International Environmental Modelling and Software Society (iEMSs)
2012 International Congress on Environmental Modelling and Software
Managing Resources of a Limited Planet, Sixth Biennial Meeting, Leipzig, Germany
R. Seppelt, A.A. Voinov, S. Lange, D. Bankamp (Eds.)
http://www.iemss.org/society/index.php/iemss-2012-proceedings

The use of models to design pest suppressive landscapes for sustainable agricultural practice

Hazel R. Parry[1], Felix J.J.A. Bianchi[2,3], Nancy A. Schellhorn[1]
[1] *CSIRO Ecosystem Sciences, Brisbane, Australia hazel.parry@csiro.au*
[2] *Centre for Crop Systems Analysis, Wageningen University, Wageningen, The Netherlands*
[3] *Biological Farming Systems Group, Wageningen University, The Netherlands*

Abstract: This study integrates field-based survey data with spatially-explicit simulation modelling to assess the relative benefits of different landscape management strategies for sustainable agricultural practice. We focus on the role of native vegetation remnants in Australian agricultural landscapes in harbouring pests and beneficial insects for Integrated Pest Management (IPM). Native vegetation remnants exist in most agricultural regions of Australia, although their extent and composition varies greatly. Field-based surveys conducted in 2010 and 2011 across three states provide important information on source habitats for pests and natural enemies and their movement between habitats during the cropping season. Building on this novel information, spatially-explicit simulation models were constructed integrating natural enemy life history traits, dispersal behaviour and habitat use, to examine the implications for pest and beneficial insects of modifying agricultural landscapes for IPM. Computer simulated landscapes were modified by manipulating the amount, quality and composition of native vegetation. We use the models to identify landscape designs associated with effective top-down suppression of pest populations by natural enemies. Throughout the project, stakeholders (farmers, agronomists and policy makers) have been actively engaged to advise the project about IPM options that are compatible with current farming systems, and to regularly communicate the findings of the field studies, model development and potential management plans. The findings of the experimental work and the modelling are combined to produce a set of guiding principles for IPM practices that consider the landscape context. This will allow farmers to (i) increase their benefit from the ecosystem service of pest control, and (ii) enhance the sustainable use and management of natural resources. This work has potential to influence agricultural land use policy in Australia, with further work planned to model the implications of landscape change and non-crop habitat management strategies for multiple ecosystem services.

Keywords*: spatially-explicit modelling; spatial ecology; biological control; ecosystem services; transition processes; sustainability*

1 INTRODUCTION

During the past 60 years, agriculture has become heavily reliant on chemical pest control. In order to move from our current unsustainable reliance on broad-spectrum chemical pesticides to a more sustainable future, we need make a transition to a ‘total system’ approach (Lewis *et al.* 1997). This means that the ecosystem, encompassing not only the within-crop habitat but the surrounding landscape, needs to play a much greater role in the philosophy of agricultural practice. A new way of thinking about pest management has emerged; addressing the health of our agricultural environments as a whole, rather than simply responding to symptoms (Figure 1). An important factor in this paradigm shift is our perception of the role of non-crop vegetation in agricultural landscapes. Evidence to support a total system approach in agriculture for pest management includes studies that acknowledge that agricultural pest problems need to be considered beyond the crop boundary (Schellhorn *et al.* 2008) and that the landscape matrix matters for the suppression of pests in crops as well as providing other ecosystem services, such as pollination (Bianchi *et al.* 2006).

