Acarine Biology, Ecology and Behaviour
Oral Presentation.

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Factors affecting the carrying capacity (*K*) of a mattress for the house dust mite *Dermatophagoides pteronyssinus* (Acari: Pyroglyphidae)

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Abstract

Experiments were conducted in order to determine the effects of carrying capacity (*K*) on populations of the house dust mite (HDM) *Dermatophagoides pteronyssinus* (Trouessart) within a mattress. Initial experiments were conducted using a set amount of food, thereby providing the mites with a finite environment, in terms of food and space (for the purposes of this experiment HDMs lived in the food). Mite growth was monitored over time and found to resemble a sigmoid curve. Once the population had peaked it remained constant for 6 weeks before gradually declining. At this stage it appeared likely that the population at its peak was being limited by space and its decline was being caused by a reduction in food quantity or quality. In order to clarify this point a) space in the form of ground up vermiculite and b) food, which also added space, were added to a population of mites whose numbers had stabilized. Both populations increased significantly in comparison with the control (the original culture), indicating that space was a constraining factor. However, the populations to which extra food was added grew to higher levels than those with vermiculite. This indicated that according to circumstances *K* can be affected by both food quantity/quality and space. Experiments were conducted that showed that both the number of mites added to food (2 mating pairs vs.1163 and 5810 mites) and the initial amount of food to which mites were added (0.5 to 1.5 g) could have a profound effect on the mite populations (mites per gram) within the tubes. The effects of population size on mite migration behaviour were also examined. It was found that mite migration increased significantly once the population had reached certain threshold levels.

1. Introduction

Allergens derived from house dust mite faeces play a major role in allergic disease such as asthma, perennial rhinitis and atopic dermatitis (Tovey *et al.* 1981)

House dust mites feed on human skin scales, which accumulate in bedding, regularly used soft furnishings and carpets. As humans spend a considerable amount of time in a bed, skin scale can accumulate within the mattress thus providing an ideal food source. The mattress is also a favourable habitat for house dust mites in terms of its physical characteristics, the space provided and the virtual absence of predators (Bronswijk 1981). As a result, the rate of growth and ability of house dust mite populations to survive within the mattress are primarily dependent on temperature and relative humidity (hygrothermal conditions). These in turn have been found to be greatly affected by hygrothermal conditions within the bedroom, which vary considerably over time and even from house to house (Crowther *et al.* 2001, Pretlove *et al.* 2001). This explains why low allergen concentrations and low mite populations are usually correlated with low indoor relative humidities. (Hart & Whitehead 1990, Korsgaard 1983, Munir *et al*. 1995, Strien et al. 1994).

In a recently completed project by the authors, a combined transient hygrothermal and population model has been produced to simulate the effect of varying hygrothermal conditions within the home on house dust mite populations in beds (Crowther *et al*. 2001, Pretlove *et al*. 2001). This will allow researchers to assess the effects of modifying factors such as heating and ventilation regimes within houses on hygrothermal conditions within mattresses and hence on the house dust mites residing there. In this way it will be possible to determine which modifications are most effective in reducing mite infestation to acceptably low levels. The mite population model has been constructed using published data and data derived from our own experiments, which included the experiments reported here to determine the carrying capacity of the mattress for mites.

The mattress ecosystem represents a large but finite environment both in terms of space and the amount of food available (skin scales). These limitations mean that HDM populations, even under continuously

favourable conditions, cannot increase indefinitely. In order to successfully model a population in such an environment it is essential to know the factors affecting its carrying capacity (K) so as to put a limit on the maximum mite population that can develop. Carrying capacity can be defined as “The capacity of a particular habitat with reference to the maximum number of organisms, which that habitat can normally support, e.g. the maximum number of wading birds an estuary can support.” (Hale *et al.* 1995).

