski Index for the Northern and Central Regions.

Parasite	**Total Parasites in Northern Region**	**%**	**Total Parasites in Central Region**	**%**	**Lowest %**
Raillietiella frenatus	134	4.03	267	7.91	4.03
Thelandros sp.	499	15.01	387	11.5	11.5
Spauligodon sp.	209	6.28	29	0.86	0.86
Pharyngodon sp.	154	4.63	747	22.14	4.63
Skrjabinodon sp.	15	0.45	76	2.25	0.45
Oochoristica javaensis	12	0.36	26	0.77	0.36
Paradistomum geckonum	352	10.6	188	5.57	5.57
Postorchigenes ovatus	1396	42.	244	7.23	7.23
Geckobia bataviensis	552	16.6	1410	41.8	16.6
Czekanowski Index					**51.2**

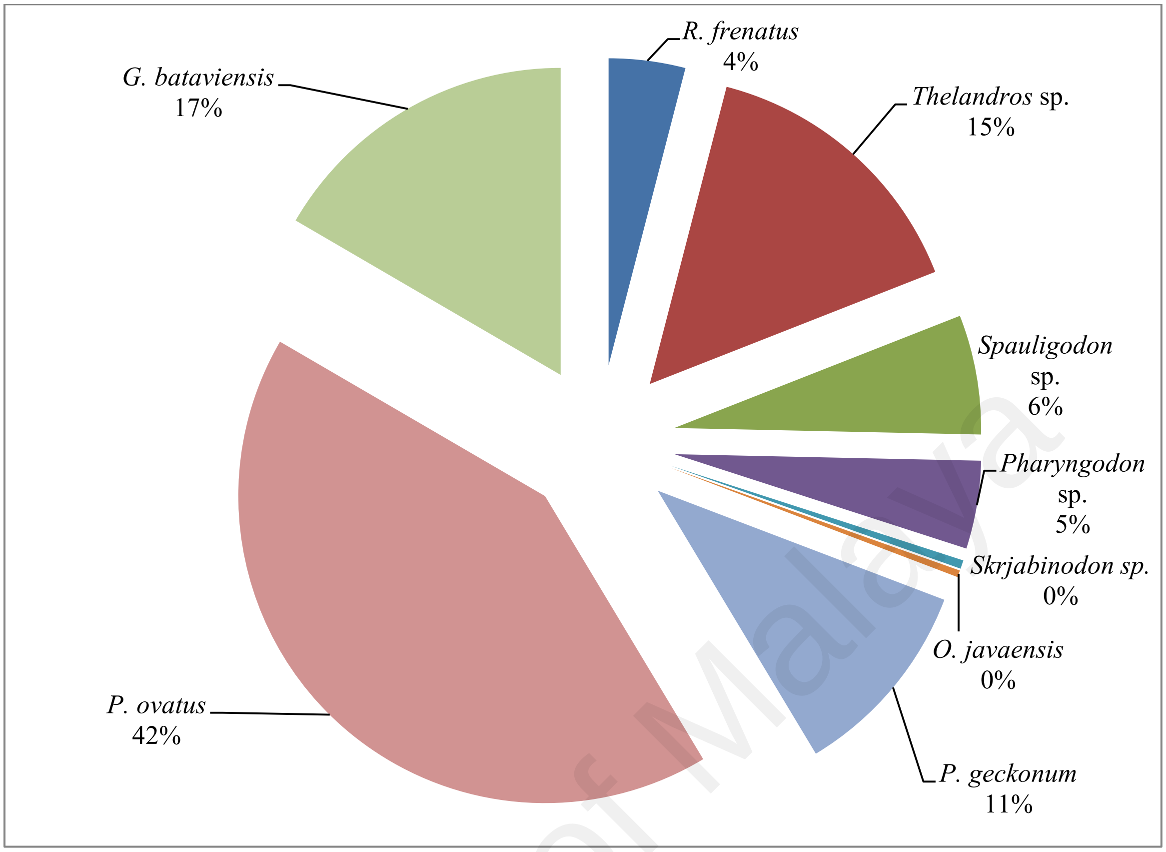

Figure 5.10 Parasite species composition of the house gecko population from the northern region.

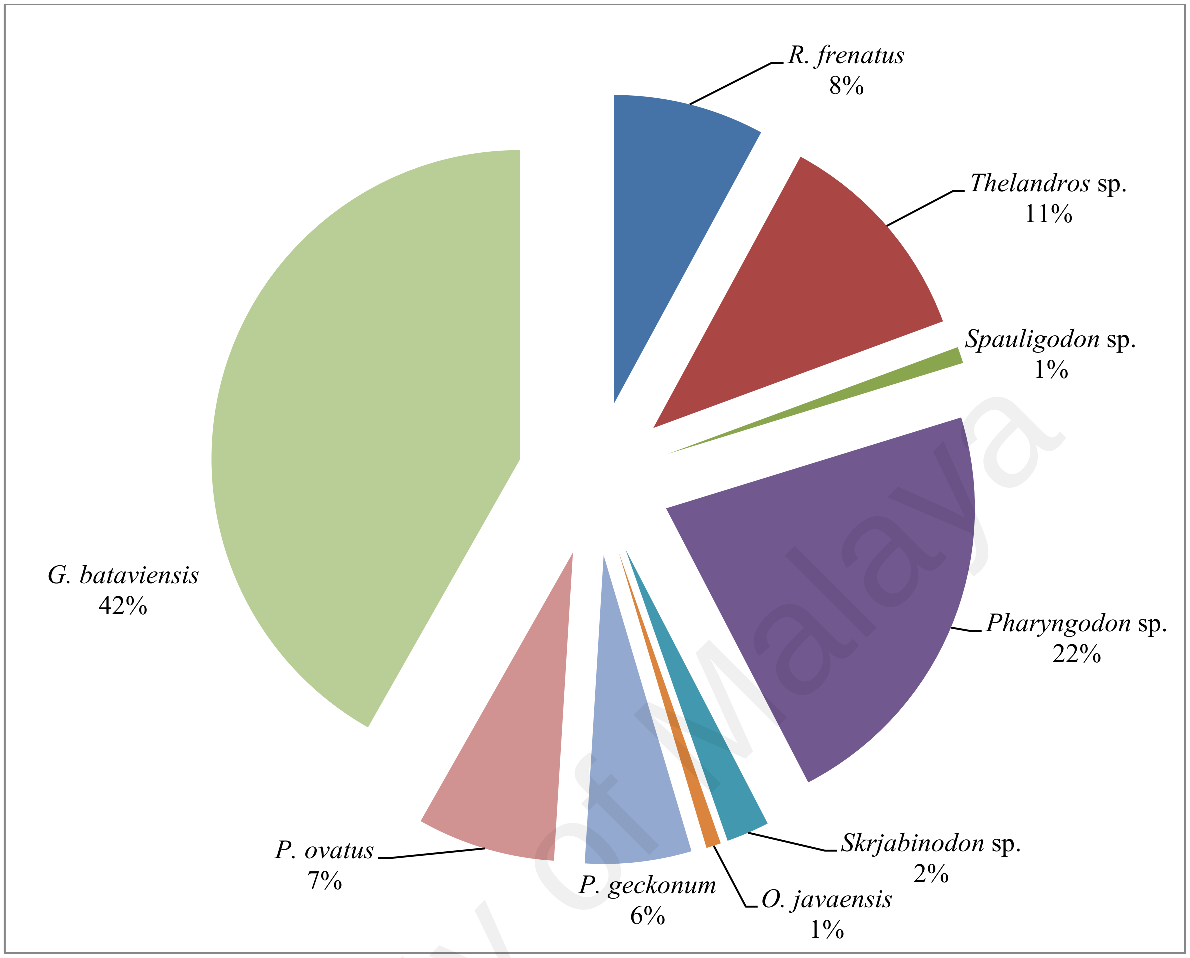

Figure 5.11 Parasite species composition of the house gecko population from the central region.

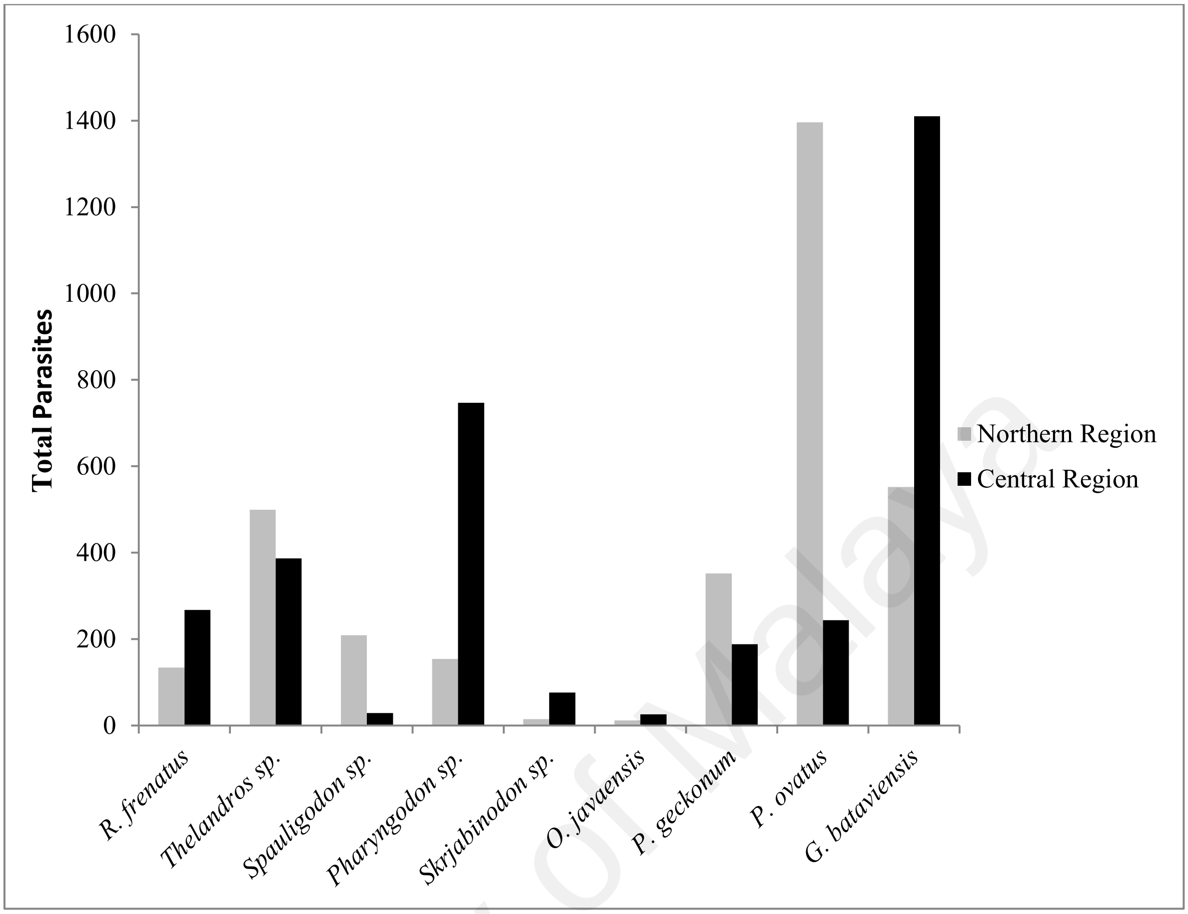

Figure 5.12 Parasite abundance in northern and central regions. Northern region has a higher abundance of trematodes and two species of nematodes while the central region has a higher abundance of pentastomids, two species of nematodes and ectoparasitic mites.

