The effect of some ecological factors on the intestinal parasite loads of the Asian elephant (*Elephas maximus*) in southern India

T N C VIDYA and R SUKUMAR*

Centre for Ecological Sciences, Indian Institute of Science, Bangalore 560 012, India

Corresponding author (Fax, 91-80-3602280; Email, rsuku@ces.iisc.ernet.in)

Some ecological factors that might potentially influence intestinal parasite loads in the Asian elephant (*Elephas maximus* Linn.) were investigated in the Nilgiris, southern India. Fresh dung samples from identified animals were analysed, and the number of eggs/g of dung used as an index of parasite load. Comparisons across seasons and habitats revealed that parasite loads were significantly higher during the dry season than the wet season, but were not different between the dry-deciduous and dry-thorn forests in either season. After accounting for the effect of age on body condition, there was no correlation between body condition, assessed visually using morphological criteria, and parasite load in either season. Individuals of different elephant herds were not characterized by distinct parasite communities in either season. When intra-individual variation was examined, samples collected from the same individual within a day differed significantly in egg densities, while the temporal variation over several weeks or months (within a season) was much less. Egg densities within dung piles were uniform, enabling a simpler collection method henceforth.

1. Introduction

Parasites can have a wide range of impact on the ecology of their hosts, in terms of health (Arme and Owen 1967), behaviour (Milinski 1984; Moore 1984), sexual selection (Howard and Minchella 1990; Watve and Sukumar 1997), and regulation of host populations (Freeland 1983). This makes it interesting to examine the ecological factors that determine parasite loads. Potential factors determining the transmission of parasites include environmental conditions that affect the viability and behaviour of parasite propagules (Rogers and Sommerville 1963), and feeding, movement, and defecation patterns of the host, which determine the parasites encountered (Price *et al* 1988; Lozano 1991; Watve 1992). Upon transmission, internal conditions in the host like gut physiology (see Rogers and Sommerville 1963), existing infection (Read 1951; Krupp 1961; Quinnell *et al* 1990), and immune response affect successful establishment and reproduction. Environmental conditions and host behaviour are influenced by habitat and season, while physical state reflects internal condition, though this may also be affected by external factors. In this study, we examine the effect of habitat, season, and physical condition, on the intestinal parasite loads of the Asian elephant (*Elephas maximus* Linn.). We also investigate whether different elephant family groups exhibit distinct parasite communities, whether parasite loads within an individual show considerable temporal variation, and whether the sampling method employed is reliable.

Watve (1992) pioneered work on the ecology of host-parasite interactions of large mammals, including the Asian elephant, in Mudumalai Wildlife Sanctuary (MWS), southern India. Parasite propagules in faeces were des-

cribed, quantified, and parasite loads correlated with measures of host ecology (Watve and Sukumar 1995). It was also found that parasite loads in elephants were higher in the dry season than in the wet season (Watve 1992). The effect of habitat type on parasite loads, however, was not examined. Since feeding patterns of elephants vary between habitats during each season, the effect of habitat on parasite loads could be important. Hence, we designed the study taking habitat types into consideration. In addition, in the present study, samples from identified individuals were used.

1.1 *The host and the parasites*

Elephants live in matriarchal herds (generally 6–7 individuals) consisting of adult females, and young of both sexes. Adult males are usually solitary but may temporarily form all-male herds, or associate with herds depending on their age and sexual state (Moss and Poole 1983). The density of elephant within a 130 km^2 area of MWS, over the last ten years, has been in the range of 1·6–5·6 (mean 2·95) elephants per km^2 (Centre for Ecological Sciences, unpublished transect data). Elephants in the Nilgiri Biosphere Reserve, southern India have large home ranges of 200–800 km^2 (Baskaran 1998).

The intestinal parasites of the Asian elephant that have been reported from taxonomic studies include the nematodes *Murshidia*, *Quilonia*, *Amira*, *Decrusia*, *Equinurbia*, *Choniangium*, and *Bathmostomum*, all of the order Strongyloidea, and *Parabronema* of order Spiruroidea, and the platyhelminths *Brumptia*, *Pseudodiscus*, *Paramphistomum*, and *Fasciola* of order Digenea, and *Anoplocephala* of order Taenioidea (Bhalerao 1933, 1935; Gupta 1974; Chandrashekaran *et al* 1979). Those reported from MWS include *Quilonia*, *Murshidia*, *Coniangium*, *Decrusia*, *Anoplocephala*, and an unidentified trematode (Watve 1995, Dharmarajan 1999). Strongyles, the most common parasites, exhibit a direct life cycle, wherein eggs are released with the host's faeces, and the infective stages that emerge crawl up grass blades under cool, moist conditions, to be ingested by herbivores (Hyman 1992a). Spiruroids and anoplocephaline tapeworms exhibit indirect life cycles with intermediate arthropod hosts (Hyman 1992b).

