Manaaki Whenua
Landcare Research

Terrestrial macrofauna invertebrates as indicators of agricultural impacts

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'Think piece' on Regenerative Agriculture in Aotearoa New Zealand: project overview and statement of purpose

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Find the full project overview, white paper and topic reports at ourlandandwater.nz/regenag and www.landcareresearch.co.nz/publications/regenag

This report is one of a series of topic reports written as part of a 'think piece' project on Regenerative Agriculture (RA) in Aotearoa New Zealand (NZ). This think piece aims to provide a framework that can be used to develop a scientific evidence base and research questions specific to RA. It is the result of a large collaborative effort across the New Zealand agri-food system over the course of 6 months in 2020 that included representatives of the research community, farming industry bodies, farmers and RA practitioners, consultants, governmental organisations, and the social/environmental entrepreneurial sector.

The think piece outputs included this series of topic reports and a white paper providing a high-level summary of the context and main outcomes from each topic report. All topic reports have been peer-reviewed by at least one named topic expert and the relevant research portfolio leader within MWLR.

Foreword from the project leads

Regenerative Agriculture (RA) is emerging as a grassroot-led movement that extends far beyond the farmgate. Underpinning the movement is a vision of agriculture that regenerates the natural world while producing 'nutrient-dense' food and providing farmers with good livelihoods. There are a growing number of farmers, NGOs, governmental institutions, and big corporations backing RA as a solution to many of the systemic challenges faced by humanity, including climate change, food system disfunction, biodiversity loss and human health (to name a few). It has now become a movement. Momentum is building at all levels of the food supply and value chain. Now is an exciting time for scientists and practitioners to work together towards a better understanding of RA, and what benefits may or not arise from the adoption of RA in NZ.

RA's definitions are fluid and numerous – and vary depending on places and cultures. The lack of a crystal-clear definition makes it a challenging study subject. RA is not a 'thing' that can be put in a clearly defined experimental box nor be dissected methodically. In a way, RA calls for a more prominent acknowledgement of the diversity and creativity that is characteristic of farming – a call for reclaiming farming not only as a skilled profession but also as an art, constantly evolving and adapting, based on a multitude of theoretical and practical expertise.

RA research can similarly enact itself as a braided river of interlinked disciplines and knowledge types, spanning all aspects of health (planet, people, and economy) – where curiosity and open-mindedness prevail. The intent for this think piece was to explore and demonstrate what this braided river could look like in the context of a short-term (6 month) research project. It is with this intent that Sam Lang and Gwen Grelet have initially approached the many collaborators that contributed to this series of topic reports – for all bring their unique knowledge, expertise, values and worldviews or perspectives on the topic of RA.

How was the work stream of this think piece organised?

The project's structure was jointly designed by a project steering committee comprised of the two project leads (Dr Gwen Grelet[1] and Sam Lang[2]); a representative of the New Zealand Ministry for Primary Industries (Sustainable Food and Fibre Futures lead Jeremy Pos); OLW's Director (Dr Ken Taylor and then Dr Jenny Webster-Brown), chief scientist (Professor Rich McDowell), and Kaihāpai Māori (Naomi Aporo); NEXT's environmental director (Jan Hania); and MWLR's General Manager Science and knowledge translation (Graham Sevicke-Jones). OLW's science theme leader for the programme 'Incentives for change' (Dr Bill Kaye-Blake) oversaw the project from start to completion.

The work stream was modular and essentially inspired by theories underpinning agent-based modelling (Gilbert 2008) that have been developed to study coupled human and nature systems, by which the actions and interactions of multiple actors within a complex system are implicitly recognised as being autonomous, and characterised by unique traits (e.g. methodological approaches, world views, values, goals, etc.) while interacting with each other through prescribed rules (An 2012).

Multiple working groups were formed, each deliberately including a single type of actor (e.g. researchers and technical experts only or regenerative practitioners only) or as wide a variety of actors as possible (e.g. representatives of multiple professions within an agricultural sector). The groups were tasked with making specific contributions to the think piece. While the tasks performed by each group were prescribed by the project lead researchers, each group had a high level of autonomy in the manner it chose to assemble, operate, and deliver its contribution to the think piece. Typically, the groups deployed methods such as literature and website reviews, online focus groups, online workshops, thematic analyses, and iterative feedback between groups as time permitted (given the short duration of the project).

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[1] Senior scientist at MWLR, with a background in soil ecology and plant ecophysiology - appointed as an un-paid member of Quorum Sense board of governors and part-time seconded to Toha Foundry while the think piece was being completed

[2] Sheep & beef farmer, independent social researcher, and project extension manager for Quorum Sense

Approaches for using terrestrial macrofauna invertebrates as indicators of agricultural land management practices

Contract Report: LC3954-16

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1 Introduction

Terrestrial invertebrates perform several important ecosystem functions, including pollination, improving soil structure and fertility, increasing plant productivity and organic decomposition, regulating the populations of other organisms through predation and parasitism, as well as being a primary food source for many vertebrates (Ward & Larivière 2004). Terrestrial invertebrates are typically grouped into macrofauna (e.g., insects, spiders, earthworms, millipedes), mesofauna (e.g., mites and springtails), and microfauna (microscopic organisms such as nematodes and tardigrades) (Table 1.).

