Diploma in Permaculture Design 9

DESIGNING FOR PEST CONTROL IN AN ORCHARD

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OVERVIEW OF AN APPROACH TO NATURAL PEST CONTROL IN ORCHARDS

Design Aims

1. To design a well-researched and logical outline approach for achieving low input pest control in my orchard.

2. To use the design as the basis for an article so others are encouraged to use the approach and hence multiple gains can be achieved

Design Objectives

The design must:

- Encourage me to take a scientific and permaculture approach to the creation and implementation of a management plan for natural pest control in my orchard.
- Make the observation and evaluation stages of managing my orchard more efficient and thorough.
- Provide enough background information on my thinking and management for future owners of my orchard to understand why thing are as they are..

The design should:

- Be written up as an article to disseminate ideas and knowledge.
- Encourage a change of people's attitude, and hence behaviour, towards the control of pests in orchards.
- Encourage a holistic approach to the management of orchards.
- Have enough information to provide other orchard managers with a logical argument for using natural pest control.
- Make creating a management plan for orchards more straight forward.

Project and Design Outline

- **Survey** the information on orchard systems, their health, natural pests and natural pest enemies. Collect information on natural ways to improve orchard health and reduce pest damage
- **Analyse** the information collected and decide on what approaches towards pest control would be most appropriate.
- **Design** the approach that should be taken and present this as an article so it can be used by others.
- **Implement** the design by trying the approach out on my own orchard and publish the article.
- **Maintain, Evaluate and Tweak** over time as I learn more and see how the approach works in practice. Evaluate and tweak the article by sending to friends, family and other orchard enthusiasts for review.

Accreditation and Complementary Criteria involved

Demonstrating Design Skills.

Site development

Education

Holmgren Domain involved

Land and Nature Stewardship

Education and Culture

Permaculture Ethics and Principles involved

- **People Care, Earth care, Fair shares**
- **Observe and interact, Catch and store energy, Obtain a yield. Apply self-regulation and accept feedback. Use and value renewable resources and services, Produce no waste, Design from pattern to**

detail. Integrate rather than segregate. Use small and slow solutions, Use and value diversity, Use edges and value the marginal. Creatively use and respond to change.

These are looked at in more detail in my Assessment of how this design meets the ethics and principles of permaculture

Methods used

Thinking tools: Mind-maps.

Design frameworks: SADIMET (Survey-Analyse-Design-Implement-Maintain-Evaluate-Tweak**), Incremental**

Evaluation: 4P's (Process-Product-Personal-Peers).

Results Summary

The design process resulted in:

- An article which is an informative piece of work which can helps others.
- An approach that has helped me to be organised and see a path to follow over the years to come as I implement natural pest control in my orchard.

Evaluation Summary

The design process SADIMET was fine for this design but as I learnt more I should have purposefully tried to clarify my goals for the article in an organised form. The final product (in the form of an article) will keep me on track and also help those who look after the orchard and land after me. Being able to add to the tables over time as new things are learnt will, I believe, be a major advantage.

This is looked at in more detail in my Assessment of this design

Reflection

The design process SADIMET was good for this project. I realise that I should have been more focused on my target before starting and more organised in the Survey/research stage. I wish I had taken a more structured and detailed approach, categorising information and writing down sources. Once things became clearer I did use mind-maps to organise my ideas and these helped. I felt that this project was more difficult to tie down than my other land projects in many ways.

Self-Assessment

I am not entirely happy with this design or my approach to it. I changed course and nearly gave up several times. Part of this was because it involved reproducing information and there is already so much of this about, making me ambivalent. I hope the article brings together various strands of information in a way that is accessible and useful for others.

My assessment of how successful the project has been and how it fits with the assessment criteria is analysed in my Assessment of this Design

INTRODUCTION

This design is created for use in my own orchard but as one way of creating multiple yields it makes sense to publish this approach. It also improves the return for the energy put in. The design is, in general, about increasing diversity and lowering input for output over the long term. It aims to create a logical outline approach for achieving low input natural pest control in an orchard. The design must:

- Encourage me to take a scientific and permaculture approach to the creation and implementation of a management plan for natural pest control in my orchard.
- Make the observation and evaluation stages of managing my orchard more efficient and thorough.
- Provide enough background information on my thinking and management for future owners of my orchard to understand why thing are as they are..

The design should:

- Be written up as an article to disseminate ideas and knowledge.
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- Encourage a holistic approach to the management of orchards.
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- Make creating a management plan for orchards more straight forward.

The approach will be presented in the form of an article that I and others can use.

This design falls into two distinct parts which are necessary to achieve natural pest control. The attitudinal and the behavioural. Nurturing the right attitude is an important part of this design as it affects how we perceive and tackle the problems which arise. Attitude plays a hugely important part in the problems we face today and by addressing its influence directly in this design (and publishing it) it is hoped that its importance, in general, will be brought to the fore.

Survey

Much of this approach to pest control involves designing for natural tree health however it also incorporates Conservation Biological Control and forms of Beneficial Planting. I was concerned about reproducing falsehoods and so did quite a bit of research into the scientific studies behind these two approaches. For this design I needed to ensure that scientific evidence supported both the Conservation Biological Control and Beneficial Planting approaches and the associated theories.

For Conservation Biological Control I needed to ensure that:

1. The habitat surrounding an orchard can positively affect the natural pest enemy (NPE) populations within the orchard and that this reduces pest populations.
2. Increasing plant diversity or adding specific plant species within or around an orchard actually has a negative impact on orchard pests and a neutral or positive impact on natural pest enemies.
3. Using man-made habitat boosters has a positive impact on natural pest enemies (NPEs) and a negative impact on orchard pests.

For Beneficial Planting I needed to ensure that:

1. Beneficial plants can affect pest and predator behaviour.
2. Beneficial plants can affect their environment in ways beneficial to orchard tree health.

To do this a large amount of research was required and many of the relevant findings have been incorporated into the article.

Analysis

Although the scientific evidence on the efficacy of Conservation Biological Control and Beneficial Planting was mixed, overall it did support the theories above. It appears that both of these subjects are difficult to study and get good reproducible data from. There is evidence for and against the use of both these approaches. For instance, just increasing plant diversity as a form of pest control in orchards appears to have mixed results. Mostly it has a positive impact, however, often it has no impact and sometimes a negative impact. It also became evident that the research that has been carried out is very limited in value in that it can only present snap shots of particular situations at a particular time. Due to nature being incredibly complicated and interactions varying from site to site, over time and with the weather research results can only be used as a guideline of what to expect when certain changes are made locally. Overall the research was encouraging and supported the concept of creating a naturally healthy, diverse environment that fits with the fruit trees' natural needs. It also supported the ideas that manipulating the environment in small ways to favour some species over others and creating system health in general does have positive effects on pest control

This approach to pest control is more complicated and less certain in its outcome than spraying on a pesticide would be, its results are not the complete eradication of the pest and the process will take time to establish. For these reasons a person's attitude towards pest control is hugely important if they are going to follow this approach - hence its inclusion in the design.

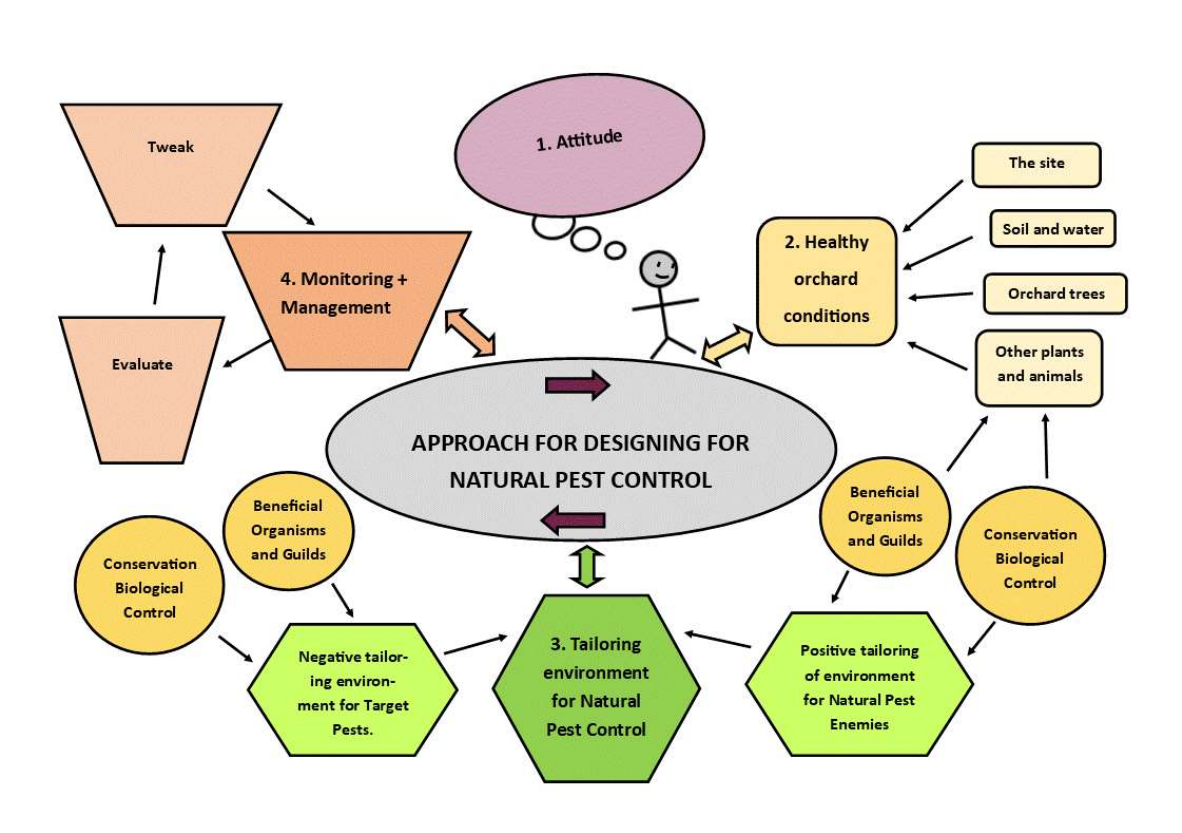
Design

The design is written up in the format of an article, available here.