2.   Study area

Most of the field work was carried out in MWS, part of the Nilgiri Biosphere Reserve in southern India. Lying between latitudes 11°31′N and 11°39′N, and longitudes 76°27′E and 76°43′E, at a general altitude of 850–1250 metres above MSL, the sanctuary covers an area of 321 km^2. The gradient in annual rainfall, from 800–1800 mm, gives rise to various vegetation types including tropical dry-thorn, dry-deciduous, moist deciduous, and semi-evergreen forests, moist bamboo brakes, and riparian fringing forest (Champion and Seth 1968). Part of the study was carried out in Sigur Reserve Forest (SRF), contiguous with the eastern end of MWS. Receiving a low annual rainfall of 500–800 mm, the vegetation here is composed of thorn forest. A few samples were collected from similar thorn forests of the Satyamangalam Forest Division (SFD), further east of SRF.

Elephants were observed in dry-deciduous forest (in MWS) and thorn forest (in MWS, SRF, and SFD), since these habitats cover a major proportion of the study area. This dry-deciduous forest belongs to the *Anogeissus-Tectona-Terminalia* series. The undergrowth is dominated by tall grass, especially *Themeda* (Sukumar *et al* 1992), which constitutes over 60% of the diet of elephants here (Baskaran 1998). The dry-thorn forest is dominated by *Zizyphus* and several species of *Acacia*, which form the principal diet of the elephant (Baskaran 1998). The grass *Heteropogon contortus*, also fed on by the elephant, flourishes in the undergrowth. During the dry season, browse forms a large proportion (over 50%) of the elephant's diet in the thorn forest, while grass is the principal diet (85%) in the dry-deciduous forest (Sukumar and Ramesh 1995; Baskaran 1998). However, in the wet season, browse forms only about 10% and 5% of the diet in the thorn and dry-deciduous forests respectively (Baskaran 1998).

3.   Methods

3.1   *Field study*

Sampling was carried out during the dry (< 100 mm rainfall/month; Feb–June 1999 in the dry-deciduous forest, May–June 1999 in the thorn forest) and wet seasons (Aug–Nov 1999 in the dry-deciduous forest, Sep 1999–Jan 2000 in the thorn forest), after allowing for a few weeks' time lag for seasonal effects to show on body condition or parasite load. Elephant herds were tracked and individuals aged, sexed, and identified based on natural markings (see Sukumar 1989). Body condition was assessed non-invasively using a modified version of the index used for captive elephants (V Krishnamurthy, personal communication). Six parameters of body condition, the backbone, pectoral girdle, pelvic girdle, ribs, temporal depression, and buccal depression, were ranked from zero (best condition) to three (poorest condition) depending on their visibility and the sum of the ranks used as the body condition index, which therefore ranged from 0 to 18. In a study on African elephants, Albl (1971) had found that lumbar depression was a good indicator of physical condition, and that temporal and buccal depressions could also be used, though they were also affected by age.

Dung samples were collected within a few hours of defecation, and stored in 10% formalin. Each sample was a mix of dung from the outer layers of the different boli of a dung pile. Since parasite eggs may not be distributed evenly among the boli of a dung pile or even within a bolus, 9 samples each were also collected from 15 different dung piles. These included a sample from the outer layer and one from the inner layer from each of three boli, a sample of the outer layers of the three boli mixed (the kind of sample that was usually collected), one of the inner layers mixed, and one of the outer and inner layers of all three boli mixed.

3.2 *Analysis of dung samples and identification of parasites*

The sedimentation-floatation technique (Watve 1992) was followed to get a minimum estimate of the number of eggs per gram of dung, which was used as an index of parasite load. Intestinal parasites are best identified by examining adult worms, but eggs are the only available stages in the dung on which classification can be based. Within the family Strongylidae, eggs are similar in shape, colour, and surface ornamentation, but egg sizes can be used to classify many strongyles to the generic level (Bhalerao 1935). A *K*-means clustering was performed using egg dimensions to assign strongyle eggs to different operational taxonomic units (OTUs).