5.3.2 Parasite community structure

An overall correlation analysis on the parasite abundance versus host body size (SVL) showed weak correlations (Table 5.4, 5.5; Figure 5.13a-d). Abundance of both endo- and ectoparasites negatively correlated with host body size. However the parasites do consider the size of the host as an important criterion for infection. Smaller hosts have a higher abundance of parasites. Similar observation is obtained when looking at the density of parasites. The size of the hosts negatively correlates with the density of the parasites; smaller hosts have higher density of parasites (Table 5.5). These observations may be due to smaller collection of geckos with SVL less than 4 cm (Figure 4.1). The figure also highlighted the highest concentration of infected geckos are from the 4 – 6 cm SVL range. Larger geckos with SVL of >6 cm do have much lower abundance and density of parasites compared to the smaller geckos. Species richness of parasites however is not affected by the size of the gecko hosts.

Table 5.4 Parasites of house geckos collected from

parasite/host SVL).

Host: *Hemidactylus frenatus*

Parasite	NP	P		SD	D (parasite/mm)
Ectoparasite					
Pterygosomatid					
Geckobia bataviensis	2135	43.47	9.93	11.4769	0.1018
Endoparasites					
Pentastomid					
Raillietiella frenatus	338	22.09	0.805	1.8731	0.1504
Trematode					
Lecithodendriidae					
Postorchigenes ovatus	197	12.11	16.21	6.7566	0.2522
Dicrocoeiliidae					
Paradistomum geckonum	1183	18.05	5.63	21.51	1.5449
Cestode					
Linstowiidae					
Oochoristica javaensis	28	2.613	0.067	0.4318	0.0152
Nematode					
Pharyngodonidae					
Thelandros sp.	385	32.78	2.48	4.2017	0.462
Spauligodon sp.	85	9.264	0.548	1.7439	0.1032
Pharyngodon sp.	30	33.49	0.194	0.6355	0.0403
Skrjabinodon sp.	1	0.713	0.0065	0.0803	0.00143
Host: *Hemidactylus platyurus*					
Parasite					
Ectoparasite					
Pterygosomatid					
Geckobia bataviensis	20	5.333	1.0526	2.7177	0.0247
Endoparasites					
Pentastomid					

Table 5.4, continued

Raillietiella frenatus	46	18	0.4334	0.9464	0.0567
Trematode					
Lecithodendriidae					
Postorchigenes ovatus	294	28	5	6.6	0.01
Dicrocoeiliidae					
Paradistomum geckonum	59	11.33	5.44	6.29	0.046
Cestode					
Linstowiidae					
Oochoristica javaensis	13	6.667	0.0867	0.3051	0.0183
Nematode					
Pharyngodonidae					
Thelandros sp.	238	70	1.9194	1.8636	0.3604
Spauligodon sp.	25	8	0.2016	0.9194	0.0386
Pharyngodon sp.	21	8.667	0.1694	0.634	0.0324
Skrjabinodon sp.	4	1.333	0.0323	0.3592	0.0059
Host: *Hemidactylus garnotii*					
Parasite					
Ectoparasite					
Pterygosomatid					
Geckobia bataviensis	131	34.15	9.3571	7.1102	0.0714
Endoparasites					
Pentastomid					
Raillietiella frenatus	1	17.07	0.1	3.872	0.0017
Trematode					
Lecithodendriidae					
Postorchigenes ovatus	209	34.15	29.857	48.358	0.4696
Dicrocoeiliidae					
Paradistomum geckonum	5	12.2	2.5	2.1213	0.0105
Cestode					
Linstowiidae					
Oochoristica javaensis	0	0	0	0	0
Nematode					
Pharyngodonidae					

Table 5.4, continued					
Thelandros sp.	10	26.83	0.833	1.467	0.0171
Table 5.4, continued.					
Spauligodon sp.	0	2.439	0	0	0
Pharyngodon sp.	9	29.27	0.75	1.3568	0.0142
Skrjabinodon sp.	0	0	0	0	0
Host: *Gekko monarchus*					
Parasite					
Ectoparasite					
Pterygosomatid					
Geckobia bataviensis	29	5	14.5	14.85	0.01
Endoparasites					
Pentastomid					
Raillietiella frenatus	25	41.38	0.83	15.96	0.0122
Trematode					
Lecithodendriidae					
Postorchigenes ovatus	12	5	3	1.1547	0.008
Dicrocoeiliidae					
Paradistomum geckonum	9	7.5	3	0	0.0045
Cestode					
Linstowiidae					
Oochoristica javaensis	0	0	0	0	0
Nematode					
Pharyngodonidae					
Thelandros sp.	31	17.5	1.033	2.0592	0.0154
Spauligodon sp.	4	7.5	0.1333	0.5074	0.0025
Pharyngodon sp.	5	5	0.1667	0.7467	0.004
Skrjabinodon sp.	80	15	2.67	8.7625	0.0478
Host: *Gehyra mutilata*					
Parasite					
Ectoparasite					
Pterygosomatid					
Geckobia bataviensis	11	5	5.5	0.7071	0.006
Endoparasites					
Pentastomid					
Raillietiella frenatus	14	40	0.6364	5.73	0.012

Table 5.4, continued

Trematode					
Table 5.4, continued.					
Lecithodendriidae					
Postorchigenes ovatus	69	15	7.67	8.73	0.06
Dicrocoeiliidae					
Paradistomum geckonum		10			
Cestode					
Linstowiidae					
Oochoristica javaensis	1	2.5	0.005	0.2132	0.002
Nematode					
Pharyngodonidae					
Thelandros sp.	52	37.5	2.3636	2.421	0.0451
Spauligodon sp.	3	2.5	0.1364	0.4676	0.00284
Pharyngodon sp.	17	27.5	0.7727	2.385	0.0149
Skrjabinodon sp.	0	0	0	0	0

Table 5.5 Pearson correlation of abundance, numerical density and species richness of parasites with the parasite body size (SVL).

Parameter		All hosts (n=650)		Infected host (n=451)	
		r	P	r	P
log Abundance	All	-0.00305	0.93915	-0.03461	0.471368
	Endoparasites	0.116601	0.002909*	0.146068	0.00188*
	Ectoparasites	-0.13039	0.000893*	-0.19019	4.9E-05*
log Numerical density	All	-0.12949	0.00098*	-0.16767	0.000368*
	Endoparasites	-0.08007	0.041455*	-0.10153	0.031997*
	Ectoparasites	-0.08322	0.034373*	-0.10872	0.021795*
Richness		-0.00513	0.895469	0.000722	0.9863

* Significant at P<0.05

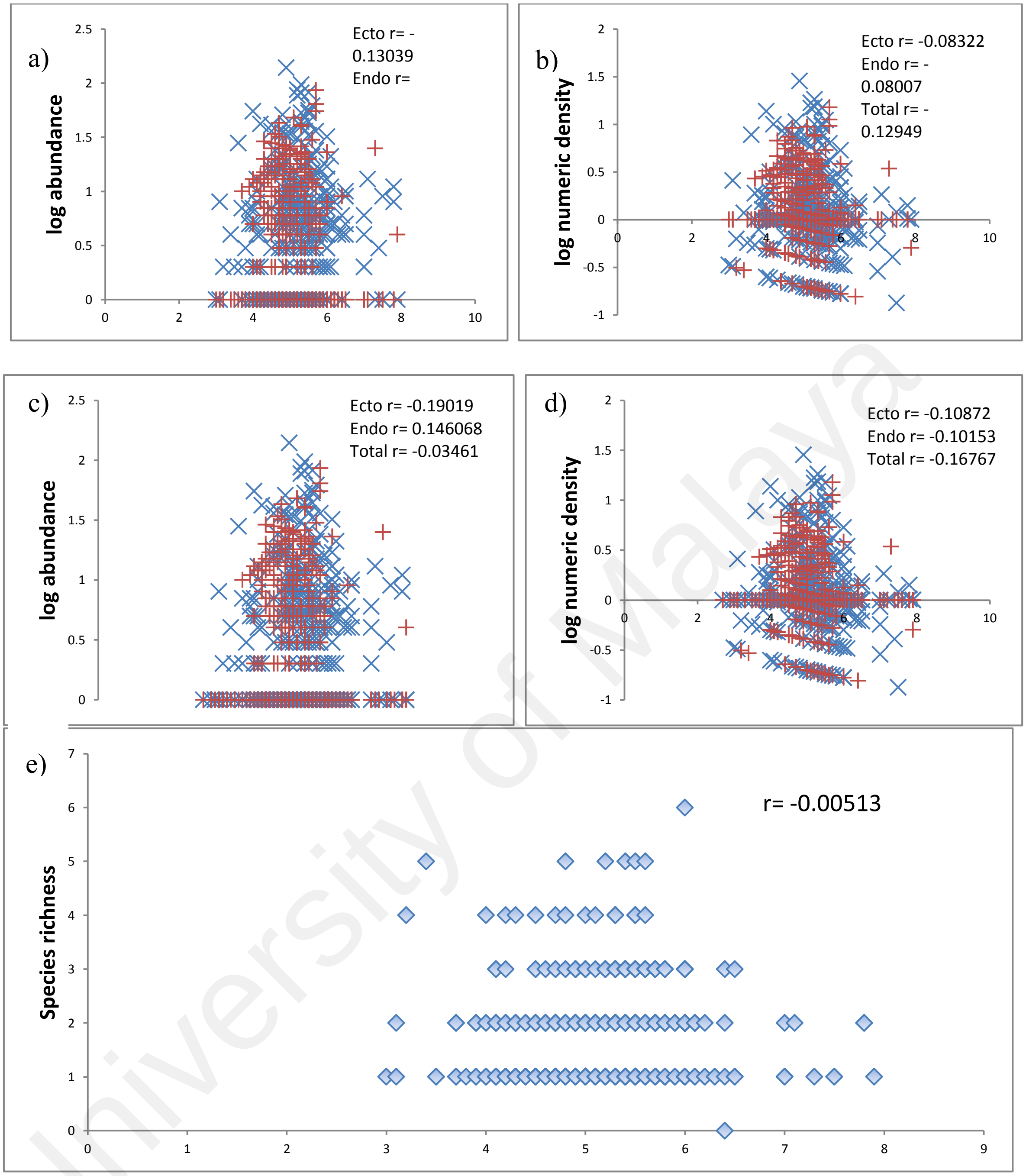

Figure 5.13 Pearson correlations between abundance, numerical density and species richness of endoparasites (+) and ectoparasites (x) with host body size of 650 specimens of Malaysian house geckos. r= correlation coefficient; significant probability (*) P<0.05. Figure (a) and (b) represented all gecko hosts while figure (c) and (d) represent only the infected hosts. Figure (e) show the species richness.