The outline of the design/approach involves:

1. Adopting the required attitude.
2. Providing appropriate orchard conditions for the fruit trees present.
3. Tailoring the environment in favour of NPEs and against pests through:
    a) conservation biological control, which relies on creating good, all year round, conditions for naturally occurring enemies of the pests so they can thrive and deal with the pests as they arrive and reproduce.
    b) beneficial plantings, which involves the use of plants that improve tree health through a variety of means and discourage pests or lure them away from the trees.
    c) thoughtful management.
4. Observation which allows for informed management, continued evaluation of the situation and tweaking of strategies.

Figure 1 An approach for designing an orchard to allow for low input tree health and natural pest control.



The approach makes use of five tables:

Table 1 - Organism qualities that can be exploited

Table 2 - Positive Tailoring of environment for NPEs

Table 3 - Negative Tailoring of environment for Pests.

Table 4 - Monitoring NPEs and Pests on fruit trees

Table 5 - Monitoring NPEs and Pests on orchard site and surroundings.

Implement and Maintain

Implementation in the orchard will require a lot of ongoing observation and work. It is a part of the long-term management for the orchard. However, using the flow diagram as an outline for structuring my approach and the tables in the article for helping me to keep an eye on how well I am manging to care for the orchard makes things easier.

Attitude.
I have done my best to adopt the right attitude and have educated myself on orchard care and maintenance.

Healthy Orchard Conditions.
I have already done a number of things to ensure healthy orchard conditions:

- **Orchard trees** - The trees are planted well apart to create airy light conditions. They have been pruned well to create open frameworks that allow light, sun and air to get through the tree and onto the fruit so it remains healthy and they have tree guards fitted to prevent, deer, rabbits and voles damaging them. The two walnut trees have been planted apart from others, particularly from the apple trees which are known to suffer badly from the effects of the **negatively allelopathic** chemical, Juglone, produced by walnut trees.
- **Other plants and animals** -

Conservation biological control, relies on creating good, all year round, conditions for naturally occurring enemies of the pests so they can thrive and deal with the pests as they arrive and reproduce. **Beneficial organisms and guilds** involves the use of plants and animals that improve tree health through a variety of means and discourage pests or lure them away from the trees. To achieve these ends I have added and/or encouraged a number of plants that can be used

to help (as described in Table 1 in the article) For example: I have added soil fungi (which have **mutualistic** relationships with many trees) by planting the trees with some bought inoculum of fungi and with some soil from the woodland which will also act as a fungal inoculum. I have also been encouraging soil fungi by leaving the cut hay (used as a **mulcher**) to increase surface organic matter and maintain a damper soil, both good for improved fungal growth and also to reduce root competition between the grass and tree roots. The **dynamic accumulator** comfrey *Symphytum × uplandicum, "*Bocking 14" has been planted by all the trees and more will be added over the years using root cuttings from the current plants. This plant acts as a nutrient pump bringing nutrients to the surface for the tree's shallow roots but it also acts as a **competitor** with the grass so reducing its root competition with the trees. I myself have been acting as an **enabler** by introducing useful plants that can help the trees or reduce the pest problems. Over time I will have created guilds of organisms which will be beneficial to the trees. The next job on my list is to try to introduce nitrogen fixers such as clovers to the sward. The sward is vigorous and so this will involve cutting out patches to plant the plants in rather than sowing. I have sown red and white clovers as a green manure in a community garden so I can thin these to take some to the land.

Positive tailoring of environment for NPEs

The orchard is already surrounded by a diverse natural habitat which already has many species and habitat features suitable for NPEs so adding species that are missing from the mix and are regarded as generally beneficial has been my main focus. For the NPE's well-being I have already sown several species. Details are written in the pink rows of the table (Table 2 in the article) below.

PEST ENEMY	POSITIVE TAILORING FOR NPEs
Ground beetles	Favoured habitat: leaf litter, bark and logs retaining a slightly damp environment Diet: Pupae and larvae of many orchard pests and any pest that drops to the ground. Favoured plants: Low growing perennial plants Avoid: tansy *Tanacetum vulgare* and spearmint *Mentha spicata* under trees as it deters beetles.
CURRENT MANAGEMENT (No specific problem but for moth larvae probably in the future).	2018 Tansy *Tanacetum vulgare* has been planted on site but well away from fruit and nut trees. Logs are being laid at the base of trees as they become available and tree pruning's are chopped up small and left at the base of the tree. Hay is piled up as a beetle habitat improver when the grass is cut.
Ladybirds	Favoured Habitat - Summer: Widespread, grassy banks, hedgerows and woodland. Winter: in dry vegetation for winter. Hibernating boxes can be made. Dry stalks of plants for overwintering such as Lemon balm and stinging nettle, umbellifors etc Diet::- aphids, scale insects and mites, some eat pollen. Favoured plants: - common yarrow *Achillea millefolium,* queen Anne's lace *Daucus carota,* tansy *Tanacetum vulgare,* dandelion , *Taraxacum officinale,* spiked speedwell *Veronica spicata,* hairy vetch *Vicia villosa,* honeysuckle *Lonicera periclymenum,* cornflower *Centaurea cyanus,* fennel *Foeniculum vulgare,* stinging nettles *Urtica dioca.* Avoid:
CURRENT MANAGEMENT for General aphid problems	common yarrow *Achillea millefolium* is already growing on site and is being encouraged through being mown around and allowed to set seed. 2017,2018,2019 , queen Anne's lace *Daucus carota,* tansy *Tanacetum vulgare,* dandelion , *Taraxacum officinale,* are being sown where there is clear patches of soil and in mole hills, Stinging nettles are growing of their own accord. Cutting of these could be an option when trying to shift the ladybirds onto the fruit trees if there is an aphid outbreak
Rove beetles *(Tachyporus* spp.)	Favoured habitat: - Woodland leaf litter and similar decaying plant matter. Diet: Favoured plants: Avoid: tansy *Tanacetum vulgare* and spearmint *Mentha spicata* under trees as it deters beetles.
CURRENT MANAGEMENT (No specific problem but for moth larvae probably in the future).	2018 Tansy *Tanacetum vulgare* has been planted on site but well away from fruit and nut trees. Logs are being laid at the base of trees as they become available and tree pruning's are chopped up small and left at the base of the tree. Hay is piled up as a beetle habitat improver when the grass is cut.
Empid flies (Empididae)	Favoured habitat: - Field, pasture, wetlands and lightly wooded areas. Predators at all stages. Aphids, bugs, midges, larvae in soils Diet: Favoured plants: Avoid:
Hoverflies (Syrphidae)	Favoured habitat: - Closely associated with woodland habitats. Diet: - Adults eat pollen, nectar, larvae eat aphids, thrips and other leaf hoppers Favoured plants: Tend to favour yellow and white flowers with open structure, particularly from the Umbelliferae, and Compositae families. However, many are non-selective about flowers - lemon balm *Melissa officinalis,* pennyroyal *Mentha pulegium,* spearmint *Mentha spicata,* wild bergamot *Monarda fistulosa,* feverfew *Chrysanthemum parthenium,* common yarrow *Achillea millefolium,* queen Anne's lace *Daucus carota,* spiked speedwell *Veronica spicata,* common toadflax *Linaria vulgaris,* cornflower *Centaurea cyanus,* fennel *Foeniculum vulgare,* wild oregano *Origanum vulgare,* wild thyme *Thymus vulgaris.* mayweed *Tripleurospermum spp.* Avoid:

CURRENT MANAGEMENT General aphid problems	common yarrow *Achillea millefolium* is already growing on site and is being encouraged through being mown around and allowed to set seed. Queen Anne's lace *Daucus carota,* is being sown where there are clear patches of soil and I mole hills,
Predatory bugs	Favoured habitat: - Hedgerows, commonly found in Blackberry in Autumn. Diet: - Insect, mites and larvae. Favoured plants: Avoid:
Lacewings (Chrysopidae)	Favoured habitat: - Widespread. Hibernate - buildings and leaf litter. Lacewing shelters are used and can be made easily. They like open plant structure to fly through to lay eggs. Diet: - Adults eat fungal hyphae, pollen, nectar and honeydew. Young eat most orchard tree pests. Favoured plants: - queen Anne's lace *Daucus Carota*, tansy *Tanacetum vulgare*, dandelion *Taraxacum officinale*, honeysuckle *Lonicera periclymenum,* fennel *Foeniculum vulgare*, Avoid:
CURRENT MANAGEMENT General problems	Queen Anne's lace *Daucus Carota*, tansy *Tanacetum vulgare* and dandelion *Taraxacum officinale*, are being sown where there are clear patches of soil and I mole hills. Six honeysuckle *Lonicera periclymenum* have been planted in the woodland.
Spiders	Favoured habitat: - Widespread. Diet: - almost everything that moves Favoured plants: – more permanent plants such as perennial shrubs. Avoid:
Earwigs	Favoured habitat: - Widespread, often in ground litter, often moist, also in fruit trees, within flowers, behind bark, in leaf sheaths and under dense vegetation. Earwig shelters should be made and hung in every fruit trees. Diet: - Mainly predators and scavengers, some dead and fresh plant matter, they eat most orchard pests at various stages of their lifecycle. Favoured plants: Avoid:
CURRENT MANAGEMENT General problems	Collected many green plastic, olive oil bottles to make earwig homes to hang from trees. Only one hung in Crimson Bramley so far..
Parasitoid wasps	Favoured habitat: - Widespread; there are about 6.400 species in the UK. Diet: - Adults primarily nectar. Larvae, aphids, leaf hoppers scale insects and more depending on species. Favoured plants: - Umbelliferae family Avoid:
Parasitoid flies (Tachinid) And other Syrphid?	Favoured habitat: - Widespread Diet: - Adults, nectar. larvae - larvae and sawflies Favoured plants: - Umbelliferae family Avoid:
Predatory mites	Favoured habitat: - Widespread Diet: - Red spider mites, other mites and thrips Favoured plants: Avoid:
Bats	Favoured habitat: - Woodland and buildings. Boxes can provide roosting sites. Water such as ponds or lakes attract them as do clear spaces adjoining trees. Diet: - Moths and other flying insects Favoured plants: Avoid: - lighting and insecticides.
Shrew	Favoured habitat: - Dense vegetation, understory cover of woodland, hedge edges, shrubbery and rough grassland. Diet: - larvae, pupae, eggs, and adult pests on orchard floor. Favoured plants: Avoid: - harming them, they have protected status
Birds	Favoured habitat: - Widespread. Good nesting sites/ bird boxes, many seed plants, scrubby tree structure. Old cracked bark for tree creepers. Hollow and dead wood for woodpeckers. Diet: - seeds, fruit, insects, aphids, larvae etc. Provide late hanging fruit for winter support. Some need insects all year round others just during the breeding season. Favoured plants: - anything bearing berries,, seeds etc. Tits use lavender as an antiseptic in their nests. Avoid:
Fungal pathogens of aphids	Favoured habitat:: There is evidence that nettle aphids *Microlophium carnosum* carry these and act as a source for killing aphids on nearby crops. Diet: Favoured plants: Avoid:

Negative tailoring of environment for target pests.

