Using invertebrate bioindicators to assess agricultural sustainability in Australia: proposals and current practices

Maurizio G. Paoletti, Linda J. Thomson and Ary A. Hoffmann

Abstract. The papers in this special issue, ‘Using Invertebrate Bioindicators to Assess Agricultural Sustainability in Australia: Proposals and Current Practices’, highlight the diversity of invertebrates in agricultural environments and associated environments, and the varied roles they play in agricultural production. The papers demonstrate the various ways that the constitution of the invertebrate fauna can change rapidly in response to environmental inputs such as chemicals and landscape management. Given these factors, invertebrates show enormous potential to be used as indicators of sustainability in agriculture. However, this potential remains to be realised.

Invertebrate biodiversity is much higher than plant biodiversity as there are only ~20000 species of plants in Australia. The biomass of soil macroinvertebrates like earthworms, termites and ants can exceed the combined biomass of humans and livestock (Pimentel 2002). The high abundance and diversity of invertebrate fauna living across many different types of environments means that invertebrates are likely to include many sensitive indicators of land use and condition (Paoletti 1999; Lee et al. 2000). Invertebrates are particularly suitable as indicators of agroecosystems, the part of the land intensively occupied by agricultural activities. Studies by Lee and colleagues (Lee and Wood 1971; Lee 1985) on termites and earthworms show that soil formation in Australia is closely related to soil life. Invertebrates perform many other important roles in agroecosystems, by acting as detritivores, predators and parasitoids, and pollinators. Invertebrates also have the potential to act as unwanted pests, but this is counteracted by their many beneficial effects on environments and crops.

There are possibly 800 or 900 native Australian edible plant species (Brand Miller et al. 1997; Zola and Gott 1992) and a similar number of vertebrates and invertebrates have been utilised by humans (Roberts et al. 2001; Yen 2005). European colonisers were uncomfortable when confronted by the very diverse local plants and animals, and in the first years they starved (Kirk 1986; Brand Miller et al. 1997). Colonisers deliberately or inadvertently brought familiar seeds, plants and animals from their countries of origin. Many of these have become agricultural and environmental pests. With the exception of Macadamia, non-native crops are cultivated in Australia. The main Australian livestock and crops are, therefore, alien to the Australian fauna and flora.

Invertebrates have often arrived accidentally into Australia, but they have also been imported for a variety of reasons. Recent introductions of invertebrates have focussed on their beneficial effects on agroecosystems. Examples include the introduction of many insects to control noxious weeds, including the classic example of the moth Cactoblastis cactorum for controlling prickly pear, and the introduction of 45 species of dung beetles from a range of different countries to improve degradation and soil incorporation of cow dung (Tyndale-Biscoe 1990). There is the potential to bring in additional species to control pest invertebrates and weeds, and there are ongoing programs designed to identify target beneficials overseas. There is also the potential for introduction programs aimed at organisms such as exotic earthworms to improve soil conditioning. However, this could only occur after accurate investigation on the numerous native species had taken place (Blakemore and Paoletti 2007).

When rural areas are populated by dominant exotic invertebrate species, the exotics can sometimes undermine native organisms. In the landscape, there is an exchange of species among remnant forests, relatively undisturbed vegetation and shelterbelts, as well as with the more disturbed managed environments of our farms and cities. Managed environments are often predominated by exotics, such as the preponderance of exotic earthworms in cultivated and pasture soils (Baker 1999). Nevertheless, there is often a diverse and underappreciated native invertebrate fauna that can be effective in pest control and soil conditioning. Native species can be underappreciated because knowledge about their role can be minimal. For instance, native mesostigmatic mites, whose role could be focal in biological control, are remarkably poorly known in Australia (Halliday et al. 1998). Matt Colloff and Ger Fokstuen at CSIRO in South Australia have shown that in citrus orchards with abundant soil mesotigmatic mites (17 generalist predatory mite species), there is effective control of the common citrus pest, thrip (Pezothrips kellyanus). This group of predatory mites also has the potential to control the blue and...
red-legged mite complex (Umina et al. 2004) and other pests as discussed by Beaulieu and Weeks (2007). For the first time in Australia, we recently found an efficient predator of mites Oligota pusillima (Grav.), in Victorian vineyards and their nearby forests.