If the bed is slept in constantly the mattress receives an approximately equal supply of food throughout the year. However, in most situations mite populations exhibit wide seasonal fluctuations as a result of the differing hygrothermal conditions found within houses at different times of the year, tending to be highest in late summer/autumn and lowest in early spring (Bronswijk 1973, Arlian *et al* 1983). As a result food has the potential to accumulate whilst mite populations are low. This means that during subsequent periods of favourable hygrothermal conditions mites have a plentiful supply of food and populations are likely to grow unconstrained until limited by space. On the other hand, if favourable hygrothermal conditions occur all year round, as can occur in some houses, mite growth is more likely to be limited by food. Food supply may also be at least partially reduced by regular vacuuming. Other factors include food quality, the age of the mattress (new ones taking time to be colonised - Bronswijk, 1981), its specific construction type and its past history. For example, if an old mattress full of food that has never been infested with mites becomes infested, space is likely to be a constraining factor as food will be in abundance.

Carrying capacity can thus be affected by several factors and the experiments we have carried out are only stepping stones on the path to a fuller understanding. Considerable further work is essential in order to understand it fully.

2. Materials and Methods

Mites were obtained from an established laboratory culture fed on and living in a (1:1, weight:weight) mixture of dried porcine liver (OXOID) and brewers yeast. The culture was maintained at 25*C and 75% RH and the food was gently agitated at regular intervals to prevent coagulation. In order to greatly simplify experimentation, the mite food/culture was used as a proxy for the bed habitat.

Unless otherwise stated experiments were carried out in small 7.23cm^3 plastic vials with screw on plastic lids; the lids were punctured with 3 holes of approximately 4mm diameter allowing diffusion of air and water vapour to take place. To prevent mites from escaping a layer of "mite proof" vapour permeable fabric was placed between the lid and the top of the plastic tube. Any "fresh food" added to the tubes was acclimatized in the appropriate hygrothermal conditions for 24hrs prior to its addition to the experiment. Mites were added to the experimental medium either as mating pairs or in additional food/habitat medium. When the density of mites had been calculated prior to their addition, cultures were selected that represented a full mixture of developmental stages.

The number of mites per tube was ascertained by calculating the weight of culture in the tube and by taking a sample of this, counting the number of mites in it and from that calculating the number of mites in the entire culture, the sample of culture was returned to the tube after the mites in it were counted. In order for the results to be comparable the mite densities in a tube are expressed as mites per gram of culture.

Long term carrying capacity.

Two sets of experiments, separated by a time interval, were carried out over 57 weeks. The experiments were started with 1.5 g of food and two mating pairs of mites. Sets 1 and 2 each initially consisted of 15 replicates of which 10 were randomly selected for counting every three weeks. However, part way through the experiment, after 3 months, mite populations in a number of replicates had failed to develop. From that point all the tubes that had initially contained developing populations of mites were counted on a three

weekly basis. Only the data from the tubes containing mite populations that had developed were used in the analysis.

The addition of space plus extra food and space.

0.5 g of mite culture containing approximately 7,900 mites was added to each of 30 tubes, of which 10 were left unmodified forming the control. Space in the form of ground up vermiculite was added to 10 of the tubes. The vermiculite was ground down to the same size as the food and an amount was added that approximately doubled the amount of space available to the mites. 0.5 g of food was added to the remaining 10 tubes again doubling the space and adding just more than twice the amount of food (the mites living within the initial 0.5g of culture will have consumed part of it and lowered its nutrient quality). Each tube was counted on a three weekly basis.

Effects of initial numbers of mites and food quantity.

Differing amounts of food and numbers of mites were added to 30 experimental tubes.

Wt Food (g)	0.5	1.0	1.5	1.5	1.5	1.5
No mites	1,165	1,165	1,165	4	1,163	5,800
No Replicates	5	5	5	5	5	5

The number of mites in each tube was calculated every three weeks. The experiments lasted for a total period of 12 weeks, except that the tubes to which the two mating pairs of mites had been added were counted for a total period of 15 weeks as their populations had taken longer to develop.

Density dependent migration.

An average of 552 mites were added to 0.5g of mite food contained within an experimental tube and the lip of the tube was surrounded by sticky tape (rather than the lid and mite proof material). The experiments were conducted at 15 and 25*C and there were 10 replicates at each temperature. Each week the sticky tape was changed and the area around the top of the tube cleaned. The numbers of mites caught on the sticky tape were counted and the total number of mites was calculated for each tube. From this, the percentage of the total number of mites in each tube that had migrated onto the sticky tape could be calculated.

3. Results and Discussion

Long term carrying capacity (Set 1), see Fig 1.