The focus of this report is on macrofauna, which are sensitive to disturbances and useful as potential indicators to evaluate the impacts of management practices (Ward & Larivière 2004). Other characteristics that make invertebrate macrofauna desirable indicators include: the ease of collecting a substantial number and variety of taxa from a given habitat, fluctuations in the abundance of many species in response to changes in environmental conditions, and their ability to move in response to changing conditions (Gerlach et al. 2013). For example, studies have shown that invertebrate communities are more diverse and abundant in crops free of synthetic fertilisers and pesticides (e.g., Todd et al. 2015; Malone et al. 2017), and in crops adjacent to hedgerows with greater plant diversity (e.g., Howlett et al. 2021). Consequently, a great deal of research has gone into devising systems or indices that use invertebrate diversity and abundance to measure the state of an ecosystem, or the impacts of disturbance on an ecosystem (Gerlach et al. 2013; McGeogh 1998).

Table 1. Examples of taxa used as environmental indicators (modified from Gerlach et al. 2013)

Taxa	*Application*	*Limitations*
	Microfauna	
Nematodes	Includes soil-dwelling bacterial and fungal feeders that play an important role in the availability of plant nutrients through soil microbial biomass turnover (Bardgett et al. 1999). Community composition can indicate land-use history and soil quality (Pate et al. 2000; Cluzeau et al. 2012): resource pulses (e.g., irrigation, organic matter) or land management (e.g., organic) increased Rhabditidae abundance; resource limitation (e.g., heavy metal addition), or decreased soil porosity, increased Cephalobidae abundance, (Yeates 2003).	Use as indicators needs to be developed. Taxonomy incomplete, morphological identification difficult. Molecular techniques may help overcome this taxonomic challenge (e.g., Kenmotsu et al. 2020).
	Mesofauna	
Collembola (springtails)	Detritivores and fungivores useful as indicators of habitat characteristics, management, and restoration. They are sensitive to pollutants because they can be highly abundant and sensitive to litter depth and type.	
Acari (mites)	Species can be herbivores, detritivores, or predators. They are very sensitive at the micro-scale and have been used as ecological indicators.	Their small size and limited morphological features make identification difficult.
	Macrofauna	
Opisthopora (earthworms)	Considered soil engineers because they modify the physical, chemical, and biological properties of the soil they inhabit (Fusaro et al. 2018), falling into 3 functional groups: epigeic earthworms live at or near the soil surface in areas containing high organic matter and do not form permanent burrows; endogeic species live in the top 20 cm of soil and consume large amounts of soil and organic matter, forming shallow, semi-permanent burrows; and anecic earthworms form extensive permanent burrows up to 2 cm in diameter that extend laterally and vertically as deep as 3 m below the soil surface. The presence of epigeic earthworms can indicate good soil litter conditions, endogeic earthworms can indicate low disturbance of the upper soil layers, while anecic earthworms may indicate optimal soil condition because of their major influence on soil structure (Stroud 2019). They are one of the most frequently used invertebrate groups to evaluate the sustainability of soil use.	Identification to species level can be difficult.
Isopoda (woodlice and relatives)	Encompass scavengers, detritivores, and herbivores, and used as environmental indicators in moist areas. They may take a long time to return to a recovered/restored site, so may indicate habitat quality or advanced stages of habitat recovery (Pryke & Samways 2009).	As with nematodes, their taxonomy is incomplete, and identification of species is challenging.

Taxa	*Application*	*Limitations*
Chilopoda (centipedes)	Predators used as ecological indicators. Most species are highly mobile and not much is known about their microhabitat sensitivity. Their use may also be limited since their diversity has been reported as relatively low in most studied systems.	Taxonomy is incomplete and identification of species is challenging.
Araneae (spiders)	Predators, generally considered environmentally sensitive, and used as ecological and biodiversity indicators. Some families are relatively easy to identify to species, e.g., the cosmopolitan families Gnaphoside (ground-dwelling) and Theridiidae (web-spinners). Studies have used a group of species or families to indicate specific habitat characteristics or habitat change, including agricultural management practices (Jeanneret et al. 2003; Perner & Malt 2003; Schmidt et al. 2005; Kapoor 2008; Vitanović et al. 2018; Depalo et al. 2020; Benhadi-Marín et al. 2020)	Identification is difficult within some families.
Opiliones (harvestmen/ daddy long legs)	Predators that have been used as ecological indicators: they can reflect changes in the food web of litter habitats. Most species are slow to recolonise disturbed areas due to their poor dispersal abilities. Consequently, they are good indicators of 'high quality' habitats, but not early stages of ecosystem recovery.	Their taxonomy and identification can be difficult.
Odonata (dragonflies and damselflies)	Widely used as ecological, environmental and biodiversity indicators of freshwater systems (in-water and riparian), often to indicate stream health that can in turn indicate catchment health. Along with Ephemeroptera (mayflies), Plecoptera (stoneflies) and Trichoptera (caddisflies) they can be used to assess riparian and in-water restoration, including river and floodplain systems.	
Orthoptera (grasshoppers, crickets)	Used as ecological (e.g., change, habitat management) and environmental indicators (e.g., pollutants), especially in grasslands.	
Blattodea (cockroaches and termites)	Used as ecological indicators (level of disturbance), indicating litter quality in forested and wet areas.	Taxonomic challenges in lower and southern latitudes.
Hemiptera (true bugs)	Include sucking herbivores as well as predators; have only rarely been used as indicators. They are an underexplored group that could potentially be very useful as ecological, environmental and/or biodiversity indicators in both freshwater and terrestrial environments.	
Coleoptera: Carabidae (ground beetles)	Considered keystone predators that can indicate state of the environment, including agricultural management practices (e.g., Pizzolotto et al. 2018; Sommaggio et al. 2018; Sáenz-Romo et al. 2019; Depalo et al. 2020).	