5.4 Discussion

5.4.1 Species composition and Czekanowski Index

Population of geckos' parasites in Langkawi, Kedah showed an equal distribution of nematodes and trematodes. As one of the trematode species, *Postorchigenes ovatus* shares the same niche as the nematodes; competition exists between these two groups of parasites for resources (i.e. space and food). The high concentration of mites infesting the gecko population suggests the population is highly dense and aggregated which allows easy transfer of mites. The site has very little similarity with other sites. Although the species richness does not differ, the species composition is different; the closest similarity is with the mainland site, i.e. Jitra, Kedah. However discretion must be practised while comparing between these two sites due to different sampling sizes. Another site that is very different from the others is Genting highlands. This site has high vegetation cover, high altitude and medium density of human population. However the index value of this site also must be evaluated with discretion as the sample numbers is low. Sampling was done with similar effort to all sites, however it did not yield a sizeable number of parasites population to allow proper comparison.

Parasites population from BERNAS Complex and Kg. Parit Maharaja have similar species richness and composition because both sites are near each other. Both sites are trematode-rich, contributed by availability of molluscs and insects (especially beetles) in the paddy field and rice mill. Both sites share similarities with University Malaya. The latter is an urban environment with high density gecko population, which explains the high abundance and intensity of nematodes and mites in the gecko population.

Carey island has the highest similarity with Pangkor island (68%). Both sites have the highest abundance of mites and oxyurid nematodes, suggesting that both sites have highly dense gecko population as the mites require direct transfer and the nematodes have a direct life cycle (Grear & Hudson, 2011). Both sites have very low trematode abundance. *Paradistomum geckonum* follows the standard life cycle of a trematode, with a freshwater molluscs as the first intermediate host (Kennedy *et al.*, 1987). It is not surprising that the trematode population is so low in these geckos. Carey island is a small island, protected from strong waves by thickets of mangrove forests, an environment of high salinity and not suitable for freshwater snails. Pangkor island is larger, and faces the open sea.

Even though both central and northern regions have the same parasites species, the composition is vastly different. The northern region consists of sites that are densely populated, from suburban and small towns, to small, fishing and farming villages, with pockets of green areas. The central region on the other hand consists of highly dense human population, urban environment, with pockets of green areas. The differences between these two regions appear to be the type of human activities and density of the human population in the areas. Northern region consist of denser vegetation compared to central region; with human activities related to paddy farming, fishing, and nature tourism. The sites where the geckos were collected featured a less dense human population compared to the central region.

The northern region has a higher percentage of trematodes compared to the central region; more than 50% of total parasite composition in the northern region consists of trematodes while in the central region, trematodes account for only 13% from the total composition. This suggests that the northern region has diverse invertebrates as intermediate hosts for the trematodes. A community dominated by trematode parasites provides certain clues about the habitat; trematodes are known to utilize molluscs and arthropods as first and second intermediate hosts before reaching its final host (Poulin & Cribb, 2002). Sites from northern region are near or surrounded by paddy fields, which has an abundance of both molluscs and arthropods, especially coleopterans, a common pests of paddy fields and rice.

The gecko population in the central region is denser, allowing easy transfer of ectoparasites. Little is known about the life cycle of *G. bataviensis*, although if it does follow the basic life cycle of a mite, the data on the population dynamics of *G. bataviensis* will be able to show the environmental conditions of the macrohabitat it inhabits, such as soil condition as mites spend some time as free-living organisms before infecting its final host (Baker & Wharton, 1952; Bauer *et al.*, 1990). Infection is speculated to occur from gecko-to-gecko during a short period when the mites are motile in their larvae form (Bauer *et al.*, 1990). Therefore it is possible due to the spatial limitation (from living on a small island or a highly dense population), the geckos interacted more with each other, allowing more transfer of mites.

More pentastomids were recorded from the central region than northern region. One of the main intermediate hosts for the pentastomids is the cockroach, a common pest in human habitation. Cockroaches are more common in densely populated area, where there is a steady supply of food. The central region also has bigger composition of nematodes compared to northern region. The nematodes in this study are from the family Oxyuridae, a family known for having a direct life cycle. Therefore transmission is through autoinfection (ingestion of fecal matter) or via fomites. The abundance and intensity of nematode infection rely more on the density of the gecko population, and the geckos' immunological factor although previous work showed evidence of temperature and rainfall as two factors controlling the oxyurid infection (Gambhir *et al.*, 2013).

5.4.2 Parasite community structure

The negative correlation between abundance and numerical density as observed in the results may be explained by the combination of resources, time and prey. Geckos suffer more infectionas they matured, and then started to lose that infectionas age-related acquired immunity was developed. The sampling of the house geckos yielded more geckos within small (SVL < 4 cm) to medium sized geckos (SVL 4 – 6 cm). The larger geckos (SVL > 6 cm) only formed a small portion of this study. Even though larger hosts have more space, higher food intake and more microhabitats for parasites compared to small hosts, the parasites face another obstacle as the geckos acquire immunity through prolonged interaction with the environment (Brown & Symondson, 2014). In most animal groups, the parasite diversity and load increase as the animal matures into adulthood (Poulin, 1997). This is no exception for the geckos; parasite diversity and abundance increase as the gecko grows bigger. This supports observations of parasites from other groups of animals such as the slow worm, *Anguis fragilis* (reptile) (Brown & Symondson, 2014) and fishes (Rohde, 1993; Muñoz *et al.*, 2002). As the gecko matures into adulthood, its dietary component expands, incorporating bigger and higher abundance of prey to cope with its physiological needs.

Bigger geckos are able to accommodate higher diversity and intensity of parasites (Sousa *et al.*, 2014). Size of the niche is crucial especially to the spatially dependent ectoparasites such as mites (Bauer *et al.*, 1990). However after the gecko reached a certain size, parasitism appears to decrease in abundance and intensity (Figures 4.1-4.6). The general hypothesis is that parasite numerical density would decrease as the host body weight increases because the metabolic rate of a large host had shifted (i.e. flux of energy per gram), so there would be a smaller number of parasites per gram of host (George-Nascimento *et al.*, 2004). However this does not appear to be the case with the house geckos. Abundance of ectoparasites and densities of endo- and ectoparasites are negatively correlated with the host body size. Smaller geckos harbor higher abundance of ectoparasites, and the density of both ecto- and endoparasites are higher in smaller geckos compared to larger geckos. This can be attributed to the sampling of the house geckos. More geckos with snout-vent-length (SVL) of 4 to 6 cm were captured, therefore affecting the correlation. The geckos started to lose some of their parasites as they reach certain age which may be due to age-related acquired immunity (Brown & Symondson, 2014). Larger hosts are generally older than smaller hosts of the same species, therefore been in contact with the environment longer and are exposed to more opportunities for infection (Muñoz & Cribb, 2005) but fortunately due to the mature immune system, they are able to cope better with parasitic infection.

Species richness is not affected by the gecko host size. The parasites are not age-specific, only highly opportunistic. Geckos acquire parasitic infection at any age; the only difference is the prevalence and intensity which can be contributed by the diversity of the gecko's diet. The gecko's small size also limits the intensity of infection as there is less space for the parasites to occupy. Since the geckos have not start their reproductive phase yet, contact with other geckos is considerably less which limits transfer of ectoparasites. Smaller geckos with SVL of less than 4 cm are more susceptible to cestode infection. . This suggests that either the cestodes prefer the young geckos because of their undeveloped immune system, or the cestodes might increase the mortality rate before the geckos reach adulthood. Cestodes were very rarely found in medium or large adults. It may also be that the adults have better immune system to repel or at least minimize the infection of cestodes.

5.5 Conclusion

House gecko parasites make a poor indicator of an environment as they are widely distributed. They do however provide information to a certain degree, on the health of the ecosystem through their intermediate hosts. Nevertheless elements such as physical parameters must be included in order to support this notion as the parasitofauna information alone is not robust enough. The species composition does offer a small glimpse into the condition of the gecko population; an ectoparasite-rich population shows a high density gecko population sharing a small niche, which is also environment that is suitable for pests such as cockroaches. Therefore the environment is expected to have a composition of cockroach-borne parasites such as pentastomids, nematodes and cestodes. On the other hand, a trematode-rich environment may have high diversity, as trematodes usually require more than one invertebrate as intermediate hosts; usually a mollusc and an insect (Poulin, 1997). The northern region of Peninsular Malaysia, which is a trematode-rich region, does have more vegetation cover which can support higher diversity of organisms compared to the central region (mites-rich region). The central region has very high abundance of ectoparasitic mites, an indication of a dense population sharing a small niche. The region also host more parasites that require coprophagial insects as an intermediate host, which may suggest pests such as cockroaches.

The abundance and density of the gecko parasites negatively correlated with the host size highlighted one fact; the gecko's immune system developed to withstand and minimize parasitic infectionafter a certain age. The abundance of parasites dropped significantly once they have reached a certain size. Abundance, intensity and density of parasites are highest during reproductive phase. This may be caused by hormonal influence as the male geckos invested more energy on mating and defending their territories while female geckos invested their energy on egg production. This leaves them more susceptible to parasite infection. Close contact during mating and fighting allow transfer of ectoparasites. Reproduction also requires more energy therefore geckos will consume more prey, opening them to more endoparasite infection. Geckos invested their energy on reproduction during the reproductive stage at the expense of their immune system, however as the reproductive stage passes, the energy is diverted to bolstering their immune system.

House geckos act as a good model to study parasite behaviour as they are so closely dependant on humans. They are considered as invasive species in some parts of the world, the information on parasite community structure will be helpful in designing a management system to monitor invasive species. Threats posed by gecko parasites on humans may be minimal, but they do provide some insight to the condition and to certain extent, the health of the habitat. The infection behavior is different from other animals such as fishes (where parasite load increases with host size and weight, George-Nascimento *et al.*, 2002), and mammals (where host size and body weight did not influence the parasite load, Watve & Sukumar, 1995). Geckos allocated their energy on reproduction, and only switched to improving immunity after reaching certain size. Heavy parasitism, especially as observed in/on house gecko *H. frenatus*, does not appear to harm gecko population in any way as the geckos appear healthy and the population does have a good number of older, surviving geckos.

