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LENScience Senior Biology Seminar Series

Harnessing Biodiversity

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Sustainability, Biodiversity, Eco-this and Eco-that...

We've all heard these words so often they've virtually become clichés, but what do they actually mean and why does science increasingly see them as important concepts? Likewise we're all familiar with the clean green image that is used to market New Zealand overseas. But is this image really justified? What impacts are agriculture and other human activities having on New Zealand ecosystems? Should we be worried? Is New Zealand agriculture and horticulture capable of meeting the environmental and economic demands of the 21st Century?

Questions like this are at the heart of research being carried out by the Bio-Protection Research Centre at Lincoln University. The Centre's goal is to lead a shift away from pesticides to manage pests and towards fully sustainable productive ecosystems for New Zealand's plant-based primary industries

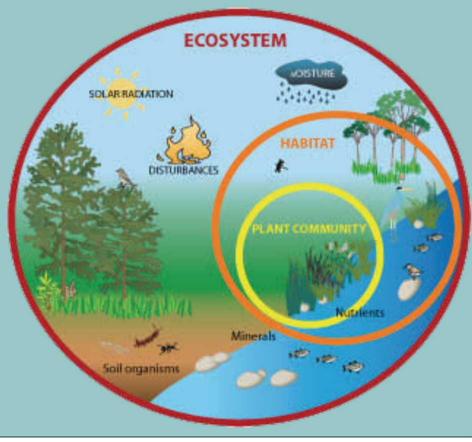
To be able to answer questions about the impact of agriculture and other human activities on our ecosystems, we need to understand the importance of ecosystems to the functioning and survival of human societies.

Ecosystems provide us with goods such as fuel, timber, food for humans and domesticated animals, and pharmaceutical products. What many people don't appreciate is the importance of ecosystems in providing fundamental life-support services. These include the purification of air and water, detoxification and decomposition of wastes, regulation of climate, maintenance and regeneration of soil fertility, and the lessening of the impact of droughts and floods(1).

Historically, society has tended to undervalue the importance of the functions provided by ecosystems, yet our survival depends on them. Therefore understanding how to maintain healthy ecosystems is of vital importance and the reason behind the establishment of the Bio-Protection Research Centre.

What is an Ecosystem?

A collection of plants, animals and micro-organisms that interact with each other and the abiotic environment.



Steve Wratten (on the right) is Professor of Ecology at Lincoln University and Deputy Director of The Bio-Protection Research Centre. The Centre focuses on finding new, sustainable non-pesticide solutions that protect New Zealand's plant-based, productive ecosystems from existing and potentially invasive pests, diseases and weeds.

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This increasing awareness has led to the development of the concept of **Ecosystem Services**—the range of benefits that humans obtain from ecosystems that sustain and underpin life. They are sometimes called environmental or nature's services. Ecosystem services can be categorised according to their function—Provision, Support, Regulation and Culture (Figure 1).

