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Short communication

Modeling of the annual cycle of *Melophagus ovinus* (L.) in two sheep flocks of Patagonia, Argentina

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ABSTRACT

The ked *Melophagus ovinus* (L.), one of the most common obligate external parasites in sheep, is a recurrent problem in temperate sheep production areas worldwide. Modeling of its annual dynamics, which is lacking, can contribute to delineate integrated management strategies. We sampled ked density along a one-year period in two sheep farms of Northwest Patagonia, Argentina. In one farm with semi-intensive sheep management, we sampled 20 lambs and 10 adult Corriedale-cross sheep naturally parasitized prior to our study. In a second farm with extensive management, we sampled 10 Merino lambs, which we artificially infested in early autumn. We fitted bell-shaped curves to describe the annual ked population dynamics in each animal group and used global fitting to compare the models. In the two-cohort flock, the peak ked density in lambs was almost two-fold higher ($N_{\max} = 186$ vs. 86) and occurred 1.5 months earlier (early August) than that in adult sheep; time span parameter was equal in both curves ($SD \approx 64$ days). In the artificially parasitized lambs, the ked population showed a ca. five-month lag period, after which density increased sharply to a peak of $N_{\max} = 155$, reached well into spring (late October); the span of the model was $SD = 38$ days. Based on the ked annual cycles modeled and considering the traditional sheep management practices, we suggest monitoring flocks at least twice a year: at pre-mating in mid-autumn and at the annual shearing in spring (pre-lambing shearing or traditional shearing). Ked detection and treatment at pre-mating can prevent keds from entering the exponential phase and the consequent sanitary and economic impacts. In case keds are detected, treatment after pre-lambing shearing may prevent infestation of newborn lambs. Monitoring at traditional shearing is also an opportunity for ked detection, although it could be hard since ked populations will be in a phase of advanced decline in both adult and young sheep. Future works that statistically model the annual population dynamics of keds, under well-defined conditions, may allow meta-analyses of the behavior of this widely distributed plague, especially under the accelerating climate and agricultural changes worldwide.

1. Introduction

The most recent review of the sheep ked *Melophagus ovinus* (L.) warns of its possible resurgence as an important pest in Europe and other regions worldwide (Small, 2005). In that review, South America is not mentioned as an important area within the distributional range of this blood-feeding permanent ectoparasite, a fact that reflects the lack of available information. In the Patagonian region of Argentina, *M. ovinus* has always been present in humid areas and, over the last decades, it has also spread into drier zones (Olaechea et al., 2006). The effects of this parasite on sheep health and the negative economic impacts in flocks, i.e. loss of weight and body condition and reduction in fleece amount and quality (Nelson, 1988; Legg et al., 1991; Small, 2005), are of great concern to regional producers and sanitary authorities. In Argentina, Melophagosis of sheep is a notifiable disease and when detected, the affected farm is placed under quarantine until all the sheep are treated and the outbreak is controlled. In general, control consists in the application of external antiparasitic products immediately after traditional, summer shearing, when ked populations are expected to be at low, residual levels, thus enhancing the probability of treatment success. In spite of the sanitary measures implemented, the regional prevalence of this plague does not seem to be decreasing. In a survey of 123 sheep farms encompassing humid, mesic and arid locations, we found that *M. ovinus* was present in 72% of the cases (Larroza, 2013).

One main information gap to guide monitoring and control strategies is the absence of regional models of the annual ked cycle. Based on a few early works, developed mainly in sheep production systems of the

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northern hemisphere (i.e. with breed, management and climatic conditions very different from those of Patagonia), it is broadly assumed that sheep ked populations have annual cycles with increases in parasite loads during the cold season and decreases in summer, in close association with temperature. Although some general patterns can be extracted from those works, e.g. annual "boom and boost" cycle type, large variances around mean loads and high variability in population peaks and timing (Graham and Taylor, 1941; Macleod, 1948; Evans, 1950; Nelson and Qually, 1958; Pfadt, 1976; Legg et al., 1991), the annual cycle of ked populations in sheep flocks has never been modeled. On a broad scale, modeling ked population dynamics is useful for identifying (statistically based) patterns among studies in the behavior of this widely distributed plague. From an applied point of view, models are necessary for guiding precise monitoring and control strategies. With this purpose, we aimed at modeling the annual cycle of *M. ovinus* under natural environmental conditions in Northwest Patagonia, where information is very scarce in comparison to other sheep production regions worldwide. Specifically, we focus in two flock types: i) two-cohort flock, with lambs and adult sheep under semi-intensive management, with longstanding and recurrent ked parasitism and ii) newly parasitized lambs under extensive farming. We discuss the implications of the annual cycle modeling to delineate more efficient monitoring and control strategies than those currently implemented.

