

## Parasite populations in the brown rat *Rattus norvegicus* from Doha, Qatar between years: the effect of host age, sex and density

M.A. Abu-Madi<sup>1\*</sup>, J.M. Behnke<sup>2</sup>, M. Mikhail<sup>3</sup>, J.W. Lewis<sup>4</sup> and  
M.L. Al-Kaabi<sup>3</sup>

<sup>1</sup>Department of Applied Sciences, Qatar College of Technology,  
PO Box 36007, Doha, Qatar: <sup>2</sup>School of Biology, University of Nottingham,  
Nottingham, NG7 2RD, UK: <sup>3</sup>Department of Health-Affairs, Ministry  
of Municipal Affairs and Agriculture, Doha, Qatar: <sup>4</sup>School of Biological  
Sciences, Royal Holloway, University of London, Egham, Surrey,  
TW20 OEX, UK

### Abstract

A total of 179 urban rats were sampled in the city of Doha in Qatar across the winter seasons (February–April) of 2002 and 2003. Only two parasites were identified, with overall prevalences of 35.8% and 41.3% for the cestode *Hymenolepis diminuta* and the flea *Xenopsylla astia* respectively. The prevalence of *H. diminuta* was markedly influenced by both year of study and host age, being higher in 2003 and amongst older rats. The abundance of infection of *H. diminuta* was influenced by the year of study, host age and sex. Worm burdens in adult rats were almost twice as heavy in males compared with females and adults of both sexes harboured heavier infections than juveniles. The prevalence of *X. astia* was influenced by both year and host age, being higher in juvenile rats in 2002 and in adults in 2003. The abundance of *X. astia* was significantly higher in 2003 and both male and female rats showed similar abundances, but in 2003 females were more heavily infested. Reasons for this are discussed in relation to the differing foraging strategies shown by male and female rats. The prevalence and abundance profiles for both *H. diminuta* and *X. astia* were higher overall in 2003 due to a significant increase in the rat population density, although this did not reflect in any increase in parasite species richness. Rats that were infected with *H. diminuta* were almost twice as likely to be infected with *X. astia* than those without the cestode, but when controlled for the effects of year, host age and sex, no quantitative interactions were detected between the two parasite species.

### Introduction

Studies on parasitic infections in wild rodents inhabiting temperate regions of Europe have often revealed rich and taxonomically diverse species, occurring in

structured and dynamic communities (Lewis, 1968a,b; Montgomery & Montgomery, 1989; Haukisalmi & Henttonen, 1993; Tenora & Stanek, 1995; Webster & Macdonald, 1995; Behnke *et al.*, 1999). In the Middle East and Africa, with the exception of Behnke *et al.* (2000) and Abu-Madi *et al.* (2001), there is comparatively little information on variation in patterns of infection and in the parasite infra- and component community structures of small rodents inhabiting these regions. The component community structure of helminths in wild rodents in any geographical region is influenced by both extrinsic (year,

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Address for correspondence: Department of Health Sciences,  
Faculty of Arts and Science, University of Qatar, PO Box 2713,  
Qatar  
Fax: (+974) 4880337  
E-mail: abumadi@qu.edu.qa

season, site) and intrinsic (host sex, age, reproductive status) factors (Haukisalmi *et al.*, 1988; Boggs *et al.*, 1991; Abu-Madi *et al.*, 1998, 2000; Behnke *et al.*, 1999). In general, extrinsic factors exert the most important influence in shaping the component community structure in ways that vary from site to site (Kisielewska, 1970; Mollhagan, 1978; Montgomery & Montgomery, 1990; Abu-Madi *et al.*, 2000) and through seasonal and annual changes (Langley & Fairley, 1982; O'Sullivan *et al.*, 1984; Haukisalmi *et al.*, 1988; Montgomery & Montgomery, 1988). Seasonal influences on the abundance of helminth infections harboured by rodents are well established (Lewis, 1968a; Langley & Fairley, 1982) but there is still a paucity of information on the stability or otherwise of infections in small mammals extending over periods of several consecutive years and the relative importance of annual versus seasonal cycles has not been thoroughly investigated (Keymer & Dobson, 1987).