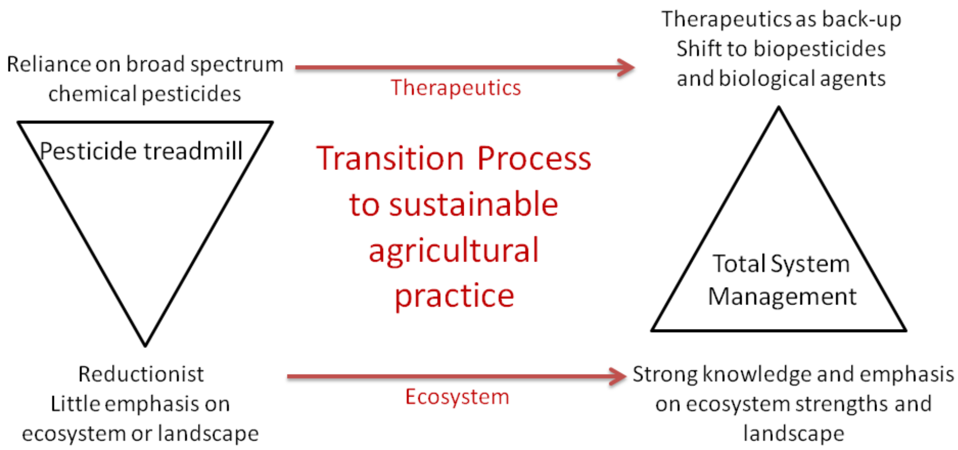

Figure 1: Illustration of the transition process to a total system approach to pest management, highlighting the importance of an understanding of ecosystem processes alongside a reduction in reliance on broad spectrum chemical pesticides (based on Lewis et al. 1997).

The prevailing socio-technical regime of Australia's agriculture is dominated by a strong focus on high intensity production, relying heavily on oil-based agro-chemical inputs. In recent years, the combination of low fertilizer and pesticide prices and a lack of rigorous regulation have resulted in a stagnation of the transition processes. Australia is now lagging behind other regions such as Europe and the USA in reducing the use of pesticides and implementing more sustainable alternatives. For example, more than 80 of the pesticides registered in Australia are no longer authorised in Europe (WWF, 2012), whilst a new EU Council Directive 2009/128/EC of 21 October 2009 has been developed to promote the adoption of IPM.

This paper presents a framework for the use of models in the transition process from wide-spread chemical insecticides towards more ecologically and biologically-based pest management provided by natural enemies (e.g. predators and parasitoids) of agricultural pests. Individual and ecosystem impacts of natural enemies are difficult to observe and measure in the field. Computer simulation allows us to explore the outcomes of potential interventions (such as natural enemy habitat plantings) and help with operational choices (e.g. how much and where). We present a case study from Australia where we combine the development of mechanistic, spatially-explicit simulation models for interactions between pests and natural enemies in a landscape context with the quantification of pest and natural enemy population dynamics in crop and non-crop habitats.

2 TRANSITION PROCESSES IN AGRICULTURAL LANDSCAPES AND THE ROLE OF MODELS

There are a number of ways modelling can be used to assist transition processes towards sustainability. We believe these can be separated into two key functions: *1) scientific exploration of the system* and *2) practical enabling tools to provide information and facilitate decision making*. (1) relates to studying the mechanisms underlying natural pest control and may have a more theoretical nature e.g. by using artificial maps/simple models, whereas (2) aims to predict/forecast and uses biologically plausible models (i.e. sufficient detail) and realistic landscape maps (figure 1). Standard practices can act as barriers to change, for example the belief that large mono-cultures are the most efficient and effective method of cultivation. However, *model exploration* may assist in overcoming barriers, as the insight into the way the system functions generated by model exploration allows us to establish grounds for change. By exploring the impacts of landscape diversification with a model, we can begin to both test and build hypotheses that can give us important theoretical insights into alternative land management practices. Both data and communication are important to the modelling process, to ensure the model engages with reality. Communication with stakeholders in the model building process as well as communication of theoretical insights from the model (e.g. by formal statement of the problem and visualizations) can be a powerful tool in translating model-based knowledge into enabling actions.