Mite population size over time represented a sigmoid curve before gradually decreasing. Initially it grew slowly as there were only two mating pairs of mites at the start of the experiment. It then began to increase rapidly before leveling off. The leveling off of the population is likely to have been caused by space limitations rather than by a poor food supply as the population persisted at that level for over 6 weeks. The population then began to gradually decrease whilst experiencing a couple of oscillations. The decline is believed to have been caused by a gradual reduction in food quality (further experiments have been carried out to examine these factors in more detail). The sudden increase at the end of the experiment is caused by the addition of food. This shows that the mite populations are being reduced by a lack of food and not by any form of pathogen.

The standard errors are large, especially at the beginning of the experiment. This is a consequence of the low starting populations that resulted in the initial slow growth, which in turn meant that as a result of random factors mite populations in different replicates peaked at different times, giving rise to high standard errors*.* The averaging process smoothes out the means to give the highest average population total of 11,673 and an SE of 2,506. This is deceptive as the highest peak in population size was 28,665 mites per gram and the lowest 8,511. The average of the highest peaks was 16,430 with a standard error of 2,753.

Long term carrying capacity (Set 2), see Fig 2.

Mite population size over time initially started to resemble a sigmoid curve. However, a fungal problem developed that caused a brief dip in population growth, which affected this experiment. Whilst being superficially similar to the results from Set 1, an ANOVA test showed that there were significant differences between the two with a P-value of 0.0078. The populations did reach a similar peak as in the first experiment. However, they did not remain at their high point of 10,736 mites with an SE of 1,402 for a

prolonged period of time, possibly as a result of the fungal infection. By the end of the experiment, they had declined to a level similar to Set 1.

The addition of space plus extra food and space, see Fig 3.

Mite populations in the replicates to which additional space, in the form of ground up vermiculite, and food, which also added space, increased considerably when compared with the control. The differences were found to be highly significant with a P-value of <<0.001. The variation within replicates was found not to be significant with a P-value of 0.88. The replicates to which vermiculite was added, doubling the space available to the mites, enabled the average mite population to almost double when compared with the control over a 3 week period. The total mite population per tube increased to an average value of 22,788 with an SE of 862, compared to 12,303 with an SE of 338 for the control. As the amount of food was identical to that in the control the extra space must have been the factor allowing the population to increase. The replicates containing mite populations to which food was added, thereby adding food and space, increased the mite population even more to an average density of 31,977 mites per tube, with a standard error of 1,132. This shows that food had also been a constraining factor. The tubes to which just space was added could not sustain their population peak, presumably due to a lack of food, and subsequently decreased rapidly. The growth in the population when food was added was more sustainable.

Interestingly, by the end of the experiment, all three sets contained a similar number of mites. Indeed the control to which no extra space or food had been added, contained more mites than the other two sets. This is interesting as it shows that a sudden upsurge in population caused by the addition of food/space is not necessarily beneficial in the long term.

Effects of initial mite number and food quantity on mite populations, see Table 1.

The maximum size of a mite population in mpg (mites per gram) can be affected by the initial amount of food available to the mites. Mites added to 0.5 and 1 gram of food responded in a similar fashion with the

populations peaking at 33,346 mpg and 35,790 mpg respectively. An ANOVA test showed that these two results were not significantly different with a P-value of 0.428. When added to 1.5 grams of food mite, populations increased to a peak of 55,757 mpg, which is 161 % higher than the average of the other two. The ANOVA test showed that this difference was significant with a P-value of <<0.0001. It may be because the extra food and space allowed the population more growing room and also provided them with extra resources. However, this idea conflicts with the fact that Sets 1 and 2 have a similar maximum population size. If the hypothesis were correct 1g of mites would be expected to have a significantly higher mpg concentration than 0.5g.

The initial number of mites present within the food source has a profound effect on the size and rate of growth of the mite population. Replicates containing medium or high numbers of mites increased rapidly to extremely high population levels of 45,725 mpg (SE 1,565) and 44,977 mpg (SE 386) respectively. Replicates that contained a low initial mite population of two mating pairs of mites increased more slowly and had much lower maximum population level of 10,754 mpg (SE 4,040). This result is similar to the maximum populations in Exp 1 sets 1 and 2, which were also started with two mating pairs of mites. An ANOVA analysis showed that the differences between the maximum population sizes were statistically significant with a P-value <<0.001. The difference between the medium and high populations was not significant with a P-value of 0.65. This finding is extremely important. It indicates that mite populations are somehow able to self regulate i.e. prevent their populations from getting too high. The exact mechanism behind this is not understood. However, mites have been shown to exhibit behavioural changes as their densities within experimental tubes increase (see Mite migration below). It is also interesting to note that the more mites initially added to the culture, the lower the standard error amongst replicates.