CHAPTER 6: GENERAL DISCUSSION

6.1 Host Selection

6.1.1 Host Species

Previous works were based on the premise that reptile parasites are generalists and rarely discriminate their hosts (Bursey & Goldberg, 1999a, b, 2002; Hoskin, 2011). One possible reason for the parasites' host preference may be due to the availability of hosts in the community. Generalists are opportunistic; they go for what is available for them. Gecko community consists of different species of geckos. *Hemidactylus frenatus* made up almost 60% of the total gecko community. It is susceptible to two species of parasites, the nematode *Pharyngodon* sp. and the ectoparasitic mite *G. bataviensis*. However these parasites have also been known to infect other species of geckos (Bursey & Goldberg, 1999a, b, 2002; Sri Prawasti, 2011; Bertrand *et al.*, 2013; Sri Prawasti *et al.*, 2013). The genus *Hemidactylus* has a worldwide distribution, and *H. frenatus* is among one of the most successful invader species in the world (Barton, 2007; Newberry & Jones, 2007; Hoskin, 2011). *H. frenatus* has the ability to adapt to diverse localities in the world, even taken in the local reptile parasitofauna and cope well with the infection (Goldberg, *et al.*, 1998; Barton, 2007). Therefore, it is not surprising to find *H. frenatus* hosting all nine species of parasites in the current study. Unlike other species of house geckos, the parasites in *H. frenatus* co-exist in a moderately lower abundance and prevalence in their hosts. This observation might shed a clue as to why *H. frenatus* is such a successful invader species. They are able to adapt to their new environment very quickly, from dietary needs to local parasitofauna, in certain cases out-competing the local gecko fauna for food (Hoskin, 2011) and coping better with the local parasitic infection better than the local gecko hosts.

The availability of intermediate hosts may also contribute to the pattern of infection in the gecko community. These geckos are always found within areas of human activity. Waste products provide a steady flow of food source to most insects living in a parasitic or commensalistic relationship with humans. Insects such as cockroaches and ants are intermediate hosts for various types of parasites such as pentastomids in cockroaches (Ali *et al.*, 1981; Ali *et al.*, 1986), nematodes in ants (Poinar, 2012), cestodes in beetles (Case & Ackert, 19 0). Pollution is capable of disrupting animal's life cycle, especially those sensitive to environmental changes such as frogs (Simon *et al.*, 2011). Water pollution can easily disrupt the life cycle of frogs, an important predator of a wide range of insects. Without frogs, insect population will rise, causing resource shortage and the emergence of various insect-borne diseases. With the insect population boom, the geckos are a secondary substitute as an apex predator, exposing them to more potentially deadly, parasitic infections.

Each gecko species may have its own level of tolerance for parasitic infection. Spatial niche is a limiting factor for certain parasites, as in the case of ectoparasitic mites. Bigger geckos are ideal hosts for ectoparasitic mites, however other factors such as host availability in the community and inter-/intraspecies interactions also contribute to successful infections. Different gecko species have their own carrying capacity when it comes to parasitic infections. Certain gecko species are able to harbour more parasites without displaying symptoms of diseases. Others are able to harbor a higher diversity of parasites without any ill effects. Both are possible strategies employed by the parasites and the geckos in order to survive. Some parasites propagate to an intense population in its host in order to drive out any other parasites species sharing the same niche (the trematode community in the current study), while some have no problems co-existing with other species in the same niche (i.e. the nematode community from the current study). There are also parasites which cause tissue damage (Dezfuli *et al.*, 2011), potentially making the niche unsuitable for other parasites to survive in, such as *Trichinella spiralis* and *Hymenolepis nana* in humans (Parija, 1990).

One interesting finding from this study is the ecotone gecko species, *Gekko monarchus* has a lower species richness compared to the exclusively human dependant house gecko species, *Hemidactylus frenatus, H. platyurus* and *Gehyra mutilata*. It is widely accepted that the ecotone harbours a high diversity of organisms due to the fact that it is an overlap of two habitat types. It overlaps two distinctly different habitats, therefore the diversity is richer. *G. monarchus* are found in both human habitation and forested habitats, and also in the ecotones between the two habitats. Compared with other house gecko species such as *H. frenatus, H. platyurus* and *G. mutilata*, it does have lower species richness. However in certain parasites, intensity and abundance is much higher in *G. monarchus* compared to the other house gecko species. In *H. frenatus*, high diversity of parasitofauna encourages competition for space and food resources, therefore controlling the infection pattern and inhibiting symptoms that may have detrimental effects on the gecko. Certain parasite species exists in higher intensity than others i.e. the oxyurid nematodes, which all have direct life cycles and transmit through autoinfection. The ability to maintain high abundance can be contributed by two factors. One is the fecundity of the parasite itself; some parasites have higher fecundity thus allowing them to better colonise the niche successfully (Jennings & Calow, 1975). The other factor is the density of the gecko population. Autoinfection involves ingestion of fecal matter or transmission via fomites, therefore a dense gecko population facilitates easy transmission of these nematodes regardless of the gecko species they are infecting.

Most invader species are successful competitors (i.e. *Macaca fascicularis*), out-competing the local fauna for food and spaces, although unfortunately carrying parasites with zoonotic capabilities such as *Plasmodium knowlesi* (Antinori *et al.*, 2013) and simian foamy virus (Engel *et al.*, 2013). Outside of South-east Asia, *H. frenatus* is considered such species, inflicting harm on the local fauna through competition. It has been shown to put pressure on not just local lizard species (Kelehear *et al*, 2013), but also toads (Kelehear *et al.*, 2012) via means of introducing its parasites.

6.1.2 Host Gender

The notion that parasites do not have hosts' gender selection is true to a certain extent. However male or female host supremacy is often observed throughout nature (Addis, 1946; Brown *et al.*, 1995; Zuk, 1996; Duneau *et al.*, 2012; Kelehear *et al.*, 2012; Brown & Symondson, 2014). Gender based infection is commonly found in higher vertebrates such as birds and mammals (Addis, 1946; Soliman *et al.*, 2001). This form of parasite competition is believed to be introduced by two main routes; ecological or immunological; or a combination of both (Zuk & McKean, 1996). Previous literatures (Ressel & Schall, 1989; Schalk & Forbes, 1997; Salkeld & Schwarzkopf, 2005; Brown & Symondson, 2014) have shown countless cases that male host bias is commonly observed in nature. Males are believed to engage in behaviors that provide more channels for parasite transfer, especially in the case of ectoparasites. Males engage in fights for self defense, hunting for food, mating rights or nest protection. Other than aggression, males also are prone to more infection because of a decrease in male grooming rate during the mating season (Mooring & Hart 1995; Mooring *et al.* 2006) or spatial aggregation within the members of one sex (Zuk & McKean 1996). Previous studies reported a greater intensity of ectoparasites in male lizards (Schall *et al.*, 2000; Eisen *et al.*, 2004; Amo *et al.*, 2005). Females on the other hand most likely acquire ectoparasite infection through mating, food hunting or in some species, nesting.

Female host bias or supremacy although exist in nature, is less common compared to male host bias. Female-biased parasitism has been shown in certain species of birds and small mammals. Female wood ducks was observed to have higher prevalence of platyhelminthes infections compared to their male counterpart (Drobney et al, 1983). Female-biased parasitism was also exhibited by flea infection on *Acomys russatus*, a desert rodent, but seasonal factor seemed to play a role in this as female-biased parasitism occurred during winter (Krasnov et al, 2005). Female estrogen is believed to encourage parasites' growth and development in the hosts (Bojalil *et al.*, 1993; Terrazas *et al.*, 1994; Morales-Montor *et al.*, 2002). This information might explain the situation observed in gecko parasitism. The female geckos of three gecko species (*G. monarchus, G. mutilata* and *H. frenatus*) appear to be the more dominant species of hosts, harbouring higher number of parasite species compared to the male geckos. The pentastomid (*Raillietiella frenatus*) and the ectoparasitic mite (*Geckobia bataviensis*) prefer female hosts in all dioecious gecko species. Both parasites are blood-feeding arthropods; female host bias may tie strongly to the gecko's hormonal properties. The female geckos may have physiological properties that appeal more to these parasites, especially the mites.

H. frenatus was observed to be susceptible to five parasite species infection. Apart from *R. frenatus* and *G. bataviensis*, *Thelandros* sp., *Spauligodon* sp., and the trematode *P. ovatus* also showed female host bias. Although *Thelandros* sp. and *Spauligodon* sp. showed female host bias in *G. mutilata* as well, both parasites do not seem to show strong bias in *G. monarchus* and *H. platyurus*. In the case of the gut parasites such as the trematode (*P. ovatus*) and the nematodes, host selection will only become crucial once the parasites arrive at the final host, where physiological factors such as hormones and immune system play a role in determining the success of the infection.

In certain cases, although prevalence of parasites is higher in female geckos, intensity is higher in the males. Such is the case with the infection of *R. frenatus* in *G. mutilata* where prevalence is higher in female geckos, but infection is more intense in males. Infection of *Thelandros* sp. in the same gecko species also exhibited this pattern, with the males having higher intensity. It appears that in these cases, although prevalence of the parasite is low in the male geckos, but once the parasite is able to infect the male gecko, it proliferates better in the male geckos compared to the females. This may be contributed by immunological factors; the male hormones facilitate the parasites' growth, or the females have a better immune system to cope with parasitic infection as they invest less energy on obtaining mating rights.

As mentioned earlier, two reasons of the possible gender-biased infections are either ecological, immunological, or a combination of both. Results of this study showed that the parasites prefer female geckos over the males; therefore behavioral ecology contributes less in the infection mechanism of the parasites compared to immunological factor. The current study did not focus on immunological component to confirm the immunological factor that might explain female-biased parasitism exhibited in the geckos. However previous works provided a window as to how immunocompetence plays an important role in order for the parasites to choose the best host to continue their life cycle (Drobney et al, 1983; Bojalil *et al.*, 1993; Terrazas *et al.*, 1994; Morales-Montor, *et al.*, 2002 Krasnov et al, 2005). Immunocompetence is the general capacity of an organism to mount an immune response against pathogens and parasites (Schmid-Hempel, 2003). Explanation as to why parasitic infection between host genders differs may well lie in the biological differences of the sexes.

As predicted, the highest diversity was exhibited in female gecko population (*G. mutilata,* H’ 1.7). However the males also had the higher diversity of parasites in *H. frenatus* (H’ 1.57), which show that although males are not the parasites’ preferred hosts, they still provide an equally good habitat for the parasites, as evident in the high diversity index. The males also appear to have a more even distribution of parasites across the parasite community they host as shown by the parasite’s evenness values. With the exception of *H. frenatus*, all parasites in/on male geckos has higher evenness value than in females. This suggests that the distribution of parasites in female geckos is highly abundant, aggregated and skewed towards some species of parasites, especially those with higher fecundity. This also suggests female geckos may able to tolerate high levels of parasitism without affecting its fitness. On the other hand, parasitism in males is still abundant and aggregated, but on a lesser degree compared to the females.

The parthenogenetic, all-female gecko *H. garnoti* provided a unique insight on how gender-biased selection works. It appears to be an adept host, equal to the rest of the dioecious gecko species. Although its dominance value is the lowest, diversity and evenness value are still high and the gecko is host to eight parasite species. The gecko species highlighted the fact that with the absence of male geckos, parasitism occurs similarly to the infection behavior in dioecious geckos. Previous works however showed unisexual geckos have lower parasitism compared to sexual geckos (Brown *et al.*, 1995; Hanley *et al.* 1995b).

6.1.3 Host Size

Geckos within the SVL range of 4 to 6 cm harboured the most parasites, in terms of abundance and species richness. Therefore size of the niche plays important role in parasitic infection in geckos; the abundance and species richness of parasites increase as geckos mature (> 4cm). As the geckos grow bigger, its carrying capacity for parasite populations also increases. Bigger geckos mean more space and food resources for the parasites. Therefore it is logical to assume that the bigger the geckos are, the more diverse and abundant the parasites it harbours.