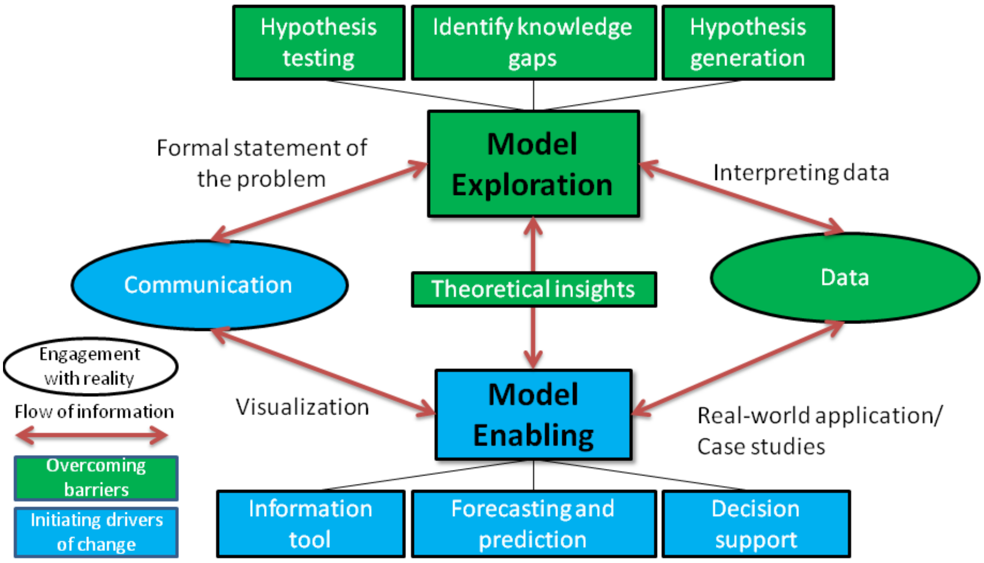

Figure 2: The dual function of models to overcome barriers and initiate drivers in transition processes: exploration and enabling (after Turchin 1998, p 33).

It can be difficult for actors to initiate change without the ability to consider options that can lead to greater sustainability. *Model enabling* can use models to demonstrate scenarios and allow actors to consider such options. Model enabling can build on the model developed for exploration, or be a modelling exercise in its own right. Ideally, the two will work together and feedback to one another through the lines of communication and data, as well as theoretical insight (figure 2). The use of models as both information and decision support tools can lead to valuable forecasts and predictions of given scenarios, in collaboration (communication) with stakeholders and incorporating real data. By demonstrating case study scenarios the model facilitates drivers of change, providing an information tool and decision support that enables actors to consider options that can lead to greater sustainability of a system.

2.1 Overcoming barriers to the transition process
2.1.1 Model Exploration

There are some specific barriers to the implementation of revegetation for the capture of ecosystem services and biodiversity in Australia. These generally take the form of persistent beliefs amongst land managers, which are not necessarily supported by data. For example, many actors in agricultural landscapes may not think beyond the crop when it comes to pest control, hence they are unaware that landscape context can be important (e.g. Thies and Tscharntke, 1999). Also, there is a belief that there are no natural enemies in native vegetation surrounding crops (particularly in summer). This basically amounts to a poor understanding of how natural enemies are using and moving between many habitat types across the agricultural landscape.

From previous studies, some key observations were made in the field: 1) pests are mobile, and do not recognise field or farm boundaries, therefore pest management beyond the field or farm scale is likely to be more effective, 2) understanding the appropriate spatial scale for the control of pests to create pest suppressive landscapes requires knowledge of the ecological function of the habitats present in the landscape, combined with a basic understanding of how pests and natural enemies move in the landscape.

Therefore, having identified these gaps in knowledge, our project has set out to test three key hypotheses:

1. What are the source habitats of key grain pests and natural enemies?
2. How do pests and natural enemies move between habitats?
3. Can we determine the time of crop colonization, and can early arrival of natural enemies lead to more effective pest suppression?

We demonstrate how we are using field and modelling studies to test these hypotheses and make recommendations on landscape management for pest suppression.

2.1.1 Data

In the context of overcoming barriers in the transition process, empirical data can be extremely important in building confidence in, and informing the development of, exploratory models, as well as providing a link to the ‘real world’ in terms of a case study. Such a case study can then inform and enable the decision making process. Preliminary results from two years of field studies associated with the model building process have already identified some important relationships between pests and their natural enemies in agricultural landscapes that relate to each of our three hypotheses. For instance, an empirical observation that relates to the first hypothesis around the identification of source habitats is:

There are particular locations (both in crop and non-crop habitat) and particular times of year where pests and predators tend to be most prolific.

