**Introduction**

Guilds, ecological groups, or functional groups are important concepts in food web modeling and in studies attempting to link community structures to ecosystem functions (ref). An ecological or functional group provides a proxy for certain species without detailed knowledge on the taxonomic identity and ecology of individual species. In studies focusing on the soil ecosystem, this is frequently the only feasible approach as the large numbers of species in soil fauna, most of which are unknown to science, make incorporating individual species into models practically infeasible (ref). This is true not only for microscopic animals, such as nematodes and collembolans, but also for organisms that are relatively large and perceived as being well-studied, such as earthworms.

Earthworms are the dominant group of soil fauna in many temperate and tropical ecosystems. Their feeding and burrowing behaviors lead to translocation and transformation of detritus and soil organic matter, affect soil microbial communities, and change resource available to other soil animals (Frelich et al., 2019; Ferlian et al., 2020; Chang et al., 2021). They are often considered “ecosystem engineers” as their presence fundamentally changes the soil habitat. About 30 earthworm species have become invasive worldwide, particularly forest ecosystems in the temperate and tropical regions. When present, these invasive species have dramatic impacts on soil properties, vegetations, soil microarthropod and microbial communities, nutrient dynamics, and soil C and N cycles (Craven et al., 2017; Frelich et al., 2019; Ferlian et al., 2020; Chang et al., 2021).

Earthworms are generally categorized into three main ecological groups, epigeic, endogeic, and anecic, based on their morphology, spatial distribution and feeding habits (Bouché, 1977). Although researchers quite often credited and therefore cited Bouché (1972, 1977) for the three terms, the concepts and definitions of these ecological categories have been modified by various authors and have evolved considerably (Lavelle, 1981; Lee, 1985). With nearly 50 years of research on earthworm taxonomy, evolution, life history, physiology, and ecology after Bouche’s 1972 article, we now have a better understanding on the spectrums of the ecological diversity of these organisms (Curry and Schmidt, 2007; Zicsi et al., 2011), partially aided by studies focusing on invasive earthworms and their ecological impacts (Craven et al., 2017; Taheri et al., 2017; Frelich et al., 2019; Ferlian et al., 2020; Chang et al., 2021).

Currently, two different systems of earthworm ecological categorizations are most frequently used by earthworm taxonomists and ecologists: (1) Bouché’s (1972, 1977) original system and (2) Lavells’s (1981) modified system. Bouché’s (1972, 1977) original system is composed of three main categories, epigeic, endogeic, and anecic, and four intermediate categories, epi-anecic, endo-anecic, epi-endogeic, and intermediate. Lavelle (1981) took Bouché’s (1977) three main categories and further divided the endogeic group into three categories: polyhumic endogeic, mesohumic endogeic, and oligohumic endogeic. Through years of use, the term epi-endogeic was also included by subsequent authors into their vocabulary to describe species that not only live in the leaf litter but also spend a considerable amount of time in the surface soil. This system has been widely adopted by earthworm workers (cite Earthworm Ecology 2nd eds), likely for being relatively comprehensible and easy to use.

Regardless of which system was adopted, a simplified version containing only the three main categories, epigeic, endogeic, and anecic, have been widely used to investigate how invasive earthworms affect the structure and function of the ecosystems they invade. Such studies have been summarized in meta-analyses focusing on plant growth (van Groenigen et al., 2014; Xiao et al., 2018), soil nutrient and toxic elements (van Groenigen et al., 2019; Ferlian et al., 2020; Sizmur and Richardson, 2020), soil faunal and microbial biodiversity (Ferlian et al., 2018), plant communities (Craven et al., 2017), and greenhouse gas emission (Lubbers et al., 2013). In most of these studies, the categories epigeic, endogeic, and anecic are considered as “ecological groups”, while in some they are considered as “guilds” (van Groenigen et al., 2019) or “functional groups” (Ferlian et al., 2018). In studies focusing ecosystem functions, different species in the same group have frequently been reported having inconsistent or even contradictory effects on the targeted ecosystem properties (ref), calling into question whether these ecological categories are meaningful proxies for functional entities.