This study has shown that parasites such as the trematodes (*Paradistomum geckonum* and *Postorchigenes ovatus*) and the ectoparasitic mite (*G. bataviensis*) were limited by space during the early stages of the hosts' adulthood. All three parasites consistently increased in abundance and intensity as the geckos grow into adulthood. However after reaching a certain size (≈ 6 cm onwards), their numbers and intensities dropped significantly. The decrease is dramatic; suggesting there is a mechanism that actively eliminates the parasites. This observation may be contributed to two possible explanations; the geckos' immune system and the geckos' behavior.

As the gecko reaches adulthood, its' immune system is now fully developed and it has better ability to cope with parasite infection. Both exposure to the environment and interaction with other geckos contribute in parasitic transmission, which will result in three possible outcomes; the infection ultimately kills the host, or the immune system recognizes the infection and employs either one of these strategies; eliminate the infection or keep the infection under control, or the third outcome, physical or behavioral modification in the case of ectoparasites (i.e. grooming, frequent ecdysis).

The second possible explanation for this observation is the geckos' behavior itself. As the gecko matures, their spatial niche expands. Their habitat range widens and its dietary component diversifies. The geckos are exposed to more diverse infections from the various species of prey consumed. It is possible that the different dietary component may have effects on the parasitic population already established in/on the geckos; either by chemical properties of the diet that may either encourage or expel the available parasite population, or the introduction of a new parasite species which may induce competition for niche in the existing parasite population, or employ mechanisms in order to occupy their niche successfully. Interaction with other geckos through mating and defensive behaviours also contributed to the spread of parasite, especially in the case of ectoparasitic mites.

Gecko hosts susceptibility for parasitic infection within certain size range is very pronounced with most of the parasites preferring medium sized geckos. One particular parasite however, preferred smaller geckos with SVL less than 4 cm to infect. The cestode *Oochoristica javaensis* was more prevalent in small geckos. However the intensity of infection is low, one gecko harbouring usually one cestode at one time, and no more than two in rare instances. Cestode infection in animals generally causes some form of deterioration to the tissues or organs infected. For example, the infections of *Trichinella spiralis* and *Hymenolepis nana* in mammals such as rats, wild boar, bear, or even humans (Parija, 1990). Therefore it is no surprise that the intensity of this parasite is low. All it takes is a single cestode to colonize the gut to drive out other competitors, even from the same species. Once a cestode colonizes the stomach or small intestine, no other gut parasites was found. One possible cause apart from the cestode being a successful competitor is that the damage to the stomach lining or small intestines are severe and no longer a suitable habitat for other gut parasites.

6.2 How parasite species diversity shape the distribution and community structure of the gecko parasites.

Species diversity of house gecko parasites in Malaysia is similar to the observation recorded from Indonesia (Matsuo & Oku, 2002), Sri Lanka (Mahagedara & Rajakaruna, 2015) Australia (Kelehear *et al.*, 2012; 2013; 2015; Barton, 2007; 2015), Africa (Obi *et al.*,

2013) and South America (Anjos *et al.*, 2008). Hotter climates support a higher diversity of reptiles. It also supports a healthy insect population, which serve as intermediate hosts to the parasites.

The parasite compositions in both northern and central regions of Peninsular Malaysia are similar in terms of species diversity but showed a difference in species composition. Both regions show a similarity index value of 51.2%. This provides some clues to the subtle differences between these two regions. The sites from the northern region are less dense with human habitation and it has a higher vegetation cover. The northern region showed higher composition of parasites (i.e. the trematodes) that require more than one host. A basic trematode life cycle requires two intermediate hosts; usually a freshwater mollusc and another invertebrate, preferably insects with coprophagial behaviour. Thus trematodes require a longer route of infection compared to other species of endoparasites. However this does not appear to affect the abundance and intensity of trematode infection in the gecko population. Requirement for more intermediate hosts suggests the environment has the ability to support higher diversity of animals. Therefore it is more stable in terms of the ecosystem ability that can support a healthy environment.

The nematodes found in the gecko population are known to be mildly pathogenic or commensals (Rataj *et al.*, 2011); they do not pose a danger to the geckos' health unless the geckos' immunity is compromised and causes the nematode population to proliferate. Heavy infection of these nematodes may cause some detrimental effects to the gecko. The four species of nematodes from this study are from the family Oxyuridae. Oxyurids are known to have a direct life cycle (Grear & Hudson, 2011); mode of transmission is through fecal ingestion or via fomites. A high level of autoinfection is facilitated by close proximity, therefore suggesting regions with higher abundance of nematodes may have a dense gecko population. Similar to mite transmission, a dense gecko population increases the success of transmission exponentially.

The central region showed a higher percentage of possible cockroach-borne infection compared to the northern region. A higher percentage of nematode infection and mite infection also describes the central region as a highly dense, very human-impacted environment with lower species diversity and evenness compared to the northern region. This is not surprising as the sites in the central region consist of locations in cities. On the contrary the sites in northern region consisted of low to medium density of human population; human impact is minimal to moderate as the main activities in the sites are paddy farming and nature tourism.

6.3 Community structure of gecko parasites.

The gecko community consists of different gecko species co-existing in the same habitat. The competition between geckos is visible with *H. frenatus* emerging as the most successful gecko species. Previous studies have shown how the *H. frenatus* displaced local gecko to the margins by active competition for food and habitat (Kelehear *et al.*, 2013) or by their resiliency towards new parasitic infection (Barton, 2015). However it is unclear whether the situation is similar in Malaysia. Based on the observation from this study, gecko parasities are spatially limited and a niche-based community. Parasitic infection is an opportunistic process from the intermediate hosts to even the final hosts in the case of *R.*

frenatus. Infection is largely shaped by the size of the gecko host (Kelehear *et al.*, 2012). Larger hosts offer more space for the parasites to occupy, especially in the case of the pentastomids.

Certain gecko parasites also appear to have a parasite regulating mechanism in the form of a population of another species occupying the same niche. The gut parasites, the nematodes and the trematode (*Postorchigenes ovatus*), appear to be regulated by the existence of the cestode *Oochoristica javaensis*. The cestode occupies the small intestines, while the trematode occupies the small intestines and the nematodes the large intestines to the rectum. The cestode controls the population of the trematodes and the nematodes; a cestode occupying the stomach can greatly diminish the numbers of trematodes or nematodes occupying the lower region of the gut, in certain cases there were no parasites found in the gut infected by *O. javaensis*. This may be due to the tissue damage inflicted by the cestodes causing the other parasites mobility and feeding problems. Cestodes are known to cause tissue damage on the sites of attachment (Parija, 1990).

The community structure of gecko parasite is largely shaped by the size of the host i.e. the geckos (snout-vent-length). Prevalence, intensity and density of parasites are negatively correlated with the size of the host. Bigger geckos may offer a bigger niche for the parasites to colonize. However the abundance (with the exception of the endoparasites) and density of parasites are higher in small to medium sized geckos. Bigger and older organisms are exposed to more infection (Morand *et al.*, 1996; Lo *et al.*, 1998; Soliman *et al.*, 2001; Valera *et al.*, 2004). They have a varied diet, supposedly giving them more opportunities to obtain endoparasitic infection (with the exception of the oxyurid nematodes which don’t require intermediate hosts) from more intermediate hosts (Roca *et al.*, 2005). However when gecko reaches certain size/age, it will invests more energy on bolstering its immune system, thus helping the gecko to better withstand and minimize parasitic infection. There is a significant drop of parasite abundance once the geckos reach SVL of 6 cm or more (see Figure 3).

Parasitic infection is highly opportunistic; even though the parasites appear to discriminate amongst host species or host gender to a certain extent, the size of the geckos is ultimately the main criterion for a successful infection. With the exception of cestode-infected geckos, parasitism does not appear to affect the geckos’ health as it is able to grow to adult size. However as the geckos grow older, larger sizes no longer play an important role for parasitism, as the age-acquired immunity is capable of minimizing parasite abundance. Cestodes infection on the other hand appears to negatively correlate with gecko host size. This may be due to cestodes preferring to infect smaller, younger geckos with weak immune system with two scenarios; the cestode infection may eventually kills its host before reaching adulthood, or the immune system of the gecko expels the cestodes once the gecko reaches a certain age as there were no geckos with SVLs larger than 4 cm were infected with cestodes.

CHAPTER 7: CONCLUSION

Reptilian parasitofauna may not be as diverse as in fishes and birds; however it provides an excellent opportunity to observe patterns and behaviour of parasite infection with minimal risk of parasite transfer to the observer. Reptile zoonoses are much more contained compared to the mammals; in the case of the geckos, zoonoses are largely accidental infections and most cases leave minimal or no lasting effects.

7.1 Importance of baseline data on parasite community

Gecko parasites have established themselves as generalists with very wide distribution; especially in the case of the pentastomid (*Raillietiella frenatus*), the cestode (*Oochoristica javaensis*), and the trematodes (*Paradistomum geckonum* and *Postorchigenes ovatus*). The nematodes were only identified up to genus level and these genera are known to have worldwide distribution as well. None of the nine gecko parasites studied are specialists; they have been found in hosts apart from the gecko family.

Due to the nature of the house geckos being widely distributed around the world, their parasites make poor indicators. The parasites may also be so versatile in utilizing various intermediate hosts; they are able to make use of a wide range of invertebrates to complete their life cycle. However it is possible to gauge to a certain extent, the level of diversity in an environment based on the parasite composition. A trematode-rich environment may have a higher diversity as most species of trematodes require more than one intermediate host. A pentastomid-rich environment on the other hand may be a densely populated, human-habitated environment, as the main intermediate host for gecko pentastomids is the cockroach. A mite-rich environment may show the environment is densely populated; contacts between the geckos are often which allows easy transfer of mites.

House gecko parasites also are poor indicators of their environment because they are widely distributed. However it is possible to use the information to gauge the ecosystem health if physical parameters are included.

The parasites with potential zoonotic properties are the pentastomid *Raillietiella frenatus*, the mite *Geckobia bataviensis*, and the nematodes *Thelandros* sp., *Spauligodon* sp., *Pharyngodon* sp., and *Skrjabinodon* sp. While there have been cases reported of *Raillietiella* infecting humans, there has been no reports of zoonoses caused by the mite and the nematodes. However due to the similarity of life cycles of these parasites to parasites from the same group that are proven zoonotic or have zoonotic potential, it is important to remain vigilant

7.2 Host specificity affecting infection of gecko parasites.

Previous studies have shown that the nine species of parasites recorded in this study are not host specific. However there is some form of host species susceptibility in the gecko community studied which may be contributed to the gecko species composition in the habitat. The parasites infect all five house gecko species; however their pattern of infection differs. *Hemidactylus frenatus* may host all nine species of parasites, but it is not the most susceptible gecko host compared to the other gecko species. As documented worldwide, this gecko species can host a high diversity of parasites, taking in local parasitofauna of new habitats they are not native in. A mark of a successful invader, these geckos have strategies to maintain their parasite load so that it does not interfere with their ability to compete with local gecko fauna for food and space. The difference between the infection behaviour between house geckos with very similar life histories maybe down to possible dietary preferences of the geckos.