Taxa	*Application*	*Limitations*
Coleoptera: Scarabaeidae (scarab beetles)	Include nectarivores, herbivores, fungivores, and detritivores. They can be very sensitive to vegetation change. Consequently, they can be effective ecological and environmental indicators, and considerable research has been done on this.	
Coleoptera: Coccinellidae (ladybirds or ladybugs)	Most are predators, especially of pests such as aphids and scale insects, and play a significant role in biological control strategies (Iperti 1999). They can be used to indicate impact of agricultural management practices (Canovi et al. 2017).	
Coleoptera: Staphylinidae (rove beetles)	Most are predators; some are fungivores or pollen feeders. About half of the known species are found in leaf litter, forming one of the most common and ecologically important insect groups of soil fauna (Bohac 1999). Their diversity and abundance can be used to measure impacts of disturbance and land management practices (Sommaggio et al. 2018; Depalo et al. 2020).	Their taxonomy and identification can be difficult.
Lepidoptera (moths and butterflies)	Nectarivores or herbivores; some butterfly species are conspicuous and relatively easy to identify. Species active in the day (diurnal) have been widely used as environmental and ecological indicators. Butterflies have been used to indicate habitat changes/quality, management, including in agriculture and pollution (Maes & Van Dyck 2005; Kadlec et al. 2009; Greco et al. 2018; Hiyama et al. 2018; Sánchez-Fernández et al. 2020).	Their high mobility makes them less sensitive to smaller scale disturbances/habitat evaluation. Although this can be overcome by including behavioural studies.
Diptera (flies)	Can belong to various feeding guilds and freshwater or terrestrial habitats, depending on the life cycle, e.g., some hoverfly (Syrphidae) and bristle fly (Tachinidae) larvae are predatory or parasitic, but become nectarivores/pollenivores as adults (and hence some are pollinators). Larvae of some species have become important environmental indicators in freshwater habitats (e.g., macroinvertebrate community index for freshwater systems).	
Hymenoptera: sawflies, wasps (including parasitic), bees (Halictidae, Apidae), and ants (Formicidae)	Belong to various feeding guilds (predators, herbivores, omnivores, fungivores, pollenivores/nectarivores). Consequently, some have been used extensively as environmental or ecological indicators (Tscharntke et al. 1998; Garratt et al. 2019; Billaud et al. 2020).	
Neuroptera (lacewings, mantidflies, ant lions, and their relatives)	Considered sensitive to ecological shifts, although this has not been well explored. They have been used to indicate agricultural management and pollution (Clarke 1993; Booth et al. 2003; Ruano et al. 2004; Thomson & Hoffman 2006).	

Previously, efforts to use invertebrates as indicators considered the identification of individual invertebrates to species level to be a crucial component of the process. Recently, use of higher taxonomic groupings has been employed or suggested to making the process more accessible to non-experts (e.g., Storey & Wright-Stow 2017; Garratt et al. 2019). More recently, a trait-based analysis of invertebrate species identified from community sampling has been promoted as an alternative to the taxonomic species-based approach (Moretti et al. 2017). Although outside the scope of this review, molecular techniques are also being investigated and are offering promising avenues to monitor invertebrates as indicators of ecosystem health (e.g., metabarcoding, reviewed by Ruppert et al. 2019, environmental genomics for ecosystem monitoring reviewed by Cordier et al. 2020, etc.). In this report, the potential to use a species-based approach as well as higher taxonomic groups is discussed, followed by a summary of the trait-based approach. Examples of studies that apply different approaches to the use of terrestrial invertebrate macrofauna to measure the impact of land management practices in agriculture are discussed.

2 Species-based assessments

By far the bulk of the research carried out in the past to evaluate invertebrate biodiversity for ecological and environmental monitoring has involved collecting and identifying individuals to species level using morphological characteristics (Porter & Hajibabaei 2018; Wong et al. 2019). The species and their abundance were then analysed using various statistical methods and indices that help explain their community evenness or diversity in a given habitat. Measuring diversity to such a fine taxonomic level assumes species within the ecosystem/habitat have been described, requires a relatively stable taxonomy (i.e., species status well recognised), and practitioners often needed a high degree of technical knowledge to accurately identify individuals to species level. This can be a barrier to the more widespread use of invertebrates as indicators of ecosystem quality and disturbance. The taxonomic challenge posed by this approach has presented a barrier to widespread adoption of invertebrate indicators as a means of monitoring and assessing land management practices.

An approach proposed to overcome the taxonomic challenge is the use of Recognisable Taxonomic Units (referred to as 'morphospecies') as species surrogates when taxonomic expertise is not available (Oliver & Beattie 1996; Ward & Larivière 2004; Gerlach et al. 2013). This approach involves using voucher specimens to create a reference collection of all the species encountered across a study. The morphospecies approach uses surrogate names for species (Fig. 1), with the crucial step being the ability of non-specialist taxonomists (parataxonomists) to assign all the individuals from the same species to the morphospecies name. Sorting errors by parataxonomists can occur and can result in underestimating or overestimating number of species (Barratt et al. 2003; Krell 2004), which can in turn lead to errors in assessing the impact of a disturbance on an ecosystem.