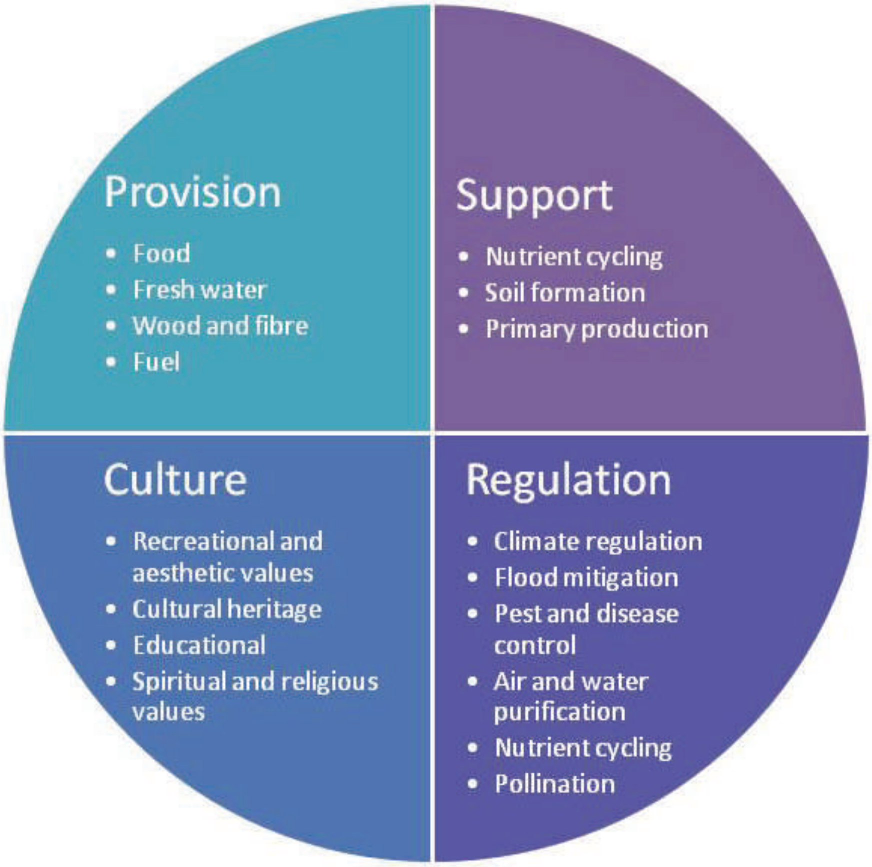

Figure 1. Ecosystem Services (adapted from Millennium Ecosystem Assessment, 2005).

Increasingly ecosystem services are being assigned a monetary value as a way of measuring and comparing their contribution to our society and the impact of human activity on ecosystems and their ability to continue to deliver the services.

Improving Ecosystem Services

Research at New Zealand's Bio-Protection Research Centre has focussed on increasing biodiversity in and around vineyards and pastoral farms with the goal of significantly increasing the variety, quantity and quality of ecosystem services provided, including the biological control of pests and diseases. Deputy Director of the Centre, Steve Wratten is particularly interested in improving conditions for natural enemies by using Conservation Biological Control (CBC) - the management of pests by modifying the environment to encourage the presence of natural enemies.

Conservation Biological Control can potentially improve farm profitability by increasing yields as pest damage is reduced. Profitability increases due to a reduction in pesticide use therefore lowering costs without loss of yield, and increased demand for the product due to reduced levels of pesticide residues. There is a further benefit from public perception of a healthier environment.

How do you go about improving conditions for natural enemies? Steve uses the acronym SNAP to summarise the four key factors that natural enemies need: Shelter, Nectar, Alternative food and Pollen (Figure 2 on the next page). By providing food and habitat sources for beneficial species, biodiversity is boosted and hopefully the numbers of natural enemies are increased.

Shelter Nectar Alternative food Pollen

Figure 2: A beetle bank provides **S**helter. Extracting **N**ectar from Muehlenbeckia. A predatory beetle feeds on aphids as an **A**lternative food source before other pests arrive. A hoverfly takes **P**ollen from a daisy.

Biodiversity

Biodiversity delivers ecosystem services. If biodiversity changes then this can effect ecosystem processes such as primary production, nutrient and water cycling, pollination, pest and disease control as well as soil formation and retention. Increased biodiversity is correlated with stability of ecosystems and lower rates of ecosystem collapse and extinction of species.

The changes in biodiversity caused by human action have been more rapid in the last 50 years than at any other time in human history. We are now in a situation where virtually all of earth's ecosystems have been changed in some way by human activity. One of the main causes of loss of biodiversity is the conversion of land to agricultural use. More land was converted to farmland in the 30 years after 1950 than in the 150 years between 1700 and 1850. One quarter of Earth's land surface is now cultivated[3].

> Biodiversity is the variety of living organisms from all sources, including terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part. This includes diversity within and between species and of ecosystems. Biodiversity also includes diversity at multiple scales of biological organisation (genes, populations, species, and ecosystems)[3]

The expansion and intensification of agriculture has occurred in response to demand for food and fibre from an increasing world population but at the cost of the ability of ecosystems to provide ecosystem services. Modern agricultural ecosystems tend to be large-scale monocultures (the production of one crop over wide areas with high inputs of fertilisers, pesticides and water). This lack of biodiversity is associated with low provision of ecosystem services. Figure 3 shows a natural ecosystem and an agricultural ecosystem. Look closely at the pictures and think about the differences between these ecosystems in, for example, their food webs.