Target pests - deer, rabbits and voles.
I have erected tree guards which will prevent all these mammals getting to the bark of the trees.

Target pest - woolly aphids in the Crimson Bramley tree. I have put an earwig home in this tree in the hopes that earwigs will come, stay and eat the woolly aphids.

I am unsure whether some of the aromatic plants proposed to deter pests will survive in the vigorous grass sward. If the planting of the clover works and it looks like it will survive then I might take a few cuttings of some herbs to add

to the sward. However, I would need to do more research first as it appears that some of the aromatics deter ground and rove beetles. These beetles are likely to be very important NPE's for fruit trees where some of the really problematic pests such as pear midge, apple sawfly and winter moth spend a part of their lifecycle in the ground. To aid these NPE's I have been putting logs and chopped pruning's on the ground by the trees

Monitoring and management.

I have not done any official monitoring for pests and NPE's on the fruit and nut trees or in the surrounding areas using Table 4 Monitoring chart for NPEs and Pests on fruit and nut trees or Table 5 Monitoring chart for NPEs and Pests on land in and around orchard trees. I aim to use the monitoring forms properly next year, especially as some of the trees are getting to be a reasonable size and may produce more than the odd apple. Not being close to the orchard and seeing it at short regular intervals has made the observation of pests and NPE's more difficult. In addition the trees are only a few years old and on large rootstocks so, in general, there haven't been many flowers or fruit. During informal observation I have noticed some aphid (unknown species) damage to leaves on several trees, woolly aphids on the "Crimson Bramley" and a little capsid bug damage on the apples of the cider apple tree "Late Gold". None of these have been of a level to worry about

Evaluate and Tweak

It is too early to evaluate effects of the methods started and it is unlikely it will be possible to reliably assess ever as years and conditions change over time and any ecological surveys would not have the replication required to overcome normal standard errors within the data. Evaluation of effectiveness might be done by looking at a large number of orchards, paired for similar conditions but with this form of management in one of the pair and an external input methods of pesticides (natural or not) in the other.

The article itself has been read by a friend and family members for feedback and changes have been made as a result.

References

The Holistic Orchard, Michael Phillips. Chelsea Green Pub.2011

Modern Fruit Growing, W.P. Seabrook. Ernest Benn Ltd. 1929

The Organic Gardeners Handbook of Natural Pest and Disease Control, Ed. F.M. Bradley, B.W. Elis, D.L. Martin. Rodale Inc. 2009

The Gardener's Guide to Common-sense Pest Control, William Olkowski, Shiels Daar, Hega Olkowski. The Taunton Press. 1995

Biological Control in Plant Protection, N. Helyer, K. Brown, N.D.Cattlin. Manson publishing. 2003

Pests and Diseases, a complete guide to preventing identifying and treating plant problems, P. Greenwood, A. Halstead. Dorling Kindersley. 1997

Designing and Maintaining your Edible Garden Naturally, Robert Kourik. Metamorphic Press. 1986

The Earth Care Manual, Patrick Whitefield. Permanent Publications. 2004

Wild Flower Gardening, John Chambers. WI Books Ltd. 1989

A Guide to Habitat Creation, Chris Baines. Packard Publishing Ltd. 2nd ed.1991

Comfrey- controversial crop, http://conservancy.umn.edu/handle/11299/141442

The facts about dynamic accumulators, https://permaculturenews.org/2015/04/10/the-facts-about-dynamic-accumulators/

Agricultural chemicals and the soil, http://eap.mcgill.ca/publications/eap1.htm

Biological Control: A Veritable Natural Pest Management Strategy, http://ijaer.in/uploads/ijaer_02__05.pdf

Economic Gains and Analyses of Successes in Biological Pest Control,

http://www.faculty.ucr.edu/~legneref/biotact/bc-5.htm

Use of Allellopathic Plants as Living Mulch in Apple Orchards,

https://www.researchgate.net/publication/292090946_Use_of_allelopathic_plants_as_living_mulch_in_apple_orchards

Controlling Pests with Plants: The Power of Intercropping, https://learn.uvm.edu/foodsystemsblog/2014/01/09/controlling-pests-with-plants-the-power-of-intercropping/
Early-season predation on aphids by winter-active spiders in apple orchards revealed by diagnostic PCR http://orca.cf.ac.uk/49887/
Mechanisms for flowering plants to benefit arthropod natural enemies of insect pests: Prospects for enhanced use in agriculture http://onlinelibrary.wiley.com/doi/10.1111/1744-7917.12000/full
Companion Planting, https://web.archive.org/web/20140221224847/http://www.ccechemung.org/wp-content/uploads/2013/09/companion-planting.pdf
Tending Fruit Trees - A Template for Success file:///C:/Users/charlotte/Documents/Orchards/tending-trees.pdf
Habitat manipulation to mitigate the impacts of invasive arthropod pests, https://researcharchive.lincoln.ac.nz/bitstream/handle/10182/4848/habitat_manipulation.pdf;jsessionid=B3E53DF749132AD0AB2680B84EC7789C?sequence=1

Aphid Natural Enemies and Biological Control, https://digitalcommons.usu.edu/cgi/viewcontent.cgi?referer=&httpsredir=1&article=1813&context=extension_curall
Interaction of the dominant pests and natural enemies in the experimental plots of the intercropping aromatic plants in pear orchard [2010],

http://agris.fao.org/agris-search/search.do?recordID=CN2011001559

Orchard pests and Pest Control, https://ptes.org/campaigns/traditional-orchard-project/orchard-practical-guides/fruit-tree-health/orchard-pests-and-pest-control/

Plants that Attract Beneficial Insects, http://www.farmerfred.com/plants_that_attract_benefi.html

Functional biodiversity to improve pest control, http://orgprints.org/24363/1/24363_Pfiffner_Ifoam2014_MM.pdf

Influence of Wild Flowers on Parasitism of Tent Caterpillar and Codling Moth, https://www.researchgate.net/publication/249070634_Influence_of_Wild_Flowers_on_Parasitism_of_Tent_Caterpillar_and_Codling_Moth

Integrated control of apple pests in New Zealand 17. Relationships of Amblyseius fallacis to phytophagous mites in an apple orchard, https://www.researchgate.net/publication/254290323_Integrated_control_of_apple_pests_in_New_Zealand_17_Relationships_of_Amblyseius_fallacis_to_phytophagous_mites_in_an_apple_orchard

Olfactory Cues, Visual Cues, and Semiochemical Diversity Interact During Host Location by Invasive Forest Beetles,

https://link.springer.com/article/10.1007/s10886-016-0792-x

Relationships between Plant Diversity and the Abundance and α-Diversity of Predatory Ground Beetles (Coleoptera: Carabidae) in a Mature Asian Temperate Forest Ecosystem, https://www.researchgate.net/publication/259492727_Relationships_between_Plant_Diversity_and_the_Abundance_and_a-Diversity_of_Predatory_Ground_Beetles_Coleoptera_Carabidae_in_a_Mature_Asian_Temperate_Forest_Ecosystem

Attracting Beneficial Insects with Native Flowering Plants, http://www.canr.msu.edu/nativeplants/uploads/files/E2973.pdf

Plant Essential Oils as Arrestants and Repellents for Neonate Larvae of the Codling Moth (Lepidoptera: Tortricidae), https://www.researchgate.net/publication/233606002_Plant_Essential_Oils_as_Arrestants_and_Repellents_for_Neonate_Larvae_of_the_Codling_Moth_Lepidoptera_Tortricidae

APPENDIX

Supporting documentation

The design as an article for publication

AN APPROACH TO NATURAL PEST CONTROL IN ORCHARDS

There is more and more evidence that the chemicals used for pest control are detrimental to us and our planet, and as a result more people are choosing to grow organically. However, this hasn't stopped some organic producers using sprays containing natural toxins and chemicals to control pests Whether using natural toxins or synthesised toxins such as organophosphates the aim is the same: to treat the symptoms, i.e. remove the pest. These treatments will usually affect more species than just the targeted pest and will be detrimental to the pests' natural enemies and nature on a wider scale. Various non-chemical, more sophisticated methods of pest control have emerged using hormones, pest contraceptives, microbial pest control products, pest predator and pathogen introductions and more. Currently, these are deemed more acceptable than toxic chemicals but they are in some ways the same. They are an external controlling influence that does not address the cause of the problem or enhance the orchard system's health; in fact, they may upset it and cause other problems. These types of control are therefore not a part of the approach proposed here. This approach aims to get natural pest enemies (NPEs) and beneficial plants to create orchard health and carry out as much of the pest control as possible through good design and cultural methods. In this way natural homeostatic processes from within the system can reduce the need for management and external inputs.