3.3 *Data analyses*

Non-parametric tests (see § 4.) were performed since parasite loads were not normally distributed. The analyses were done using STATISTICA for Windows–Kernel release 5·5 A (StatSoft, Inc. 1999), and codes written in C.

4. Results

A total of 190 samples were collected–86 and 31 samples from the dry-deciduous forest and thorn forest, res-

pectively, during the dry season, and 44 and 29 samples during the wet season. As mentioned earlier, in addition to the above, 15 sets of 9 samples each were collected during the wet season as 'multiple-samples'. Of these, the samples with the outer layers mixed were included along with the other wet season samples for analyses of habitat- and seasonal differences.

4.1 *Parasites present*

Of the 320 samples that could be analysed, 278 (86·8%) had at least one parasite propagule, and 270 (84·4%) had at least one strongyle egg. The ranges of egg sizes obtained by performing a cluster analysis on the strongyle eggs are shown in table 1. Mixed infections were found in 11·9% of the samples (4·8% with OTU1 and OTU2, 4·5% with OTU1 and OTU3, 3·1% with OTU2 and OTU3, and 0·6% with all three OTUs). Juvenile stages of strongyles, which are usually not observed in fresh dung, were also present in 13 samples. Unfortunately we could not hatch the eggs and raise the juveniles to the infective stages for better identification. Tapeworm (*Anoplocephala*) eggs (68–75 × 62–69) were found only in samples from two individuals.

4.2 *Seasonal and habitat variation in parasite loads*

Samples from unidentified individuals, and samples from the same individual in the same season and habitat were excluded for this analysis. The distributions of parasite loads were skewed (figure 1), showing the aggregated nature of the parasites. The median parasite loads, variance/mean ratios, and the percentage of animals infected are shown in table 2. There was a significant difference in parasite loads among the four categories by the Kruskal-Wallis ANOVA ($H[3, N = 159] = 27·98$; $P < 0·001$). Pairwise Mann-Whitney U tests revealed no difference between habitats in either season (dry season: $P = 0·234$; wet season: $P = 0·936$), but parasite loads in the dry season in each habitat were higher than those in the wet sea-

Table 1. Dimensions and prevalence of the three operational taxonomic units obtained from a *K*-means cluster analysis.

Operational taxonomic unit	Length (μ)	Breadth (μ)	Prevalence (%)	Percent propagules
OTU1 (*Quilonia* like eggs)	68–84	36–44	48·6	47·3
OTU2 (*Murshidia indica* like eggs)	50–69	31–48	33·0	34·2
OTU3	72–88	48–69	14·5	18·5

"Prevalence" refers to the percentage of samples in which a particular OTU was present, and "Percent propagules" is the percentage of the total number of propagules represented by a particular OTU.

son (dry-deciduous forest, $P < 0.001$; thorn forest, $P = 0.012$).

4.3 *Body condition and parasite load*

The body condition indices of the four categories (table 3.) were significantly different by the Kruskal-Wallis ANOVA ($H[3, N = 73] = 12.38$; $P = 0.006$). Mann-Whitney U tests showed a significantly higher body condition index (poorer condition) of elephants in the dry-deciduous forest during the dry season, than the other three categories, which were not significantly different from one another (dry season, across habitats: $P = 0.032$; wet season, across habitats: $P = 0.223$; dry-deciduous forest, across seasons: $P = 0.019$; thorn forest, across seasons: $P = 0.109$).