Although community ecologists have long acknowledged that guilds, ecological groups, and functional groups encompass different concepts, yet in practice, these terms have frequently been used interchangeably (see Blondel, 2003 for detailed discussion). In earthworms, even when “ecological groups” was used, as in most studies noted above, it appeared to be treated implicitly as synonymous to functional groups, as the categorization was used to infer ecological impacts on other organisms or ecosystem functions, rather than niche partitioning between groups or interspecific interactions within groups. However, given that ecological groups are, by definition, not synonymous to functional groups, the inconsistent results researchers have observed so far should not be surprising. Indeed, as noted by Zicsi et al. (2011), “species in different ecological categories may exhibit similar behavior, and species in the same general ecological category can differ in their role in leaf litter disappearance and soil mixing.” If species in the same ecological category already differ in litter feeding and soil mixing, two fundamental characters that define the three main ecological categories, how could we expect these species to have similar influence on ecosystem functions?

In the last decade, there have been calls for stop calling these ecological categories functional groups (Bottinelli and Capowiez, 2021), for strictly adhering to Bouché’s (1977) original definition of the three main groups and four intermediate groups (Bottinelli et al., 2020), for using species identity instead when investigating ecosystem functions (Chang et al., 2016), or for redefining or refining these groups (Neilson et al., 2000; Zicsi et al., 2011). Recently, the trait-based approach was used to numerically re-define Bouché’s seven categories based on 13 anatomical and histological morphologies, offering the first quantitative approach to categorize earthworm ecological groups (Bottinelli et al., 2020). The study concluded that rather than categorical, earthworm’s ecological strategies are continuous, and epigeic, endogeic, and anecic are just the three end points of this continuous distribution, and called for new traits that can be linked to earthworms’ ecology and behavior, rather than just morphology.

Stable isotopes have been widely used to investigate the feeding ecology of soil invertebrates, particularly nematodes (Kudrin et al., 2015; Melody et al., 2016), mites (Maraun et al., 2011), proturans (Bluhm et al., 2019), collembolans (Ferlian et al., 2015; Potapov et al., 2021), and earthworms (Neilson et al., 2000; Melody and Schmidt, 2012; Ferlian et al., 2014; Potapov et al., 2019c Oecologia). This technique is also instrumental in our current understanding on trophic niche partitioning of soil fauna, and how different groups of soil fauna are involved in processes taking place in the soil (Pollierer et al., 2009; Hyodo et al., 2010; Klarner et al., 2014; Potapov et al., 2019a, b Functional Ecology, Biological Reviews). Isotopic studies focusing on earthworms largely confirmed the three main ecological groups (Schmidt et al., 1997, 2004; Scheu and Falca, 2000; Briones et al., 2001; Pollierer et al., 2009; Potapov et al., 2019c Oecologia), provided evidence for niche differentiation and competition (Melody and Schmidt, 2012; Chang et al., 2016), and further highlighted the importance of soil microbes in the diet of earthworms (Ferlian et al., 2014; Larsen et al., 2016). However, while stable isotopes, sometimes coupled with other techniques, have been instrumental in redefining feeding groups in collembolans and mites (Maraun et al., 2011; Potapov et al., 2016, 2021) and, as noted above, many studies have indeed focused on the natural abundance of stable isotopes of earthworms, the stable isotope technique has not had meaningful influence on refining earthworm ecological groups.

The objective of this study is to examine the idea of using the natural abundance of carbon and nitrogen stable isotopes (13C and 15N) to further refine the widely used ecological groups of earthworms, and to offer an updated framework of earthworm ecological groups based on Lavelle’s system and isotopic niches. We hypothesized that the three main ecological groups can be divided into more refined groups and that species can be further categorized as being a specialist or a generalist based on their 13C and 15N signatures.