Because crop fields and grazing pastures are not impermeable systems, (but exchange pathogens and an incredible amount of small invertebrates with associated environments such as shelterbelts and remnant vegetation areas), invertebrates need to be considered in a landscape context. One accredited strategy to mitigate the effects of pest and pathogens, which is defined as integrated pest management, incorporates ecological engineering. This includes proper management of tillage, rotation, crop resistance, intercrops, margin vegetation and trap crops. It also includes the reconstruction of refuges on field margins and in the rural landscape such as shelterbelts, and trap crops. It also includes the reconstruction of refuges on field margins and in the rural landscape such as shelterbelts, hedgerows, beetlebanks, and buffer zones, which can improve agroecosystem resilience towards pests (Gurr field margins and in the rural landscape).

One methodology issue concerns the level of invertebrate identification. Sorting by orders, represents the simplest approach, but lower level sorting to families, genera or species may be required to differentiate between environments (Cranston and Trueman 1997; York 2003; Neville and Yen 2007). For instance, when sorted to order, there was little difference between grazed and non-grazed dry eucalypt forests in NSW (York and Tarnawski 2004). In contrast, lower level sorting of groups such as ants was successful in differentiating between burnt and unburnt sites (York 2000). The time and expertise required for lower level sorting can to some extent be obviated by rapid methods for determining taxa. Neville and Yen (2007) discuss the need for standardisation to ensure that methods produce comparable results between studies.

Another issue relates to the nature of the invertebrate groups that are evaluated: should assessments focus on one group in detail or several groups in less detail? Monitoring invertebrate combinations in soils can suggest better management...
approaches to increase abundance and diversity (King and Pankhurst 1996; Paoletti 1999; André et al. 2001; Doran 2002). Pest control organisms (predators or parasitoids) have a direct impact on productivity. Horne (2007) suggests carabids, mostly beneficial in terms of biocontrol of pests in agriculture, could act as potential indicators of sustainable farming. However, New (2007) argues that predatory arthropods may have little value as bioindicators in agricultural systems. However, groups such as Carabids (and probably spiders) have minor amounts of introduced species in disturbed environments and in other places in Australia. More than detritivores such as isopods or earthworms. Michaels (2007) explores the potential for two of the largest beetle families, staphylinids and tenebrionids, as indicators for sustainable landscape management in Australia. Table 1 summarises current data on Australian v. ‘Introduced’ species. The data are estimations; however, in most cases, with the exception of nematodes and mesostigmatic mites, which show a trend in more introduced species among the detritivores.

Thomson et al. (2007) focus on broadly based groups of beneficials involved in biocontrol, while King and Hutchinson (2007) consider broadly based groups involved in sustainable pasture and grazing land. Finally, detritivores constitute a large component of the invertebrate biomass in most environments and provide a key role in organic materials turnover. They also provide alternative food for the phytophagous predators that can be active in pest control on crops. Because of their importance, detritivores have been selected as indicators of landscape stress and soil degradation, both as a functional group using a diverse range (the slaters, millipedes and oribatid mites discussed in Paoletti et al. (2007) and single taxa such as Collembo (Greenslade 2007), earthworms (Blakemore and Paoletti 2007) and mesostigmatic mites (Beaulieu and Weeks 2007).

The papers in this volume highlight the diversity of invertebrates in agricultural environments and associated environments, and the varied roles they play in agricultural production. The papers demonstrate the various ways that the constitution of the invertebrate fauna can change rapidly in response to environmental inputs such as chemicals and landscape management. Given these factors, invertebrates have enormous potential to be used as indicators of sustainability in agriculture, but this potential remains to be realised. There are gaps in our knowledge about many important invertebrate groups, particularly in the area of the economic impact of indigenous taxa that can suppress pests and facilitate soil turnover. The incredible diversity of Australia’s invertebrate fauna can be harnessed to provide important indicators of landscape sustainability, but an ongoing research effort is required in order to achieve this.