Figure 3. (a) A natural ecosystem (Auckland's Waitakere Ranges) **(b)** Example of a farming monoculture ecosystem .

Intensification and Diversification of New Zealand Land Use

In New Zealand about half of our land area is in arable, pastoral or horticultural use. Although the total area of New Zealand land in pasture has decreased since 1972, this period has also seen a significant intensification of agricultural land use. This shift has occurred as farmers respond to economic signals by converting suitable non-irrigated pasture, exotic forestry, and existing farms into more intensive farm operations, generally dairy[4].

Intensification of agriculture threatens both the environment and the sustainability of food production. The long-term detrimental environmental effects of agriculture generally go unmeasured, but they include:

- loss of biodiversity and the vital functions it provides, through the increase in land area in monocultures,
- a decrease in water quality as a consequence of fertiliser and pesticide use,
- the loss of soil fertility,
- damage to landscapes and
- ultimately, negative impacts on human health.

Arable farming—producing crops such as wheat, oats, barley and maize.

The impact on biodiversity in this context refers not just to the biodiversity of natural ecosystems but also the biodiversity of the agricultural land. Agricultural biodiversity consists of the "microbes, plants, and animals that provide ecosystem services such as nitrogen fixation, decomposition, facilitation of nutrient uptake by plants, pollination and pest control"[5]. Intensification usually results in a loss of these ecosystem services.

Pastoral farming—raising livestock such as sheep and cattle on pasture.

Some ecosystem services may be provided by adjacent natural ecosystems, such as ladybirds (a predator of some agricultural pests) colonising farmland, but most are provided by the agricultural ecosystem itself. If the services are impacted on by farming practices, for example through misuse of pesticides, then the farmer must provide them artificially and at some cost to the farm, the environment and ultimately human health. These are called "external costs" by resource economists. External costs have traditionally not be recognised by either the farming community or society. Likewise, until recently, the environmental and societal impact of agricultural practices has had little impact on farmer choice of production methods[2].

Horticulture—growing fruit, vegetables, and flowers.

Intensification of land use leads to simplified landscapes and a decline in the ability of the ecosystem to provide ecosystem services. However, services such as biological control of pests and diseases can provide economic benefit to both the farmer and to society as a whole. If we can improve the conditions for natural enemies, this has the potential to be economically and environmentally beneficial for both the farmer and society (through reduction in use of chemicals to control pests and diseases, with a corresponding reduction in costs and pesticide residues in the environment)[6]. Such improvements can also provide eco-tourism opportunities and maintain or increase export markets as demonstrated by the Greening Waipara Project.

Case Study: Increasing biodiversity in vineyards to increase ecosystem services

Figure 4a: Leafroller caterpillar. From: United States Department of Agriculture, Agricultural

Leafrollers are one of the major pests of grapevines in New Zealand and Australia. Leafroller refers to the larval or caterpillar stage (Figure 4a) of a number of moth species. The larvae feed on grapes, flowers and stalks causing a reduction in yield. More importantly the damage caused by the larvae encourages the spread of a fungal disease, *Botrytis cinerea* or grey mould (Figure 4b). This reduces grape yield but also affects the flavour and ageing of the wine.

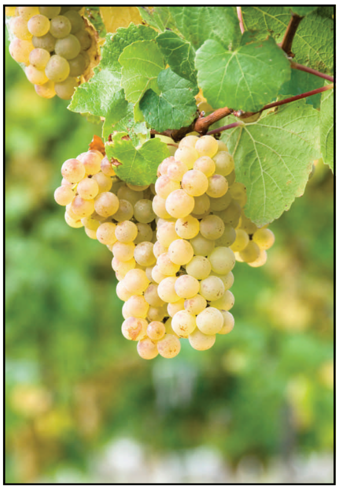

Figure 4b: Close up of botrytis spores on vine debris

Traditional control of leafrollers is through frequent spraying of insecticides. Sprays are applied when more than 5% of the bunches of grapes have one or more caterpillars. There are three problems with this approach. Firstly notice how in Figure 4a, the caterpillar rolls the leaf edges together and joins them with a web. This structure makes it very difficult for pesticide sprays to come in contact with the pest. The second problem is that spraying results in pesticide residues in the grapes. Society is increasingly demanding fewer pesticide residues in food, which requires a different approach to controlling the caterpillars. Finally, the pesticide will kill natural enemies within the ecosystem.