Mite migration as a function of density, see Fig 4.

The mite population within the tubes increased rapidly. The percentage of mites migrating (as a percentage of the total mite population within a tube) did not remain constant as one might expect if mite migration was not affected by population density. The largest peak for × change of mite migration (×7.11) occurred 3

weeks after the peak × change for mite growth when the mite population was between 14,627 and 23,341. Moreover the % migration was still high (5.98 times) at the next sampling point when the mite population had continued to grow, from 23,341 to 36,505. Thereafter the rate of migration fell as the population growth rate fell. This shows that between 14,627 and 23,341 mpg a threshold is reached that initiates a step change in mite migration. The percentage of the mite population migrating also increased considerably at the end of the experiment when the total mite population was decreasing due to poor food supply. The results from this experiment allow us to look at carrying capacity in a different way, by looking at how it affects the behaviour of the mites, the very large increases in migration, that occur between 14,627 and 23,3341 mpg, could be considered to be another way of looking at carrying capacity.

4. Summary

The work on carrying capacity was carried out in order to answer the following questions. What is the carrying capacity of a mattress for mites? And, to what extent do mites move within the mattress when carrying capacity has been reached? The answers for both of these questions have significant implications for the production of a spatially explicit mite population model.

Carrying capacity within a mattress is an extremely complex issue that depends on many interlinking factors. Apart from hygrothermal conditions, these include the age and type of mattress, amount of food (skin scales) and the infestation history of the mattress, as well as factors such as bed occupancy. Mite populations in culture in experimental tubes, used as a proxy for the real life environment of the mattress, initially grow rapidly when supplied with a finite amount of food. After this rapid growth space and food constraints cause the population to level out for a short period of time before declining. The level that the population reaches in these circumstances is dependent on a number of factors including the initial amount of food available to the mites and their population size. The primary factors that affect carrying capacity within tubes are thus food and space. Within the mattress, however, there will often tend to be a far greater ratio of space to food. This means that the primary factor affecting the carrying capacity of the mattress for house dust mites will tend to be food, assuming favorable environmental conditions. It is also important to remember that a mattress will have a daily amount of food being added to it, from its occupant. It is therefore essential to carry out further experimental work, again under favorable hygrothermal conditions, but with food being added daily, rather than all at once at the beginning of the experiment. Only then, as we increase the degree of realism, will we know the true carrying capacity of a mattress.

The results also show that in an experimental context the initial amount food can affect the peak density of mites attained within that food, i.e. mites added to 0.5g of food have a significantly lower maximum population level than the same number of mites added to 1.5g of food, when the results are expressed as mites per gram. The initial number of mites present within the food source also has a profound effect on the

eventual size and rate of growth of the mite population. It is possible that such differences would be reduced if the more realistic scenario of a continuously refreshed food supply were adopted.

A further point of interest is that if the population is started with two mating pairs of mites it grows much more slowly and its maximum population is much lower than if the population is started with 1,000 mites. This implies that mites exhibit a degree of "self regulation". By comparison, when a mite population is started with a high number of mites it tends to overshoot the sustainable maximum (about 4 times the level of the population started with two mating pairs) , followed by a subsequent population decline.

We have also found that mites respond to an increase in their population density beyond a threshold value by migrating. The level at which they start migrating is another way at looking at carrying capacity in situations where migration is possible (as it is not in experimental tubes). The mattress, we now know (Crowther et al 2001, Pretlove et al 2001), provides and extremely varied hygothermal (relative humidity and temperature) environment, such that some areas may exhibit much more favourable conditions than others. If carrying capacity were to be reached in an area with favourable environmental conditions, one might expect migration to occur, even if this was to a less favourable area and represented a relatively small percentage of the population. We also know, from experiments to be reported, that house dust mites are capable of movement within the mattress. It is therefore relevant to consider the density at which migration tends to occur to further enhance the distribution function of the mite model. It is also important to note that the percentage of the population that migrates shows a marked increase when the food quality becomes depleted towards the end of the experiment. This is one further step in making the spatially explicit population model more accurate and realistic.