Molecular diagnostic techniques offer a promising method to accelerate the process and reduce the need for expert knowledge (Porter & Hajibabaei 2017; Liu et al. 2020). However, such methods are still in the development stage and require specialised equipment and sample DNA of the organisms in the community. Molecular diagnostic techniques are only as accurate as the reference sequence libraries (e.g., DNA libraries) that are available and for many New Zealand invertebrate taxa the reference data are still absent. As with identifying taxa to morphospecies, sequences can also be divided into OTUs (operational taxonomic units) or ITUs (identifiable taxonomic units), but this comes with similar issues, including an inability to know functions or traits of the species these sequences represent.

2.1 Case study: invertebrates in orchards (New Zealand)

The biodiversity of ground-active invertebrates (predators, herbivores, and detritivores, including fungivores) was greater in organically managed kiwifruit orchards than in conventionally managed ones (Todd et al. 2015). The greater diversity of natural enemies and detritivores was attributed to fewer toxic agrichemical sprays applied in organic orchards. In contrast, Malone et al. (2017) reported that apple orchards that were managed using integrated pest management had similar assemblages of key insect predators as those collected from organic orchards. In the kiwifruit orchard study, insects were collected across 20 orchards, over three sampling periods in spring (October), summer (January), and autumn (March) using flight intercept traps, yellow pan traps or pitfall traps (Todd et al. 2015). In the apple orchard study, insects were collected in 15 orchards using integrated pest management or organic management, in December or February/March, using sticky traps, pitfall traps, or branch tapping (Malone et al. 2017).

Advantages: Simple techniques can be used to collect invertebrates.

Challenges: Counting and identifying the species of invertebrates collected (over 600 taxa from the kiwifruit orchards, over 750 taxa in the apple orchards) is time consuming and labour intensive. It also requires a relatively high degree of technical expertise.

2.2 Case study: Spiders in winter wheat (Germany)

Spiders were sampled using pitfall traps in paired conventionally or organically managed crops in late spring (May) or summer (June), and adults were identified to species. Non-crop perennial habitat was found to increase spider diversity regardless of whether a winter wheat crop was conventionally or organically managed (Schmidt et al. 2005). The results showed the value of perennial habitat as a refuge for invertebrates such as spiders. Also, some spider species were more abundant in organically managed than conventionally managed wheat, indicating a potential for greater predator activity in the organically managed crops (Schmidt et al. 2005).

Advantages: As in the orchard studies described above, collecting spiders from the field was simple. Also, focusing on one group (spiders) reduced the processing time for samples.

Challenges: As with the orchard examples described above (Todd et al. 2015; Malone et al. 2017), identifying and counting species is time and labour intensive. Taxonomic expertise in identifying spider species was necessary.

3 Trait-based assessments

The taxonomic approaches described above are limited for explaining the mechanisms that underpin ecosystem function in relation to biodiversity (Wong et al. 2019). Consequently, there is growing interest in applying a trait-based approach to biodiversity-based studies, to better address macro-ecological questions by reducing context dependency (i.e., the species-specificity of a given site or region) (Moretti et al. 2017). Functional traits are also more fundamentally linked with ecosystem services (Díaz et al. 2007). Trait-based assessments allow for testing mechanisms that underlie species assemblages (Moretti et al. 2017) and are still based on identifying the species present in assemblages.

This approach incorporates more than just the species identity and abundance. Traits can include aspects of an organism's morphology, feeding, life history, physiology, and/or behaviour (Table 2.). Traits can be either a feature that determines the response of a species to an environmental change (response trait), and/or contribute to the effect a species has on an ecosystem function (effect trait) (Moretti et al. 2017). Traits include phenotypic features measured on individual organisms that affect its fitness through their interaction with biotic and abiotic variables (functional traits) and affect or regulate higher-level ecological process (ecosystem functionality) (Wong et al. 2019). In a review by Hevia et al. (2017), body size, feeding habit and diet were identified as three of the most common invertebrate traits showing significant relationships with land use.

One of the key challenges with this approach is having information on the traits of interest, especially those related to ecology (i.e., feeding, life-history, physiology, behaviour), for the key species identified in a community (Figure 1). Given the crucial roles invertebrates perform in a wide range of ecosystems, knowledge of their functional traits is key to understanding multi-trophic processes and ecosystem functioning.

Table 2. Traits identified by Moretti et al. (2017) considered to be critical in a terrestrial invertebrate's response to the environment and/or affecting ecosystem processes and services

Morphology	*Feeding*	*Life history*	*Physiology*	*Behaviour*
Body size	Feeding guild	Ontogeny (egg to adult)	Standard metabolic rate	Activity time
Eye morphology	Ingestion rate	Clutch size	Relative growth rate	Aggregation
Respiration system	Biting force	Egg size	Desiccation resistance	Dispersal mode
Hairiness		Life span	Inundation resistance	Locomotion speed
Colour		Age at maturity	Salinity resistance	Sociality
		Parity (the number of times an individual reproduces)	Temperature tolerance	Annual activity rhythm
		Reproduction mode	pH resistance	
		Voltinism (number of broods or generations per year)		

3.1 Case study: Earthworm surveys (Italy)

A study in Italy developed a soil biological quality index based on earthworms (QBS-e), where the higher index value indicates better soil conditions (Fusaro et al. 2018). The authors compared the QBS-e approach with a traditional earthworm diversity method to assess the impact of organic and conventional management systems on earthworms in an annual cropping system and in a perennial crop. Fusaro et al. (2018) suggest the index can be used by non-experts, despite the study using earthworms identified to species, which is likely to require a high degree of technical knowledge before assigning them to functional groups. The sampling method was to dig 30 × 30 × 20 cm pits, counting the earthworms from the sample for 15 minutes, and assigning them to functional groups based on species identity.

