The Role of Orchard Habitats and the Surrounding Landscape in Supporting Apple Production and Conserving Biodiversity: Report of a Hudson Valley Pilot Project.

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INTRODUCTION

In the mid 1800s, as the extent of agricultural land in the Hudson Valley was peaking, orchard observers began to notice a blossoming of apple orchard pests. Not only that, but they associated this with the decline in natural enemies, specifically birds. It was a decline due both to direct hunting and to the loss of avian habitat (see Trimble, 1865). It should thus be no surprise that, when we look at other creatures, such as spiders, wasps and native bees, we – and others - see a detectable influence of landscape context. And, predictably, in broad strokes, and given that ours was a largely forested landscape, the abundance of those organisms is usually enhanced by the presence of forest in the neighborhood and reduced by the abundance of more altered land including residential or commercial development and more orchards.

Although Native Americans no doubt created openings of various sizes, this region's land was surely a wilder place prior to European settlement. In those forests, wetlands, and scattered openings, various insects made a living, feeding on plants, microbes and other animals, including other insects (in this report but not in taxonomy, "insects" includes spiders). As European agriculture expanded, new habitats were created or old ones reached novel extents. These habitats were dominated by the likes of grains, fodder, and fruits. Some of the creatures which had been living in the wild surroundings, moved into these new areas, where they fed upon the crops (thus earning themselves the 'pest' or, if feeding on pollen or nectar, 'pollinator' designations), or upon each other (and so often earning themselves the 'natural enemy' designation or its historical equivalent).

Prior to appearing on crops, native North American insect pests had often fed on the wild precursors of the crop plants, such as early corn or potatoes, or upon wild relatives, such as the native roses and shadbushes (which are in the same botanical family as apples, peaches, pears, and cherries). Aside from these residents, who slowly took advantage of the new landscape, additional pests were introduced into the mix from the 'Old World'. Many of the crops being raised here originated in Europe and Asia, where they already had their well-developed pest communities. Sooner or later, these pests made the trans-oceanic voyage. Some of them have subsequently been able to leave the crops and survive, at least at low levels, in wilder habitats.

The origins of the beneficial insects have likewise been mixed as those of pests. Honey Bees, praying mantids, Asian Multicolored Lady Beetle, and a variety of "beneficials" were introduced from other regions in order to benefit crops and/or, as in the case of the Honey Bee, humans directly. Likewise, some of our native insect parasites or predators, such as certain wasps, flies, and spiders, simply followed their native hosts into the farm fields and/or began to attack some of the imported organisms they encountered when they got there. At the same time, some native pollinators had little trouble extending their pollen and nectar foraging to include apples and other fruit trees. Finally, some species began to use the croplands, but had little direct influence, one way or another, on the crops themselves. For example, moth traps strung through an apple orchard pick up a variety of moths, many of whom have no known relationship with the apples themselves. For a bit more on the history of pests and their control, see Jentsch (n.d), Chapman & Lienk (1971), and McWilliams (2008).

The point of this short introduction is to help you visualize the flow of agriculturally relevant insects over the landscape. Some base their life cycles in the crop fields, only occasionally ranging farther afield. A map of their abundances, shaded from light to dark to indicate increasing abundance, would show dark blotches coinciding with the crops they prefer, interspersed with largely light or vacant areas. Others, often our native species, would show a less sharply patchy distribution. Their maps might indeed show dark concentrations at some points in some fields, but much of the intervening land would also be shaded. In other words, crops like apples have become part of our ecological landscape and, to greater or lesser degrees, interact with their surroundings. Immigrants from the non-crop landscape have the potential to help or hinder agriculture and, at the same time, that agriculture has the potential to hurt or encourage native biodiversity.

GENERAL IDEA BEHIND THE PROJECT

These considerations lead one to ask, "What role do 'wilder', uncultivated lands play in the insect communities of our fields and orchards?" The habitat management or land use planning considerations implied by such a question are one (but only one) ingredient of horticultural methods that rely less on pesticides and more on natural controls. They are also a component of the discussions that are needed around biodiversity conservation in the 'middle ground', that is., in those increasing areas of land which are neither asphalt parking lots nor roaring wilds, but are instead areas utilized by humans but also, potentially and perhaps with some tweaking, of use to some of our native biodiversity. Such biocontrol based upon habitat management and having one eye on nature conservation is sometimes called "Conservation Biological Control" (see for example, Barbosa, 1998; Gurr, Wratten, Altieri, & Pimentel, 2004; New, 2005).

As one thinks of researching the question of "What role do 'wilder', uncultivated lands play in the insect communities of our fields and orchards?", it becomes clear that that question has multiple parts. Focusing for a moment on beneficials, one could break that question into at least four sub-questions:

- Which beneficials find habitat in the surroundings?
- Which of these show evidence of regularly moving into the farm from those surroundings?
- Which of these can be shown to have a measurable impact on agricultural production?
- And, finally, for which of these is the abundance of their habitat in the surroundings associated with increased benefits for production?

A similar set of questions could be phrased for pests and for non-agronomic species (albeit, in that case, without the 'crop impact' aspects). A corollary of these questions arises when one recognizes that, for some of these insects, the farm or orchard potentially provides additional habitat beyond that coming from the crop or its associates. The question then becomes,

- How can the farm or orchard habitat be so managed as to create the most (or "least", depending upon the insect's desirability) favorable habitat and so the most benefits to production?

Last season's study was meant to explore these questions for some apple orchard insects. The study was only a 'pilot project', meaning that it was an exploration of the practicality and utility of trying to study the above questions, rather than an attempt to rigorously tackle them. The goal was to identify some of the methods that would be most suitable for addressing these questions on regional orchards and to collect some preliminary data that might hint at whether a larger study would be useful.

I took something of a shotgun approach to data collecting and included only seven orchards. In general, the more study sites one has, the more confident one can feel in one's conclusions. However, because I was focusing largely on test-driving methods, I exchanged working on a large number of orchards with a few methods for working on a few orchards with a diversity of methods. As a result, I now have more familiarity with a wider range of techniques, but may have less to say with any certainty about orchard ecology.