2. Materials and methods

2.1. Study system and animal groups

We carried out a descriptive study in two farms, (F1 and F2) representative of the main sheep management systems of Northwest Patagonia. Farm F1 (41°05′ S, 71°31′ W, 800 m a.s.l.; mean annual precipitation = 1600 mm) is located in the ecological zone of *Cordillera*, in which management is usually semi-intensive and mainly characterized by natural pastures and night closures. In F1, no antiparasitic treatment had been applied for at least two years prior to our study. From a 90 Corriedale-cross flock, we randomly selected 30 sheep naturally infested with keds, in two age cohorts: 20 lambs under one year of age (L-NI: naturally infested lamb group) and 10 adult sheep (over one year of age) (A-NI: naturally infested adult group). Overall, wool length was WL = 6.01 ± 2.08 cm. The sheep were identified with ear tags and kept with the rest of the flock all along the study period. Farm F2 (41°07′ S, 70°44′ W, 950 m a.s.l.; mean annual precipitation = 330 mm) is located in the ecological zone of *Sierras and Plateaus West*, where sheep management is characterized by extensive farming on natural pastures (Bran et al., 2000). In F2, we sampled only one animal group composed of lambs under one year of age, which we artificially infested with five (L-AI$_5$; n = 5 lambs) and 15 keds (L-AI$_{15}$; n = 5 lambs) extracted from naturally infested sheep (March 17th 2009 = day 0). We carefully placed the keds by hand on the right rib and below the midline of each lamb; at this moment, wool length was WL = 2.90 ± 1.14 cm. The lambs remained under the usual management of the area, but isolated from other sheep along the study period.

We used mean monthly air temperature to characterize the thermal environment of both locations during our study; data were obtained from the weather station at Bariloche Airport and the area of Climatology of the National Institute of Agricultural Technology (INTA) Bariloche.

2.2. Survey on the ked population and sheep condition

In both farms, we applied a sampling protocol with monthly to bimonthly intervals (10 and eight observations in F1 and F2 respectively), to obtain individual ked load along 319 days in F1 (March 20th 2009–February 2nd 2010) and 304 days in F2 (March 17th 2009–January 15th 2010). Following Nelson et al. (1957), we counted keds on the right side of each animal (in case of not finding keds, we carefully inspected the left side) from head to tail, and we multiplied the counts by two to estimate the total ked number per sheep. We also recorded the presence of pupae.

In each visit, we assessed body condition score (BCS) and weight (W) as indicative of the nutritional, physical condition of each animal, since this may affect susceptibility thus introducing noise in the results. We estimated BCS by the palpation of the lumbar region (Jefferies, 1961; Russel et al., 1969), using a 1–5 scale with 0.5 units of sensitivity. To detect animals with atypical physical conditions (i.e. too low or too high BSC), we tested for the discrepancy between their mean BCS and BCS = 2 (hypothetical value), which is usual in the region under normal environmental and management conditions. Since the mean is sensitive to outliers, a significant difference would indicate an abnormal body condition. Results reporting the BSC by animal group are expressed as group median, calculated over individual means, and its 25%–75% percentile.

2.3. Modeling ked population dynamics

To describe the annual ked population dynamics in each farm and sheep group, we fitted bell-shaped curves to the data using the Prism 5.00 software (GraphPad Software, San Diego, CA, USA) for nonlinear regression. Bell-shaped models have proved useful to describe population dynamics in insects that display "boom and bust" annual density cycles (e.g. Matis et al., 2009; Catangui et al., 2009). The equation fitted to the number of days since the first survey (t) and ked number per sheep (y) data was:

$$y = N_{\max} \times \exp\{-0.5 \times [(t - t_m)/SD]^2\}$$

where $N_{\max}$ is the peak ked number per animal, t_m is the day when the ked population peak occurred and SD is the standard deviation parameter of the model. The SD parameter represents half the time span (in days) between the inflection points of the Gaussian curve. We individually examined the accuracy of the parameters via the ratios between the standard errors of the estimate (SEE) and the best-fit values (Zar, 1999). We compared the best-fit parameters between groups using global fitting. This is based on fitting two models to the data: a null model, which consists of separate curves by group (e.g. A-NI vs. L-NI), and an alternative model, which consists of one common curve for the whole data set, i.e. across groups. The absolute difference between the corrected Akaike Information Criteria (AIC$_c$) of both models was used to calculate the evidence ratio $ER - 1/\exp(-0.5 \times \Delta\text{AICc})$, which equals the ratio between the probabilities of the null and the alternative models being correct (Motulsky and Christopoulos, 2003). The ratio of probabilities ER is reported as a measure of statistical evidence in favor of separate models by animal group.

3. Results

3.1. Model fit to the data

In farm F1, the naturally infested lambs (L-NI) and adult sheep (A-NI) had different ($t = -6.7245$, $p < 0.001$) initial (first survey) mean ked loads: $y = 43 \pm 24$ in L-NI and $y = 4 \pm 6$ in A-NI. In both groups, ked populations displayed typical "boom and boost" patterns, with individual counts reaching maximum values of $y = 158$ (A-NI) and $y = 392$ (L-NI) keds. The Gaussian model fitted to the data with coefficients of determination of $R^2 = 0.59$ and $R^2 = 0.54$ respectively, and ratios between the SEE and the best-fit parameters lower than 8%.

$$y = 85.7 \times \exp\{-0.5 \times [(t - 179)/62.2]^2\} \qquad \text{(model 1: A-NI)}$$

$$y = 186 \times \exp\{-0.5 \times [(t - 136)/65.4]^2\} \qquad \text{(model 2: L-NI)}$$

Both groups differed in their maximum ked load parameters ($N_{\max}$) and in the time at which populations peaked (t_m), with evidence ratios in favor of separate fits of $ER = 99.99/0.01$ and $ER = 98.14/0.86$