7.3 Gender and size-based infection and its implications.

Gender-based infection although exist in some of the parasites studied may be due to sample size, as the sample of each species randomly collected consisted of mostly female geckos. Two species showed female host-biased infection, the pentastomid (*Raillietiella frenatus*) and the ectoparasitic mite (*Geckobia bataviensis*). Both parasites feed on blood, which suggest that female hormones may be the controlling factor in the infection of these parasites. Most of the gut parasites showed different host gender infection bias or no bias at all in different gecko species. This ambiguosity may be due to the numbers than to actual preference, as some parasites have higher fecundity. However it is uncertain whether it is down to the numbers or real host bias as this may require indepth study of the hosts' immunology profile and physiology.

Host size plays the most important criterion for infection of these parasites. The hosts had a higher abundance of parasites during the reproductive stage, with the exception of the cestode, *Oochoristica javaensis*, which was most abundant in smaller, younger hosts. Three conclusions can be drawn from this observation; 1. the parasite prefers younger hosts because the immune system is still underdeveloped, allowing easy infection, or 2. this observation is the product of infection, where the cestode infection affects the growth and fitness of the gecko, eventually killing the geckos before it reaches adulthood, or 3. the geckos have a defense mechanism where as they grow older, the immune system manages to control or expel cestode infection.

With the exception of *O. javaensis*, parasites abundance increases as the geckos grow bigger in size, and then slowly decrease as the geckos reach certain size (age). This bell-curve observation in both prevalence, intensity, and abundance of infection of parasites suggests that while choosing a host to infect/infest, physiological factors such as host availability and fitness play a bigger role. Infection is largely due to chance, but ability to latch on is contributed to strategies employed by the parasites and the defense mechanism of the hosts. Hosts in the reproductive phase obtain higher amount of food in order to keep up with high energy consumption required during the phase, therefore exposing them to more parasitic infection. Once inside/on the hosts, the parasites are able to proliferate better on a host that has a high fitness as it consumes more food which translates to higher body mass. This provides a bigger niche and more food source for the parasites. As the host grows older, its immune system matures and is more able to cope with parasitic infection. Also as the gecko undergoes moulting, some ectoparasites may be lost, which help decreases the total parasite load.

7.4 Parasite community structure of house geckos.

Species composition varies between mainland and island sites. Island habitats are more than the mainland. Therefore gecko community that lives in crowded clusters allowing easy transfer of ectoparasites. Parasites also exist in higher densities in island habitat, and this may be a strategy to ensure species survival by forming a reservoir in a limited resource (of gecko hosts). However this explanation must be viewed with discretion as gecko parasites have been known to infect animals limited to the gecko family. As there have been no gecko parasite data on host species apart from geckos from the sites studied, comparisons could not be accurately performed.

The study sites have similar species richness but with different species composition. While the sites in northern region have higher nematode and trematode abundance, the central region has higher abundance of mites and cestodes. This suggests that the northern region has a higher diversity of intermediate hosts as the trematodes require at least two intermediate hosts in order to complete their life cycles. The nematodes are oxyurids; therefore complete their life cycle via autoinfection. The sites in the central region have the highest abundance of pentastomids and ectoparasitic mites. The pentastomids are transmitted by the common household pest such as cockroach. The mites on the other hand are transmitted through direct contact of the geckos. This suggests that the geckos in the central region exist in high concentration, similar to the geckos in island habitats. However the reason they concentrate in the sites may be due to high abundance of food instead of geographical limitations instead.

There are very little similarity between three island habitats examine in this study. The highest similarity was between Langkawi and Carey island, with an index of slightly over 50%. This observation may be due to geographical factors and human activities. Carey island is very close to the mainland while Langkawi is much further away. Carey island consists of vast oil palm plantations, with oil palm processing centre while Langkawi relies on tourism and fishing.

Parasite abundance is weakly correlated to the size of the geckos (snout-vent-length). The abundance of endo- and ectoparasites are shown to be negatively correlated with SVL; the bigger the geckos, the less abundant the parasites. The density of parasitic infection also becomes less dense as the geckos grow older. This observation is due to low samples of young geckos (SVL > 4 cm) therefore affects the outcome of the analysis. Other possible explanations include 1. As the geckos grow older, the immune system mature and are able to withstand parasitism. 2. Geckos undergo more moulting and grooming as they get bigger, which may help to reduce the ectoparasites. 3. Geckos in reproductive phase participate in fights and mating rituals, which can cause both transfer and loss of mite infection. Species richness is not affected by the size of geckos; parasites appear to be able to infect the geckos at any stage of the gecko development, however they do thrive better at a certain phase of the gecko’s life.

7.5 Suggestions for future research

Recent breakthroughs in Lyme disease research offered a brilliant insight; lizards bitten by ticks infected by the bacterium *Borrelia burgdorfferi* is capable of stopping the infection from reaching its final mammalian host. Lizards are maligned due to their part in the spread of Lyme disease in the past. However with these findings; researchers can design a novel way to engage the lizards as a zooprophylaxis against Lyme disease. The researchers are currently working on determining what is the exact component in the lizard's blood that kill off the bacteria once it enters the bloodstream through a tick's bite. Similar approach can also be applied to other blood-borne parasitic diseases. Ticks and mites are hosts to protozoans and microfilarial worms, both are known as zoonotic agents transmissible via blood. It is also essential to look at immunological properties that may have effects on parasitism as this is a mean to control and even possible eradication of parasitic diseases.

Most reptilian parasites behave in such a manner that is only comparable to a pioneer species. Parasite such as *Raillietilla frenatus* has the ability to adapt to many different final hosts and not just confined to geckos. It has shown a formidable capability of displacing other pentastomids species in a new population of geckos. This pentastomid species is as invasive as the host its name was derived from, the gecko *Hemidactylus frenatus*. It may be beneficial to study the patterns of distribution of this pentastomid species and the mechanisms adapted in order to become a successful invader species as this may provide researchers a model on how to deal with invasive species effectively. It is also beneficial to study other gecko parasites in this study especially the cestode *Oochoristica javaensis* and the trematodes *Paradistomum geckonum* and *Postorchigenes ovatus* in different hosts as they have the potential to become as widespread as the *R. frenatus*. So far there are no evidence of these parasites causing serious harm to their hosts, therefore they provide a good and safe model to work with.

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LIST OF PUBLICATIONS AND PAPERS PRESENTED

1. Oral presentation at the 14th Biological Science Graduate Congress 2009 in Chulalongkorn University, Thailand. Title: Pentastomid Infection in Seven Species of Malaysian Geckos.
2. Effects of host's gender on the infestation pattern of ectoparasitic mite, *Geckobia bataviensis* (Actinedida: Pterygosomatidae) submitted to Current Science. Date of submission 11th April 2016
3. Parasite community structure of two house geckos (Family Gekkonidae: *Hemidactylus frenatus* and *H. platyurus*) from Peninsular Malaysia in relations to host body size. Submitted to Tropical Biomedicine. Date of submission 27th December 2016

APPENDIX A

Appendix A Past Parasitofauna Studies of Lizards.

No	Host Species	Parasites		Locality	Author
		Group	Species		
1	African, South-East-Asian and Indonesian lizards	P	*Raillietiella hemidactyli* *R. mabuaie* *R.frenatus* *R.Gehyrae* *R.maculatus* *R. geckonis*	East Asia and Indonesia	Ali *et al*. (1981)
2	*Hemidactylus frenatus*	P	*Armillifer* sp *Raillietiella frenatus*	Brazil	Anjos *et al.* (2008)
3	*Gehyra mutilata*	P	*Raillietiella gehyrae*	Malaysia	Inder Singh *et al*. (1985)
4	*Gekko monarchus*	P	*Raillietiella* sp.	Malaysia	Jeffrey *et al*. (1985)
5	*Platyurus platyurus* *Hemidactylus frenatus* *Hemidactylus sp.* *Gehyra mutilata* *Gekko monarchus*	P	*Raillietiella frenatus* *R.gehyrae* *R. monarchus* *Raillietiella* sp	Malaysia	Jeffrey *et al*. (1994),
6	*Gekko smithi*	P	*Raillietiella* sp.	Malaysia	Jeffrey *et al*. (1997)
7	*Hemidactylus frenatus*	P	*Raillietiella* sp.	Malaysia	Jeffrey *et al*., (2003)
8	*Mabuya homalocephala*	P	*Raillietiella gehyrae*	Kenya, Africa	Pence & Canaris (1973)
9	*Gekko gekko* Egyptian desert lizards	P	*Raillietiella affinis*	Scotland	Ali, *et al.* (1981)
10	*Egyptian desert lizards* *Gekko gecko*	P	*Raillietiella aegypti* *Raillietiella affinis*	Egypt Indonesia	Ali, *et al.* (1982)

	Hemidactylus brooki		*Raillietiella geckonis*	Nigeria	
11	*Egernia inornata* *Nephrurus laevissimus*	N	*Kreisiella chrysocampa* *Physalopteroides filicauda*	Australia	Jones (1985)
12	*Tarentola annularis*	N	*Physalopteroides tarentolae*	Sudan	Elwasila (1990)
13	*Hemidactylus brooki*	P	*Raillietiella sp.*	Africa and Caribbean	Riley *et al.* (1991)
15	*Hemidactylus frenatus*	N	*Spauligodon Hemidactylus*	Oceania	Bursey & Goldberg (1995)
16	*Anolis gingivinus*	C	*Oochoristica macoyi*	Lesser Antilles	Bursey & Goldberg(1996)
17	*Gehyra mutilata*	C	*Cylindrotaenia allisonae*	Micronesia	
	Gehyra oceanica		*Oochoristica javaensis*		Goldberg *et al.* (1998) .
	Hemidactylus frenatus	T	*Allopharynx macallisteri*		
	Lepidodactylus lugubris	N	*Pharyngodon lepidodactylus* *Spauligodon gehyrae* *Spauligodon hemidactylus* *Skrjabinodon machidai* *Oswaldcruzia* sp.		
18	*Lepidodactylus lugubris*	N	*Physalopteroides arnoensis* *Pharyngodonlepidodactylus* *Hedruris hanleyae* *Maxvachonia chabaudi* *Ascarops* sp.	Oceania	Bursey & Goldberg (2001).
19	*Perchydactylus turneri*	N	*Madathamugadia hiepei*	South Africa	Hering-Hagenbeck *et al.* (2000)
20	*Hemidactylus garnotii*	N	*Hedruris hanleyae*	Cook Islands	Bursey & Goldberg (2000)
21	*Eublepharis angramainyu*	M	*Geckobia anocellatus*	Iraq	Bochkov & Mironov (2000)