OUR RESULTS

The study was conducted during 2014 on seven orchards in the Hudson Valley; two each in Ulster, Dutchess and Columbia Counties, and one in Saratoga County (Fig. 1). Three of the orchards were organic, two were ipm, and a third was organic but, aside from mowing, essentially unmanaged during this season.

<u>The Influence of Habitat on Orchard Pests and Beneficials.</u>

Below, I discuss the questions stated above using a mix information from others (which I credit accordingly) and data that we gathered this past summer.

Which orchard beneficials or pests are found in the surrounding landscape?
Although the 'surrounding landscape' might include not only forest but also unworked fields, wetlands and shrublands, I focused on forests. As a historically dominant part of our landscape (Vispo, 2014), an array of native beneficial insects are thought to reside in forests, including certain parasitic wasps; native or, at least, wild bees; and a diversity of spiders (see for examples Griffiths, Holland, Bailey, & Thomas, 2008; Miliczky & Horton, 2005; Sarvary, Nyrop, & Reissig, 2010; Watson, Wolf, & Ascher, 2011). At least during certain times of year, forests or forest trees have also been reported to harbor a variety of orchard pests, such as various Torticid moths (Chapman & Lienk, 1971) and Plum Curculio (Garman & Zappe, 1929; J. C. Piñero & Prokopy, 2006; Racette et al., 2012).

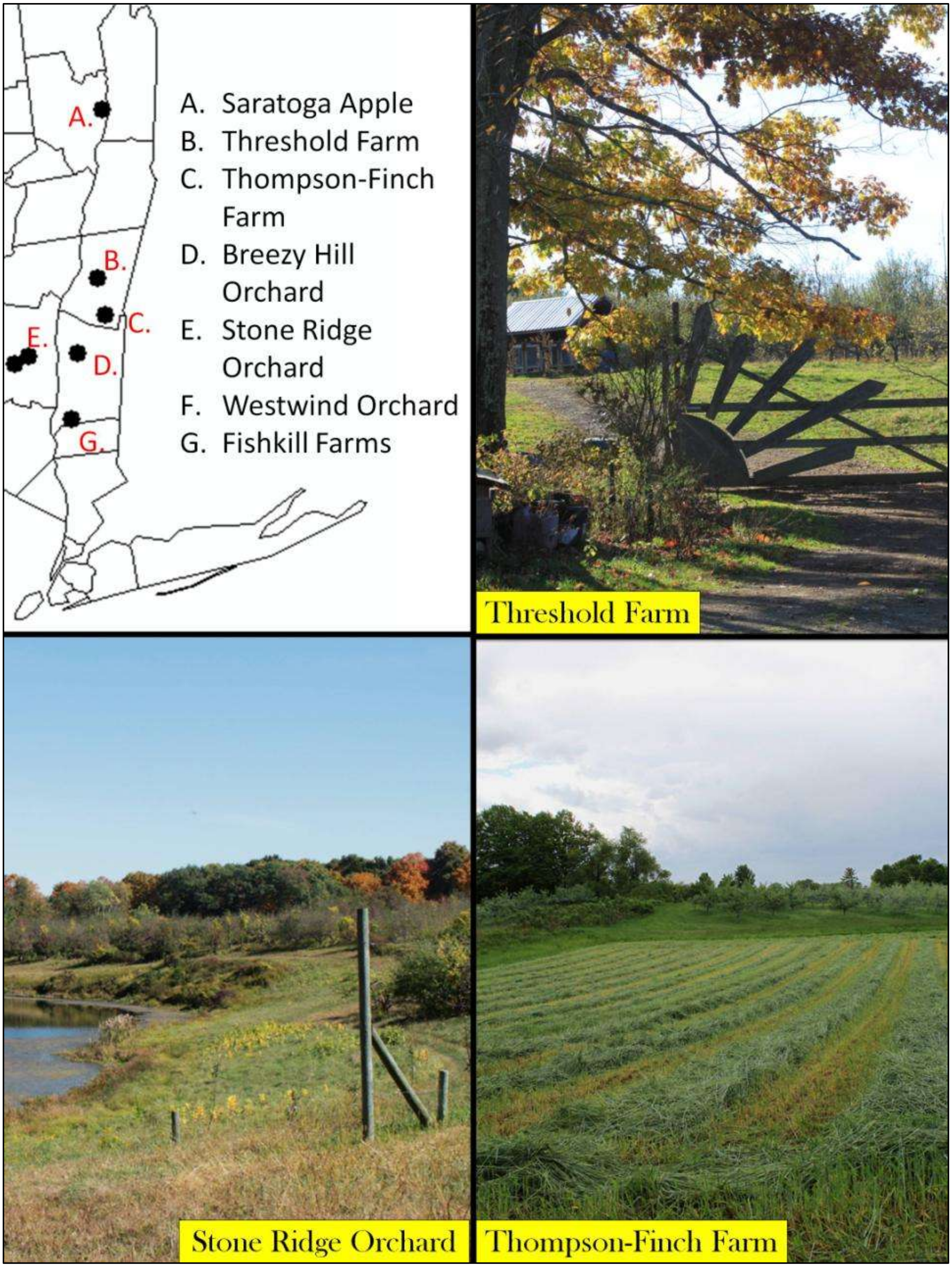

Figure 1. Locations of and scenes from the collaborating orchards.


Breezy Hill Orchard
Saratoga Apple
Westwind Orchard
Fishkill Farms
Fig. 1 (cont'd)

Our own sampling in 'wild' forest adjacent to the orchards was limited to using pheromone traps for Marmorated Stink Bugs (none were captured anywhere, but the efficacy of these traps is questionable), Codling Moths, and Oblique Lined Leaf Rollers (both were captured in the forests near some orchards), together with yellow pans (shallow pans filled with soapy water and meant to catch primarily wasps, Fig. 2) , yellow sticky traps baited with enticing plant oils (Jones et al., 2015), black-light equipped moth traps, and, at two orchards, time lapse cameras. These same techniques, minus the pheromone traps, were used together with vacuuming, scouting and net trapping (using a so-called Malaise trap) to assess populations in the orchards.