In contrast to small rodents such as wood mice and voles, and perhaps surprisingly, larger rodents such as rats have been relatively neglected by helminthologists. The brown rat, which is cosmopolitan in distribution, is primarily a burrowing species and is commonly found living near sources of food and water, such as refuse and drainage ditches, streams or sewers. Brown rats are typically ground dwellers as opposed to black rats, *Rattus rattus*, which tend to climb more. In the wild, *R. norvegicus* may live for up to three years, but few live beyond two years of age, with most surviving only one year (Davis, 1948; Whitaker, 1980). *Rattus norvegicus* has historically been one of the most harmful rat species known causing extensive damage to human habitations and stored foods in addition to being major vectors of disease. In a recent survey of *R. norvegicus* in the United Kingdom, Webster & Macdonald (1995) reported 13 zoonotic and 10 non-zoonotic parasite species from a total of 509 rats examined.

As elsewhere, brown rats are commonly encountered in the cities and suburban areas throughout the Gulf States (WHO, 1991), but in marked contrast to other locations (e.g. the UK) their helminth communities appear to be dramatically limited. Abu-Madi *et al.* (2001) reported an exceptional data-set reflecting monospecific helminth and arthropod infections in an urban population of *R. norvegicus* from a hot and arid region in the Middle East, the suburbs of Doha, Qatar. No nematode infections were recorded and helminth infections comprised solely of the cestode *Hymenolepis diminuta*. The rats also harboured a single arthropod, the flea *Xenopsylla astia*.

As part of a long-term study of the parasite communities in this urban population of brown rats, ectoparasites and endoparasites were collected over a period of 2 years from 2002 to 2003. The first objective of the present study was to assess whether, with two intrinsic factors (host age and sex) taken into consideration, changes in the parasite fauna had occurred over time, i.e. since the earlier study and across 2 years of the present project (Abu-Madi *et al.*, 2001). The second objective was to assess the consequence of deterioration of environmental conditions in the same urban site on the diversity and abundance of parasite species in *R. norvegicus*.

## Materials and methods

### Study site

The study area, known as the Abu-Hamour district, is situated to the south of Doha city, (grid reference 22703860). The site consists of vegetable, fish and livestock markets and an abattoir adjoining less developed suburbs. Here public services have become increasingly substandard with refuse collection either infrequent or *ad hoc*. Recently an environmental survey in the Abu-Hamour district by Elhag *et al.* (2002) reported on the poor living conditions, which pose a threat to communicable disease transmission in the less developed areas.

### Collection and analysis of parasites

Rats were caught live in cage-traps, which were placed around active burrows, close to refuse and drainage ditches. Fifty traps, pre-baited with cheese and tuna, were set out on each of four trapping nights per week from February–April in 2002 and 2003. This period coincided with a peak in the breeding and reproductive behaviour of *R. norvegicus* (WHO, 1991) and at a time when all age ranges of the rat population could be expected (Davis, 1951). Traps were inspected in the early morning and fresh traps replaced as necessary. Rats were retrieved from traps and killed by exposure to chloroform-soaked cotton wool. For each rat examined, the date of trapping, body length (head and body), and sex were noted. Rats were separated into two age-weight groups, juveniles (<100 g) and adults (>150 g), as previously described by Brooks & Rowe (1987) and Webster & Macdonald (1995). Rats were examined and analysed for ectoparasites and endoparasites using the same procedures and statistical methods as previously described by Abu-Madi *et al.* (2001).

## Results

### Parasite species richness

One hundred and seventy nine rats were sampled across two years with a total of 60 (32 adults, 28 juveniles) in 2002 and 119 (69 adults, 50 juvenile) in 2003. Of 179 rats sampled, 64 were found to harbour *H. diminuta* (overall prevalence = 35.8%  $\pm$  7.02 (95% CL)) while 74 were infested with *X. astia* (overall prevalence = 41.3%  $\pm$  7.2 (95% CL)).

