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PATTERNS OF *HAEMOPROTEUS* OCCURRENCE
IN WILD POPULATIONS OF *PODARCIS MURALIS*

SUMMARY

The common wall lizard *Podarcis muralis* is widespread in the Italian territory and, for this reason, it was studied extensively in the last decades. However, some aspects of its biology are still unclear and require specific research. This is the case of the parasite-host interaction with ubiquitous blood parasites of terrestrial vertebrates such Apicomplexa. Given the broad distribution of the common wall lizard in the territory and the frequent presence of haemoparasites in wild populations of reptiles, it is worth investigating how the two counterparts interact and the possible factors affecting presence and abundance of such parasites in lizard populations. In this study we have investigated 61 populations of the Italian peninsula from 2008 to 2017, analyzing frequency and intensity of the presence of *Haemoproteus* spp. in blood samples in relation to lizard size, latitude and checking for any effect of seasonality. The analyses showed that females are generally parasitized more frequently and intensely than males; moreover, in both sexes size has a positive effect on parasite presence as larger individuals are parasitized more frequently and intensely; on the other hand, latitude has a negative effect on as northern populations show lower parasite presence and load in both sexes. Eventually in terms of seasonality, we recorded a slight though significant effect in both sexes on both parasite presence and intensity. In conclusion, our study highlights that many different factors can influence such parasite-host interaction, although seasonality appears to play a marginal role in comparison to life-history traits or geographic factors.

Key words. *Podarcis muralis*, haemoparasites, life-history traits, seasonality.

RIASSUNTO

Modello di presenza di Haemoproteus in popolazioni di Podarcis muralis. La lucertola muraiola *Podarcis muralis* è una specie ampiamente distribuita nel territorio italiano, e per questo è stata ampiamente studiata sotto differenti aspetti negli scorsi decenni. Tuttavia, alcuni aspetti della sua biologia rimangono poco chiari e richiedono studi mirati. Questo è il caso del rapporto parassita-

ospite con parassiti ubiquitari dei vertebrati terrestri quali gli Apicomplexa. Data l'ampia distribuzione di *P. muralis* e la frequente presenza di suddetti emoparassiti nelle popolazioni selvatiche di rettili, è meritevole di attenzione studiare come le due controparti si interfacciano, cercando di indagare i fattori che influiscono sulla presenza e abbondanza di suddetti parassiti nelle popolazioni di sauri. In questo lavoro abbiamo studiato 61 popolazioni di lucertola muraiola nel territorio italiano tra il 2008 e il 2017, analizzando prevalenza e intensità della presenza di *Haemoproteus* spp. nei campioni di sangue in relazione alla taglia dell'individuo e alla latitudine e verificando la presenza di possibili effetti della stagionalità. Le analisi hanno indicato che le femmine di suddette popolazioni sono in media più parassitate dei maschi; ulteriormente, in entrambi i sessi taglia ha un effetto positivo sulla presenza del parassita in quanto gli individui di dimensioni maggiori tendono ad essere parassitati più spesso e più intensamente; di converso, la latitudine mostra un effetto negativo in quanto le popolazioni settentrionali mostrano presenza e carica parassitaria inferiore in entrambi i sessi. Per quanto riguarda la stagionalità, abbiamo rilevato un effetto lieve seppur significativo in entrambi i sessi, più marcato nei maschi. Di conseguenza il nostro studio evidenzia come molteplici fattori possono influenzare questa interazione parassita-ospite, tuttavia tra questi la stagionalità appare marginale mentre fattori come life-history traits o geografici hanno un peso più significativo.

Parole chiave. *Podarcis muralis*, emoparassiti, *life-history traits*, stagionalità.

INTRODUCTION

The study between the coexistence of wild population and non-virulent or endemic parasites is a growing field in parasitological research (ANDERSON, 1995). Therefore, in order to provide preliminary insight about how wild populations cope with persistent and endemic parasites, it is necessary to investigate a widespread host species and its interactions with such parasites. Blood parasites such as Apicomplexa are commonly present in wild populations of terrestrial vertebrates (AMO *et al.*, 2005; LEI *et al.*, 2013); moreover, the common wall lizard *Podarcis muralis* is a largely common species in the Italian peninsula, therefore, given that apicomplexan parasites are frequently reported in reptiles (TELFORD, 1984) and in *P. muralis* as well (OPPLIGER *et al.*, 2004), they appear to be excellent models to investigate host-parasite interactions.

MATERIALS & METHODS

In our research we analyzed a broad sample of 892 lizards (549 and 232) from 61 populations of the Italian Peninsula, collected throughout their activity period (Feb-Oct) between 2008 and 2017. On average we collected 15 ± 14 individuals per population and for each individual we recorded SVL (males = 63.4 ± 5.8 mm; females = 59.3 ± 5.3 mm), latitude, date, and collecting blood samples in order to perform the count of the presence of *Haemoproteus* spp.

Analyses

We performed Bayesian analysis on two different models. Formerly we ran a random intercept logistic model with i) presence/absence records (defined as probability of infection) as the dependent variable, ii) sex, SVL, season (Cosinor model with amplitude and phase) and latitude as predictors, iii) population as random effect. Secondly, we ran a random intercept zero-inflated negative binomial model with i) n° of parasites/10.000 erythrocytes as the dependent variable, ii) same predictors and random effect of the previous model.

RESULTS

The outcome of the first model indicates that both sexes are generally parasitized with comparable frequency. Latitude affects negatively the probability infection thus Northern population are less likely to be parasitized than Southern ones, with a greater effect in males. On the other hand, size (standardized SVL) has positive effect on the probability of infection in both sexes, with a more significant effect in females. Eventually, seasonality has a more marked effect on the probability of infection in males, that reach their peak later than females.

The outcome of the latter model is coherent with the former one, indicating that females are more intensively parasitized than males. Similar effects of size and latitude on parasitic load have been recorded: size has more marked positive effect on parasitic load in females than in males while latitude has larger negative effect on males. Eventually, seasonality affects more significantly the parasitic load of males, that reach their peak of infection later than females.

CONCLUSIONS

Our analyses indicate that, although females are equally likely to be parasitized as males, that their parasitic load is comparatively higher. Furthermore, females are also parasitized more frequently and intensively than males with growing size. Contrastingly, following a North-ward gradient, males are likely to be parasitized less frequently and intensively. Similarly, seasonality has more marked effect on both probabilities of infection and parasitic load in males.

Taking into consideration the immunocompetence handicap hypothesis (ICH) (FOLSTAD *et al.*, 1992), it would be reasonable to expect that males showed higher rates of parasite prevalence and intensity, however our findings, similarly to extant literature (OPPLIGER *et al.*, 2004), do not support suf-

ficiently such hypothesis and indicate that it is still necessary to investigate deeply the ecological and physiological constraints and factors that determine how lizard hosts cope with parasitic infestations.

Taking into consideration the potential effects of such interaction in lizards, it has been reported that Apicomplexan parasites often do not induce significant detrimental effects on the hosts (SULIEMAN *et al.*, 2021) although their prevalence in wild populations can be relevant (O'DONOGHUE, 2017, PICELLI *et al.*, 2020). Therefore, it is important to provide further information about hosts' physiological response to parasitization, with particular attention to its immunological response through white blood cells differential count.

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