Not surprisingly, we found wasps, flies, moths, spiders, beetles, ants, leafhoppers and several other groups in both orchards and adjacent woods. As groups, beetles and moths were substantially more common in forest (although I did not record any Plum Curculios) vs. the adjacent orchard. Leafhoppers were also common in forests, although, again, identification would be needed in order to determine whether these were the same as those found in the orchards. In fact, to be truly meaningful, such data should be coupled with more precise identification (i.e., were the woodland creatures the same *species* as those found in the orchard?). More taxonomically detailed work that we have done regional tomato fields and their surroundings suggest that within each group it is but a subset that occurs in both forest and adjacent agricultural settings (Vispo & Knab-Vispo, 2012). Presumably however, given the greater ecological similarity between forest and orchard, the potential biodiversity overlap may also be greater. In any case, despite its importance in interpreting patterns in applied ecology (see for example, Birkhofer, Wolters, & Diekötter, 2014), species identification was largely beyond my abilities this summer. However, this work at least indicates those groups in which some species are likely sharing forest and orchard.

Figure 2. A yellow pan trap and, behind it, a yellow sticky trap located in a forest habitat.

If forests are indeed a reservoir of insects that subsequently make their way into adjacent orchards, then one would expect the populations in the forest to be correlated with that in the adjacent orchards. In other words, for example, if the woods around one orchard were particularly mothy, one would expect the adjacent orchard to be so as well. In a general way, this may have been the case – 8 out of 12 correlations between forest and orchard insect populations were positive (meaning that more in the forest was associated with more in the orchard), as one would predict, but none of the individual relationships was strong. Those organisms showing positive, but weak, correlations were a mix of pests (e.g., aphids, leafhoppers, small moths) and beneficials (wasps, spiders).

Do we have evidence of insects actually moving from the forest into the adjacent orchard?
We looked at this in two ways. First, we used a two sided Malaise trap, placed at the orchard edge, to intercept insects moving towards or away from the forest. A Malaise trap (see Fig. 3) looks like a market canopy-tent made out of mosquito netting and having a net wall in the middle and on the ends. Insects flying in from one side get funneled into one collecting jar while insects entering from the other side get collected in a second jar. The patterns were quite strong – during daytime trapping, captures of insects apparently moving into the orchard averaged four times that of insects apparently moving out of the orchard; during all three sampling periods and for all insect groups classified, movement into the orchard exceeded movement out (see Fig. 4). Sporadic nighttime sampling and sampling farther into the orchard suggested there was no reverse flow at night (at least not at the height of the traps) and that the pattern became less evident as one moved away from the forest edge.

Figure 3. Two Malaise traps set up in an orchard. In both cases, the openings are to the left and right.

Although we caught no Plum Curculios during our Malaise trapping, this was probably due to the tardiness of our sampling (first done in late May) and perhaps the sub-optimal trapping technique rather than the absence of such movement. Using two-sided panel traps, Piñero & Prokopy (2004) documented substantial early-spring Curculio movements for woods into adjacent orchards.

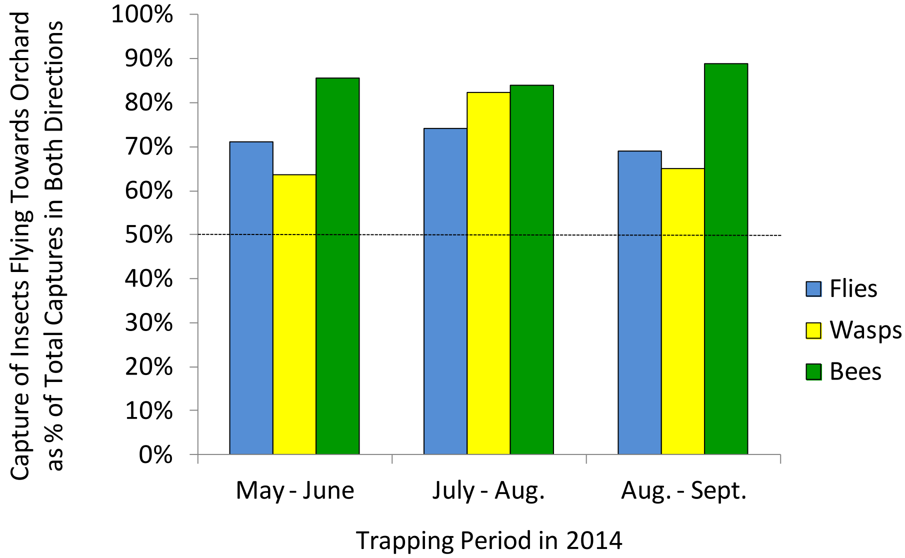

Figure 4. Malaise trap captures at three points during the season. Captures are expressed as percent of total catch that entered the trap from the forest side, and so appeared to be flying into the orchard. The dotted line represents equal captures on both sides. In all cases, flight into the orchard exceeded that out of the orchard.

The second way that we looked for evidence of flow was by establishing a series of three sampling points extending from the apple tree nearest to the edge to a point 150' into the orchard (see Fig. 5). Along those points, I tried to capture or see insects on the trees (using scouting and vacuuming), and to record insect damage. Our prediction was that the there would be a gradient of insect populations and/or insect damage. For the most part, however, such a gradient was not evident in our results (see, for example, Table 1), although it has been reported by others in apple orchards and other crops (see for examples, Altieri & Schmidt, 1986; Dyer & Landis, 1997; Morandin, Long, & Kremen, 2014).

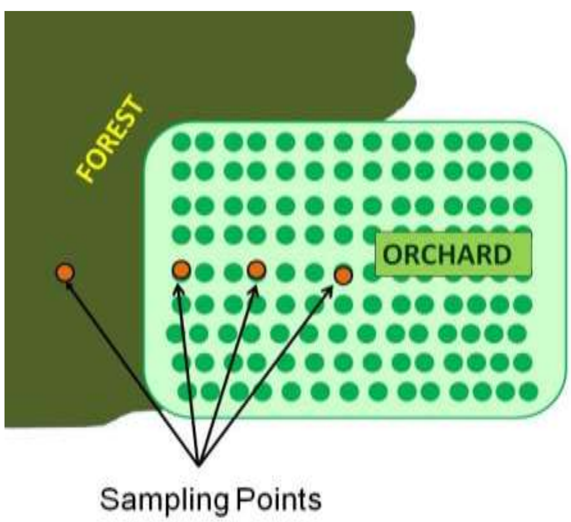

Figure 5. A schematic diagram indicating the generalized arrangement of sampling points. Orchard points were separated by approximately 75'.