From Watve's (1992) results, and from our data, regressions of parasite load on host age were not significant (dry season: $n = 78$, $R^2 = 0.016$; wet season: $n = 70$, $R^2 = 0.008$. $P > 0.05$; 1000 randomisations). However, that of body condition index on age was significantly positive ($n = 43$, $R^2 = 0.349$, $P < 0.001$), meaning that body condition deteriorates with increasing age. Therefore, the Spearman rank order correlation coefficient between body condition and parasite load was computed using the residuals from the respective regressions on age. These correlations were not significant: dry-deciduous forest, dry season: $n = 30$, Spearman's $R = 0.084$, $P = 0.659$; thorn forest, dry season: $n = 15$, Spearman's $R = -0.114$, $P = 0.685$; habitats pooled, wet season: $n = 28$, Spearman's $R = 0.119$, $P = 0.548$. There was also no significant cor-
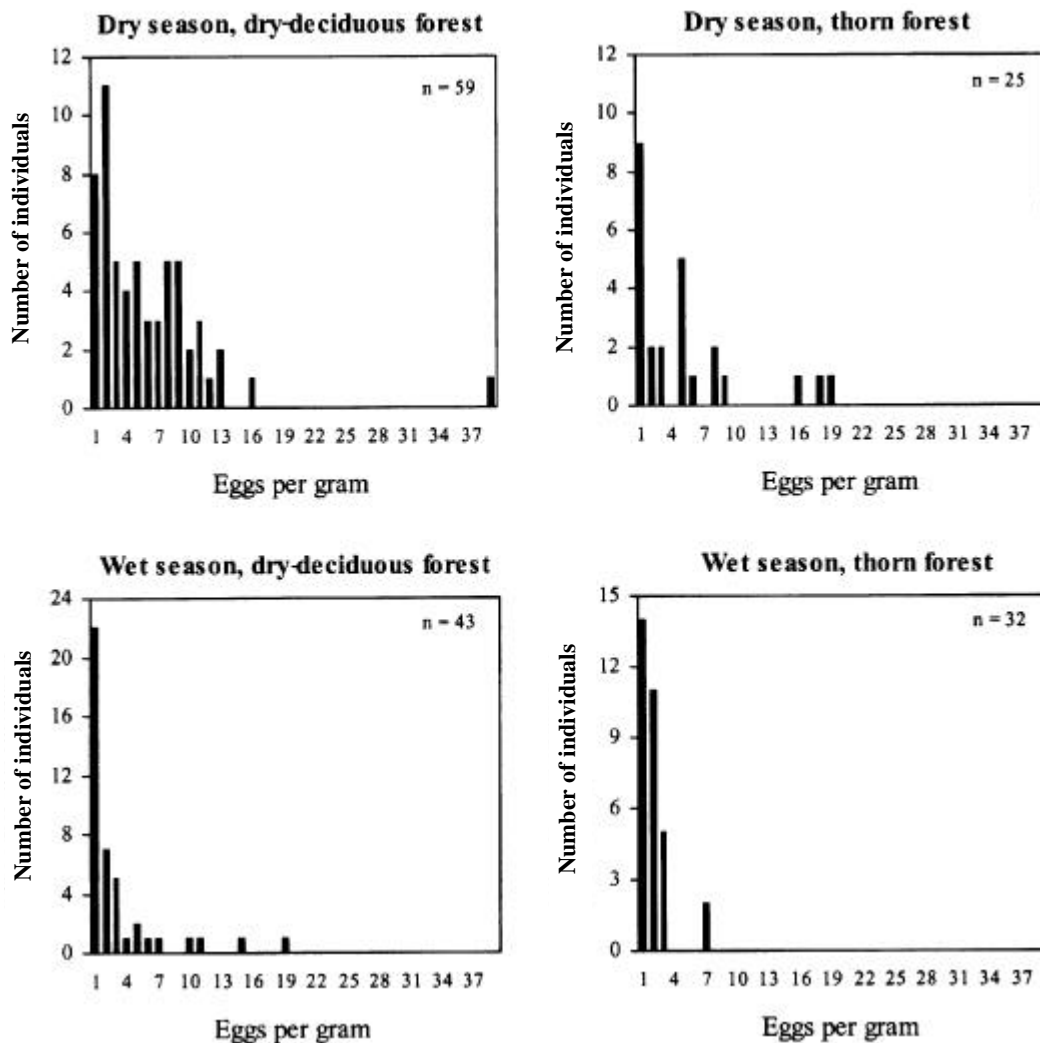

Figure 1. Frequency distributions of parasite loads in the dry-deciduous and thorn forests during the dry and wet seasons. The distributions are skewed, showing the aggregated nature of parasites. Thus, there are few individuals with high parasite loads, and many individuals with low parasite loads.

Table 2. Prevalence, mean and median parasite loads, and variance for the four distributions.

Season, habitat	N	Prevalence (%)	Mean eggs/g	Variance/ mean	Median eggs/g	MW U test
Dry season, dry-deciduous forest	59	91·53	5·449	6·24	4·268	b
Dry season, thorn forest	25	96·00	4·634	6·12	2·667	b
Wet season, dry-deciduous forest	43	81·40	2·495	6·56	0·980	a
Wet season, thorn forest	32	81·25	1·437	1·68	1·290	a

Results of pair-wise comparisons using the Mann-Whitney U test are shown in the last column ('b' is significantly higher than 'a').