	Tenuidactylus caspius		*Geckobia hirsti*	Turkmenistan	
22	*Cosymbotus platyurus* *Gehyra mutilate* *Hemidactylus frenatus* *Lepidodactylus aureolineatus* *Hemidactylus garnotii* *Hemiphyllodactylus typus*	C N	*Oochoristica javaensis* *Parapharyngodon maplestonii* *Spauligodon hemidactylus*	The Phillippines and Thailand	Goldberg & Bursey (2001)
23	*Gehyra mutilate* *Gehyra oceanica* *Hemidactylus frenatus H.garnotii* *Lepidodactylus lugubris L. moestus L.paurolepis*	C N	*Cylindrotaenia allisonae* *Oochoristica javaensis* *Hedruris hanleyae* *Maxvachonia chabaudi* *Parapharyngodon maplestonii* *Pharyngodon lepidodactylus* *Physalopteroides arnoensis* *Skrjabinodon machidai* *Spauligodon gehyrae* *Spauligodon hemidactylus* *Ascarops* sp. *Physaloptera* sp.	Oceania	Goldberg & Bursey (2002)
24	*Liolaemus* spp	N	*Spauligodon loboi*	Argentina	Ramallo *et al*. (2002)
25	*Cosymbotus platyurus* *Gehyra mutilata* *Hemidactylus frenatus*	C T	*Oochoristica javaensis* *Paradistomum geckonum* *Postorchigenes ovatus*	Indonesia	Matsuo & Oku, Y. (2002)

		N	*Spauligodon hemidactylus*		
		P	*Raillietiella gehyrae* *R. frenatus*		
26	*Cnemidophorus mexicanus* *C.deppii*	N	*Spauligodon garciaprietoi*	Southern Mexico	Jimenez-Ruiz *et al*. (2003)
27	*Calotes versicolor* *Laudakia caucasica* *L. nupta* *L. tuberculata* *Trapelus agilis* *Uromastyx hardwickii* *Eublepharis macularius* *Hemidactylus flaviviridis* *H. triedrus* *Acanthodactylus cantoris* *Eumeces schneiderii*	T	*Paradistomoides orientale*	Pakistan	Goldberg *et al.* (2003)
		N	*Abbreviata achari* *A. kolayatensis* *Parapharyngodon calotis* *Pharyngodon frenatusi* *Pharyngodon mamillatus* *Spinicauda hardwickii* *Strongyluris calotis* *Tachygonetria indica* *T. paradentata* *Thelandros baylisi* *T.masaae* *T.taylori*		
		P	*Raillietiella hemidactyli*		
		A	Cystacanth		
28	*Hemidactylus mabouia*	M	*Geckobia hemidactylii*	Caribbean and South America	Rivera *et al.* (2003)
29	*Podacris sicula*	N	*Spauligodon aloisei*	Italy	Casanova *et al.* (2003)
30	*Anolis frenatus*	N	*Rhabdias anolis*	Panama	Bursey *et al.* .(2003)
31	*Mabuya dorsivittata*	N	*Physaloptera retusa* *Skrjabinodon*	Brazil	Rocha et al (2003)

			spinosulus		
32	*Norops limifrons*	A	*Acanthocephalus saurius*	Costa Rica	Bursey & Goldberg (2003)
		T	*Mesocoelium monas*		
		N	*Piratuba digiticauda*		
			Strongyluris panamaensis		
			Acuariidae		
33	*Anolis biporcatus*	N	*Strongyluris panamaensis*	Panama	Bursey *et al*. (2003)
			Crytosomum penneri		
			Oswaldcruzia bainae		
		T	*Piratuba digiticauda*		
			Mesocoelium monas		
			Parallellopharynx arctus		
			Urotrema scabridum		
34	*Gekko gekko*	C	*Oochoristica rachiensis*	USA	Reese *et al.* (2004)
		T	*Mesocoelium monas*		
			Paradistomum geckonum		
		N	*Pharyngodon kuntzi*		
			Skrjabinodon sp.		
			Parapharyngodon.		
			Meteterakis longispiculata		
			Physalopteroides sp		
			Strongyloides sp.		
			Porrorchis sp		
			Raillietiella affinis		

		A P			
35	*Prionodactylus eigenmanni* *P. oshaughnessyi*	N T A	*Oswaldcruzia vitti* *Mesocoelium monas* *Acanthocephalus saurius*	Brazil and Ecuador	Bursey & Goldberg (2004)
36	*Leiosaurus belli* *Leiosaurus catamarcensis* *Liolaemus andinus* *Liolaemus buergeri* *Liolaemus chiliensis* *Liolaemus elongatus* *Liolaemus lemniscatus* *Liolaemus neuguensis* *Liolaemus neuguensis* *Liolaemus pictus argentius* *Liolaemus tenui* *Liolaemus vallecurensis* *Phymaturus palluma*	Ce N P	*Oochoristica travassosi* *Physaloptera retusa* *ParaPharyngodonPharyngodon riojensis* *Spauligodon maytacapaci* *Kiricephalus* sp	Argentina	Goldberg *et al.* (2004)
37	*Hemidactylus mabouia*	N	*ParapharyngodonPharyngodon sceleratus* *ParaPharyngodonPharyngodon largitor* *Physaloptera sp.*	Brazil	Anjos *et al.* (2005)
38	*Norops oxylophus* *Norops cupreus*	T	*Urotrema shirleyae*	Costa Rica	Zamparo *et al.* (2005)

39	*Emoia atrocostata* *E. boettgeri* *E. cyanura* *E. caerulocauda* *E. cyanogaster* *E. impar* *E. nigra* *E. nigromarginata* *E. penapea* *E. sanfordii* *E. trossula*	T N	*Paradistomoides gregarium* *Hedruris hanleyae* *Maxvachonia chabaudi* *Moaciria* sp. indet. *Parapharyngodon maplestoni* *Physalopteroides arnoensis* *Spauligodon gehyrae*	Oceania	Goldberg *et al.* (2005)
40	*Uranoscodon supercilious*	T N	*Allopharynx daileyi* *Mesocoelium monas* *Africana chabaudi* *Cosmocerca vrcibradici*	Brazil	Bursey *et al.* (2005)
41	Gekko, Scincid, Agamid, etc	Ce N	*Oochoristica ameivae* *Ophiotaenis flava* *Amphibiocapillaria freitaslentii* *Cyrtosomum longicaudatum* *Oswaldcruzia peruvensis* *O.vitti* *O.azeuedoi* *ParaPharyngodonPharyngodon scleratus* *Physaloptera retusa* *Physalopteroides venancioi* *Piratuba digitacauda* *P.lainsoni* *P.zeae* *Rhabdia Anolis*	Peru	Bursey *et al.* (2005)

			Skrjabinelzaia intermedia *Spauligodon oxkutzcabiensis* *Spinicauda spinicauda* *Strongylus oscari* *Dujadinascaris* sp. *Hastospiculum* sp.		
42	*Gehyra mutilata* *Hemidactylus frenatus* *Mabuya cumingi* *M.multifasciata*	C	*Oochoristica excelsa* *O.javaensis*	The Philippines	Goldberg *et al.* (2005)
		T	*Mesocoelium monas* *Plagiorchis taiwanensis* *Postorchigenes ovatus*		
		N	*Kalicephalus viperae chunkingensis* *Pharyngodonoceanicus* *Spauligodon hemidactylus*		
		P	*Raillietiella frenatus*		
43	*Lepidodactylus novaeguineaensis*	N	*Spauligodon zweifeli*	Papua New Guinea	Goldberg & Bursey (2005)
44	*Agama caudospina*	N	*Parapharyngodon kenyaensis* *Thelandros* *Thelandros samburuensis* *Abbreviata ortleppi* *Strongyluris ornata*	Kenya, Africa	Goldberg & Bursey (2005)

45	*Sphenomorphus jobiensis*	T	*Zeylanurotrema sphenomorphi*	Papua New Guinea	Goldberg *et al.* (2005)
		Ce	*Oochoristica javaensis*		
		N	*Meterakis crombiei* *Physalopteroides milensis* *Abbreviata oligopapillata* *Aplectana macintoshii* *A.zweifeli* *Cosmocerca zugi* *Maxvachonia adamsoni* *Oswaldcruzia bakeri* *ParaPharyngodonPharyngodon maplestoni* *Acanthocephalus bufonis*		
		P	*Kiricephalus* sp		
46	*Egernia stokesii*	N	*PharyngodonPharyngodon tiliquae* *Thelandros Thelandros trachysauri*	Australia	Hallas *et al.* (2005)
47	*Gehyra mutilata* *Hemidactylus frenatus* *Mabuya cumingi* *Mabuya multifasciata* *Ramphotyphlops braminus*	C	*Oochoristica excelsa* *Oochoristica javaensis*	The Philippines	Goldberg *et al.* (2005)
		T	*Mesocoelium monas* *Plagiorchis taiwanensis* *Postorchigenes ovatus*		
		N	*Kalicephalus viperae chunkingensis* *PharyngodonPharyngodon oceanicus*		

		P	*Spauligodon Hemidactylus Raillietiella frenatus*		
48	*Ctenosaura pectinata*	C	*Oochoristica leonregagnonae*	Mexico	Arizmendi-Espinosa, *et al.* (2005)
49	*Gallotia atlantica*	P	*Raillietiella morenoi*	Canary Islands	Abreu-Acosta *et al.* (2005).
50	*Cyrtodactylus lousiadensis*	C T N	*Gekkotaenia novaeguineaensis Cyclophyllidea* sp *Mesocestoides* sp. *Allopharynx macalliste rii* *Cosmocerca zugi Abbreviata* sp *Aplectana macintoshii Oswaldcruzia bakeri Parapharyngodon maplestoni*	Papua New Guinea	Bursey *et al.* (2005)
51	*Laudakia caucasia L. stellio*	C N	*Oochoristica tuberculata* *Foleyella candezei ParaPharyngodonPharyngodon tyche Thelandros Thelandros baylisi Foleyella candezei ParaPharyngodonPharyngodon kasauli P. tyche Thelandros Thelandros taylori Strongyluris calotis* Ascaridoid	Turkey	Yildirimhan *et al.* (2006)

			larvae		
52	*Ameiva festiva*	N	*Oswaldcruzia nicaraguensis*	Nicaragua	Bursey *et al.* (2006)
53	*Chameleo inturensis*	N	*Macaraya africana*	Congo	Bouamer & Morand (2006)
54	*Petrosaurus repens* *Petrosaurus thalassinus*	N C	*ParaPharyngodonPharyngodon grismeri* *Spauligodon giganticus* *Strongyluris similis* *Ascarops* *Physaloptera* sp. *Oochoristica* sp.	Mexico	Bursey & Goldberg (2007)
55	*Norops capito*	N A	*Rhabdia nicaraguensis* *Oswaldcruzia nicaraguensis* *Acanthocephalus saurius*	Nicaragua	Bursey *et al.* (2007)
56	*Hemidactylus frenatus*	P	*Raillietiella frenatus* *Waddycephalus* sp.	Australia	Barton (2007)