There are several possible explanations for this lack of gradients, and they are not mutually exclusive: 1) No gradients exist, because most insects do not arrive from the forest edges, disperse almost instantaneously throughout the orchard, and/or are residents in the orchard; 2) Some sort of gradient does exist but was not clearly evident in our data, because our sampling was not accurate, the distances we chose were inappropriate (for example, one study [Miliczky & Horton, 2005] looking for such edge effects compared populations within 0-180' with those at 180-360' while all our work occurred within 150' feet), and/or the gradient is not simple (e.g., greater sunlight and warmer temperatures away from the forest edge may rapidly draw insects deeper into the orchard).

Table 1. A table summarizing the captures garnered by vacuuming trees in late June and early July. As this table suggests, captures nearest the edge were often slightly higher than those farther away, but differences were not statistically significant. We looked for a gradient using a variety of other techniques employed at various times during the season; none of the results were conclusive.

distance from edge tree	Number of Individuals found per Vacuum Sample							
	Small Wasps	Long-legged Flies	Other Flies	Spiders	Weevils	Moths	Leaf-hoppers	All
0 ft	0.4	0.5	3.5	0.5	1.5	3.6	4.6	14.6
75 ft	0.3	0.2	2.9	0.5	0.4	1.4	7.4	13.0
150 ft	0.1	0.5	2.6	0.6	0.8	0.5	3.7	8.8
All Trees	**0.3**	**0.4**	**3.0**	**0.5**	**0.9**	**1.8**	**5.2**	**12.1**

It is likely that edge effects would be most apparent for *terrestrial* insects and those re-entering *conventional* orchards each season, given that the rates of dispersal are presumably slower for terrestrial insects and the chances of resident populations lower in conventional orchards. However, we made almost no observations of terrestrial invertebrates (spiders, while nominally terrestrial, often disperse aerially via ballooning) and had only two conventional (ipm) orchards in our study.

In sum, our evidence of insect movement into the orchards from the adjacent 'wilds' is mixed. Direct trapping suggested ample movement, but this was not clearly reflected in an observed gradient of insect populations into the orchard. However, some of these results work and the additional works cited above give good cause to believe such exchange is happening.

Have any of the insects which move into the orchards been shown to have a measurable impact on agricultural production?

Despite the above-mentioned admission that the precision of our taxonomic identification was pretty low, based upon natural history, we can often provide blanket 'pest' or 'beneficial' labels for insect species or groups. For example, Honey Bees and Native Bees are considered beneficial because they are pollinators; numerous flies and wasps are predators or parasites (Apple Sawfly is however an example of a wasp pest and Apple Maggot an obvious fly pest; these were generally rare or absent in our catches); moths and leafhoppers, on the other hand, are more often described as 'pests'. In any case, even if there were no gradient of effect, we might still predict that there to be correlations between beneficials or pests and their effects on the fruits, even when broadly defined according to such general groups.

Our most direct measure of production was average apple weight. We also measured seed number as a purported correlate of pollination and an influence on apple size. (However, seed number and apple weight were not correlated in our data; according to bee researcher Mia Parks, such relationships may only hold for certain apple varieties.) We also recorded evident damage on each apple. We did not collect any total harvest statistic such as yield per tree. In part, this was because of practicality and in part it was because, even if possible, differences in tree size and varieties would make meaningful total harvest comparisons among orchards difficult. We thus have no measure of insect damage that caused premature apple drop. (See the discussion of possible future plans for a potential way around this.)

In addition to our few apple measures, we also had several indirect measures of insect activity, including damage to leaves and fruits. Aside from time-lapse camera data showing who fed on strips of Codling Moth eggs (mainly, ants and slugs, see Table 2 and the similar results of Grieshop et al., 2012), we had no direct index of insect predation or parasitism. We can look for correlations between natural enemies and pests, but it is hard to know what patterns to predict in a collection of orchard snapshots: for example, would predators be positively correlated with pests, because predators will accumulate where prey is available, or would they be negatively correlated, because predators will reduce prey abundance? The truth is that, over the normal cycle of predator/prey (or parasite/host) interactions, there are probably stages during which each of these opposite relations might hold. We thus focus here on correlations between insect groups and apple characteristics at harvest, in other words, on the bottom line, so to speak.

Table 2. A table summarizing photos taken by time-lapse cameras focused on yoghurt tops holding freeze-dried meal worms and freeze-killed Codling Moth eggs. These were placed on the ground at our sampling points in two orchards. Slugs and ants were the most frequent visitors, and so, based on this very preliminary work, might be the most proficient consumers of Codling Moth eggs.

Invertebrate Group	% of total time during which at least one individual of given group was observed on yoghurt top	Of time on yoghurt top, % spent at Codling Moth eggs
slug	29.0%	17.2%
ant	26.0%	28.9%
harvestman	7.2%	17.5%
cricket (ground or tree)	5.4%	14.5%
beetle (adult or larva)	3.2%	0.6%
fly	3.0%	5.8%
earwig	0.7%	0.5%
spider	0.4%	1.7%

Based on data gathered from approximately 30,200 photos collected along three different transects in two different orchards.

We begin our explorations of the correlations with pollinators (Fig. 6), we did, in fact, note a correlation between Honey Bee abundance in the orchard during apple bloom and the seed number of apples at harvest (Fig. 7). However, as mentioned, there was no correlation with apple weight. Native Bees showed no relationship to seed number and may even have showed a slight negative correlation with apple weight. On average, in our orchards, Honey Bees out-numbered Native Bees two to one, and may have been the primary pollinators in the orchards we observed.

Moving on to pests, the abundance of so-called ‘micro-moths’ (the moth size group than incorporates many of the moth pests) was negatively correlated with apple weight, as was apparent caterpillar damage on leaves; predictably, micromoth abundance and caterpillar damaged were positively

Figure 6. A 'collage' of some of the bees observed during our pollination surveys, including a Honey Bee in the upper right.