Research conducted by the Bio-Protection Research Centre is focussing on encouraging natural enemies of leafroller to be present in the vineyard in numbers large enough to become an environmentally natural control agent. This is achieved by increasing biodiversity through the introduction of specific plants that enhance the effectiveness of these natural predators. The research has centred around planting introduced annual species such as tansy leaf (*Phacelia tanacetifolia),* and buckwheat *(Fagopyrum esculentum)* between the rows of vines (Figure 7) and planting selected endemic New Zealand trees and shrubs within and around the edges of the vineyards. Introducing plants like these provides beneficial insects such as parasitic wasps and hoverflies, (Figure 5) with a reliable source of nectar and pollen, alternative food and shelter. (Think back to SNAP on page 3).

Parasitic wasps are actually examples of a **parasitoid**—an organism that lives on or in a host organism. The parasitoid gets its nourishment from its host and ultimately will kill it. This is where they differ from parasites where the host is not usually killed.

Figure 5a: Parasitic Wasp

Figure 5b: Hoverfly

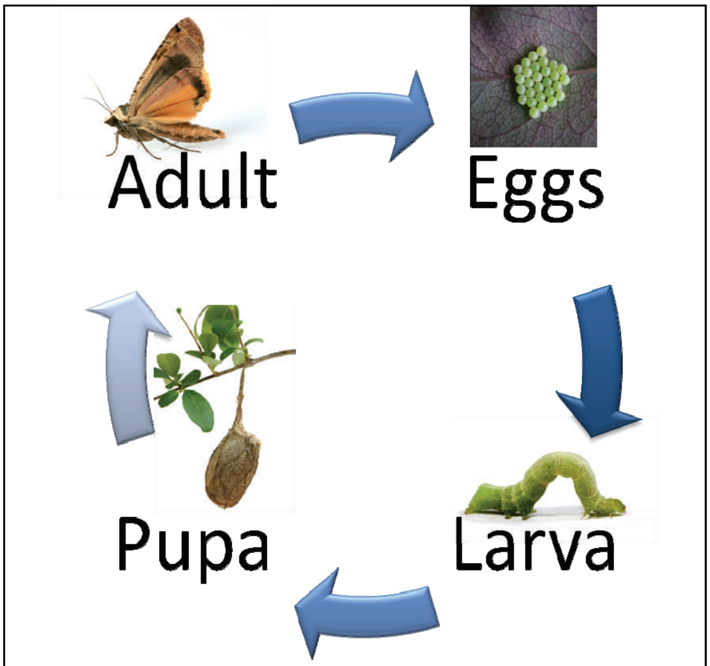

Figure 6: A general insect life cycle (complete metamorphosis)

To understand how natural predators such as parasitic wasps and hoverflies control pests like leafrollers we need to be familiar with the typical insect life cycle. (Figure 6). This life cycle is for an insect showing complete metamorphosis. Some insects like aphids undergo incomplete metamorphosis, where the eggs hatch into nymphs, which then mature into adults.

The adult (the flying stage) feeds only on nectar and pollen. Nectar contains carbohydrate, which provides energy for the adults. Pollen provides protein, which is necessary for egg production. Together they increase the life span and the number of offspring produced by the parasitic wasps and hoverflies. Hence it is important to ensure that there is a good supply of nectar and pollen producing plants for the adult.

The eggs of parasitic wasps and hoverflies are laid inside the body of the host—in this case the leafroller caterpillars. When the eggs hatch the larvae consume the caterpillar from the inside out, eventually causing it to die. By this time the larvae is ready to change into a cocoon and then emerge as an adult to continue the cycle.

The main natural predator of leafroller is the parasitic wasp *Dolichogendea tasmanica.* Technically *D. tasmanica* is an endoparasitoid—meaning that lives inside its host. Research by the Bio -Protection Centre found that adding floral resources to the ecosystem increased *D. tasmanica* numbers, with buckwheat in particular showing a significant increase. Sowing one row of buckwheat every ten rows of grape vines enhanced populations of the parasitoid sufficiently enough that the numbers of leafrollers in the grapes were reduced to below the level that would normally trigger the application of an insecticide (Figure 8). Figure 7 shows what the buckwheat row looks like in a vineyard.