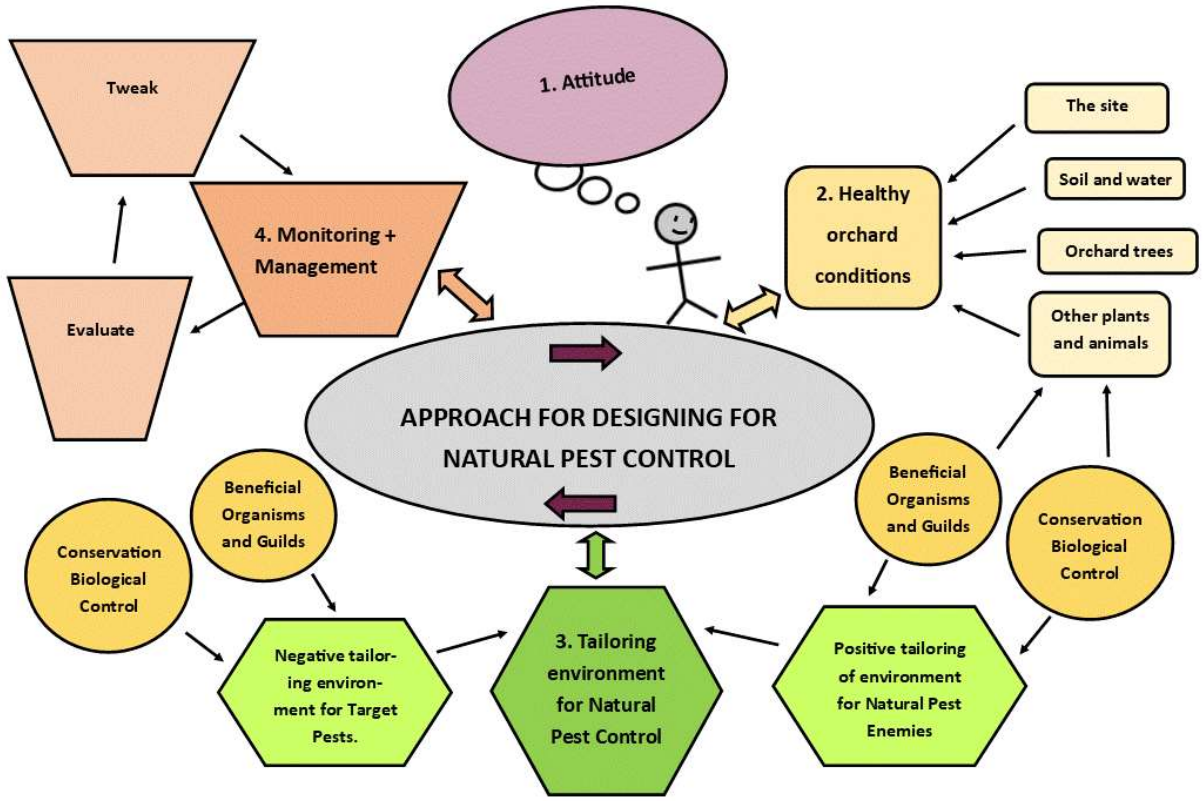
There cannot be a one size fits all plan for orchard care because sites, conditions and trees will vary, even though natural enemies of top fruit crop pests are surprisingly similar irrespective of location. However, there can be an approach that can be used in all situations. This approach aims to do that; it outlines what to consider and how to tackle the situation, rather than giving a detailed protocol on exactly what to do. It provides guidelines for the orchard owner to help them take an information and design intensive approach to orchard care. It involves an integrated, enabling approach, rather than the commonplace reactionary, controlling approach.

The task may appear daunting, especially when you look at books on pests and their enemies and see how many there are and how complicated their life cycles can be, but what matters in this approach is to consider your own site. You don't need to learn everything and know every pest and NPE – they won't all be on your land. Not every problem will relate to your orchard and you can improve your approach over time.

It should be noted that the implementation of features supporting natural pest control are likely to take more time and work initially but should give good returns, on many levels, for the initial extra effort. In addition to controlling pests, this approach should improve system health and conserve wildlife.

This approach involves:
adopting the required attitude.
providing appropriate orchard conditions for the fruit trees present.
tailoring the environment in favour of NPEs and against pests through:
conservation biological control, which relies on creating good, all year round, conditions for naturally occurring enemies of the pests so they can thrive and deal with the pests as they arrive and reproduce.
beneficial plantings, which involves the use of plants that improve tree health through a variety of means and discourage pests or lure them away from the trees.
thoughtful management.
observation which allows for informed management, continued evaluation of the situation and tweaking of strategies.

Fig. 1 Schematic diagram of approach.



ATTITUDE

Attitude is a learned predisposition and is the basis of how an individual will respond to an idea, opinion, situation etc. However, attitudes can be changed and strengthened hence, the reason for including it as a part of this approach.

Two problems we commonly suffer from are over-ambition and impatience. We need to rein these traits in. It is far better to start with a few trees that are well managed than to plant lots and not tend to them properly, particularly in their first few years. Working out from well managed areas where one can learn from mistakes/feedback on a small scale saves energy and produces a better orchard in the long run. If we treat mistakes as forms of feedback, we can use them to our benefit as we plant more trees. Orchards are naturally long term projects so it is worth taking time to think and observe before planting a single tree. Watching your land, talking to orchard enthusiasts, researching, analysing, observing and thinking over a whole cycle of seasons will reap more rewards than going out and doing something pretty permanent like planting lots of trees.

Copying others is also embedded in our psyche and is often considered the way to go. But just because a path is well trodden, it doesn't mean it is the right one. As we learn more about our world and have to respond to the changes occurring around us, we need to become more observant and adaptable, consider the latest discoveries and try out new things.

In regards to pest control, we need to move from the currently commonplace reactionary, controlling attitude to a responsible, integratory attitude. For instance, people react to pests by using pesticides to try to completely get rid of a problem predictably and quickly. But with a responsible, integratory attitude, the wider effects are considered and although the solution may be delayed and less sure, this approach promotes long term whole system health, reduces pest problems in the long run and provides fruit that is healthy for us to eat.

Instead of indulging our instinctive reactionary attitudes and trying to fix everything ourselves, we should exploit nature by getting it to help. Before starting anything it makes sense to consider our attitudes and how these may limit or enhance the way we approach orchard care.

HEALTHY ORCHARD CONDITIONS

There are many factors that can reduce excessive numbers of pests on orchard trees and it is worth considering everything, if possible from before the site is chosen and the orchard planted. The conditions within an orchard site are going to be an important part of natural pest control. If the conditions are poor the trees will be more stressed and this favours the pests. The best way to achieve pest control without the use of toxic chemicals is to design an orchard habitat and management regime that:

Allows for tree and surrounding environment health i.e. system health

Is surrounded by an area of diverse landscape which can support NPEs. However these also support many orchard pests.

Is protected from pest and pesticide drift from neighbouring land.

Contains plant assemblages specifically designed to continually support NPEs over their whole lifecycle.

Contains habitat boosters designed for a variety of NPE types.

Promotes beneficial organisms that support orchard health.

Promotes organisms which support pest control.

The site

The orchard needs to be on a reasonable site to ensure that there is a chance of achieving healthy trees and a worthwhile crop. Healthy trees are a vital part of pest control as pests tend to target stressed plants.

Climate

The general climate needs to be suitable for the orchard trees chosen; however, there are many varieties and cultivars which are hardy in what might appear to be unfavourable climatic conditions for fruit and nut trees.

Directional Sectors

These are incoming influences from certain directions such as wind, rain and sunlight. These will have major impacts and need to be considered. In the case of an orchard wishing to use conservation biological control it is also good to consider pesticide drift from neighbours as pesticides can severely affect natural enemies as well as pests – in fact, in many cases the NPEs are more affected than the pest. There are approximately 120,000 known species of parasitic wasps which are valuable insects for biological control but are highly susceptible to pesticides. An important influence will also be the pests living in the surrounding area so pest drift should be considered too.

Surrounding habitat and land use will have an impact on NPEs and pests; if it is possible to have an orchard surrounded by good hedging and a good area of natural landscape then this is advantageous for pest control.

As always, observation is crucial and it is good to visit any neighbours, particularly those with fruit trees in the area and see what they do, what pests they suffer from and also how they deal with them.

Topographical Sectors

These are influences created by landscape such as altitude, slope, orientation, flooding, frost pockets etc. and they need to allow for good orchard health.

Combined Sectors

These are where a number of influences combine to create microclimates such as wind funnels, shaded areas, fire hazards, sun traps, rain shadows, waterlogging, frost pockets etc. and they are also important considerations.

Soil and water

Soil structure, depth, fertility and pH

These need to be suitable for fruit tree growth and so should be checked before deciding to create an orchard on the site. Looking at the plant communities present can give a good idea of conditions, particularly for moisture of the soil. It is certainly worth taking note of what grows on site but there are limitations to this approach. Some soil analysis should be carried out including pH, structure, organic matter content and the soil profile to several feet. Roots dislike compacted soils and find it difficult to penetrate hard pans (a layer of hard subsoil which may be natural or caused by past ploughing). There can also be problems if the soil is too friable, especially with trees on smaller rootstocks as they easily blow over. The fertility of the soil needs to be adequate but there can be problems with fertilising so look carefully before adding any high nutrient materials. Too much can favour leafy growth over fruit production, can make the trees more susceptible to pests and upset the symbiotic relationship between the trees and mycorrhizal fungi.

In order to maintain a healthy, productive soil it is necessary to address the needs of the soil biota. The healthier the soil is, the healthier the trees will be and part of the approach to natural pest management will be to ensure that soil nutrients, biota health and structure are maintained and hopefully improved

Increasing the nutrients and organic matter, and mulching to reduce root competition and improve soil water conditions for plants can be labour intensive. However, all these things promote good tree health and hence pest control. Using the natural biological methods for helping to maintain good soil structure and health reduces labour but it is likely that in the early stages at least mulching with various organic materials will be highly beneficial. It is

important to remember that the tree root zone stretches well beyond the drip line of the tree and a lot that affects the health of the tree goes on in this area. Many pests also spend a part of their life cycle in the soils around the trees so this is a busy area worth focusing on.