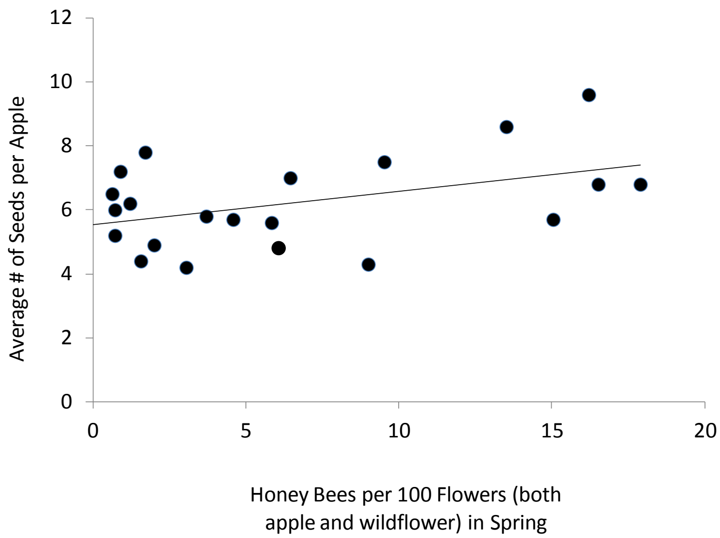

Figure 7. The relationship between the total number of Honey Bees seen on all flowers at the time of apple bloom and the number of apple seeds counted at harvest. There was a slight but significant positive correlation between these two measures, although statistical significance might be inflated by multiple measures per orchard.

correlated with each other. Apple weight was also negatively correlated with bird number, and this correlation may have come about both because birds damaged fruits directly (bird number was correlated with possible bird damage which, in turn, was negatively correlated with apple weight) and because birds tended to be most abundant where pesty caterpillars were most numerous (bird numbers and moth numbers were positively related.) Although bird damage on apples is evident to almost any orchardist, so too, as mentioned in the introduction, is the avian role as pest consumer. A different approach (see future plans for one possibility) would be needed to tease apart this relationship. Plum Curculio damage, indexed at several points across the season, showed no correlation with apple weight at harvest. This may well be because the most heavily infested apples had already dropped. Aside from the above-mentioned relations, we recorded few correlations with apple weight.

There were a variety of inter-correlations amongst insects, and many may have reflected shared responses to orchard conditions as much as any direct interaction (for example, both moths and wasps might benefit from abundant nearby nectar sources). I will not go into these here.

We need a more complete measure of apple production, more precise taxonomy, and more direct indexing of predation or parasitism, before we can really make sense of the relationship between populations of the many orchard organisms and apple damage or production.

And, finally, for which of the above organisms is the abundance of their habitat in the surroundings associated with their influence on production?
We described in-orchard management in a couple of different ways: by indexing autumn wild flower abundance (we did this in autumn because it took us that long to figure out how to do it; it should have been done earlier as well) and by a crude, subjective measure of physical management intensity related to apparent frequency of mowing.

Increased wild flower abundance was associated with more flies, total bees at apple bloom (Fig. 8), wasps, and spiders. Similar findings are reflected in the published research on the benefits of wild flower strips or flowering edges in agricultural habitats (Almeida, Cormier, & Lucas, 2008; Bostanian, Goulet, O'Hara, Masner, & Racette, 2004; Fitzgerald & Solomon, 2004; Kleijn & van Langevelde, 2006; Pfiffner & Scharer, 2014; Wyss, 1995). In some cases, such as with bees, wasps and some flies, the positive relationship with in-orchard flowers might be due directly to an increased supply of nectar and pollen foods. In other cases, it may indicate a less direct relationship: for example, increased wildflowers probably reflect more space for semi-wild areas and these, in turn, likely increase an array of insects, many of which are spider food. Our results would certainly support the idea that establishing year-around wild flower beds enhances the populations of beneficials. We saw no correlations between wild flower abundance and pests such as aphids, moths or Plum Curculio.

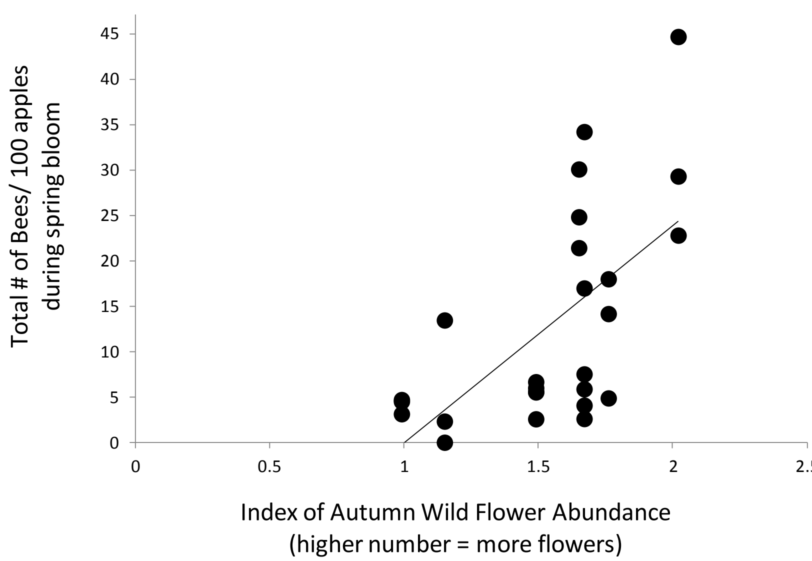

Figure 8. The relationship of autumn wildflower abundance to the total number of bees seen on apple blossoms.

We next described the landscape at two different scales around each orchard study site. We used aerial photographs to quantify the amount of land in various covers at 500 and 1500m from our study site (see Fig. 9). Our classification was relatively crude, we recognized five land covers: water/wetland, orchard, development (including lawns, buildings, roads and asphalt or concrete), forest, and field. Within circles with the two radii, we calculated the proportion of area composed of each of these cover types. In addition, as another way of indexing development, we also counted individual buildings and measured road lengths. There appeared to be quite strong relationships between land use at these larger scales and insect populations.