### Hymenolepis diminuta

The prevalence of infection with *H. diminuta* varied with host age ( $\chi^2 = 9.93$ , df 1,  $P = 0.0016$ ), increasing two-fold from the juvenile to the adult age class (23.1%, 45.5%, respectively). There was also an independent effect of year of study, prevalence varying markedly between the two years ( $\chi^2 = 39.1$ , df 1,  $P < 0.0001$ ) and, prevalence was over eight-fold higher in 2003 compared with 2002 (50.5%, 6.6%, respectively). No other factors or interactions affected the prevalence of infection (overall goodness of fit of minimum sufficient model to data  $\chi^2 = 9.54$ , df 10,  $P = 0.48$ )

Infections ranged from 0 to 20 worms in a single individual host. The frequency distribution did not

conform to positive binomial or Poisson models ( $\chi^2 = 157$ ,  $df 4$ ,  $P < 0.001$  and  $\chi^2 = 156$ ,  $df 4$ ,  $P < 0.001$ , respectively) and the negative binomial model also did not provide a good fit, but the goodness of fit to this distribution was much better ( $\chi^2 = 11.7$ ,  $df 5$ ,  $P = 0.04$ ;  $k = 0.283 \pm 0.003$ ). Moreover the index of dispersion ( $I = 4.7$ ) and the index of discrepancy ( $D = 0.776$ ) indicated aggregated data.

Data were analysed by GLIM with negative binomial error structures (three-way ANOVA, with year, age and sex as factors). Infection varied significantly between years (main effect of year,  $\chi^2 = 16.2$ ,  $df 1$ ,  $P < 0.0005$ ) mean abundance increasing more than four-fold from 2002 to 2003 (mean for 2002 =  $0.37 \pm 0.23$ , 2003 =  $1.55 \pm 0.23$ ). Older rats also carried heavier infections than young rats (main effect of age  $\chi^2 = 25.9$ ,  $df 1$ ,  $P < 0.0005$ ; mean for old rats =  $1.60 \pm 0.28$  and for young rats =  $0.56 \pm 0.14$ ). There was a significant sex difference (main effect of sex,  $\chi^2 = 3.94$ ,  $df 1$ ,  $0.05 > P > 0.025$ ) with males carrying heavier infections compared to females (males,  $1.45 \pm 0.33$ , females =  $0.90 \pm 0.16$ ).

However, these differences were confounded by two significant interactions (fig. 1). In 2002 the juvenile class of rats was not infected (fig. 1a) but in 2003 they carried a similar mean worm burden to that observed in adult rats in the preceding year, but in 2003 adult rats carried even heavier infections (interaction of year and age,  $\chi^2 = 5.4$ ,  $df 4$ ,  $0.025 > P > 0.01$ ). Figure 1b shows that whilst the mean worm burden in male and female juvenile rats was similar, in adult rats worm burdens were almost twice as heavy in males compared with females (two-way interaction age x sex,  $\chi^2 = 28.9$ ,  $df 1$ ,  $P < 0.0005$ ).

#### Xenopsylla astia

An analysis of prevalence revealed a three-way interaction (year  $\times$  age  $\times$  infection,  $\chi^2 = 6.61$ ,  $df 1$ ,  $P = 0.01$ ), which is illustrated in fig. 2a. In 2002, juvenile rats were more likely to be infected than adults, but in 2003 the situation was reversed when the overall prevalence of infestation increased markedly in both age classes compared to 2002. The prevalence of *X. astia* was higher among female compared with male rats (fig. 2b) although this difference was only just outside the cut-off for significance ( $\chi^2 = 3.7$ ,  $df 1$ ,  $P = 0.0539$ ). These were the only terms that remained in the minimum sufficient model for the prevalence of *X. astia* (goodness of fit of minimum sufficient model =  $\chi^2 = 6.0$ ,  $df 6$ ,  $P = 0.421$ ).

The frequency distribution of *X. astia* clearly conformed to the negative binomial distribution ( $k = 0.295 \pm 0.003$ ,  $\chi^2 = 3$ ,  $df 5$ ,  $P = 0.7$ ,  $I = 5.4$ ,  $D = 0.772$ ), and differed significantly from that described by the positive binomial and the Poisson. The abundance of *X. astia* differed significantly between years (main effect of year,  $\chi^2 = 15.5$ ,  $df 1$ ,  $P < 0.0005$ ) with the abundance of fleas on rats being almost four times greater in 2003 compared with 2002 ( $2.03 \pm 0.29$ ,  $0.55 \pm 0.24$ , respectively). The abundance of fleas was also significantly higher (main effect of age,  $\chi^2 = 17.68$ ,  $df 1$ ,  $P < 0.0005$ ) on the juvenile compared with adult rats ( $1.64 \pm 0.38$ ,  $1.46 \pm 0.24$ , respectively).