We have used spatial visualizations to explore these relationships in both space and time to better understand how particular pests and predators are using the landscape across the year. For instance, Figure 3 shows the abundance of the Rutherglen bug (RGB), which is a pest species in grain crops in New South Wales in 2010. This vizualisation shows how their abundance changes in time and space, and particularly highlights that RGB moves from pasture to crops as the year progresses, with a low level population throughout the year in native vegetation. The gray areas show crop that was not surveyed, and the green areas show native vegetation that was not surveyed.

In January to March (late summer) there are no cereal crops in the ground, only pasture/lucerne in NSW (Figure 3a). The RGB is found here and also in the native vegetation. In autumn to winter (Apr-Jun), cereals are planted, but the RGB doesn’t immediately move to the cereal crops (white indicating no RGB present in crops surveyed) (Figure 3b). Densities increase to very high levels in some pasture fields in Apr-Jun. Through July-Sept (Figure 3c) and Oct-Dec (Figure 3d) the RGB spreads and moves around the landscape and into the crop, in some cases moving away from pastures completely to cereal crops. During this time the RGB numbers decline, due to higher temperatures. Native vegetation supports only low population densities of RGB throughout the year (<10 bugs per sample), with a peak in Apr-Jun when the highest numbers are also reached in pasture (likely to be driven by the cooler climate at that time of year).

This spatial temporal visualization has enabled us to form hypotheses about how the RGB might be using the landscape. This will feed into landscape design and management recommendations.

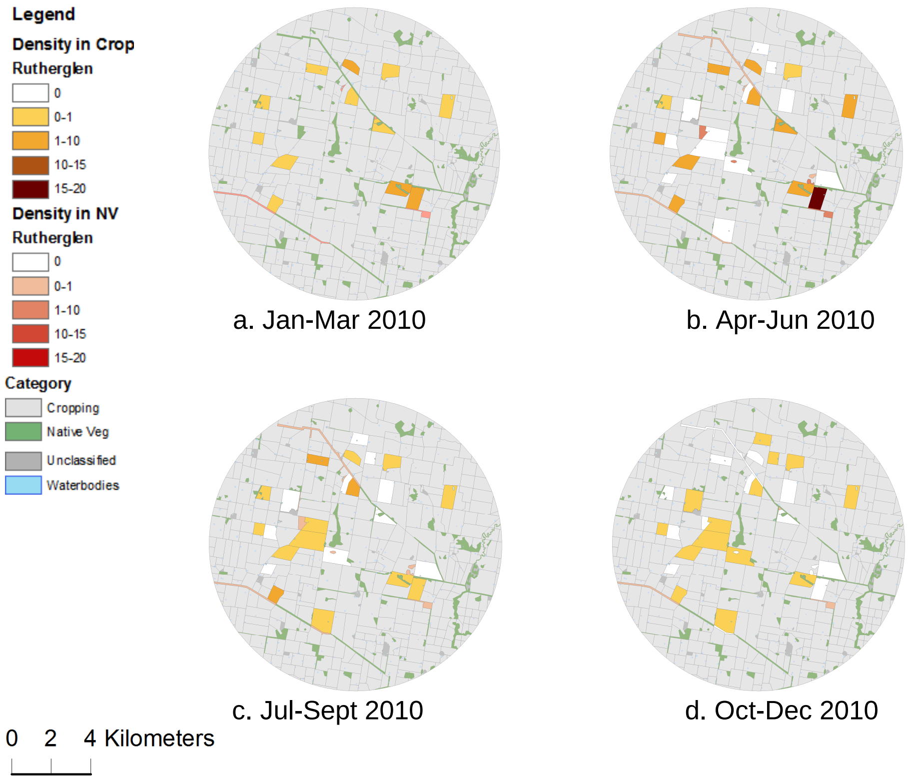

Figure 3: Seasonal spatial population dynamics of Rutherglen bug in New South Wales, 2010 (NV = Native Vegetation).