The three groups for which some relation to production was mentioned above – bees, moths and birds – did show some connection to the adjacent landscape. Nearby forest was positively related to native bee abundance, while development showed a negative effect on these bees. The abundance of all bees was also positively related to forest (Fig. 10), but Honey Bees alone showed no clear correlation. Moths seemed to be positively associated with a more forested landscape, while more orchard in the surroundings reduced their abundance. Forested area also tended to encourage more birds, while development (as measured by the length of nearby roads) was negatively related.

In addition, a surprising number of other in-orchard invertebrates, ones for which we could not make direct production linkages, did show consistent correlations with the composition of the landscape at various scales. These included wasps, spiders and butterflies (Fig. 10). Specifically, the amount of forest at 500m and/or 1500m was significantly associated with enhanced populations of flies, wasps and spiders; indicators of development (amount of developed area, number of houses and length of roadway) had a negative impact on flies, wasps, butterflies and spiders. Finally, area-in-orchard had a consistently negative relationship with wasps.

From a biodiversity conservation perspective, as others have even more clearly demonstrated (see for examples, Bianchi, Booij, & Tscharntke, 2006; Kleijn & van Langevelde, 2006; Winfree, Bartomeus, & Cariveau, 2011; Watson et al., 2011), landscape context is crucial. If we want to maintain sizeable amounts of our native regional biodiversity in the long run, we will need to consider maintaining wilder areas in our landscape and, when possible, managing intensively-used areas in ways that support more wild organisms, as well as us.

If we look for overall patterns between landscape and production as indexed by apple weight, there are no overall correlations. Although there is an intriguing pattern if one separates ipm and conventional orchards: forest around ipm orchards showed a negative relationship with apple weight (but we had only TWO ipm orchards), and apple weight tended to be highest farthest from the forest edge; meanwhile, apple weight in organic orchards was uncorrelated with surrounding forest, but was highest closest to the forest edge (although these relationships were not statistically significant). Our data are definitely too incomplete to make strong conclusions, however these partial results caution that, when exploring the interactions of landscape and production, it will be important to distinguish between organic and conventional forms of management – their relationships with the surroundings may differ not only qualitatively but quantitatively.

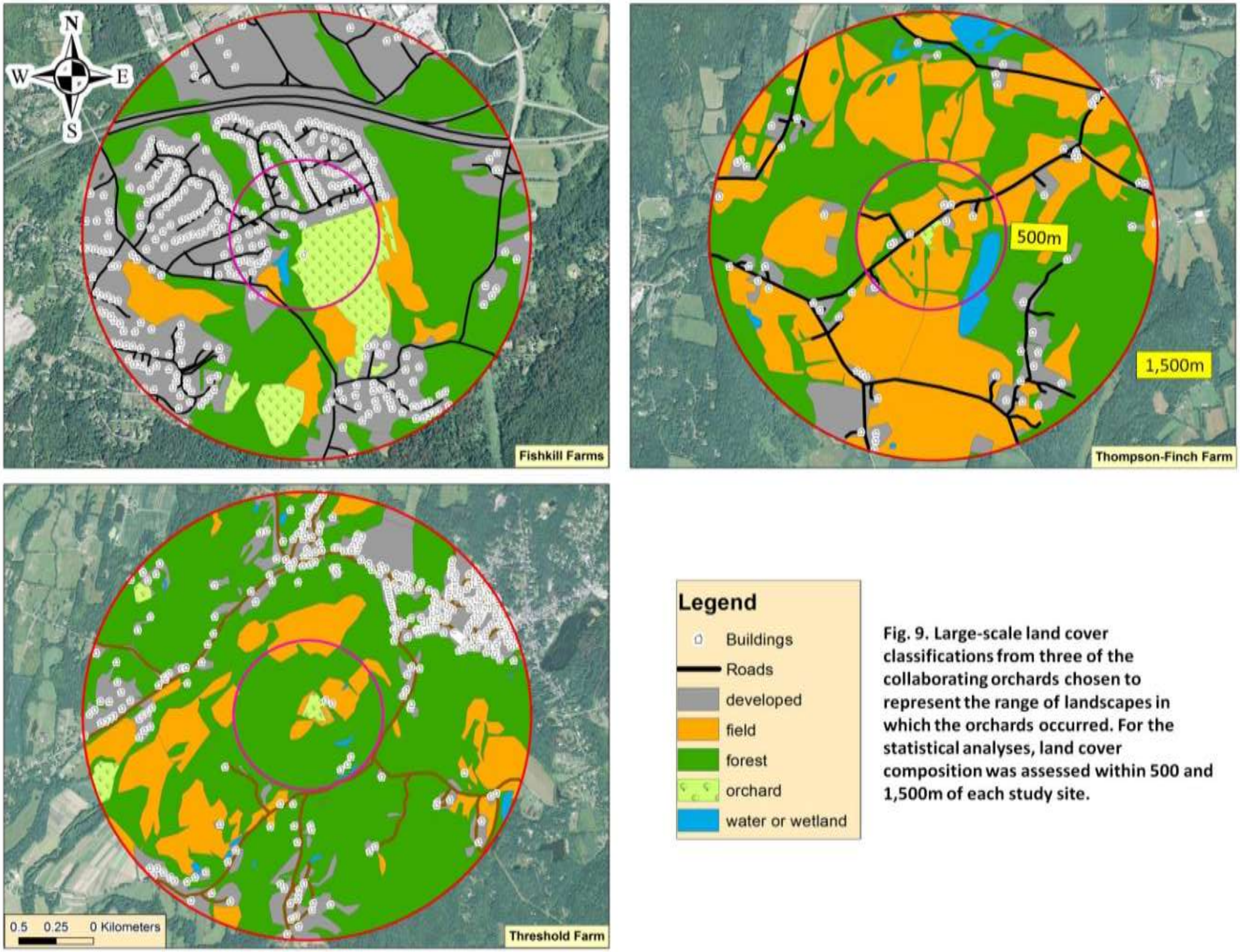

Fig. 9. Large-scale land cover classifications from three of the collaborating orchards chosen to represent the range of landscapes in which the orchards occurred. For the statistical analyses, land cover composition was assessed within 500 and 1,500m of each study site.