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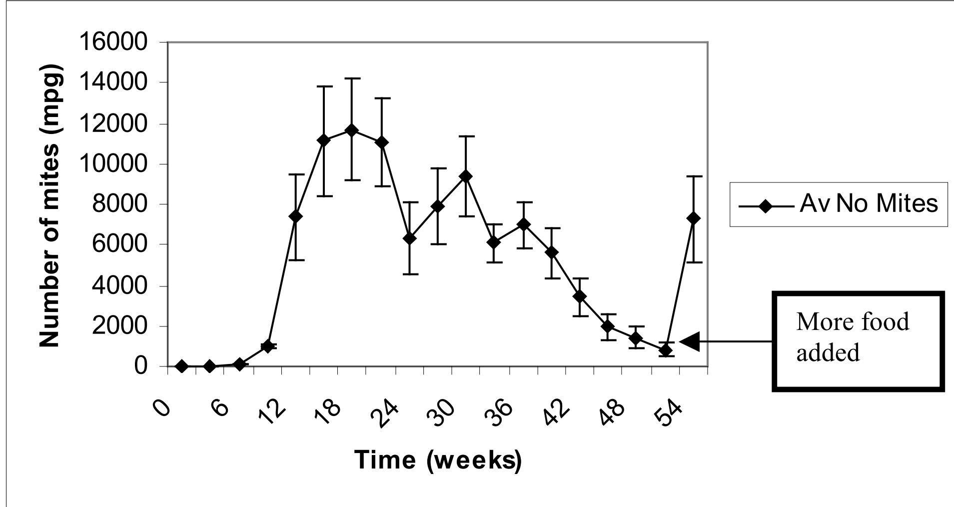

Fig1. Mite population size over time (Set 1) in 1.5 grams of mite food SE+- (mpg).

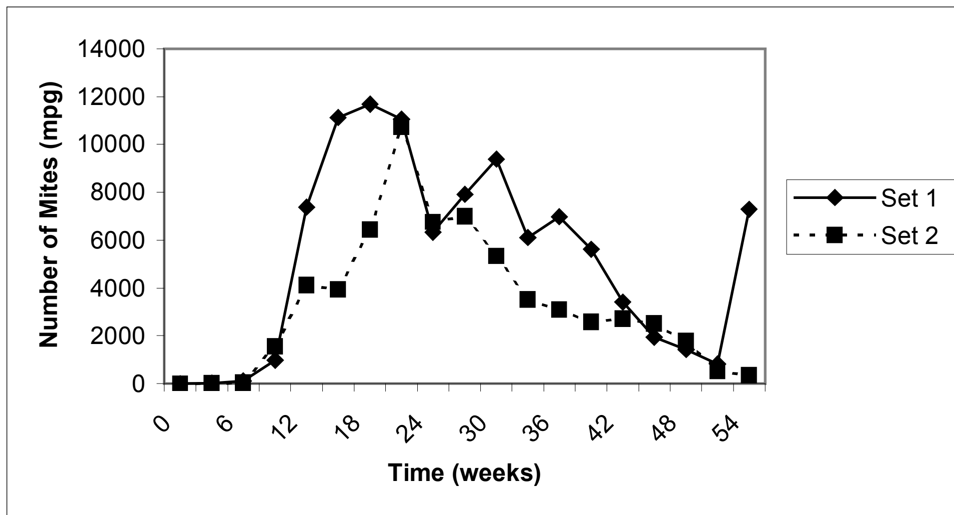

Fig 2. Mite population size over time (Set 1 vs. Set 2) in 1.5 grams of mite food (mpg).