Orchard trees

In order to take a holistic approach to designing for the trees' needs and natural health, the consideration of their background history and an understanding their favoured conditions is important. It is worth noting here that the natural environment for many fruit trees is open woodland and woodland edge and that this type of environment is what they have evolved to fit – and also what their pests and enemies of their pests will have evolved to fit. However, humans have collected and bred different rootstocks, varieties and cultivars of fruit trees for centuries and these may favour different environmental conditions. We have domesticated trees and in doing so have probably reduced their natural chemical defences. We have also favoured larger, sweeter fruit than the original wild trees provided. As a result they need more care than their wild relatives and sunnier sites than many woodland edge environments have to allow for more sugar production.

Tree species selection is hugely important if they are going to be healthy on a specific site, as is their rootstock and variety or cultivar selection. All of these can affect how well a tree thrives in certain conditions and also its susceptibility to various pests. We have a tendency to think short term but thinking in the long term we might not want all our trees to be the same age. It might be better to plant some trees on smaller rootstocks so the orchard provides fruit earlier and in 15- 30 years when these are coming to the end of their life there will be space to add new trees. Conditions will change over time as the trees grow and mature so this also needs to be considered and adapted to.

If an orchard hasn't yet been planted, this approach requires:

choosing the right species, rootstock and variety or cultivar for a specific orchard site, its soil and position within it.
avoiding the species, rootstocks and varieties or cultivars which are particularly susceptible to the pests and diseases found locally.
planting trees that naturally suit the environment of the site.
deciding on shape to prune the trees to reduce pest damage.
planting trees well apart.
reproducing a diverse ecological system that suits the trees.
reducing or removing conditions that may adversely affect the trees.
creating conditions that positively affect the trees' health.

If the orchard already exists then the last three points should still be addressed.

Other organisms

In the wider environment, diversity increases the number of interactions and because there will be different species performing similar functions the system is less reliant on one species and more stable. Hence an approach of providing a diverse range of plants that somewhat mimic woodland edge is a good overall approach. The high landscape structure of woodland edge with its many layers of vegetation also provides a diverse range of niches and microclimates suitable for a diverse arthropod population able to help with pest control. There are numerous studies which show that natural habitats surrounding orchards can help promote NPE populations and reduce pest damage, however, there are also some studies which show pests can be worse in orchard trees close by such habitats. As there are more arthropods in general in the more natural environment it is likely that there will be less extreme fluctuations in the pest and NPE numbers in an orchard close to natural habitats..

By creating a healthy, busy and diverse habitat for conservation biological control and growing beneficial plant communities we can enable organisms to create system health and control pests rather than trying to do these jobs ourselves.

Beneficial organism's quality	
Compatibles	Many organisms are compatible because they fit around each other easily rather than due to any obvious interaction. They may use different niches within the space both above and below ground. They may have evolved together; for example, one may prefer the shade produced by another or use the sun before the other produces leaves such as woodland flowers under trees. Interestingly, birds generally avoid parasitised prey. By leaving the parasitized prey the larvae of the NPE which will feed on it can grow to adulthood and reproduce. In this way bird biological control compliments that of parasitoid pest enemies. These natural relationships can be useful for creating system health and should be used where possible.

Mutualists (Between species cooperation)	These form mutually beneficial relationships with each other. The best example of this is the symbiotic relationship fruit trees have with mycorrhizal fungi, which supply nutrients and water to the tree and receive sugars in exchange. If planting an orchard in land that has not had trees on it before, it is a good idea to add an inoculum of mycorrhizal fungi from mature healthy orchards or woodland (which are free from honey fungus), or it can be bought from garden centres. The symbiotic relationship between these fungi and fruit trees is hugely beneficial for tree health so is a high priority when it comes to getting nature to do the work. The soil biota in general is hugely important for plant health and has a close symbiotic relationship with orchard tree roots. Pollinators and NPEs have symbiotic relationships with plants. Even apparent pests do; the aphid on lime trees exude sugars which fall to the ground. This stimulates Azotobacter, a free living soil bacterium which fixes nitrogen (trapping it from the atmosphere) so fertilising the lime tree. In nature things often aren't as they seem; we know very little of what goes on which is why it is good to copy it and to sit back and observe.
Dynamic accumulators/pumps	Some plants accumulate certain nutrients more than other plants and help release them from the soil for other plants. Legumes not only fix nitrogen through a mutualistic relationship with bacteria but also accumulate phosphorus and excrete it out of their roots. Some dynamic accumulators are thought to work as pumps. They have very deep roots and can gather nutrients from deep down and when their leaves die back, these nutrients end up on the surface. Comfrey *Symphytum* species and other deep rooted plants are thought to improve soil partly due to this ability. If introducing comfrey, use only the Russian comfrey *Symphytum* × *uplandicum, "*Bocking 14" from root cuttings. Other comfreys self-seed and once established are difficult to remove. There are many other plants which fit this category, bringing different nutrients into circulation as well as providing other services. Unfortunately there is little scientific research on this although there is plenty of anecdotal evidence that these plants are beneficial to soil and plant health.
Mulchers	These keep the ground surface covered and can help to conserve moisture, reduce unwanted weeds, soil erosion, compaction and nutrient leaching, while improving soil organic matter and water absorption, moderating soil temperatures and enhancing the soil biota. Fruit trees, particularly young ones and those on dwarfing rootstocks, are vulnerable to root competition from grass species. Many plants can be used as mulchers that also help to reduce this problem. However, with older trees on large rootstocks we might want to plant grass around them to reduce vigour and encourage fruiting.
Nitrogen fixers	These are plants that have a symbiotic relationship with bacteria that fix nitrogen from the atmosphere and fertilise the soil when the plant's roots die back. Of the plants and their associated bacteria, legumes are the best example but other plants, for example *Eleagnus* species and Alder also fix nitrogen. Some free-living soil bacteria can fix nitrogen from the atmosphere as well. It may be necessary to inoculate your land with the nitrogen fixing bacteria that associate with the nitrogen fixing plants on your land, especially if you are introducing new or rare varieties.
Limiters	These can be plants which deter, confuse or detract pests. Aromatic plants are often used as limiters. For example tansy *Tanacetum vulgare* has been shown to deter codling moth. NPEs are also limiters.
Trappers	These are sacrificial crops and can be used to attract pests away from the trees. Unfortunately some pests are host specific and can't be lured away. Limiter and trap crops can be used together in what is sometimes referred to as push-pull cropping.
Competitors	These organisms can be used in a number of ways. Mulching plants are often good competitors and can have an effect both above and below ground. For example, some plants may outcompete detrimental plants such as vigorous grasses above ground reducing their root competition

	with the trees' roots, which is a problem for young fruit trees and those on dwarfing rootstocks.
Allelopaths (negative)	Some plants, bacteria and fungi contain or exude chemicals that discourage the growth of plants, prevent the germination of seedlings or stunt their growth. This chemical warfare can be used to our advantage; for example, some of the clovers are allelopathic and can be used to control weeds while providing nitrogen and phosphorus under fruit trees. However, apple trees are susceptible to juglone produced by black walnut (*Juglans nigra*) so shouldn't be near any, yet peach, pear and plum trees grow perfectly well in its presence.
Allelopaths (positive)	There is not as much known about positive allelopathy but it has been shown to exist. Corn cockles have been shown to improve wheat yields through allelopathy. There are likely to be other such relationships where plants naturally grow together, so just keeping an eye out for what works well together on your own land and exploiting it is a good approach, even if the science isn't yet understood.
Bankers	These provide good habitat, food (pollen, nectar, berries, seeds, prey etc.), shelter (dry stalks, cover etc.) nesting sites, protection and more to NPEs and pollinators, keeping established populations on site. Many will harbour prey that are not pests of orchard trees but are a food source for NPEs
Protectors	These can act as barrier and/or nurse plants. They may stop pests getting to trees, protect plants from winds and create microclimates suitable for other useful plants and organisms. Enemies of pests can also be seen as protectors of plants.
Enemies	Many organisms are enemies of orchard pests, including parasitoids, parasites, predators and pathogens. These will include parasitic wasps, flies, nematodes, ladybirds, ground beetles, lacewing larvae, spiders, earwigs, birds, bats, shrews, bacteria, protozoa, fungi, viruses and more. Some pests have a key natural enemy and others a complex of enemies. If a key natural enemy is missing it may be worth introducing and nurturing it. Predatory mites are not very mobile but are good at controlling red spider mites. These can be bought but it might be better to get them from a local orchard where they are well adapted to local conditions, but beware of transporting diseases.
Enablers	This role could come under the mutualist heading but is here as a separate heading to cover mutualism practised via another organism. We are enablers as we manage for the fruit trees but our actions may be several steps away from direct management. For instance, putting up a bird box for tits enables the tits to breed on the land and a family of tits can eat hundreds of larvae and thousands of aphids in a season. Planting umbellifors, or just letting them stay on site, will support NPEs which in turn destroy the pests. Adding woodchip as a mulch will help the fungi, which can extend the nutrient reach of the tree up to 100-fold.

Many recommendations for beneficial plants are not scientifically proven and much more research is needed so some caution is required. Try a small patch and observe while remembering that sometimes plants are assumed to be beneficial companions just because they both do well in the same conditions.

In a well-designed orchard the above characteristics will be exploited and most organisms will also provide multiple yields by carrying out more than one of these advantages. One should always be thinking of organisms' natural ways and interactions, and how they can be used to advantage. This approach results in the creation of guilds of plants which create a more self-supporting system appropriate for the orchard trees' needs. With a little consideration of what else we need, or might like, we can receive additional yields from these plants as well; they may provide us with food, flowers, herbs, firewood, a beautiful place to be and more.

With this approach we need to:

observe carefully

pay attention to feedback, accept and act on it.

study natural systems and learn what to copy from them.

accept that there are many things going on in nature that we do not understand, so we should tread carefully.

accept that good designs for living systems will incorporate diversity and will not necessarily be tidy.

make the most of organisms' abilities and enable nature to do much of the work.

TAILORING THE ENVIRONMENT FOR NATURAL PEST CONTROL

In orchard crops there is no one super pest or NPE. Creating a complex landscape with a woodland-edge style of ecosystem, which encourages a large variety of NPE species to stay close to the orchard all year round, is a good general approach. However, there are bad choices and good choices of what should be included in the surrounding habitat in order to control orchard pests. Hence a better approach than just increasing biodiversity is to create a tailored biodiversity. This means that you need to understand your pests and their enemies' needs and tailor the habitat to suit them.