In contrast to the UK study described in case study 4.3 below (Stroud 2019), where farmers identified earthworms directly into functional groups without differentiating between species, Fusaro et al. (2018) identified both adult and juvenile earthworms to species, then assigned each to a functional group. In addition to the epigeic, endogeic, and anecic groups, they also included coprophagic (living and feeding on manure or compost) and hydrophilic (living and feeding in damp soils or shallow water table soils). An ecomorphological score (EMI) was assigned to each functional group, and the QBS-e index was calculated using dedicated software. Both the traditional species-based diversity approach and the QBS-e resulted in reduced diversity or a lower index in the conventionally managed annual crops compared to the organically managed crops. However, neither showed any difference between the organic and conventional perennial crop (vineyards).

Advantages: There was strong agreement between the species-based and QBS-e index approach. The authors suggest that the index and dedicated software make it possible to assess and monitor soil quality without taxonomic expertise.

Challenges: It remains to be seen if the QBS-e index could be used by non-experts, since the individual earthworms had to be identified to species to assign them to an ecological functional group. It is not clear from the study if earthworms could be identified to functional groups in the absence of the species identification to generate an index. It is also unclear how the index can inform changes in management practices, since the study did not pinpoint what management practices were causing the differences between organic and conventionally managed crops. The authors did suggest the lower QBS-e index in the conventional annual crops was due to the greater amount of tillage that occurred in these crops compared to the organically managed crops.

3.2 Case study: soil macro-invertebrates (France)

An index of biological soil quality (IBQS) was developed using soil macro-invertebrate community data collected from soil monolith samples (25 × 25 × 20 cm deep) from forest, pasture, or cropping soils (Nuria et al. 2011). Additional samples were taken to measure chemical and physical properties of the soil at the time of macro-invertebrate sampling. Adult invertebrates were identified to species level and immatures to family level. Forest soil was considered the highest quality but varied considerably with the IBQS index calculated (6–20). Some crops and pastures had indices within the lower range of the forests, suggesting their soil quality was 'as good' as forest soil.

Advantages: The study identified functional groups that could be linked to habitat quality. Disturbed environments had communities composed of pioneer or ubiquitous species adapted to a wide range of environmental conditions, while communities in stable habitats were composed of a large number of predators and species known to be sensitive to disturbance.

Challenges: The index required species-level identification and had to be calibrated and validated for each region/catchment. It has not been widely used since publication and has not been tested in farming or in the citizen scientist community.

4 Higher taxonomic units

It is not always possible to identify invertebrates to species level, especially where species that co-occur are difficult to distinguish or have been poorly described, or when the time and equipment needed to identify to species exceeds the resources available. Lawton et al. (1998) examined the species-level diversity of eight diverse animal groups (from birds to soil nematodes) along a disturbance gradient in a tropical forest and concluded that the number of morphospecies and the number of scientist-hours required to process samples increase dramatically for small invertebrate taxa. Use of higher-level taxa (e.g., genera, families, or sub-orders instead of species) may provide an alternative. This approach is well developed in application to many terrestrial invertebrate assemblages (Pik et al. 1999; Groc et al. 2010): it allows processing of more samples per unit time, requires less expertise, and potentially results in fewer identification errors.

However, use of overly aggregated taxonomic levels can sometimes decrease our ability to detect patterns related to disturbance or contamination (Hanna et al. 2015). Using higher taxonomic units assumes that species within a given higher unit are likely to respond to a disturbance in an equivalent manner (Timms et al. 2013). If this is not the case, taxonomic aggregation may result in a reduction in the quality (precision and/or accuracy) of results. Ideally, the selected level of taxonomic aggregation should maintain the ability to discern ecological patterns or assess impacts (Terlizzi et al. 2003).

Studies examining the impact of disturbance or ecosystem types (i.e., treatments) on terrestrial invertebrates at species-level and higher-level taxonomic units (genus, family) indicated similar patterns of community composition or beta-diversity between different ecosystems or disturbance levels (Timms et al. 2020). However, differences between treatments and community patterns were stronger at the species (and/or genus) level (Timms et al. 2013). Better performance of higher taxa as surrogates for community composition is expected in communities with a low species to higher taxa ratio, high evenness, and high species turnover (Rosser 2017). Some authors (e.g., Terlizzi et al. 2003; Bouchard et al. 2005) suggest that in order to know what level of taxonomic aggregation (e.g., at the genera or family level) could be appropriate in a poorly known environment, we first need to know what species are present. There are few recommendations for the level of taxonomic aggregation necessary and at a level that would be sufficient to represent ecological patterns in New Zealand environments.