2.1.2 Model

To demonstrate our approach we use a mechanistic modelling approach to consider the influence of the proportion of native vegetation in the landscape on the population dynamics of the pest *Helicoverpa armigera* and percentage parasitism by *Trichogramma* at the landscape scale. The stage structured model incorporates detailed information on *H. armigera* and *Trichogramma* life history, dispersal and functional response (see Snyder and Ives (2003) for a similar approach). The landscape is represented as a grid containing 50 x 50 cells whereby each cell (100x100m) represents either a crop or native vegetation. The location of crop and native vegetation are assigned randomly. While *H. armigera* and *Trichogramma* species occur in both habitats, harvesting of crops will result in periodic catastrophic mortality events in crops, whereas in native vegetation such mortality events do not occur.

The results of the model show that crop damage increased rapidly when the percentage of native vegetation dropped below 10%. In this case, we recommend maintaining 10-30% of native vegetation in the landscape to aid easy crop colonization of the natural enemy, and benefit biodiversity. While the model has not be validated with independent data, the mechanistic description of *H. armigera* and *Trichogramma* interaction suggests that scenarios can be compared in a qualitative way (e.g. potential for *H. armigera* suppression is better in landscapes with high percentage native vegetation than in landscapes with low percentage native vegetation). We will gain a greater understanding of the model behaviour when we apply it to real landscape scenarios from our study areas.