However, there were also two significant interactions that confounded this interpretation. Whilst there was no overall significant difference in abundance between the

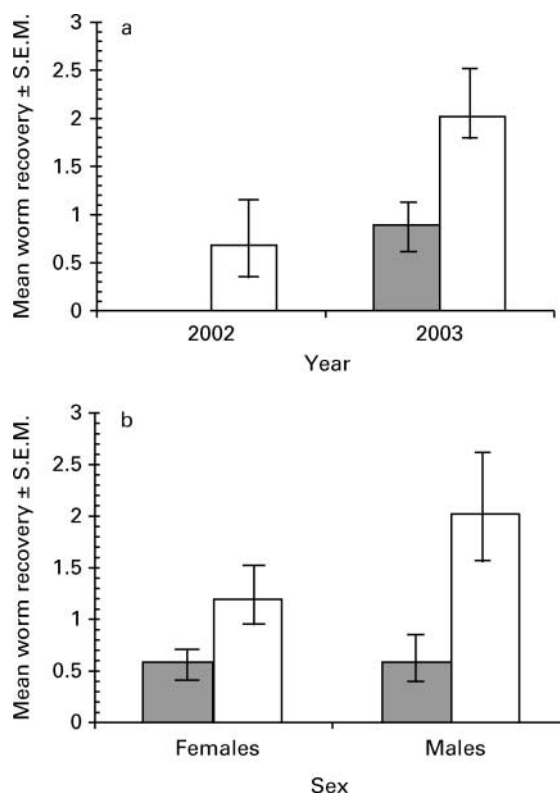


Fig. 1. Variation in the abundance of infection of *Hymenolepis diminuta* in the total rat population sampled in Doha, Qatar during the winters of 2002 and 2003 relative to (a) host age and (b) host age and sex; juveniles (■), adults (□).

host sexes, and abundance levels were indistinguishable in 2002, in 2003 female rats had more fleas than males (fig. 3, two-way interaction,  $\chi^2 = 16.8$ ,  $df 2$ ,  $P < 0.0005$ ). Moreover, in 2002, the abundance of fleas was more than six times higher on juvenile compared with adult rats, but in 2003, the abundance was virtually identical on both age classes (fig. 3, two-way interaction  $\chi^2 = 4.96$ ,  $df 2$ ,  $0.05 > P < 0.025$ ) although both age classes showed a higher prevalence relative to 2002.

#### Rat population density and infection/infestation levels

The striking differences in the prevalence and abundance of infection of rats with *H. diminuta* (table 1 and fig. 1) and *X. astia* (figs 2 and 3) could be related to the density of the rat population which had almost doubled in size in the Abu-Hamour district during February–April 2003 compared with that in 2002 (table 1). With the exception of juvenile rats infested with *X. astia*, relatively low prevalence values were otherwise recorded for *H. diminuta* and *X. astia* in 2002. These values increased significantly in both rat age classes by 2003, particularly in adult rats where up to 60.9% were infected with *H. diminuta* and 60.9% infested with *X. astia* (table 1). Similar prevalence profiles were evident in both 2002 and 2003, relative to host sex. In 2002 low prevalence levels, especially in the case of *H. diminuta*, were observed in male and female rats, whereas in 2003 the higher rat

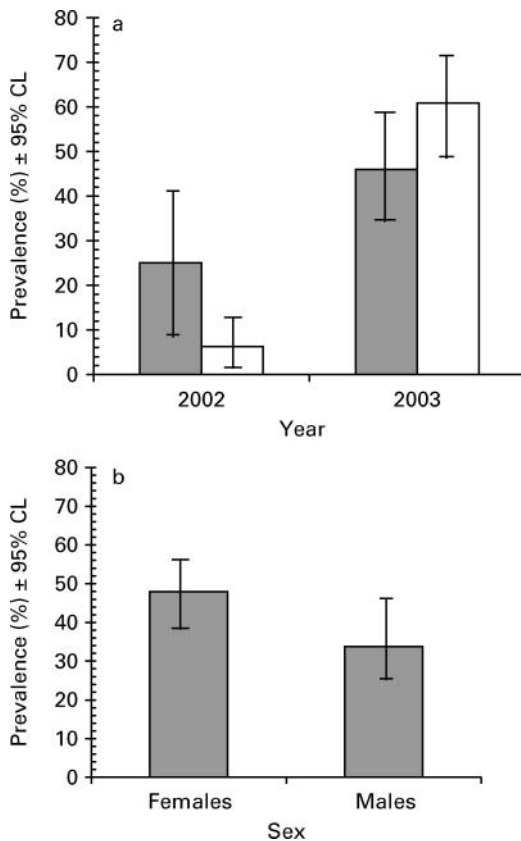


Fig. 2. Variation in the prevalence of *Xenopsylla astia* in juvenile (■) and adult (□) rats sampled in Doha, Qatar (a) during the winter of 2002 and 2003 and (b) relative to host sex.

