**Harrison’s rule explains intraspecific variation in the body size of an endoparasite**

~~Does Harrison’s rule explain intraspecific variation in endoparasite body sizes?: The body size of~~ *~~Skrjabingylus nasicola~~* ~~depends on the skull size of the host~~

~~Does Harrison’s rule explain intraspecific variation in pendoarasite body sizes?: Body size variation of~~ *~~Skrjabingylus nasicola~~* ~~as a function of host skull size~~

~~Harrison’s rule as an explanation for intraspecific variation in endoparasite body sizes: body size variation of~~ *~~Skrjabingylus nasicola~~* ~~as a function of host skull size~~

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Suggestion:

Intraspecific varation in size, abundance and location of a mammal endoparasite: new insights in mustelid nematodiasis

Parasitic organisms display considerable variation in body size, with differences observed between species, populations, and even individuals within the same population (Poulin 1996). This variability is significant because body size is an important life-history trait for many parasites, influencing their transmission efficiency (Kelehear et al. 2012), host specificity (Bush & Clayton 2006) and, notably, their overall reproductive capacity. Larger parasites are generally associated with increased lifetime fecundity and shorter maturation times within hosts (Morand 1996, Trouvé et al. 1998, Harnos et al. 2016; Skorping et al. 1991, Morand & Sorci 1998). Larger body size can amplify parasite virulence due to heightened fecundity (Poulin 2007). However, the underlying reasons for variations in parasite body size are complex and not yet fully understood.

Host body size is often cited as a key factor explaining interspecific size variations in higher parasite taxa. Harrison (1915) discovered the first evidence of a positive association between parasite and host body sizes, known as Harrison's rule. This relationship has been documented for many parasite/host associations (Leung 2022) involving endoparasites like nematodes and nematomorpha (Morand & Sorci 1998, Morand et al. 1995, Ni et al. 2021) as well as ectoparasites such as lice, fleas and rhizocephalan barnacles (Harvey & Keymer 1991, Harnos et al. 2016, Nagler et al. 2017, Maestri et al 2020). Several proposed causal mechanisms include larger hosts providing additional resources, influencing parasite size and increasing lifetime fecundity (Poulin 2007), mechanical or physical constraints associated with parasitism (Morand et al. 2000), and the simultaneous influence of environmental factors on the body sizes of hosts and parasites (Maestri et al. 2020).

The influence of host size on intraspecific parasite body size has received relatively limited attention. Previous studies have primarily focused on specific species of ectoparasites, including parasitic isopods (Wenner & Windsor 1997, Tsai et al. 2001, Welicky et al. 2019), copepods (Van Damme et al. 1993), monogeneans (Cone & Burt 1985, Thoney 1988) and rhizocephalan barnacles (Nagler et al. 2017), revealing a positive relationship between host and parasite sizes. However, conflicting results (Baker et al. 2005, Welicky et al. 2019) and observations limited to one sex of the parasite (Tsai et al. 2001) have also been documented. In contrast, there is a lack of empirical tests exploring the relationship between the intraspecific sizes of endoparasites and their hosts in the existing literature (but see Poulin & Latham 2002).

It is better established that infection intensity can have a significant role in shaping intraspecific size variation in endoparasites. Within large infrapopulations, parasites can exhibit a phenomenon known as the "crowding effect," where the average size of the parasite decreases as the number of parasites per host increases (Read, 1951). Density-dependent growth has been particularly well-documented in cestodes (e.g., Read, 1951; Heins et al., 2002; Sistermans et al., 2023), has also been observed in other helminth endoparasites such as nematodes (Poulin 1999, Mohamed et al. 2020), nematomorphes (Hanelt 2008) and trematodes (Saldanha et al. 2009). Several factors contribute to this phenomenon, including competition for host resources, host immune responses and direct interactions between parasites (Quinell et al. 1990, Bush & Lotz 2000). However, conflicting results have also been reported. Some studies examining the relationship between helminth size and worm burden in humans, for instance, did not find a significant correlation (Quinell et al. 1990, Walker et al. 2009).

Host size and infection intensity can thus both influence intraspecific size variation in endoparasites, either independently or through interaction. Poulin & Latham (2002) demonstrated a correlation between total worm length and host size in a mermithid nematode infecting an amphipod species. They also found that worm length increased with higher infection intensity, which may be specific to their study system as the size of the host increased with increasing parasite load. To the best of our knowledge, no study has compared the relative contributions of these factors in helminths parasitic in vertebrates. It is possible that limited size variation in the host or the infected organ makes it difficult to assess the influence of host size on parasite size. Also, larger individuals of the same host species often have a higher parasite load (e.g. Zelmer & Arai 1998 , Poulin 2000, Horn et al. 2023). In other words, host size and parasite load tend to be confounded, making it challenging to disentangle the effects of host size and density dependence on parasite body size.

*Skrjabingylus nasicola* is a parasitic nematode belonging to the family Metastrongyloidae. It has a widespread distribution across the Palearctic, specialising on parasitising the nasal and frontal sinus cavities of multiple species of mustelids (Anderson 2000). First stage larvae migrate from the final host’s sinuses to the back of its throat, are being swallowed and expelled with the host's faeces. The infective forms of the parasite then develop in terrestrial gastropods, while small rodents, shrews, amphibians, or reptiles can act as paratenic hosts (Anderson, 2000). In Europe, the parasite is known to occur in the stoat (*Mustela erminea*), the least weasel (*Mustela nivalis*), the polecat (*Mustela putorius*) and the American mink (*Neovison* *vison*) (Hansson 1968, King 1977, Heddergott et al. 2016). *S. nasicola* has the potential to cause significant damage to the cranial bone structure of its hosts. The impact in least weasels and stoats can be especially serious, resulting in perforations of the bones that can converge and expose the frontal sinus and nasal cavity (Hansson 1968, King 1977, Frantz et al. 2022).

According to Hansson (1968), *S. nasicola* mainly occurs in the conchae, also known as nasal turbinates, within the lateral nasal parts. In arctoid carnivores, the total turbinal surface area scales isometrically with skull length (Green et al. 2012). The skulls of the different European host species of *S. nasicola* vary in size and exhibit pronounced sexual dimorphism. The smallest skulls (based on condylobasal length) are found in the least weasel, while the largest are found in polecats. Additionally, females in all four host species have significantly smaller skulls compared to males (Reichstein 1993, Stubbe 1993, Wolsan 1993, Abramov & Baryshnikov 2000). Hosts with larger skulls, as well as males, are thus likely to provide more physical space for the growth and proliferation of the nematodes *S. nasicola*. The variation in skull size, which can be easily measured, may have an influence on worm size. Additionally, infestation intensity has been observed to differ between individual hosts (Müller & Heddergott 2009, Frantz et al. 2022). This host-parasite system thus presents a valuable opportunity to investigate the factors driving endoparasite body size.

Here, our main objective was to disentangle the drivers of endoparasite body size, using *S. nasicola* as a model system. We first employed genetic barcoding to confirm the presence of a single species of *S. nasicola* across all four host species. We then aimed to determine whether Harrison's rule or infection intensity played a more significant role in driving the body size of *S. nasicola*. Additionally, we sought to investigate the nature of the interaction between these two factors. To achieve this, we test the following three scenarios: (i) worm size is solely determined by the skull size of the host, with larger hosts have larger worms, (ii) worm size depends solely on infection intensity, with individual worms becoming smaller when the size of the infrapopulation increases, (iii) both host size and infection intensity influence worm size. Worms tend to be larger in the skulls of the larger hosts or in the skulls of males compared to females of the same species. However, the size of the worms decreases with increasing infection intensity.

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