A good book on pest damage, pests and NPE identification, their lifecycles and their requirements is required so you can identify what you find on your trees and understand their lives. In this way you can tailor your environment to suit.

As with everything there are pitfalls to avoid:
Some plants act as hosts for pests of orchard trees. e.g. Rosaceae species such as hawthorn, rowan and whitebeam
Some plants and habitats may favour the enemies of the pest enemies.
Some plants may harbour orchard diseases which cause more damage than the pests; e.g. the Rosaceae family, hawthorn, *sorbus species* and crab apples harbour fireblight, an important orchard disease which will kill trees.
Some plants are toxic for humans and domestic animals - there is legislation for control of some of these:
https://www.gov.uk/guidance/prevent-the-spread-of-harmful-invasive-and-non-native-plants#prevent-the-spread-of-invasive-non-native-plants
Some plants are invasive and could become a nuisance in themselves. These are often natives but things are usually more serious if non-native. Planting invasive natives could cause you more problems than the pests in an orchard and it is worth considering that some plants may be invasive in one area and not in another. Planting non-natives in a very natural environment in the countryside could cause more serious problems and incur fines.
https://www.gov.uk/guidance/prevent-the-spread-of-harmful-invasive-and-non-native-plants#prevent-the-spread-of-invasive-non-native-plants
Some plants may harbour many pests which fulfil the NPEs' needs, meaning they don't visit the orchard trees. These may need cutting at an appropriate time to move NPEs on to the trees.
The effectiveness of companion plants may be compromised by other plants.

There are also ways to make the most from any changes made:
Inoculation of the site with some natural predators may be advantageous. Many can be bought, usually to control pest outbreaks but also to introduce them to a site. Again, the introduction of a species to a site should be done only after ensuring it is legal and sensible.
Choosing plants that could do with a helping hand over others can result in providing for pest predators and conserving rarer species. The red data plant list will give details of such plants
Taking advantage of synergies and avoiding adverse interactions.
Choosing plants suited to local conditions.
Choosing plants with many functions.
Looking for plants that selectively benefit the NPEs and not the pests, or the NPEs' enemies.
Aiming to provide for a variety of NPE types that are different in where and how they live – for example, ground dwellers, tree dwellers, flying insects, sedentary spiders etc.

Positive tailoring of the environment for NPEs

An organised approach is required to tackle the large amount of information which will determine your actions. There is so much to consider when looking at the NPEs' needs, such as an all year round supply of food and shelter for their various life stages. Using a table such as the one below and adding to it as new knowledge is gleaned helps with positive tailoring of the environment.
Luckily NPEs tend to be less host-specific than pests and one species may help control several pest types. In the orchard earwigs, predatory hemiptera, spiders, parasitoid wasps and flies are natural enemies of most types of orchard pest. They will deal with aphids, sawflies, weevils, mites, suckers, moths, capsids and more, so creating a good environment for these is a sensible place to start.

Table 2 An approach to organising information on positive tailoring for pest NPEs. This can be supplemented as additional information is discovered and current management can also be incorporated as seen below.

PEST ENEMY	POSITIVE TAILORING FOR NPEs
Ground beetles	Favoured habitat: leaf litter, bark and logs retaining a slightly damp environment Diet: Pupae and larvae of many orchard pests and any pest that drops to the ground. Favoured plants: Low growing perennial plants Avoid: tansy *Tanacetum vulgare* and spearmint *Mentha spicata* under trees as it deters beetles.
CURRENT MANAGEMENT (No specific problem but for moth larvae probably in the future).	2018 Tansy *Tanacetum vulgare* has been planted on site but well away from fruit and nut trees. Logs are being laid at the base of trees as they become available and tree pruning's are chopped up small and left at the base of the tree. Hay is piled up as a beetle habitat improver when the grass is cut.
Ladybirds	Favoured Habitat - Summer: Widespread, grassy banks, hedgerows and woodland. Winter: in dry vegetation for winter. Hibernating boxes can be made. Dry stalks of plants for overwintering such as Lemon balm and stinging nettle, umbellifors etc Diet::- aphids, scale insects and mites, some eat pollen. Favoured plants: - common yarrow *Achillea millefolium*, queen Anne's lace *Daucus carota*, tansy *Tanacetum vulgare*, dandelion , *Taraxacum officinale*, spiked speedwell *Veronica spicata*, hairy vetch *Vicia villosa*, honeysuckle *Lonicera periclymenum*, cornflower *Centaurea cyanus*, fennel *Foeniculum vulgare*, stinging nettles *Urtica dioca.* Avoid:
CURRENT MANAGEMENT for General aphid problems	common yarrow *Achillea millefolium* is already growing on site and is being encouraged through being mown around and allowed to set seed. 2017,2018,2019 , queen Anne's lace *Daucus carota*, tansy *Tanacetum vulgare*, dandelion , *Taraxacum officinale*, are being sown where there is clear patches of soil and in mole hills, Stinging nettles are growing of their own accord. Cutting of these could be an option when trying to shift the ladybirds onto the fruit trees if there is an aphid outbreak
Rove beetles *(Tachyporus* spp.)	Favoured habitat: - Woodland leaf litter and similar decaying plant matter. Diet: Favoured plants: Avoid: tansy *Tanacetum vulgare* and spearmint *Mentha spicata* under trees as it deters beetles.
CURRENT MANAGEMENT (No specific problem but for moth larvae probably in the future).	2018 Tansy *Tanacetum vulgare* has been planted on site but well away from fruit and nut trees. Logs are being laid at the base of trees as they become available and tree pruning's are chopped up small and left at the base of the tree. Hay is piled up as a beetle habitat improver when the grass is cut.
Empid flies (Empididae)	Favoured habitat: - Field, pasture, wetlands and lightly wooded areas. Predators at all stages. Aphids, bugs, midges, larvae in soils Diet: Favoured plants: Avoid:
Hoverflies (Syrphidae)	Favoured habitat: - Closely associated with woodland habitats. Diet: - Adults eat pollen, nectar, larvae eat aphids, thrips and other leaf hoppers Favoured plants: Tend to favour yellow and white flowers with open structure, particularly from the Umbelliferae, and Compositae families. However, many are non-selective about flowers - lemon balm *Melissa officinalis*, pennyroyal *Mentha pulegium*, spearmint *Mentha spicata*, wild bergamot *Monarda fistulosa*, feverfew *Chrysanthemum parthenium*, common yarrow *Achillea millefolium*, queen Anne's lace *Daucus carota*, spiked speedwell *Veronica spicata*, common toadflax *Linaria vulgaris*, cornflower *Centaurea cyanus*, fennel *Foeniculum vulgare*, wild oregano *Origanum vulgare*, wild thyme *Thymus vulgaris.* mayweed *Tripleurospermum spp.* Avoid:
CURRENT MANAGEMENT General aphid problems	common yarrow *Achillea millefolium* is already growing on site and is being encouraged through being mown around and allowed to set seed. Queen Anne's lace *Daucus carota*, is being sown where there are clear patches of soil and I mole hills,
Predatory bugs	Favoured habitat: - Hedgerows, commonly found in Blackberry in Autumn. Diet: - Insect, mites and larvae. Favoured plants: Avoid:
Lacewings (Chrysopidae)	Favoured habitat: - Widespread. Hibernate - buildings and leaf litter. Lacewing shelters are used and can be made easily. They like open plant structure to fly through to lay eggs. Diet: - Adults eat fungal hyphae, pollen, nectar and honeydew. Young eat most orchard tree pests. Favoured plants: - queen Anne's lace *Daucus Carota*, tansy *Tanacetum vulgare*, dandelion *Taraxacum officinale*, honeysuckle *Lonicera periclymenum*, fennel *Foeniculum vulgare*, Avoid:
CURRENT MANAGEMENT General problems	Queen Anne's lace *Daucus Carota*, tansy *Tanacetum vulgare* and dandelion *Taraxacum officinale*, are being sown where there are clear patches of soil and in flattened mole hills. Six honeysuckle *Lonicera periclymenum* have been planted in the woodland nearby.
Spiders	Favoured habitat: - Widespread. Diet: - almost everything that moves Favoured plants: – more permanent plants such as perennial shrubs find out more Avoid:
Earwigs	Favoured habitat: - Widespread, often in ground litter, often moist, also in fruit trees, within flowers, behind bark, in leaf sheaths and under dense vegetation. Earwig shelters should be made and hung in every fruit trees. Diet: - Mainly predators and scavengers, some dead and fresh plant matter, they eat most orchard pests at various stages of their lifecycle. Favoured plants: Avoid:

CURRENT MANAGEMENT General problems	Collected many green plastic, olive oil bottles to make earwig homes to hang from trees. Only one hung in Crimson Bramley so far..
Parasitoid wasps	Favoured habitat: - Widespread; there are about 6.400 species in the UK. Diet: - Adults primarily nectar. Larvae, aphids, leaf hoppers scale insects and more depending on species. Favoured plants: - Umbelliferae family Avoid:
Parasitoid flies (Tachinid) And other Syrphid?	Favoured habitat: - Widespread Diet: - Adults, nectar. larvae - larvae and sawflies Favoured plants: - Umbelliferae family Avoid:
Predatory mites	Favoured habitat: - Widespread Diet: - Red spider mites, other mites and thrips Favoured plants: Avoid:
Bats	Favoured habitat: - Woodland and buildings. Boxes can provide roosting sites. Water such as ponds or lakes attract them as do clear spaces adjoining trees. Diet: - Moths and other flying insects Favoured plants: Avoid: - lighting and insecticides.
Shrew	Favoured habitat: - Dense vegetation, understory cover of woodland, hedge edges, shrubbery and rough grassland. Diet: - larvae, pupae, eggs, and adult pests on orchard floor. Favoured plants: Avoid: - harming them, they have protected status
Birds	Favoured habitat: - Widespread. Good nesting sites/ bird boxes, many seed plants, scrubby tree structure. Old cracked bark for tree creepers. Hollow and dead wood for woodpeckers. Diet: - seeds, fruit, insects, aphids, larvae etc. Provide late hanging fruit for winter support. Some need insects all year round others just during the breeding season. Favoured plants: - anything bearing berries,, seeds etc. Tits use lavender as an antiseptic in their nests. Avoid:
Fungal pathogens of aphids	Favoured habitat:: There is evidence that nettle aphids *Microlophium carnosum* carry these and act as a source for killing aphids on nearby crops. Diet: Favoured plants: Avoid:

Negative tailoring of environment for target pests

As with the positive tailoring for NPEs, an organised approach is required for negative tailoring for target pests.