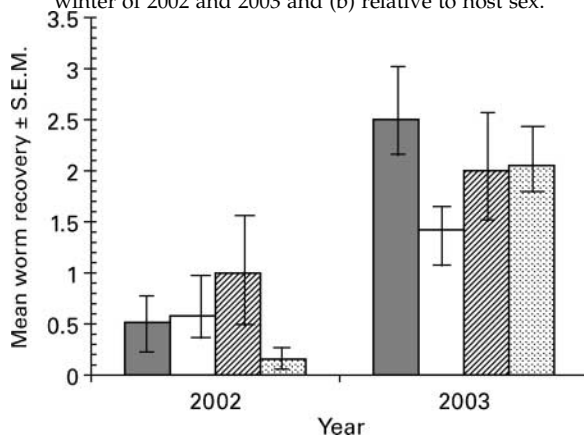


Fig. 3. Variation in the abundance of *Xenopsylla astia* in female (■), male (□), juvenile (▨), and adult (▩) rats sampled in Doha, Qatar during 2002 and 2003.

density was associated with a substantial increase in prevalence in both species of parasites. Although there was little difference in levels of infection of *H. diminuta* between sexes, the prevalence of this cestode in female rats had increased up to 14-fold in 2003 (table 1). In the case of *X. astia*, prevalence values had increased up to three-fold with female rats showing an overall prevalence of 61.2% in contrast to 46.1% among males (table 1).

#### Interactions between *H. diminuta* and *X. astia*

It has been shown that in 2003 both prevalence and abundance of infection with *H. diminuta* and infestation with *X. astia* were higher than in 2002, suggesting that there might be an association between the two species. Indeed, the prevalence of fleas on rats with *H. diminuta* was almost twice that on rats without *H. diminuta* ( $60.9 \pm 12.0$  and  $30.4 \pm 8.4\%$  respectively). However, an analysis of prevalence data (presence/absence) in a model comprising year, age, sex and presence/absence of the two species yielded a minimum sufficient model that included an interaction between *H. diminuta* and *X. astia* but this was just outside significance ( $\chi^2 = 2.96$ , df 1,  $P = 0.085$  and overall goodness of fit of model to the data  $\chi^2 = 153$ , df 19,  $P = 0.7$ ).

Quantitative analysis of data confining the analysis to rats that carried at least one parasite of each species did not yield any significant relationships (for raw data  $r_s = 0.09$ ,  $n = 39$ ,  $P = 0.6$ ). However, any relationship may have been overshadowed by the effects of year, host sex and age, and therefore we also tested the correlation between the residuals from minimum sufficient models (as described above) but this also failed to indicate any significant quantitative relationship between the two species (for residuals from Min.suf. ANOVAs in GLIM  $r_s = 0.1$ ,  $n = 39$ ,  $P = 0.55$ ).

#### Discussion

The brown rat, *R. norvegicus* has established itself in Qatar in association with human habitations and is beyond the control of natural predators (Kock *et al.*, 2002). This rat species is able to occupy ecological niches inhabited by the indigenous fauna and is capable of preying upon existing small animal populations. In many countries in the Middle East, urbanization and growth of towns have resulted in an increase in the accumulation of garbage and refuse which create favourable conditions for the proliferation of rats (WHO, 1991). The brown rat is omnivorous, consuming food and waste and the poor disposal of garbage and other types of organic refuse offer a ready supply of foodstuffs for this species (Brooks & Rowe, 1987). Therefore, *R. norvegicus* may be exposed to a potentially wide range of infective stages of micro- and macroparasites.