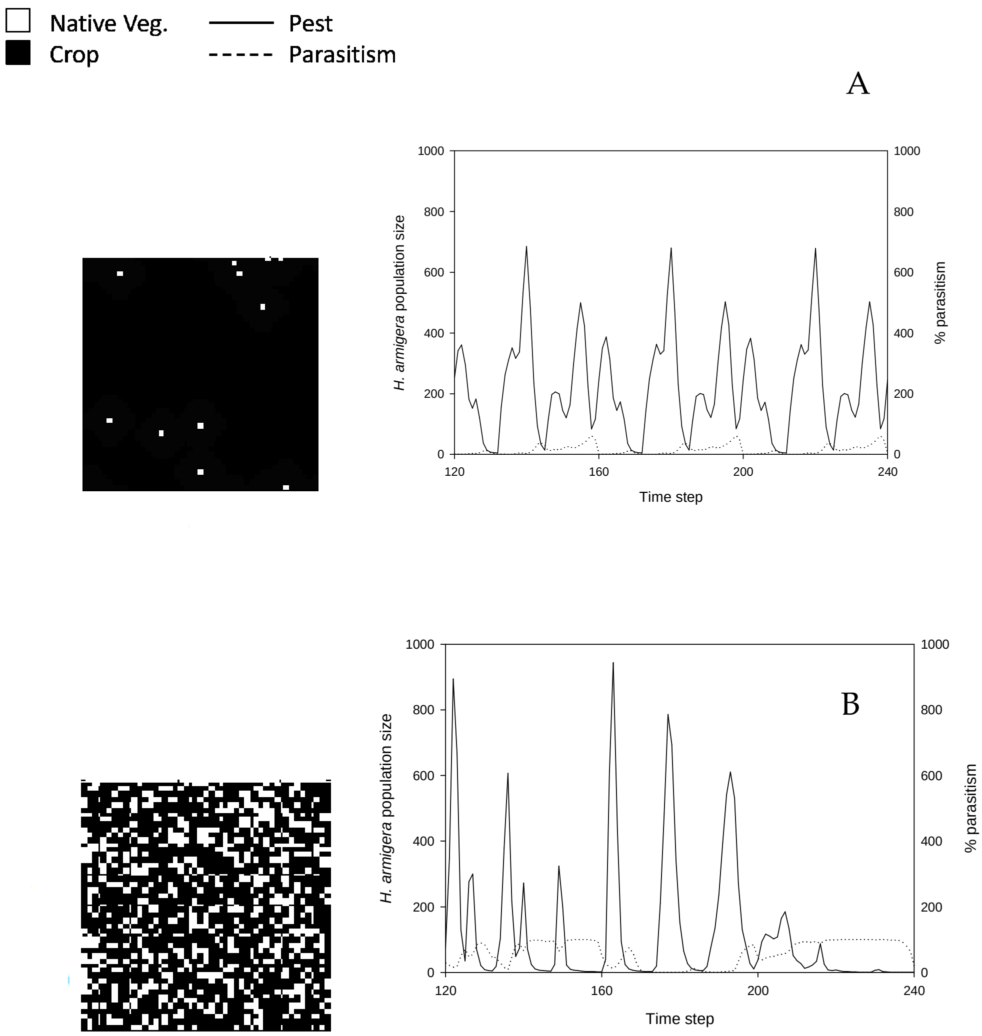

Figure 4: Population dynamics of *Helicoverpa armigera* and percentage parasitism by *Trichogramma* at the landscape scale (hence in crops and native vegetation) in landscapes with 0.5% (A) and 30% native vegetation (B). Note that parasitism percentage on right Y-axis cannot exceed 100%.

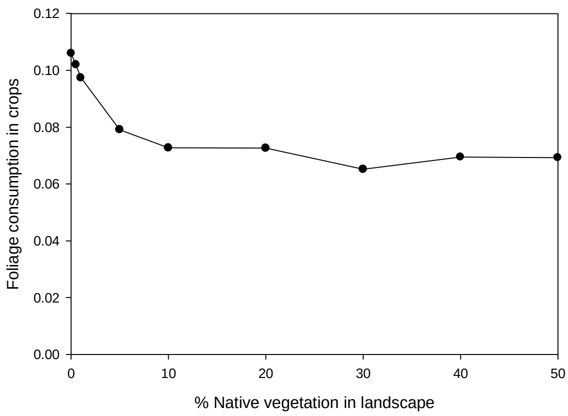

Figure 5: Foliage consumption of *Helicoverpa armigera* larvae in crops as function of percentage native vegetation in the landscape.

2.2 Initiating drivers of change

There are many ways we might enable more ecologically-based pest management through modelling. Computer simulations as presented above enable quick screening of the potential impact of interventions (e.g. native vegetation management, crop rotation) and help with making operational choices (e.g. how much, where). Application of abstract models to real landscapes allow for testing of theoretical insights under real scenarios, for example a visualization of how a pest may spread through a farm or small landscape. This can also help identify appropriate scales of action, for example can changes on a single farm make a difference, or is change needed across the whole landscape?

Throughout the study, we have engaged with farmers and practitioners at workshops and industry meetings, in order to understand existing management practices and to communicate our research. This has allowed the models to give realistic management recommendations. At the end of the study, we will produce a set of guiding principles for IPM practices that consider the landscape context. These will be communicated via interactive workshops. This will allow farmers to (i) increase their benefit from the ecosystem service of pest control, and (ii) enhance sustainable management of natural resources. As part of this set of guiding principles, key messages have emerged from our work, which can be translated into on-the-ground action. We are currently still in the process of interpreting these results. For example, the results indicate that species' abundances are influenced by the distance to native vegetation. We will use the model to explore these relationships further, with the aim of setting advisory thresholds for the proportion and configuration of native vegetation in the landscape for pest suppression: particularly answering the questions of 'where' and 'how much' to revegetate. Farmers and practitioners can benefit from this information in their economic decision making.

Table 1. Key messages about Native Vegetation (NV) and recommended actions emerging from the study

Key Message	Recommended Action
NV provides habitat for natural enemies during fallow**.**	Maintain and potentially increase areas of NV, prevent insecticide drift onto NV.
There is a spill-over of predators from NV to the crop**.**	Incorporate knowledge of this spill-over effect into farm pesticide management plan.
Distance to NV influences the presence and timing of arrival of natural enemies into a crop	Potentially increase the amount of NV in the landscape or alter the configuration of NV to augment the benefits; quantitative recommendations will emerge from the models.