### Table 1. Australian terrestrial invertebrates as potential bioindicators

<table>
<thead>
<tr>
<th>Invertebrate groups</th>
<th>Total described species known in Australia</th>
<th>Species introduced into Australia</th>
<th>Species introduced into Australia (%)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Earthworms</td>
<td>715</td>
<td>65</td>
<td>9</td>
<td>R. J. Blakemore, pers. comm.</td>
</tr>
<tr>
<td>Terrestrial isopods</td>
<td>300</td>
<td>13</td>
<td>4.3</td>
<td>Paoletti et al. (2007)</td>
</tr>
<tr>
<td>Terrestrial amphipoda</td>
<td>60</td>
<td>2</td>
<td>3.3</td>
<td>T. Friend, pers. comm.</td>
</tr>
<tr>
<td>Millipedes</td>
<td>300</td>
<td>9</td>
<td>3</td>
<td>Paoletti et al. (2007)</td>
</tr>
<tr>
<td>Collembo</td>
<td>1600</td>
<td>50</td>
<td>3.25</td>
<td>Greenslade (2007)</td>
</tr>
<tr>
<td>Oribatid mites</td>
<td>340</td>
<td>84</td>
<td>24.7</td>
<td>G. H. R. Osler, pers. comm.</td>
</tr>
<tr>
<td>Protozoa in soils</td>
<td>485</td>
<td>146</td>
<td>30</td>
<td>W. Foissner, pers. comm.</td>
</tr>
<tr>
<td>Nematodes in soils</td>
<td>447A</td>
<td>52</td>
<td>11.6</td>
<td>M. Hodda, pers. comm.</td>
</tr>
<tr>
<td>Nematodes: only detritivores</td>
<td>17</td>
<td>8</td>
<td>47.1</td>
<td>M. Hodda, pers. comm.</td>
</tr>
<tr>
<td>Nematodes: only predators and insect parasitic Carabids</td>
<td>22</td>
<td>9</td>
<td>40.9</td>
<td>M. Hodda, pers. comm.</td>
</tr>
<tr>
<td>Free-living mesostigmatic mites</td>
<td>500F</td>
<td>20</td>
<td>4</td>
<td>Beaulieu and Weeks (2007)</td>
</tr>
<tr>
<td>Spiders</td>
<td>3024B</td>
<td>37</td>
<td>1.2</td>
<td>R. Raven and O. Seeman, pers. comm.</td>
</tr>
<tr>
<td>Opilionids</td>
<td>260</td>
<td>2</td>
<td>0.7</td>
<td>M. S. Harvey, pers. comm.</td>
</tr>
<tr>
<td>Pseudoscorpions</td>
<td>150</td>
<td>3</td>
<td>2</td>
<td>M. S. Harvey, pers. comm.</td>
</tr>
<tr>
<td>Neuroptera</td>
<td>700C</td>
<td>0</td>
<td>0</td>
<td>New (2007)</td>
</tr>
<tr>
<td>StaphilinidaeD</td>
<td>1500</td>
<td>?</td>
<td>&lt;1</td>
<td>Michaels (2007)</td>
</tr>
<tr>
<td>TenebrionidaeE</td>
<td>1500</td>
<td>?</td>
<td>&lt;2</td>
<td>Michaels (2007)</td>
</tr>
</tbody>
</table>

**A**Non-helminth (not including vertebrate parasites but including entomophilics and mermithids), terrestrial (including freshwater aquatic but not marine or estuarine) nematodes are as follows [the number excludes the Australian Antarctic Territory, but includes Macquarie Island]: (i) total number of formally described and published species: 447; (ii) number of species known only from Australia: 97; (iii) probable number of species introduced recently (since European settlement in 1788): 52; (iv) number of apparently cosmopolitan species (possibly naturalised or transported naturally and known also from outside Australia): 284; and (v) unknown: 14 (M. Hodda, pers. comm.).

**B**Value was accurate at the last update (November 2006) of the ‘Checklist of Australian Spiders’ (Raven et al. 2002).

**C**Comprising all Neuroptera; Chrysopidae and Hemerobiidae included (New 2007).

**D**The figures reported are largely orientative and food preferences are quite variable in different groups.

**E**Species numbers are orientative. This family include scavengers and detritivores.

**F**Possibly only 15% of the existing species in Australia. If we include the parasitic mesostigmatics, the number of species is 800 with 50 species introduced. This relatively high percentage might be explained by the following aspects of their ecology: (i) many species disperse by phoresy, hence they have strong dispersal power or potential and (ii) many species are associated with synanthropic habitats (dung, stored products, compost) or with introduced insects (bark beetles).
Acknowledgements

Many people have inspired, helped and stimulated us to produce this special issue and two persons have to be specially mentioned: Ken E. Lee and Tim New. For providing taxonomical and ecological information and for their help on fieldwork, we are particularly grateful to: Jeffroy Allen, Martin Bafer, Patrice Bouchard, Peter Cranston, Wilhelm Foissner, Tony Friend, Beth Gott, Alison Green, Jane Gower, Alisun Green, Barrie Jamieson, Ken E. Lee, Alison Mac Gregor, Mark Harvey, David Madge, Eric Mattews, Peter Neville, Lawrence Mound, Roberto Pace, Clive Pankhurst, Sarina Pearce, Aldo Poiani, Stefano Taiti, Ken Walker and Alan York.

References


Manuscript received 31 October 2005, accepted 28 November 2006