Table 3 An approach to organising information on negative tailoring for pests. This can be supplemented as additional information is discovered and current management can also be incorporated as seen below.

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PEST TYPE	NEGATIVE TAILORING FOR PESTS
PEST OF TREE	
Woolly Aphids	Avoid: some apple varieties - Allington, Cox, Stirling, James Grieve, King Pippin, Bramley Promote: Nasturtiums deter woolly aphid. Make artificial refuges for earwigs and hang in each tree. Enemies: Key NPE = Earwigs, ladybirds, the parasitic wasp *Aphelinus mali and* most other NPEs also control.
CURRENT MANAGEMENT	Earwig homes hung in trees
Aphids in general	Avoid; over fertilising, over watering and heavy pruning producing a lot of soft new growth. Promote: Most aromatic herbs deter including, clover, coriander, eucalyptus, fennel, garlic, larkspur, marigold, mustard, nasturtium, peppermint, spearmint, *origanum vulgare* Enemies:
Moth/ larvae Winter moth	Avoid: Promote: tachinid flies, ichneumon wasps, braconid wasps, chalcid wasps, carabid beetles, predatory bugs, green and brown lacewings, ladybirds, earwigs and ants. Spiders eat codling moth eggs, moths and larvae. Higher predation of codling moth larvae by carabid beetles has been observed in orchards with significant amounts of leaf litter and mulch. Aromatic herbs including Artemesias can deter and confuse. Tansy and sage both shown to deter codling moth Enemies:
Leaf hoppers	Avoid: Promote:

	Enemies:
Midge/ larvae	Avoid: Promote: Enemies:
Capsid bugs	Avoid: Promote: Enemies:
Leaf-eating weevils	Avoid: top-grafted trees which they are worse on. Promote: Enemies:
Red spider mites and others	Avoid: : some apple varieties - Discovery, Worcester Pearmain and Gala are highly susceptible, Cox and Bramley are moderately susceptible Promote: Enemies: Key NPE = predatory mites, predatory bugs, predatory midge larvae, earwigs, lacewing larvae, ladybirds, spiders
Pear Bedstraw Aphid	Avoid: Promote: Avoid bedstraw (*Galium*) species where part of the aphids' lifecycle is spent. Enemies:
Vole, rabbit, hare deer. squirrels	Avoid: Promote: Use tree guards. Use baffles around trunk of well-spaced nut trees for squirrels. Voles dislike daffodils Choose rootstock and pruning regime to create tree trunks high enough for branches to be clear of the particular pest. Enemies:: Foxes, raptors
CURRENT MANAGEMENT	Vole plus deer guards in place, trees well-spaced for future baffle fitting to deter squirrels. Large rootstocks and pruning for high branches.
Grass	Avoid: Promote: Daffodils thin grass reducing root competition, yellow rattle parasitises grass, clover can outcompete grass and provide nitrogen and phosphorus.
PEST OF FLOWER	
Apple sucker (Psylla)	These are quite difficult to see but Look out for blobs of honey dew and wax at the base of the flower stalks. Avoid: Lord Lambourne and some cider varieties are highly susceptible. Promote: Enemies:
Apple Blossom Weevil	Apple, pear, quince and medlar affected. More common in wooded areas and around orchard margins if these are hedged. Avoid: Promote: Bird boxes and plants. habitat for parasitic wasp adults Enemies: Small birds such as tits. Parasitic wasps 2 species Ichneumonid wasp *Scambus pomorum and the* braconid wasp *Syrrhizius delusorius*
PEST OF FRUIT	
Winter moth	More common near woodland especially oak. Attacks apple and pear, Avoid: Promote: Enemies:, Insectivorous birds, polyphagous predators, Most important are parasitoids particularly the tachinid fly *Cyzenis albicans and* ichneumonid parasitic wasp *Agrypon flaveolatum,*
Moth/ larvae plum, tortrix	
Capsid bugs	Avoid: Soft lush bark, grass under tree limits growth and hardens bark making it more difficult for burying eggs in. Eggs are inserted into soft rootstock sucker growths so remove these over winter. Unfortunately plants of the Compositae family act as a summer host for the pest but are good for many NPEs. Promote: Enemies: Spiders
Apple Sawfly	Avoid: some apple varieties - Discovery, Worcester Permain, Quarrenden, Cox, Charles Ross, Ellison's orange and James Grieve. Culinary apples tend to be more susceptible except for Early Victoria and Edward Promote: Enemies: The ichneumonid parasitic wasp *Lathrolestes ensator* is an important natural enemy of apple sawfly as is parasitic wasp, *Aptesis nigrocincta*, and probably ground beetles
Pear midge	Avoid: some pear varieties - William's bon Chretin but Conference, Fertility and Dr Jules Guyot are less vulnerable Promote: Enemies:
Rosy Apple Aphid	Avoid: plantain (*Plantago*) species where part of lifecycle is spent. Bramley, Discovery, Egremont Russet, Golden Delicious and Jonagold are highly susceptible. Promote: Enemies: earwigs, predatory bugs, lacewing and hoverfly larvae, predatory midge larvae, ladybird adults and larvae and spiders, parasitic wasps, insectivorous birds.
Codling Moth	Avoid: Promote: herbs including Artemesias, Tansy and sage both shown to deter codling moth Enemies: many parasitic wasp species, tits, earwigs, predatory bugs and bata
General	Avoid: Promote: herbs such as wormwoods, rue, hyssop, penny royal and gentian provide olfactory confusion for pests. Enemies:

MANAGEMENT

A crucial part of the management for natural pest control involves observation. The frequent monitoring of what is happening is necessary; a walk around the trees checking for their overall health, pests and predator levels on them and the surrounding plants will help confer an understanding of what is happening on site and what tweaking of habitat or management might be beneficial.

The use of monitoring calendars will, over the years, give an insight into what is happening. If you find that you have a problem at a particular stage in the year this can help you provide for the NPEs you want to encourage at that time.

Table 4 Monitoring chart for NPEs and Pests on fruit and nut trees

FRUIT/NUT TREES Monitoring for Natural Pest Enemies and Pests

Year .....

X = density (x = Occasional, xx = Low, xxx = Medium, xxxx = High)

SPECIES	NPE OR PEST	LIFE STAGE	FRUIT/NUT TREE TYPE, VARIETY or NUMBER OF TREES	POSITION and COMMENTS	WEATHER	JAN FEB	MAR APR	JUN JUL	AUS SEP	OCT NOV	NOV DEC

Table 5 Monitoring chart for NPEs and Pests on land in and around orchard trees

SURROUNDINGS Monitoring for Natural Pest Enemies and Pests

Year.....

X = density (x = Occasional, xx = Low, xxx = Medium, xxxx = High)

SPECIES	NPE OR PEST	LIFE STAGE	FRUIT/NUT TREE TYPE, VARIETY or NUMBER OF TREES	POSITION and COMMENTS	WEATHER	JAN FEB	MAR APR	JUN JUL	AUS SEP	OCT NOV	NOV DEC

To some extent every orchard owner is going to have to research and experiment, then evaluate and tweak their environment and management strategies. However, if any changes made increase the biodiversity and structural complexity of the system and improve the soil then even, if pests are not reduced, other worthwhile benefits will result. This approach can be used in conjunction with many other methods of pest control such as sticky traps, pheromone traps, introduced pathogens etc. but the use of pesticide sprays that were not totally specific to a pest could badly damage the efficacy of this approach.

There will be some management required to support and maintain the natural system created and also to supplement it with standard orchard practices such as pruning, trunk protection, grazing/mowing regimes etc. However, even these should be examined for efficiency and how they might affect tree health, NPEs, pests and the wider environment. Traditionally, orchard management regards fallen fruit and leaves as a problem as they harbour pests and diseases, but removing these is a labour intensive job and doing so may be denying ground NPEs, birds, the soil biota and the trees a much needed resource. Mowing rather than removing may increase soil incorporation rate, thus reducing pests and diseases while improving the soil, encouraging NPEs and reducing labour. Composting in a covered pile in situ or grazing may be better options and which option is best may vary from site to site and owner to

owner. The problem may be the solution to fertilising the trees and improving the soil, it may not. It is worth questioning all approaches however standard they have become.

Management should be based on theory and observation of the site and will vary from year to year. For example, stinging nettles are home to the aphids *Aphis urticate* and *Microlophium carnosum.* These provide a good food source for generalist predators and so may provide a reservoir of NPEs for orchard tree pest reduction. However, things may work the other way around with NPEs leaving orchard trees to feed on nettle aphids. Cutting nettles at an appropriate time may be a good management strategy for moving NPEs into the trees. If the nettles haven't set seed they can also be used as a high nutrient mulch, so you can carry your NPEs to your trees. However, it may be that when you examine the nettles they are found to be harbouring a population of pests such as capsid bugs, in which case it might better to leave them alone to stop the capsid bugs moving on to the fruit trees.

In conclusion, it is important to point out that we are nowhere near understanding nature's complexity and so trying to present a means of pest control using natural interactions is to some extent speculative. Most of the principles and information behind this approach have scientific research behind them but some have only what appears to be much repeated anecdotal evidence. Often scientific research has been taken as proof of a positive relationship but the results are often not reproducible, or have the opposite relationship other scientific studies. All we can do is to take a holistic approach and try to understand nature's interactions while accepting that there are so many, that we are both aware and not aware of, that it is almost impossible to be sure what the influence of making many changes will be. No research paper, book or experienced orchardist can provide definite detailed recipes for success. Permaculture's principles, as used in much of this approach, make a good framework for tackling the issues and point you in the right direction - but observation, experience, intuition, speculation and experimentation are going to be a large part of the process. To many this is part of the joy of organic orchard care, we find ourselves becoming absorbed in what is going on in our orchard, we spend more time in it taking note of what is going on and end up being more integrated with our environment.