As with other wild rodents, rats rarely remain uninfected or harbour just single species infections in nature (Behnke *et al.*, 2001). Multiple species infections are much more common and are considered the rule rather than exception in most wild mammal species (Lewis, 1968a,b; Montgomery & Montgomery, 1989; Haukisalmi & Henttonen, 1993; Tenora & Stanek, 1995; Webster & Macdonald, 1995; Behnke *et al.*, 1999). Previous studies on the helminth parasites of *R. norvegicus* by Fahmy *et al.* (1969) in Egypt, Seng *et al.* (1979) in Malaysia, Zakaria & Zaghoul (1982) in Kuwait, Seong *et al.* (1995) in Korea and Webster & Macdonald (1995) in the UK have demonstrated the presence of a rich parasite fauna and wide species diversity in local rat populations. Apart from a wide range of ectoparasitic arthropods (Rifaat *et al.*, 1969), the helminth component communities of *R. norvegicus* are primarily dominated by nematodes

Table 1. Prevalence (%) values in the brown rat *Rattus norvegicus* in Doha, Qatar infected with *Hymenolepis diminuta* and infested with *Xenopsylla astia* relative to host age and sex, in 2002 and 2003.

Year	Host age/sex	No. hosts examined	<i>H. diminuta</i>		<i>X. astia</i>	
			No. hosts infected	Prevalence (%)	No. hosts infested	Prevalence (%)
2002	Adult	32	4	12.5	2	6.2
	Juvenile	28	0	0	7	25
	Male	31	3	9.7	4	12.9
	Female	29	1	3.4	5	17.2
2003	Adult	69	42	60.9	42	60.9
	Juvenile	50	18	36	23	46
	Male	52	27	51.9	24	46.1
	Female	67	33	49.2	41	61.2

and cestodes and to a lesser extent trematodes and acanthocephalans (Fahmy *et al.*, 1969). It is all the more interesting therefore that the present findings, which are consistent with the earlier study by Abu-Madi *et al.* (2001), confirm that the cestode *H. diminuta* and the ectoparasitic flea *X. astia* are the only metazoan parasites species occurring in *R. norvegicus* in the Abu-Hamour district of Doha, Qatar.

In the present paper the relative importance of one extrinsic factor (year of capture) and two intrinsic factors (age and sex) explain the observed prevalence and abundance of *H. diminuta* and *X. astia* in *R. norvegicus*. Trapping was restricted to a single season from the same site to eliminate other quantifiable extrinsic factors (site and season) and hence the only known extrinsic factor was the year of capture, thus avoiding any added complications in the analysis. However, these results are compared to those reported by Abu-Madi *et al.* (2001), which were based on rats trapped at the same site in one year, incorporating both summer and winter seasons. Of the two parasite species identified in 2002 and 2003, the overall prevalence of the cestode *H. diminuta* (38.5%) was higher than in the winter season of 1999 described by Abu-Madi *et al.* (2001), whereas the prevalence of *X. astia* (41.3%) was similar. Prevalence and abundance of *H. diminuta* were both markedly influenced by the year of study and host age. However, despite this between-year variation, in both years older rats were more likely to be infected and carried heavier parasite burdens than juveniles and this is much as expected from other studies and as reported by Abu-Madi *et al.* (2001). Such age-related differences are largely attributable to adult rats receiving a longer exposure time to infective stages in the arthropod intermediate host and also to the longevity of *H. diminuta* in the rat. Once established in the rat, *H. diminuta* can live as long as its host (Read, 1967) and worm burdens would be expected to accumulate with increasing exposure and age (Andreassen *et al.*, 1999).

In contrast to Abu-Madi *et al.* (2001), the present study has shown a clear effect of host sex with males carrying heavier infections than females, and this was especially evident in the adult rats, in which sex hormones would be most active and which show different patterns of behaviour associated with reproduction. Although the study by Abu-Madi *et al.* (2001) had indicated a difference between the sexes in the same direction, it was confounded by unexpectedly high burdens in female

rats in the summer and a lack of infection among juvenile males in the winter. The winter data for adult rats, which is comparable to the present work, suggested a bias in favour of males although this was not significant. In the present study the sex effect was mainly attributable to adult rats, since, as fig. 1b shows, the abundance of infection in juvenile males and females was very similar.