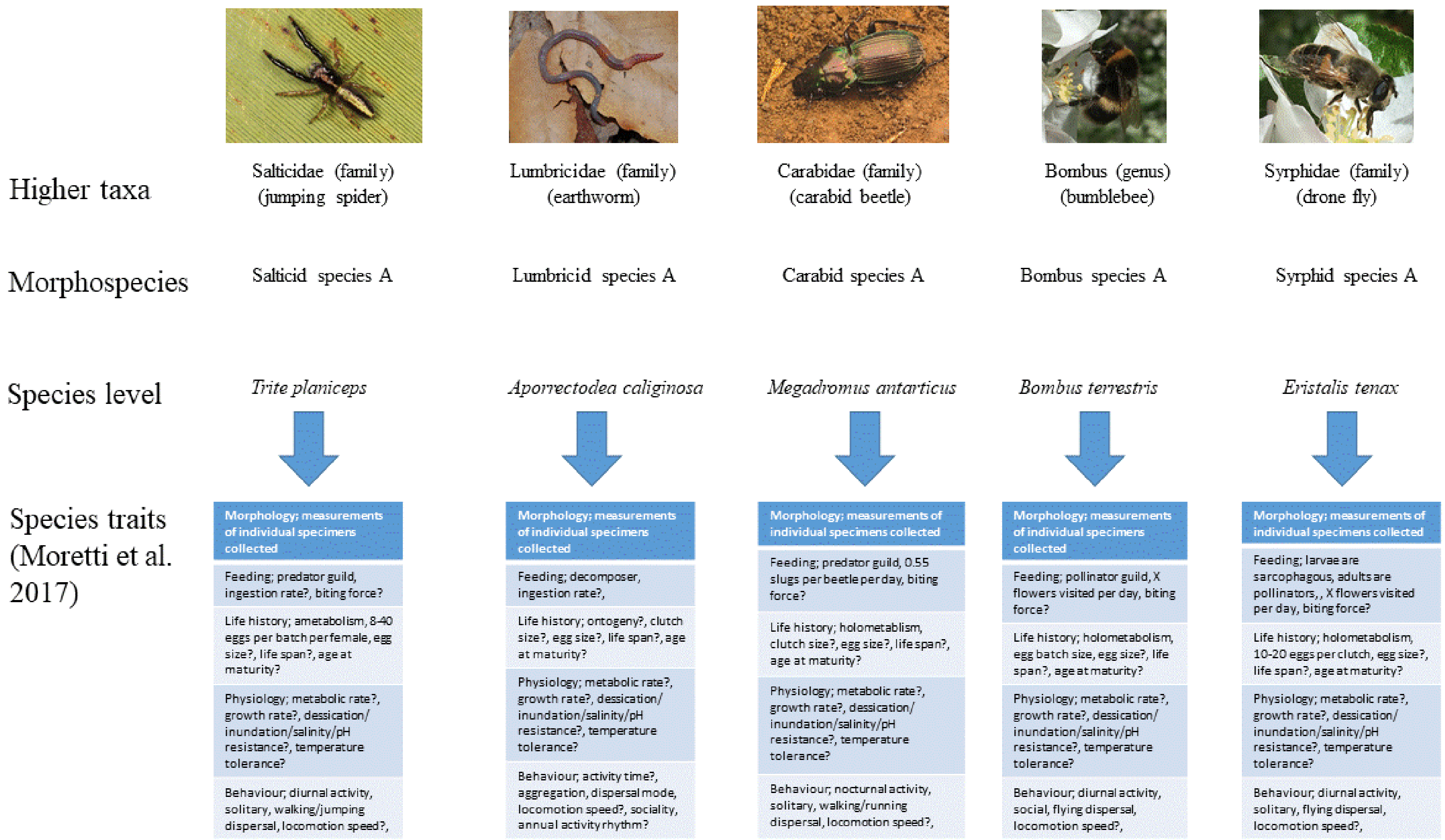

Figure 1. An example of using the different approaches for identifying individuals collected in a survey: high taxa identification to family or genera, morphospecies designation, species identification and additional information required for trait-based analysis.

Overall, higher taxonomic units, coupled with more easily identified species, may improve the usability of terrestrial invertebrates as indicators of ecosystem quality for both experts and non-professionals. For example, invertebrate indicators using higher taxonomic groups may create an opportunity to tap into farmer and citizen science participation. Extending the use of invertebrate indicators into the realm of citizen science has the advantage of combining ecological research with environmental education (Dickinson et al. 2012). The use of higher taxonomic classifications for measuring the impacts of disturbance (including land management practices) has been used in citizen science projects, some of which are reviewed below. This approach can provide a source for large-scale spatial and temporal data that is often not possible through typical research programmes (Billaud et al. 2020) and can also support evidence-based decision-making by land managers for land management practices.

4.1 Case study: farmland biodiversity and agricultural practices (France)

The abundance of five invertebrate groups – solitary bees (pollination), earthworms (soil fertility), butterflies (sensitive to land-use changes), and beetles and molluscs (including pest and beneficial species) – was monitored in a citizen science programme for 7 years (Billaud et al. 2020). The aim of the study was to determine if relating temporal abundances of these invertebrate groups to agronomic practices could help identify mechanisms to conserve invertebrates in farmland.