ASSESSMENT OF THIS DESIGN

Evaluation

The 4Ps system was used for evaluation of the approach in the format of the article.

Process This project has been really difficult and it took a while before I could see any path to follow to create a design for management. The research was difficult as the research papers often contradicted each other or had ambiguous results. The process following SADIMET was good. However, the Surveying and Analysis was disorganised. The Design of the approach evolved from the research and to be led by it was appropriate in many ways, although identifying my goal a bit better would have been advantageous. Writing the article was far more difficult than expected, in part because so much had to be left out.

Product I feel that the final outcome may be too much work for people to follow. The approach is useful for myself and I hope for others too as well as being educational for those reading it

Personal I am pleased with the basic diagram on how to think and behave and with the amount I learnt. Given that I have an orchard and am ready to implement this design it is great that I have a format and that it can be expanded upon as needed. For me it was a learning experience and I know lots of things now which I know I will forget, but, hopefully, I will retain my wider understanding and will have the article to refer to. I think what will be most beneficial for me will be having a framework to follow as I look after my orchard and an organised way to store information for quick reference.

Peers I have passed the article by various people and responses have been positive. It is easily understood, logical and informative. Permaculture terms such as sectors were confusing for people so I had to explain what they were in the article. Yields was

another term that people thought was peculiar. Incorporating attitude into the approach has been commented on as being a good idea. I have made many changes to the article as a result of comments people have made.

On a scale of 1 - 10 I feel this project deserves a 5.

How this design meets the Principles and Ethics of Permaculture.

Using conservation biological control and beneficial planting fits with the core ethics **Earth Care**, **People Care** and **Fair Shares**.

It is also easy to apply all of the permaculture principles for this approach to pest control.

Observe and Interact: This was a large part of this project. Mostly when researching the information but also when assessing my own orchard during these initial stages of implementation. I have a lot to learn about orchard pests and diseases which is why I chose to do this design.

Catch and store energy: The energy I have put in to the design and writing it up will be stored in the article and hopefully in others who read it. The practical approach and tables to fill will help me to store the information/energy in a way which can be quickly referred to. Implementing the approach will result in an environment that naturally catches and stores energy.

Obtain a yield: The design itself is a yield and its use will result in less work, a healthier environment and healthy fruit. Another yield will be an increased number of insects and other invertebrates on site which is important as they are in serious decline.

Apply self-regulation and accept feedback: This has been going on throughout the design process particularly during the research phase when I was in effect hunting out feedback. The success of the implementation of this approach is very dependent on self-regulation and feedback..

Use and value renewable resources and services: This approach is all about using natural systems and their services rather than harmful resources.

Produce no waste: None is produced in the approach design or its implementation. Habitat boosters such as bird boxes and bat roosts will be made from waste wood.

Design from pattern to detail: The need to design from pattern to detail is conspicuous, The mind-map gives the pattern of the approach and the article gives more detail. The ideas behind the approach go from designing a landscape suitable for fruit trees, similar to woodland edge, and then working down to the details of what will help provide for tree health, NPE populations' health and the resulting natural pest control. During the implementation more detailed designing will be employed as the final positioning of plants to form guilds, habitat boosting methods and locations are chosen.

Integrate rather than segregate: The design is all about using a responsible, integrated approach rather than a reactionary, controlling attitude where people use pesticides. Everything in this approach depends on integration.

Use small and slow solutions: On a world-wide scale this is a small slow part of the solution to the problems the world faces. In terms of pest control it is also a slow solution but hopefully one that saves future work and improves the environment. Implementation will be slow and small changes will be made throughout and observed to see how they work. For instance I have sown dandelions, ox eye daisies and meadow buttercups in the multitude of mole hills on site. If this works then I shall buy more seed and continue with other plants.

Use and value diversity: This is evident in the diverse habitats and microclimates created in order for the approach to succeed. It is valuing the diversity of NPEs and beneficial organisms which is behind this approach.

Use edges and value the marginal: Our NPE's have been undervalued and marginalised for a long time, only recently are we beginning to value them and this design is all about this. Implementing the approach will result in a more diverse habitat with many more edges and higher structure and surface area.

Creatively use and respond to change: This project is my response to the changes which threaten our planet. My planting of a traditional orchard was also a response to these changes. The approach demands an attitude of responding to changes. It involves close observation of the area, analysis of what changes are occurring on site and altering management to create better conditions.

Assessment of Individual Design for Feedback Table

DIPLOMA in APPLIED PERMACULTURE DESIGN System 5.2

ASSESSMENT of INDIVIDUAL DESIGN for FEEDBACK

Effective from Oct 1st 2013

Diploma Apprentice's name:	**Charlotte Synge**
Date first registered for Diploma:	**26th January 2015**
Date of this feedback:	
Name of Personal Tutor:	
Name of Assessment Tutor:	**Aranya Austin**
Project Title:	**An Approach to Natural Pest Control in Orchards**
Date Started:	**2017**
Date Completed:	**2018**
Implemented:	**Yes and ongoing**
Design Number	**9 of 10**

ACCREDITATION CRITERION: 1. Demonstrating design skills (Section C3 in the Guide to Accreditation Criteria)		
	What's gone well?	**What could have been done differently?**
Accurate and appropriate use of an intentional design process.	Yes. The outline design framework SADIMET was appropriate. Incremental design will be used when implementing the approach. Mind-maps were used as thinking tools and resulted in the final mind-map depicting the approach.	Other design frameworks and thinking tools could have been used. However, I tried using a flow chart to organise the approach and it didn't feel right as there were so many things to consider and jump between as changes occurred, so I felt the mind-map was a better way to analyse the approach. The design process was fine but my information collecting and recording was disorganised and should have been more structured. This was in part because I couldn't clearly identify my goals until I had learnt more but I should have tried to do this earlier in the process.
Use of permaculture ethics, principles and theory is appropriate to the situation.	Yes. How the design fits with permaculture principles and ethics can be seen here.	Not sure.
Use of a variety of tools which suit the needs of the client and the situation.	Yes. The table presenting organisms' qualities helped clarify how they could be used as management tools and, I think, promotes that way of thinking. The tables organising the information on NPEs and pests efficiently sorted out a mass of notes made when reading. There was a stage in	This could have been presented in an entirely different way. The article is rather long for many publications and I had wondered whether it would have been better to break it up into two, one section on the use of guilds etc. for pest control and tree health and

	this design when the amount of information was overwhelming. I like the monitoring forms as I think they will encourage careful observation that is well documented and easily accessible encouraging the continued use of the approach.	one section on Conservation Biological Control.
Design is intelligible, coherent and effective (i.e. it met the needs of the client).	Yes The mind-map is clear and makes it easy to understand the general approach. The approach follows a logical process and is usable in all sorts of orchards and situations. The tables make life easier for those starting on the journey.	Not sure
Documentation for and presentation of the design is appropriate for clients & third parties.	Yes. The presentation is clear and appropriate.	Not sure, I have battled with the idea of reducing the article's length but then important information may be lacking. I looked online about how long articles should be for people to read in one go and was interested to discover that blogs are more popular if they are 3000+ words and the 7000 word length (of my article) is more popular than shorter articles which only scratch the surface of a subject.

ACCREDITATION CRITERION: 2b. Applying permaculture to your work and projects **(Section C2 in the Guide to Accreditation Criteria)**		
	What's gone well?	**What could have been done differently?**
Identify which of the 15 categories of application the design applies to from the checklist in the Guide to Accreditation Criteria, and provide feedback on each.	**Site development** This is a slow process which is constantly responding to feedback. It is more of a journey than an event. The main thrust of the work was to control pests but it is actually about increasing	Not sure. It would have been nice to move faster, I had hoped to get some tit boxes up this winter. I have found it difficult to find good books on UK orchard

	diversity and looking after Nature. In many ways the conservation is more important than the biological control in this "conservation biological control" approach. The permaculture principles are all followed. **Education** The world desperately needs to change its attitude and I hope this article will make people think about this as well help them to look after their fruit trees. The process has been educational for me on several levels and has reinforced my belief that we can, and should, look to create edible nature reserves as a form of agriculture and as a form of gardening.	pests. I wish I had asked for more advice on resources and ideas from local orchard enthusiasts before starting this design.
Clear explanation of how the solution was developed using design process and Permaculture theory. The solutions are relevant and appropriate to the activity and content areas.	Yes. The design process used was SADIMET. Thinking tools involved mind-maps. Organisational tools involved the use of tables. The approach involves permaculture theory throughout. It is about creating stable healthy systems through diversity and interactions. It aims for low maintenance and high efficiency in the long term using multiple elements for important functions and gaining multiple functions from elements where possible. Yes.	Not sure

ACCREDITATION CRITERION: 3. Learning from and developing your permaculture practice

(Section C5 in the Guide to Accreditation Criteria)

	What's gone well?	**What could have been done differently?**
Evaluation of the effectiveness of your design work on this project.	I am reasonably happy with the design work for this project. It appears to be very simple but	Not sure, I wish I could have had the design before collecting

	because of my need to check out the science and the sheer volume of information required to carry out the approach it was really difficult.	the information so I didn't get in such a muddle.
Reflection on use of design tools and processes, and use of Permaculture theory and practice.	I am very happy with the use of the design tool SADIMET which kept me on track to a certain extent. The tables are really useful and as I glean information on tailoring the environment for NPEs or against pests it is great to have somewhere to put it. The evaluation using 4Ps was appropriate and useful, It helped to build my confidence and resulted in some positive tweaks.	Perhaps I should have formally used an analysis tool such as SWOC.
How the design shows that your competence and skills in practice and learning is progressing.	The design shows how I think in permaculture terms. I have learnt a lot and the observation/research phase of this project has made me more interested in pest control through conservation and beneficial plantings.	Not sure.

Comments about project format, general or specific issues	
Any other comments?	
Conclusions	
How ready is this design for presentation?	
What are the apprentice's next steps?	
The highlight of this design for me was….	