Infection of the rat by *H. diminuta* occurs when infected intermediate hosts (flour beetles, fleas) are inadvertently consumed in food. Differences in the infection levels between the two age classes and sexes may result from two factors. Firstly, adult males tend to range further than females and their younger counterparts, which is likely to increase their exposure to infection as reported by Mafiana *et al.* (1997). Secondly, immunocompetence is generally impaired by male hormones but enhanced by female hormones (Healing & Nowell, 1985; Bundy, 1988).

Perhaps the strongest influence on flea abundance was the between year effect. Both prevalence and abundance of fleas were relatively low in 2002 compared with 2003 and also compared with the data for 1999 (Abu-Madi *et al.*, 2001). The low flea infestations in the winter of 2002 coincided with fewer juveniles being trapped, i.e. 28 juveniles were sampled in 2002 compared with 39 and 50 juveniles in 1999 and 2003 respectively. Thus data acquired in 2002–2003 support some of the conclusions of the 1999 study. It is clear from both studies that, overall, fleas are more likely to be found on juveniles than adults. In 1999 this was particularly evident in the summer period whereas there was no age effect in the winter. The present data, based solely on rats sampled in the winter, revealed an age effect in the same direction in 2002 in respect of both prevalence and abundance but not in 2003, the year of high overall flea abundance. This suggests that age effects are less evident when flea populations are high as in 1999 and 2003 in the winter period, but become more prominent when overall flea density is low. Host age was shown to influence the number of fleas, *Ctenocephalides felis*, on cats with more fleas occurring on younger compared with older cats (Osbrink & Rust, 1984).

In agreement with Abu-Madi *et al.* (2001) there was no overall difference in abundance of fleas between the two sexes, but in contrast to the earlier study there was an indication in the borderline significance of prevalence that female rats were marginally more likely to be infested. No such difference in abundance was evident in either study, although female rats had higher mean burdens in 2003.

Thus, overall, the sex effect is not convincing. However, the combination of higher flea infestations on juvenile rats and the tendency of females in some years to show higher infestation may be linked to direct transmission and by host contact during the reproductive period. Female rats tend to remain in their burrows for longer periods than males (Davis, 1951) and, consequently, together with juveniles may accumulate heavier infestations. In the rabbit, adult females harbour more fleas than the males (Twigg *et al.*, 1998) and this was linked with responses by fleas to hormone levels in female rabbits (Rust & Dryden, 1997). On the other hand in rat populations examined by Linardi *et al.* (1985), males were more heavily infested with *Xenopsylla cheopis* than females and this was arguably attributed to the larger home range of male rats.

As in 1999 (Abu-Madi *et al.*, 2001) no quantitative interactions were detected between the flea, *X. astia* and the cestode, *H. diminuta*. However, rats that were infected with *H. diminuta* were almost twice as likely to be infested with *X. astia* than those without *H. diminuta*, although when the year of study, host sex and age effects and their interactions, were taken into account the association between the two parasites was just outside significance. These data are consistent with the overall pattern detected in 1999 during the winter when rats with fleas showed a considerably higher prevalence of *H. diminuta* than those without fleas. Deterioration in the environmental conditions in the Abu-Hamour district in Doha (Elhag *et al.*, 2002) may have contributed to a doubling of the rat population in 2003 compared with 2002 (table 1) and also in 1999 when only 29 adult and 39 juvenile rats were sampled during the winter period. Such an increase in rat density in 2003 was reflected in a corresponding increase in the prevalence and abundance values of both *H. diminuta* and *X. astia* (table 1) in older rats and, in the case of *X. astia*, older female rats (table 1). Using data from Damuth (1987) on the parasites of mammalian hosts such as *Peromyscus gossypinus* and *Apodemus sylvaticus*, Arneberg *et al.* (1998) showed that host density was positively correlated with parasite abundance and prevalence. Theoretically, the mechanisms underlying this relationship are likely to cause parasite species richness to scale positively with host density (May & Anderson, 1979). In the present study, however, there appears to be an association between host population density and an increase in the prevalence and abundance profiles of rat parasites in 2003, but species richness has remained unaffected by host density. Further epidemiological studies on the relationship between host population density and parasite species richness and diversity in *R. norvegicus* and related rat species are therefore needed to confirm whether or not the monospecific helminth and arthropod infections in *R. norvegicus* from the Abu-Hamour district, south of Doha are representative of rat parasite populations from other hot and arid urban and rural sites in Qatar.

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