Farmers monitored invertebrate biodiversity in field crops, meadows (i.e., pasture), vineyards and/or orchards, using keys provided by researchers to identify individuals, either to functional group or taxonomic unit (genus or species [sometimes]). Over 1,000 farmers participated in this programme, with participation averaging just over 1 year per farmer, typical of most citizen science programmes (Billaud et al. 2020). Monitoring methods included: trap nests for solitary bees, recording the number of butterflies flying within 5 m of an observer along a 10 minute transect, wooden boards used as an artificial habitat (30 × 50 cm, three per field) by beetles and molluscs, with other invertebrates recorded as well. Earthworms were monitored by pouring 10 L of a mustard solution over a 1 m^2 area (three per field, 6 m apart). The earthworms were collected, sorted into functional groups (epigeic, anecic, and endogeic), and counted. The aim was to monitor earthworms once a year in winter or early spring, bees, beetles, and molluscs once a month between February and November, and butterflies five times between late spring (May) and autumn (September). However, some observers skipped some of the surveys. Consequently, data from individual surveys were used instead of annual summaries. Since most individuals were not identified to species level, only total abundance for each group was used in the analysis. Farmers also provided information about their agricultural practices for their farm and the landscape surrounding their monitored fields.

Despite the high turnover of participants and consequent change in fields over time, there were obvious declines over time in bee and butterfly numbers linked to the use of pesticides and synthetic fertilisers in field crops, but not in vineyards. Earthworm numbers were positively related to reduced tillage in meadows (Billaud et al. 2020).

Advantages: Even with participant turnover and only higher taxa recorded, trends were still apparent and could be related to land use or land management practices. Since bees and earthworms provide clear functions (pollination, soil engineering) that can benefit farm ecosystems, it is easier to interpret the impact of land practices or land use on the services provided by these taxa than it is for beetles, molluscs, or butterflies.

Disadvantages: Pest or beneficial species of beetles and molluscs were not differentiated. While land use or land practices did affect their abundance, it was not possible to determine if this is a positive change (e.g., reduction in pests and/or increase in beneficial species) or detrimental (reduction in beneficial species, increase in pests). The function butterflies may perform in agroecosystems is not clear (e.g., adults may be pollinators, but larval stages could be pests), so interpreting the implications of a change in their abundance due to land use or land practices was not possible in this study. The results from this study were correlative rather than demonstrating a causal relationship.

4.2 Case study: insect pollinator surveys (United Kingdom)

A recent study from the United Kingdom examined the willingness of farmers, agronomists and the wider public (non-farming volunteers) to monitor crop pollinators and pollination services and compared their results to observations by experts (i.e., researchers) (Garratt et al. 2019). Experts and non-experts were tasked with: (i) surveying (identifying and counting) insects visiting flowers along transects in apple, oilseed rape or bean crops; (ii) collecting and identifying insects in pan traps in these crops; and (iii) measuring pollination services for tagged branches or stems on plants in their survey area. This was done by covering some branches with mesh bags to prevent insect pollination, leaving other branches open to pollinators, and supplementing pollination of flowers on corresponding tagged branches by collecting pollen from neighbouring plants and painting the pollen onto the flowers. The aim of the study was to test the protocols and measure the willingness of non-professionals to use the protocols to monitor insect pollinators. Consequently, there was no discussion regarding the quality of the data obtained by volunteers compared with professionals, or regarding measuring habitat quality.

Advantages: Most farmers and agronomists, and non-farming volunteers indicated they would be willing to carry out surveys and pan trapping as part of a wider pollinator monitoring scheme.

Challenges: Only a few farmers attempted the assessment of the pollination services method. Most farmers and agronomists indicated they would be unlikely to use such a method in the future. Farmers and agronomists were less likely to record bumblebees to species level in surveys, compared with volunteers from the wider public and experts. It is unclear from this study what the implications of not recording pollinators to species level would be. The accuracy of bumblebee species identification by non-farming volunteers was not measured, so the data quality from the volunteers is uncertain. The type of crop affected how easy it was to observe some insect groups. More training was identified as a key requirement to reduce variability between non-experts. Pan traps only recorded a proportion of the potential insect pollinators so should not be used on their own. The pollination services assessments required return visits to measure seed or fruit set; no non-experts did this.

4.3 Case study: earthworm surveys (United Kingdom)

In the United Kingdom, a standardised method using earthworms was developed for farmers ("#60min worms" project) to assess the state of soils in arable farmland (Stroud 2019). The method enabled a rapid 'traffic-light' interpretation that was designed to quantify the presence of earthworms in the field. It involved digging a 20 × 20 × 20 cm pit, and hand sorting for 5 minutes to collect the adult earthworms into a container with water; juvenile earthworms were returned to the pit. Using a simple key, adult earthworms were separated into ecological functional groups (epigeic, endogeic, anecic) and counted, with the aim of completing surveys of 10 pits in 60 minutes. In this study, the presence of epigeic earthworms was considered an indication of good soil litter conditions, endogeic earthworms of low disturbance of the upper soil layers, and anecic earthworms indicated optimal soil condition because of their major influence on soil structure (Stroud 2019). The presence of any earthworms (adults and juveniles) and presence of adults of the different functional groups in each of the pits dug per field were categorised from red (unlikely to be present and abundant) to amber (may be present and abundant) to green (likely to be present and abundant). The 'at risk' fields were identified based on the absence or rarity of epigeic and anecic earthworms.

Advantages: All the farmer participants stated they would take part in the survey again, and all stated they would recommend the survey to others. Most participants would also use scientific field trials to help interpret their own results. Over half the participants stated they would change their soil management practices because of the earthworm monitoring.

Challenges: Some farmers found the traffic light system difficult to interpret, while others, on soils with abundant earthworms, found it took longer than 60 minutes to complete the survey. Earthworm identification workshops were needed to help farmers build confidence in identifying the different functional groups. The absence of anecic earthworms could in part be an artefact of the sampling method if individuals were below the 20 cm sampling depth. The value in quantifying the abundance of earthworms is unclear, as it is highly variable annually, and depends on soil type, soil texture, moisture regime, crop type and fertilisation regime, which confounds the ability to interpret this variable.