57	*Ameiva ameiva* *Basiliscus basiliscus* *Corytophanes cristatus* *Diploglossus monotropis* *Echinosaura horrida* *Gonatodes albogularis* *Gymnophthalmus speciosus* *Iguana iguana* *Lepidoblepharis sanctaemartae* *Lepidophyma flavimaculatum* *Leposoma rugiceps* *Mabuya mabouya* *Polychrus gutturosus* *Thecadactylus rapicauda*	T Ce N	*Mesocoelium monas* *Parallopharynx arctus* *Oochoristica gymnophthalmicola* *Africana telfordi* *Aplectana herediaensis* *Cosmocercoides variabilis* *Cruzia mexicana* *Cyrtosomum longicaudatum* *Macdonaldius grassi* *Oswaldocruzia panamaensis* *Oswaldofilaria brevicaudata* *Ozolaimus cirratus* *ParaPharyngodonPharyngodon colonensis* *Physaloptera retusa* *Piratuba digiticauda* *Skrjabinelazia galliardi* *SkrjabinodonSkrjabinodon caudolumarius* *SkrjabinodonSkrjabinodon crassicauda* *SkrjabinodonSkrjabinodon scelopori* *Spauligodon oxkutzcabiensis* *Spinicauda spinicauda* *Strongyluris panamaensis*	Panama	Bursey*et al.* (2007)

		  A	*Ophidascaris* sp. *Acuariidae* Cystacanth		
58	*Kentropyx calcarata* *Potamites ecpleopus* *Leposoma osvaldoi*	N T	*Kentropyxia sauria* *Physaloptera retusa* *Falcaustra belemensis* *Brachycoelium salamandrae*	Brazil	Goldberg *et al.* (2007)
59	*Gambelia wislizenii*	N A	*Porrocaecum* sp. *Cyrtosomum penneri* *SkrjabinodonSkrjabinodon phrynosoma* Oligacanthorhynchid cystacanth	USA	McAllister *et al.* (2007)

P = Pentastomid; C = Cestode; T = Trematode; N = Nematode; M = Mite; A = Acanthocephala

APPENDIX B

Appendix B Gecko Species Found in Malaysia.

Gecko Species	WM	EM	Both
Aeluroscalabotes felinus (Günther, 1864)			+
Cnemaspis affinis (Stoliczka, 1870)	+		
Cnemaspis argus Dring, 1979	+		
Cnemaspis baueri Das and Grismer, 2003	+		
Cnemaspis bayuensis Grismer, Grismer, Wood and Chan, 2008	+		
Cnemaspis bidongensis Grismer, Wood, Ahmad, Sumarli, Vazquez, Ismail, Nance, Mohd-Amin, Othman, Rizaijessika, Kuss, Murdoch & Cobos, 2014	+		
Cnemaspis biocellata Grismer, Chan, Nasir and Sumontha, 2008	+		
Cnemaspis chanardi Grismer, Sumontha, Cota, Grismer, Wood, Pauwels and Kunya, 2010	+		
Cnemaspis dringi Das and Bauer, 1998		+	
Cnemaspis flavigaster Chan and Grismer, 2008	+		
Cnemaspis flavolineata (Nicholls, 1949)	+		
Cnemaspis grismeri Wood, Quah, Anuar M.S. and Muin, 2013	+		
Cnemaspis hangus Grismer, Wood, Anuar, Riyanto, Ahmad, Muin, Sumontha, Grismer, Onn, Quah and Pauwels, 2014	±		
Cnemaspis harimau Chan, Grismer, Anuar, Quah, Muin, Savage, Grismer, Ahmad, Remigio and Greer, 2010	+		
Cnemaspis karsticola Grismer, Grismer, Wood and Chan, 2008	+		
Cnemaspis kendallii Gray, 1845	+		
Cnemaspis kumpoli Taylor, 1963	+		
Cnemaspis limi Das and Grismer, 2003	+		
Cnemaspis mahsuriae Grismer, Wood, Quah, Anuar, Ngadi and Ahmad, 2015	+		
Cnemaspis mcguirei Grismer, Grismer, Wood and Chan, 2008	+		
Cnemaspis monachorum Grismer, Ahmad, Chan,	+		

Belabut, Muin, Wood and Grismer, 2009			
Cnemaspis nigridius Smith, 1925	+		
Cnemaspis omari Grismer, Wood, Anuar, Riyanto, Ahmad, Muin, Sumontha, Grismer, Onn, Quah and Pauwels, 2014	+		
Cnemaspis paripari Grismer and Onn, 2009		+	
Cnemaspis pemanggilensis Grismer and Das, 2006	+		
Cnemaspis peninsularis Grismer, Wood, Anuar, Riyanto, Ahmad, Muin, Sumontha, Grismer, Onn, Quah and Pauwels, 2014	+		
Cnemaspis perhentianensis Grismer and Chan, 2008	+		
Cnemaspis pseudomcguirei Grismer, Ahmad, Chan, Belabut, Muin, Wood and Grismer, 2009	+		
Cnemaspis roticanai Grismer and Onn, 2010	+		
Cnemaspis shahruli Grismer, Chan, Quah, Muin, Savage, Grismer, Ahmad, Greer and Remegio, 2010	+		
Cnemaspis stongensis Grismer, Wood, Anuar, Riyanto, Ahmad, Muin, Sumontha, Grismer, Onn, Quah and Pauwels, 2014	+		
Cnemaspis temiah Grismer, Wood, Anuar, Riyanto, Ahmad, Muin, Sumontha, Grismer, Onn, Quah and Pauwels, 2014	+		
Cyrtodactylus astrum Grismer, Wood JR, Quah, Anuar, Muin, Sumontha, Ahmad, Bauer, Wangkulangkul, Grismer and Pauwels, 2012	+		
Cyrtodactylus aurensis Grismer, 2005	+		
Cyrtodactylus australotitiwangsaensis Grismer, Wood JR, Quah, Anuar, Muin, Sumontha, Ahmad, Bauer, Wangkulangkul, Grismer and Pauwels, 2012	+		
Cyrtodactylus baluensis Mocquard, 1890		+	
Cyrtodactylus batucolus Grismer, Chan, Grismer, Wood and Belabut, 2008	+		
Cyrtodactylus bintangrendah Grismer, Wood JR, Quah, Anuar, Muin, Sumontha, Ahmad, Baeur, Wangkulangkul, Grismer and Pauwels, 2012	+		
Cyrtodactylus bintangtinggi Grismer, Wood JR, Quah, Anuar, Muin, Sumontha, Ahmad, Bauer, Wangkulangkul, Grismer and Pauwels, 2012		+	
Cyrtodactylus cavernicolus Inger and King, 1961	+		
Cyrtodactylus consobrinus Peters, 1871			+
Cyrtodactylus durio Grismer, Anuar, Quah, Muin, Onn,	+		

Grismer and Ahmad, 2010		
Cyrtodactylus elok Dring, 1979	+	
Cyrtodactylus guakanthanensis Grismer, Belabut, Quah, Onn, Wood and Hasim, 2014	+	
Cyrtodactylus ingeri Hikida, 1990		+
Cyrtodactylus jarakensis Grismer, Chan, Grismer, Wood and Belabut, 2008	+	
Cyrtodactylus jelawangensis Grismer, Wood, Anuar, Quah, Muin, Mohamed, Onn, Sumarli, Loredo and Heinz, 2014	+	
Cyrtodactylus langkawiensis Grismer, Wood JR, Quah, Anuar, Muin, Sumontha, Ahmad, Baeur, Wangkulangkul, Grismer and Pauwels, 2012	+	
Cyrtodactylus lateralis Werner, 1896	+	
Cyrtodactylus leegrismeri Chan and Norhayati, 2010	+	
Cyrtodactylus macrotuberculatus Grismer and Ahmad, 2008	+	
Cyrtodactylus malayanus De Rooij, 1915		+
Cyrtodactylus marmoratus Gray, 1831	+	
Cyrtodactylus matsuii Hikida, 1990		+
Cyrtodactylus metropolis Grismer, Wood, Onn, Anuar and Muin, 2014	+	
Cyrtodactylus pantiensis Grismer, Chan, Grismer, Wood and Belabut, 2008	+	
Cyrtodactylus payacola Johnson, Quah Anuar, Muin, Wood, Grismer, Greer, Onn, Ahmad, Bauer and Grismer, 2012	+	
Cyrtodactylus peguensis Boulenger, 1893	+	
Cyrtodactylus philippinicus Steindachner, 1867		+
Cyrtodactylus pubisulcus Inger, 1958		+
Cyrtodactylus pulchellus Gray, 1827	+	
Cyrtodactylus quadrivirgatus Taylor, 1962	+	
Cyrtodactylus semenanjungensis Grismer and Leong, 2005	+	
Cyrtodactylus seribuatensis Youmans and Grismer, 2006	+	
Cyrtodactylus sharkari Grismer, Wood, Anuar, Quah, Muin, Mohamed, Onn, Sumarli, Loredo and Heinz, 2014	+	
Cyrtodactylus stresemanni Rösler and Glaw, 2008	+	
Cyrtodactylus sworderi Smith, 1925	+	
Cyrtodactylus tebuensis Grismer, Anuar, Muin, Quah and Wood, 2013	+	

Cyrtodactylus timur Grismer, Wood, Anuar, Quah, Muin, Mohamed, Onn, Sumarli, Loredo and Heinz, 2014	+		
Cyrtodactylus tiomanensis Das and Lim, 2000	+		
Cyrtodactylus trilatofasciatus Grismer, Wood JR, Quah, Anuar, Muin, Sumontha, Ahmad, Bauer, Wangkulangkul, Grismer and Pauwels, 2012	+		
Cyrtodactylus yoshii Hikida, 1990		+	
Gehyra butleri Boulenger, 1900	+		
Gehyra mutilata Wiegmann, 1834	+		
Gekko gecko Linnaeus, 1758	+		
Gekko monarchus Schlegel, 1836			+
Gekko smithii Gray, 1842	+		
Hemidactylus brookii Gray, 1845	+		
Hemidactylus craspedotus Mocquard, 1890	+		
Hemidactylus frenatus Schlegel, 1836			+
Hemidactylus garnotii Duméril and Bibron, 1836			+
Hemidactylus platyurus (Schneider, 1792)			+
Hemiphyllodactylus bintik Grismer, Wood, Anuar, Quah, Muin, Onn, Sumarli and Loredo, 2015	+		
Hemiphyllodactylus harterti (Werner, 1900)	+		
Hemiphyllodactylus larutensis (Boulenger, 1900)	+		
Hemiphyllodactylus tehtarik Grismer, Wood Jr, Anuar, Muin, Quah, McGuire, Brown, Van Tri and Thai, 2013	+		
Hemiphyllodactylus titiwangsaensis Zug, 2010	+		
Hemiphyllodactylus typus Bleeker, 1860	+		
Lepidodactylus lugubris Duméril and Bibron, 1836	+		
Lepidodactylus ranauensis Ota and Hikida, 1988		+	
Luperosaurus browni Russell, 1979	+		
Luperosaurus sorok Das, Lakim, Kandaung, 2008		+	
Ptychozoon horsfieldii Gray, 1827	+		
Ptychozoon kuhli Stejneger, 1902	+		
Ptychozoon lionotum Annandale, 1905		+	
Ptychozoon rhacophorus Boulenger, 1899	+		

- Sources : The Reptile Database www.reptile-database.org
- WM = West Malaysia; EM= East Malaysia