Table 3. Median and range of the body condition index in different seasons and habitats.

Season, habitat	N	Median	Range	MW U test
Dry season, dry-deciduous forest	30	9·5	3–14·5	b
Dry season, thorn forest	15	7	4–11·5	a
Wet season, dry-deciduous forest	19	6·5	3–10·5	a
Wet season, thorn forest	9	5·5	0–10·5	a

The last column indicates the differences and similarities as revealed by Mann-Whitney U tests ($P < 0·05$).

relation between body condition and parasite load when individual parameters were used instead of using the body condition index ($P > 0·25$ for all correlations). This was not surprising since these parameters were correlated amongst themselves (Spearman's R 0·6–0·9).

4·4 *Intra-herd variation in parasite load*

A Kruskal-Wallis ANOVA revealed no significant difference in total parasite loads among herds (with at least five individuals sampled) during both the dry ($H[6, N = 35] = 5·296$; $P = 0·506$) and the wet ($H[3, N = 23] = 6·745$; $P = 0·081$) seasons. To examine parasite composition, a K-means clustering was done based on the OTUs present (K = number of herds). The expected and observed numbers of individuals from different family groups in each cluster were compared using c^2 tests. These were significantly different in just one cluster of the dry season (cluster 1: $n = 1$, $P = 0·549$; cluster 2: $n = 6$, $P = 0·416$; cluster 3: $n = 5$, $P = 0·766$; cluster 4: $n = 16$, $P = 0·787$; cluster 5: $n = 5$, $P = 0·731$; cluster 6: $n = 2$, $P = 0·035$), and were not different when all the clusters were pooled ($n = 35$, $P = 0·761$). There was no significant difference between observed and expected numbers of individuals from various herds in any cluster of the wet season (cluster 1: $n = 6$, $P = 0·124$; cluster 2: $n = 5$, $P = 0·526$; cluster 3: $n = 10$, $P = 0·563$; cluster 4: $n = 2$, $P = 0·458$). Thus individuals from various herds were essentially randomly distributed amongst the clusters, and there was no differ-

ence in parasite composition among herds. Since parasite load does not depend on the age of the animal, nor on the sex (Mann-Whitney U test: dry season: $n_{females} = 69$, $n_{males} = 6$, $U = 112$, $P = 0·064$; wet season: $n_{females} = 53$, $n_{males} = 14$, $U = 334·5$, $P = 0·572$), these could not have been confounding factors.

4.5 *Intra-individual variation*

Twenty three pairs of repeat samples collected from the same individuals at any later time point were analysed; the second sample from eight individuals had been obtained after 1–5 h of obtaining the first, the second sample from nine individuals had been obtained after 2–5·5 weeks of the first, and those from six individuals after 3–5 months. Wilcoxon matched-pairs tests revealed a significant difference in egg densities between the samples obtained within a few hours of each other ($n = 8$, $P = 0·043$), while those collected within a few weeks, and within a few months of each other, were not different (weeks: $n = 9$, $P = 0·051$; months: $n = 6$, $P = 0·249$).

4.6 *Variation in propagule densities within a dung pile*

There was no significant difference in propagule densities between the outer and inner layers of a bolus using the Wilcoxon matched-pairs test ($n = 45$; $P = 0·358$), nor

between the 'mixed outer layers' and 'mixed inner layers' ($n = 15$; $P = 0.530$). The results remained unchanged when each OTU was analysed separately. There was also no difference in propagule densities among the boli of a dung pile (Kruskal-Wallis ANOVA: inner layer: $H[2, N = 45] = 0.666$; $P = 0.717$; outer layer: $H[2, N = 45] = 0.310$; $P = 0.856$), even when each OTU was analysed separately ($P > 0.3$ for both layers, for all five OTUs). Further, Mann-Whitney U tests did not reveal any significant difference in egg densities between the 'mixed outer layers' or 'mixed inner layers' sample and any one (randomly picked) of the eight other samples from the same bolus ($P > 0.999$ for both layers, 1000 randomisations).