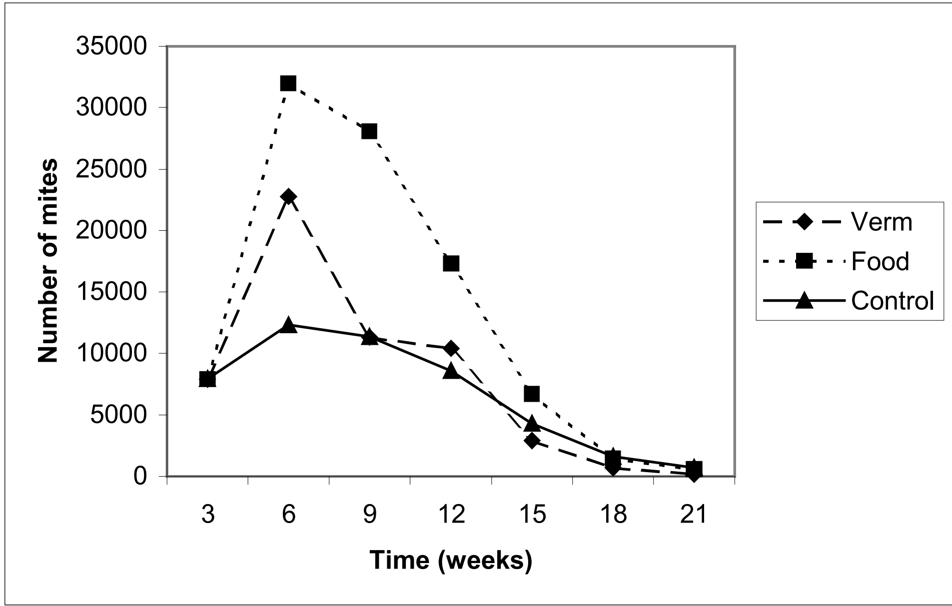

Fig 3. The effects of adding food and space to a population of house dust mites. (NOT IN MPG)

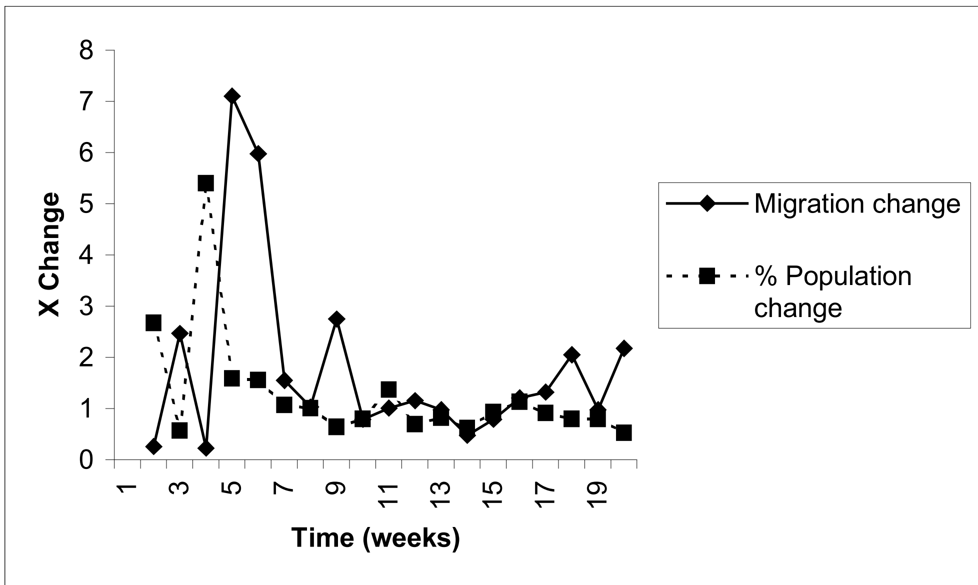

Fig. 4: × Change in mite population and % of mite population migrating

Result type	Exp	Wk 0	Wk 3	Wk 6	Wk 9	Wk 12	Wk 15
mpg	0.5 g	2,333	15,964	33,346	25,913	10,474	Na
mpg	1 g	1,170	12,204	35,790	28,802	11,979	Na
mpg	1.5g	772	10,324	55,757	43,654	33,590	Na
mpg	Low mites in 1.5g	3	60	1,300	10,754	9,398	5,597
mpg	Med mites in 1.5g	769	4,387	43,159	45,725	37,483	Na
mpg	High mites in 1.5g	3,852	18,744	44,977	26,669	7,049	Na

Table 1. The effects of the initial mite number and food quantity on mite populations.