5 Conclusions

Terrestrial invertebrate community assessments can provide direct evidence of the impact of land management practices on biodiversity and ecosystem function (and services). The methods used to determine what is present and its implications (higher taxonomic groups, trait-based analysis of species present, or species-based analysis) will depend on the purpose of the assessment (Table 3.). There are likely to be trade-offs between time, financial cost and degree of expertise required, with the chance of under- or overestimating, or missing any impact altogether. The ability to repeat the study and obtain consistent results (repeatability) could be affected by the approach used, e.g., the same morphospecies described by different observers may be distinct species, resulting in under-estimating the presence of a species (Figure 2).

For example, with the use of higher taxa to measure impact, it is likely to cost less, take less time and require less expertise, but it may be inaccurate for assessing the impact and may not be repeatable (Figure 2). If the aim is to guide farmers, support personnel and the wider public in their land management decisions, then the method needs to allow accurate and rapid identification with minimal subjectivity in the process. If the aim is to provide underpinning evidence that will inform future management decisions across a farming system, then the trait-based analysis of species present is likely to provide a richer source of information than species-based analysis alone. However, where the taxonomy and/or biology of species is poorly known, the use of morphospecies can provide a means of assessing the impact of land management practices.

Table 3. Summary of approaches using terrestrial invertebrates to assess the impact of agricultural land management practices, and their associated benefits and trade-offs

Approach	Advantages	Challenges
Species-level identification	Provides species-level information; can be meaningfully linked to land-use practices; individual species can be used as indicators of ecosystem quality.	Time and labour intensive; requires taxonomic expertise; difficult to use in citizen science.
Identifiable taxonomic units ('morphospecies')	Provides species-level information; can be meaningfully linked to land-use practices.	Time and labour intensive; individual morphospecies cannot be used as indicators of ecosystem quality.
Functional traits	Reduced context dependency (i.e., species-specificity of a given site or region); traits/functional groups can be meaningfully linked to land-use practices; traits/functional groups can be used as indicators of ecosystem quality.	Lack of information on the traits, especially those related to feeding, life history, physiology, behaviour, for the taxa identified in a community; observed patterns can be sensitive to the selected definition of functional groups.
Aggregated taxonomic units	Less time and labour intensive; can be used by non-experts and in citizen science projects; taxa can be used as indicators of ecosystem quality.	Over-aggregation can result in decreasing or losing the ability to detect differences related to disturbance or land-use practices; difficulty in choosing the level of taxonomic aggregation appropriate to represent ecological pattern of interest.

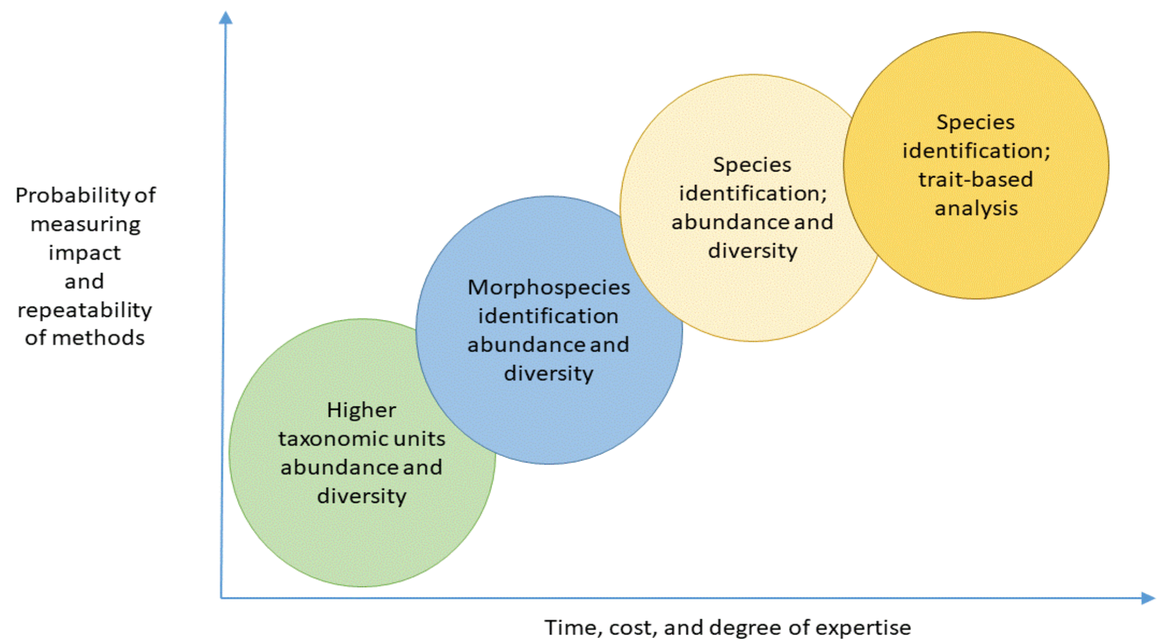

Figure 2. The potential trade-offs between time, financial cost and degree of expertise required with the probability of measuring impact consistently (i.e., the chance of under- or overestimating, or not measuring any impact at all, and ability to repeat the study and obtain consistent results).

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