5. Discussion

Higher parasite loads in the dry season compared to the wet season, which has also been reported by Watve (1992), may occur due to four reasons: transmission, diet, body condition, and uneven sampling across age classes/ sexes if age/sex has an effect on parasite loads. As mentioned earlier, the last is not the case. The lower prevalence of parasites in the wet season could be indicative of lower transmission. Transmission through contaminated forage is unlikely to give rise to the observed pattern, because survivorship of eggs and juvenile stages of many nematodes is higher under moist conditions (Rogers and Sommerville 1963), and because more food is consumed during the wet than in the dry season (Sukumar 1989; Baskaran 1998). Also, since feeding patterns vary between habitats, if the height to which juvenile stages can climb the vegetation is limited, there should be a difference in parasite loads between habitats, which is not observed. Transmission through water may play an important role since elephants often defecate near or in water (Watve 1992) and congregate at the limited water sources during summer. Experiments to assess the numbers of infective stages in stagnant and running water during different seasons, and examining the utilization of different water sources and patterns of feeding near them, may help elucidate this.

Diet influences the host's nutritional status, and hence probably resistance to parasitic attack. Browse is higher in protein content as compared to grasses (Sukumar 1989), and contributes about 70% of the organic carbon for protein synthesis among adult elephants, while grass contributes only 30% (Sukumar and Ramesh 1995). One would thus expect to find lower parasite loads in the thorn forest than in the dry-deciduous forest, especially during the dry season. This difference in diet is probably a reason for the significantly poorer body condition of elephants in the dry-deciduous forest during the dry sea-

son. However, there is no difference in parasite load between habitats, and other factors may play a more important role.

A negative correlation is generally expected between body condition and parasite load (Festa-Bianchet 1989), and based on qualitative observations, Watve (1992) had suggested that this might be true in elephants and could help monitor their health status. An explanation for not finding such a pattern could be that parasite loads fluctuate within much shorter time periods than body condition, which may change over a couple of weeks to one or two months. This is supported by our finding considerable intra-individual variation in parasite loads at the scale of a few hours. In addition, body condition may be influenced by viral/bacterial/protozoan diseases, by ectoparasites, or by blood-parasitic helminths like *Wuchereria bancrofti*, leading to the absence of a one-to-one relation between body condition and intestinal helminth loads. Thus, it is not appropriate to use helminth egg densities directly to monitor the health of elephant.

The large variation in parasite load within a day may result from a periodicity in the release of eggs by the adult worms. Analyses of our data showed that there was no overall difference in egg densities with respect to the time of defecation. Thus, the periodicity of release of eggs by the adult worms in each host individual is probably different, and this could average out over many animals, or over long time periods in a single animal, leading to no significant difference in parasite loads over a few weeks or months.

Host-parasite interactions can be very complex, with several factors acting in a varied fashion to produce patterns that may not be easily attributed to any one factor. This could be especially so when the parasite has intermediate stages, or the host is a predator sharing parasites with its prey, in which case, the predator's parasite loads could be determined by several factors related to prey dynamics. Of the factors we examined in this study, season seems to be the strongest determinant of parasite load, probably due to transmission of parasite propagules through water. The absence of inter-habitat and inter-herd differences in parasite loads may ensue from elephants being wide ranging and also sharing home ranges. These are likely to hold for other large herbivores also, as also the absence of a one to one relation between external physical condition and parasite loads. In contrast, strong troop differences in parasite composition had been found in mangabeys (Freeland 1979) which have marked territories.

The above findings hold only over normal ranges of parasite loads, the typical distribution of parasites in a population being skewed (figure 1), with most of the animals having low parasite loads and few animals with high loads. However, in times of drought or stress, when

the individuals are under pressure, factors like diet and body condition may determine parasite loads. Circumstantial evidence from post-mortems indicated that very high parasite loads may result in impoverished body condition.

Finally, it is necessary to make sure that the sampling method was not biased to give certain results. We found that the dung is homogeneous with respect to parasite eggs, and that sampling should not have been a problem. Egg density itself may not be an accurate way of assessing worm burden, but we had to use it in the absence of any other reliable non-invasive method. The presence of male worms which do not release eggs, yet derive nourishment from the host may present a problem when correlations with body condition are concerned, but as mentioned, there is anyway no one-to-one relation because of other factors like ectoparasites or blood parasites. With other analyses like habitat, seasonal, and inter herd analyses, the varying number of males across individuals may balance out and not affect the results very much.

Acknowledgements

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