Figure 7: Buckwheat in flower down the vineyard rows at Mud House Wines.

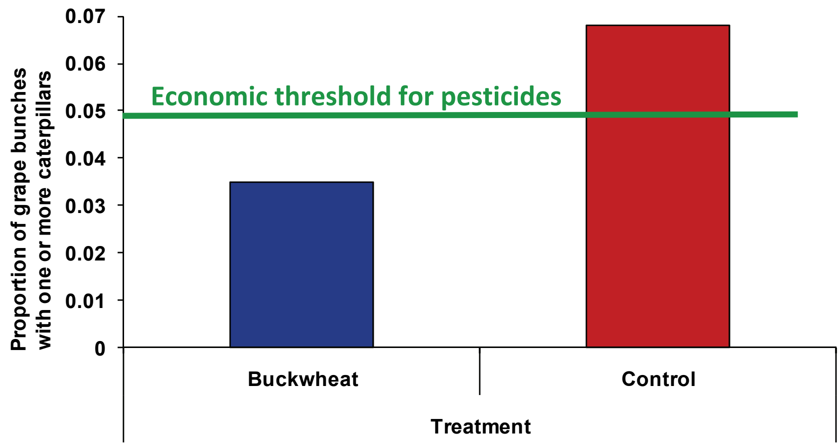

Figure 8: Mean number of leafroller caterpillars in grape bunches with and without strips of flowering buckwheat between rows and the economic threshold for leafroller management with pesticides.

How do floral resources increase the effectiveness of natural enemies?

Earlier in this paper you learnt about how agricultural ecosystems tend to be low in biodiversity, with simplified food webs. Ecosystems in this state lack the food resources, such as nectar and pollen needed by the adult stage of the parasitoids that are important in controlling pests like leafroller. Parasitoids need access to sufficient and appropriate food to ensure survival and gain maximum reproduction (fecundity)[7]. In order to ensure that natural biological control agents are as effective as possible we need to understand how increasing biodiversity improves the efficacy of the agent. This has been the focus of much of the research carried out at the Bio-Protection Research Centre. One study looked at the specific effects of providing alyssum flowers (Figure 9) as a food source for the parasitoid *D. tasmanica* on its longevity and fecundity.

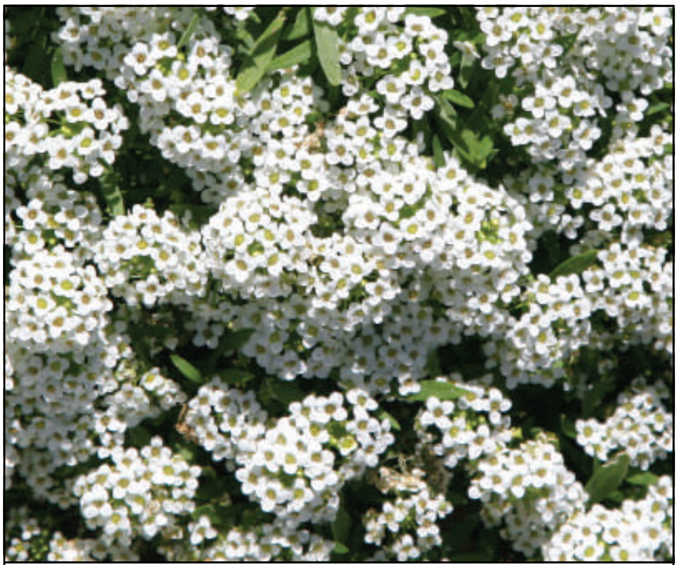

Figure 9: Alyssum flowers

The results are shown in Figure 10.