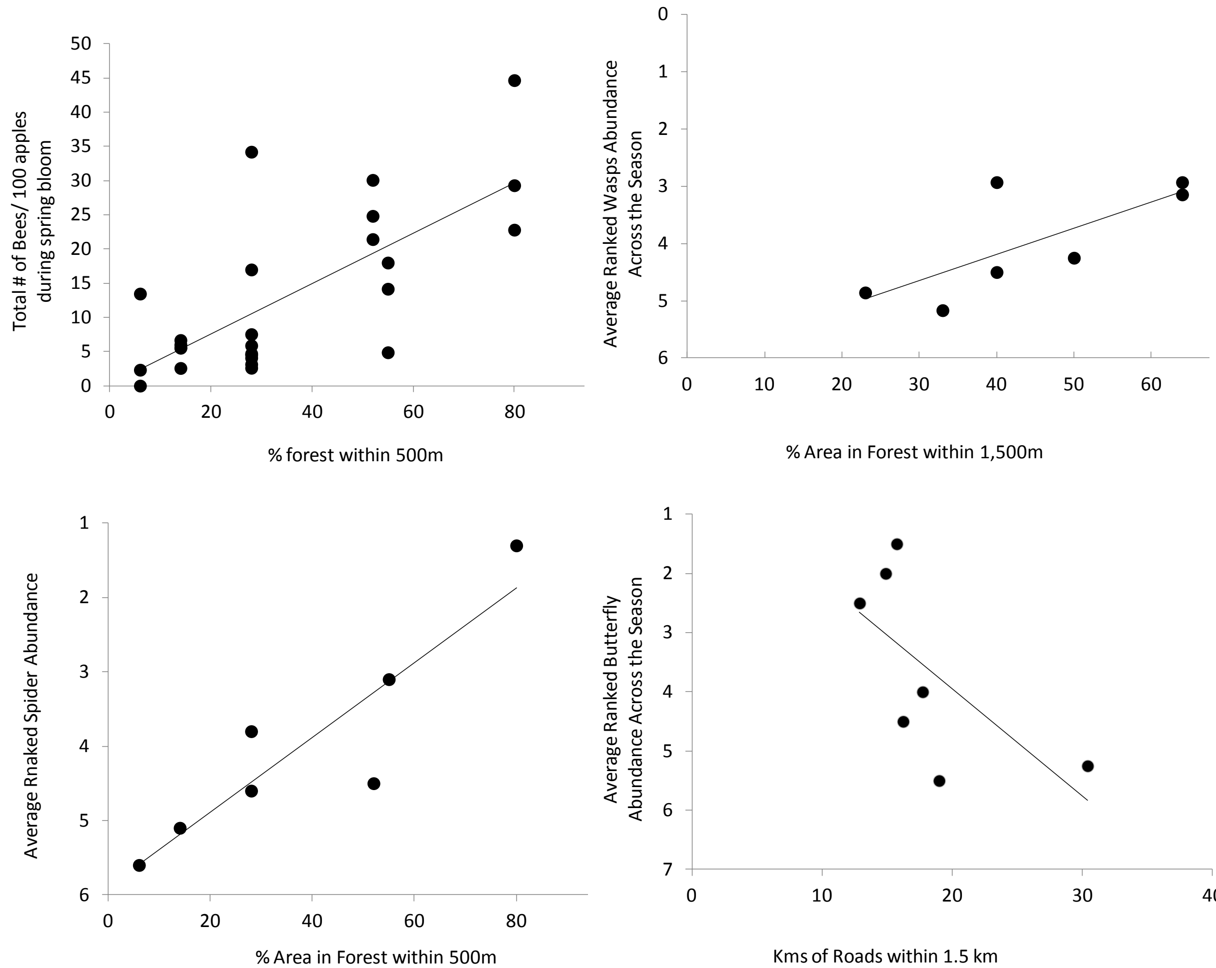

Figure 10. Figures showing the relationship between certain landscape characteristics and the abundance of different organisms. Note that the 'across the season' abundances were done by averaging abundance rankings obtained by various methods. Lower numbers meant higher ranks, and so *greater* abundances; for ease of understanding the y-axes has been inverted. Greater forest area within the landscape site was associated with higher numbers of bees (upper left), wasps (upper right), and spiders (lower left), while butterfly abundance decreased with increasing amount of roads in landscape (lower right).

Looking at our results overall and at the literature, it seems clear that there are beneficial and pest organisms in the orchard surroundings. Evidence also suggests that these creatures may move into the orchard and, related to this, that their in-orchard abundances are affected by the composition of the surrounding landscape at various scales. The weak link in our own data (and one rarely studied by others), but the one most immediately interesting to most orchardists, is an understanding of the relationship between the presence of these organisms and apple production. Our own attempts to study this were limited and equivocal.

Other Indicators of the Role of Orchards in Biodiversity Conservation

In terms of supporting native biodiversity, apple orchards have two conflicting characteristics. On the one hand, they are perennial habitats composed of trees that, while not native, do have relatively close native relatives and so might be expected to support certain native species. At the same time (and perhaps in part because of that first characteristic!), they are some of our most heavily sprayed agricultural landscapes. As mentioned above, in our studies of landscape context, area-in-orchard within .5 or 1.5 km of our study site had the most consistently negative impact on the biota of all the land use variables we measured. We did not attempt to distinguish the landscape effects of organic vs. conventional orchards, but, because none of the organic orchards in our area are large, management style and nearby area-in-orchard are strongly related. 'Area in orchard' around ipm study sites averaged two to three times greater than that around the organic orchards.

As already mentioned, we did relatively little detailed taxonomic work in the orchards (Fig. 11). At this point, we have at least some information on species diversity for butterflies, moths, birds and plants. We found little indication that orchards themselves supported a large diversity of native organisms. None of the species we found in the orchards was particularly rare, although several orchards supported a variety of hawks (including at least one that was home to a kestrel) and a couple of somewhat unusual butterflies, the Bronze Copper and Meadow Fritillary, were found on two orchards. Overall, the butterfly community of most orchards resembled that of an old field rather than an intensively managed crop field. The orchards themselves also had relatively low plant diversity.