3 CONCLUSION AND FUTURE CHALLENGES

This paper provides a framework to integrate empirical data and models to effectively overcome barriers and initiate drivers of change, in the context of the development of sustainable 'pest suppressive landscapes'. We give examples of how field data collection and communication are integrated into a simulation modelling approach that will allow us to make inferences about how best to manage agricultural landscapes and prioritize habitat management initiatives: e.g. help decide how much, and where, native vegetation will be most beneficial.

Australian agricultural landscapes are now in a period of transition. Recent changes to EU legislation are making ripples in Australian government policy. The Australian government is now funding initiatives such as the Biodiversity fund, buffer zones for pesticide spray and Carbon planting. An important aspect that seems to be lacking in this new government policy is exactly *how* such initiatives should be implemented (Burns and Lindenmayer, 2012). In particular, the questions of *what* initiatives should have priority, *where* projects should be placed, and *how much* is necessary to achieve desired outcomes, are highly important.

Many agricultural lands in Australia are subject to environmental stress and in some places have multiple, competing land use functions in an increasingly peri-urban space (e.g. the Northern Rivers region, NSW). We believe that re-vegetation plantings in agricultural landscapes will be most successful if they are multi-functional, providing several ecosystem services with a single re-vegetation planting. A simulation modelling approach is a powerful method to assess the potential impacts of landscape change, because it allows us to perform landscape analysis and land use change 'experiments' that are not possible on the ground. This approach also allows us to optimize multiple ecosystem service benefits by planning the extent and location of re-vegetation plantings.

Importantly, we cannot isolate ecosystem services of biological control from other ecosystem services that can be provided by non-crop habitat (Fielder *et al.* 2008). A major challenge for this new paradigm of landscape design is to consider how we should best synergize multiple functions of non-crop habitat, such as biodiversity conservation, carbon sequestration and pesticide spray buffering, alongside the benefits of biological control.

ACKNOWLEDGMENTS

This project is funded by the Australian Grains Research and Development Corporation. It is a collaboration between CSIRO Ecosystem Sciences, the University of Queensland, DAFWA, and DEEDI QLD and we thankfully acknowledge the other members of our project team: Art Diggle, Tony Dore, Mike Grimm, Jamie Hopkinson, Andrew Hulthen, Sarina Macfadyen, Svetlana Micic, Mick Neave, Paul Yeoh, and Myron Zalucki.

REFERENCES

ACLUMP, Land Use in Australia at a Glance, http://adl.brs.gov.au/landuse/docs/Land_use_in_Australia_at_a_glance_2006.pdf, 2006, accessed 17/02/2012

Bianchi, F.J.J.A., C.J.H. Booij and T. Tscharntke, Sustainable pest regulation in agricultural landscapes: a review on landscape composition, biodiversity and natural pest control. *Proceedings of the Royal Society B-Biological Sciences* 273(1595):1715-1727, 2006

Burns, E. and D. Lindenmayer, The Biodiversity Fund – another missed opportunity? http://theconversation.edu.au/the-biodiversity-fund-another-missed-opportunity-4889, 2012, accessed 17/02/2012

Fielder, A.J., D.A. Landis, and S.D. Wratten, Maximizing ecosystem services from conservation biological control: The role of habitat management. *Biological Control* 45: 254-271, 2008

Schellhorn, N.A., S. Macfadyen, F.J.J.A. Bianchi, D.G. Williams and M.P. Zalucki, Managing ecosystem services in broadacre landscapes: what are the appropriate scales? *Australian Journal of Experimental Agriculture* 48:1549-1559 2008.

Snyder, W.E. and A.R. Ives, Interactions between specialist and generalist natural enemies: parasitoids, predators, and pea aphid biocontrol. Ecology 84:91-107, 2003

Thies, C. and T. Tscharntke, Landscape structure and biological control in agroecosystems. Science 285(5429):893-895, 1999

Turchin, P., Quantitative Analysis of Movement: measuring and modeling population redistribution in plants and animals. Sinauer Associates, Sunderland, MA. 1998

WWF, Dangerous pesticides are still sold in Australia, http://support.wwf.org.au/review-needed-for-dangerous-pesticides-in-australia.html, 2012, accessed 17/02/2012