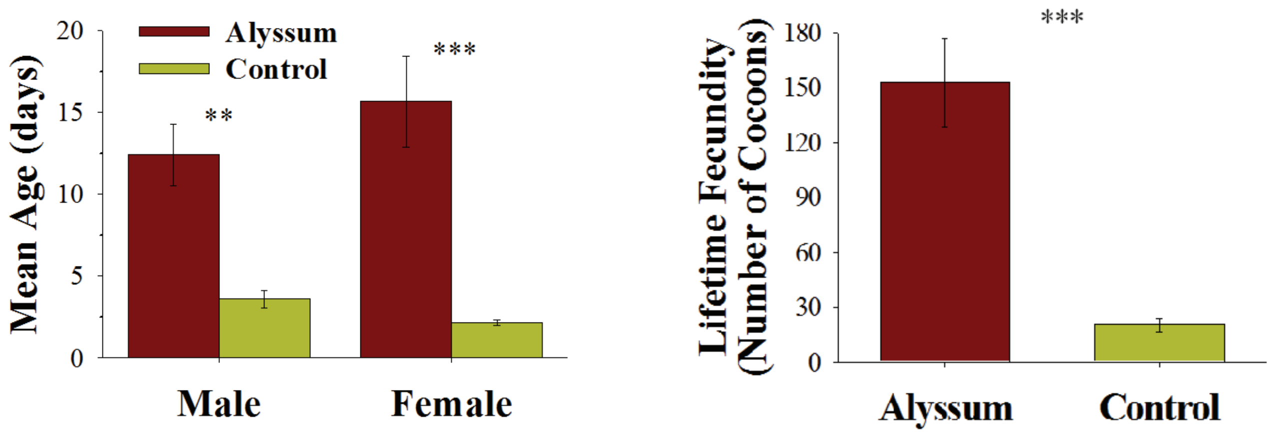

Figure 10. A: Effect of alyssum on the life span (longevity) of *D. tasmanica.*

B: Effect of alyssum on fecundity—estimated by the total number of offspring of each parasitoid reaching the pupal stage.

These results showed that providing *D. tasmanica* with access to alyssum flowers increased the lifespan and fecundity (reproductive capacity) of the parasitoid. An increase in longevity allows the parasitoids more time to attack their hosts, the leafrollers, therefore making them a more efficient biological control agent.

The other interesting finding to come out of this research was, that in the absence of floral resources, the sex ratio of *D. tasmanica* became very male-biased. However, in the presence of alyssum flowers the sex ratio was closer to the ideal of 1:1. These results again show how the lack of appropriate floral resources in an agricultural ecosystem can affect the population dynamics and potentially the efficacy of natural predators[7].

The double-edged 'sward': The potential disadvantage of increasing floral diversity

As you have seen, increasing floral diversity in agricultural ecosystems can have a beneficial effect on natural biological control agents. But other research suggests that increasing biodiversity can also benefit the pest the biological control agents are targeting. How can this happen?

Think back to the discussion on page 5 about insect life cycles. The majority of pests found in agricultural ecosystems are insects, so their adult stage also requires nectar and pollen. Consequently the nectar and pollen resources provided for the adult parasitoid may also be the type of resource that the pest likes, leading to increasing survival and fecundity of the pest. This can result in unintended enhancement of pest populations when floral resources are introduced to improve the effectiveness of natural enemies.

One study[8] that looked closely at this compared the responses to different floral resources of two insects: the diamondback moth (*Plutella xylostella),* whose larvae is a major pest of Brassica crops (e.g. cabbage, cauliflower, broccoli) in New Zealand, and its parasitoid *Diadegma semiclausum.* The longevity and fecundity of both the diamondback moth and the parasitoid were assessed using the following treatments: the flowering plants phacelia, bentham, buckwheat, and alyssum, plus diluted honey and water. The results are shown in Figures 11 and 12.

Buckwheat significantly increased the longevity of the diamondback moth, but phacelia did not (Figure 12). There was no impact on fecundity as 90% of the diamondback moth eggs were laid within the first 4 days. For the parasitoid, buckwheat had the biggest impact on longevity, with phacelia increasing survival more than water and alyssum (Figure 11).

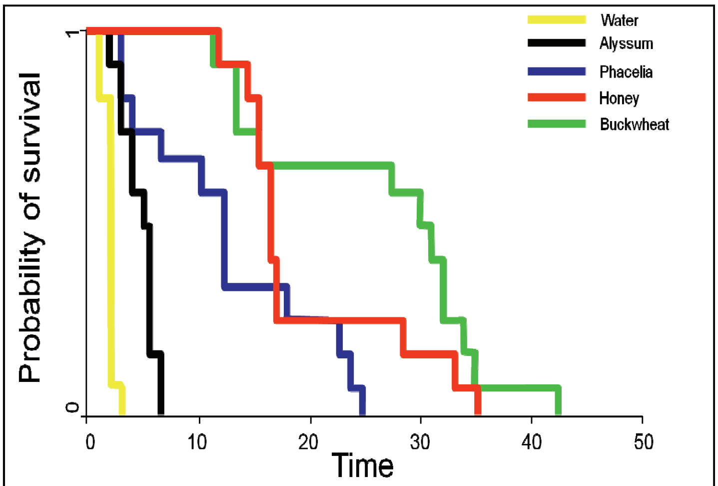

Figure 11: Estimate of the survivorship of the parasitoid *D. semiclausum* under different food resources

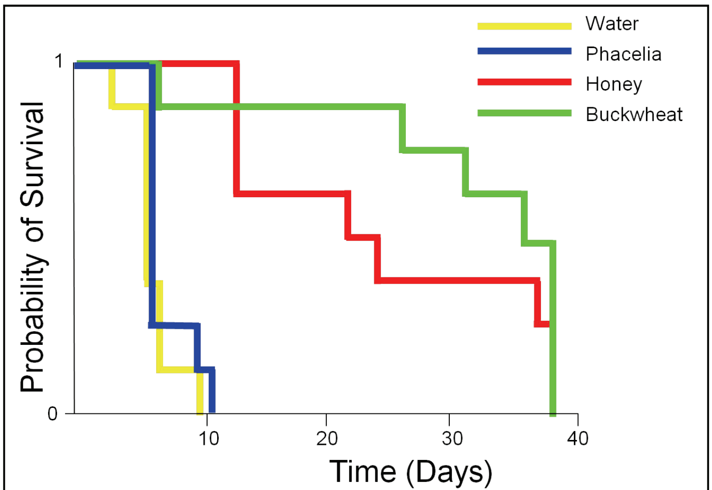

Figure 12: Estimate of the survivorship of the diamondback moth under different food resources

So what does this mean?

In the situation above buckwheat increases longevity of the both the parasitoid and the diamondback moth. But because the majority of the diamond back moth eggs are laid in the first 4 days, the increase in longevity caused by the buckwheat would, compared to the parasitoid, benefit the diamondback moth less. This means the parasitoid will be more effective at controlling the diamondback moth [7]. Additionally planting phacelia as well as buckwheat benefits the parasitoid more than the diamondback moth.

What this means is that careful selection of the flowering species for use in the field needs to be made to ensure the nutritional requirements of the parasitoid are met while minimising positive impacts on the host species.

The fact that adult herbivore pests also benefit from flowers has highlighted the need for more experiments to identify plant species that strongly favour natural enemies rather than their hosts.

The Greening Waipara Project

The practical application of this research can be seen in the Greening Waipara Project. This was established in 2005 by the Bio-Protection Research Centre, the Hurunui District council and Landcare Research. It aims to enhance the sustainability, biodiversity and marketing of winegrowing by giving vineyards "ecological makeovers". Like other forms of modern agriculture vineyards are also monocultures (Figure 12) with low biodiversity. Greening Waipara restores vineyard habitats by planting mainly introduced species such as buckwheat and phacelia, and natives among and near the vines. These species should provide nectar and pollen to support beneficial insects – those that control pests of the grapevines.

Figure 12: The Greening Waipara Project before (left) and after (right)

There are now 51 Waipara Valley properties including farms and other horticultural operations signed up to the project, their owners having seen how adding biodiversity to agricultural ecosystems makes them more sustainable, profitable and marketable.

Four vineyards (Mud House Wines, Pegasus Bay Winery, Waipara Springs and Torlesse Wines) and the local primary school have each developed biodiversity trails, complete with information boards and an educational quiz for children. The trails wind through vines and native plants, leading visitors to areas where Greening Waipara is in action.

Conclusion

Society faces the huge challenge of how to continue to meet the growing demand for food from an increasing world's population without further damaging ecosystem services or, more preferably, how to enhance them. Research like that being carried out by the Bio-Protection Research Centre is an important part of meeting this challenge.

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Acknowledgements

Photos and diagrams from Steve Wratten, The Bio-Protection Research Centre , i-Stock or LENScience, unless otherwise stated.

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