As illustrated in our habitat maps (see Appendix), all the orchards had greater or lesser amounts of adjacent, wilder lands, some of which were quite interesting in terms of biodiversity, including habitat for not only somewhat unusual plants but also rarer vertebrates. Although we cannot state that orchards in particular were directly responsible for the conservation of those habitats, orchards did reflect a general pattern that we have seen repeated across agricultural lands: properties owned by farms often, although not always, include some forms of wetlands. In part, this is probably because good soils tend to be in the valleys rather than the high hills. Orchards are more of a hill crop than some products, but nonetheless five of the seven orchards we studied were associated with streams or wetlands, and these were the areas that often harbored the more interesting species from a conservation perspective. The wetlands of one orchard were already known to harbor a rare vertebrate and, at another, we found a dragonfly species unseen in the State since at least 2005. At least a couple of the properties harbored state-listed rare plants, and most had at least one regionally-rare or scarce species (Kiviat & Stevens, 2001) .

In this context, the role of the orchards themselves might be one of potentially providing 'auxiliary support' for the organisms of those wilder lands. For example, that Bronze Copper butterfly was found an orchard located adjacent to a wetland. The caterpillars of the Bronze Copper feed upon wetland plants, but the adults stray from wetlands in pursuit of nectar. Understanding and mitigating, to the degree possible, the negative influence of orchards, mentioned earlier, would likely be important not only for in-orchard beneficials but also for the biodiversity in the surroundings.

Figure 91. Some of the diversity of wasps caught in one orchard sample. This diversity can have both agronomic and biodiversity significance, but we have yet to work through these samples.

SUGGESTIONS FOR THE FUTURE

Based on input from others, the literature and a review of our initial results, I outline below my ideas for a more complete but hypothetical study program focused on understanding the interactions of habitats in and adjacent to orchards with orchard production.

General Considerations

As mentioned in the introduction, 'conservation biological control' is sometimes used to describe a form of biological control that relies heavily on habitat management to encourage beneficials and discourage pests. The idea is that by selectively conserving semi-natural habitats not only can one help low-input apple production, but one can also contribute to nature conservation. In that sense, and with the inclusion of land use planning adjacent to orchard sites, conservation biological control is the focus of the research proposed here.

It is important to emphasize that, while I focus on conservation biological control here, it should definitely not be the only tool in an orchardist's toolbox: choice of proper varieties, experimentation with specific biocontrol systems, and search for pest control treatments with minimal non-target impacts are all important and potentially very complementary areas of research. The need for multiple tools was clearly documented in Ron Prokopy's 20 years of work on his Conway orchard(Prokopy, 2003). Fortunately, much of this other research is already being undertaken by university researchers.

That the ecological relationships between orchards and their surroundings are active, dynamic ones fueled by constant interchange between orchards and their surroundings is indicated by the trapping that we and others (cited earlier) have done at the orchard edges and by the edge-to-center gradients of certain insects that others (cited earlier) have recorded (but that were not so clear in our results).

Likewise, much work (including ours; and the references cited earlier) in orchards and other agricultural habitats has demonstrated that greater wild flower abundance, planted or incidental, can enhance bee populations and, in some cases, those of other nectar or pollen feeding insects such as wasps or certain flies. Finally, more taxonomic and structural diversity and more 'wild biomass' may tend to be associated also with more herbivores and more top predators such as spiders, although it has the potential to also provide more pest habitat (see for example, Rypstra, Carter, Balfour, & Marshall, 1999; Landis, Wratten, & Gurr, 2000).

While the above generalizations may not be true everywhere and all the time, the findings of others lend credence to our own results and suggest these patterns are often true. So far, so good.

The 'slip twixt the cup and the lip' comes when one asks, "What does this mean for apple production?". If one's sole goal were in-orchard biodiversity conservation, the recommendations would be relatively straightforward. However, in apple orchards, nature conservation is but a joint goal with food production, which, in turn, is both an agronomic and economic endeavor, will all the mixture of business acumen and sociology suggested by the latter word. Certain members of an orchard's biodiversity have, because of their interaction with apple production, taken on agronomic significance that makes their encouragement or discouragement particularly desirable.

In our own data, there were no simple correlates between broadly-described insect groups and apple weight, nor between various purported natural enemies and the abundance of pests or their damage. Such links are rarely seen, even in much more detailed work than ours (Bianchi et al., 2006; Brown, 2001). There are several possible reasons why we did not see such relationships, and, because I feel this aspect should be one focus of future work, it's worth considering those reasons:

First, the crude taxonomic groups we used (like 'bees', 'wasps', 'flies', and 'spiders') are not labels for teams of uniformly beneficial invertebrate teams. Only a relatively few species of wasps, flies, and spiders, for example, are parasites or predators of apple orchard pests (see for example, Agnello et al., 2006).

Second, even within groups or possibly even within species, an organism might not be 100% beneficial or 100% pest (Fig. 12). For example, an ant might guard aphids from predators one moment and consume Codling Moth eggs in another. Likewise, even Tarnished Plant Bug, which is widely recognized as a pest, can be a beneficial natural enemy in some cases (Cleveland, 1987).

Thirdly, there may be counteracting habitat effects; for example, in our own work, increased amounts of adjacent forest was linked with more beneficial ants, spiders and bees (generally considered beneficial groups), but also with more leaf blotching resulting from rusts or other diseases (Fig. 13).

Fourthly, predator/prey (or parasite/host) systems in orchards may rarely be simple. Rather than always being tight 'natural enemy A controls pest B' linkages, there is probably often a suite of enemies working on an array of pests. Under one set of environmental conditions, natural enemy A might be the 'hero', in another natural enemy C might take the credit, and in yet another, only A and C combined might do the trick.

And, finally, what does being the 'hero' mean in this context? Complete elimination of the prey or host would be a bad plan ecologically for the specialist predator or parasite (it would mean local extinction); likewise, the generalist may well switch its focus to another prey or host before completely eliminating a particular pest. As agroecologists have long pointed out, there is often a coexistence of enemy and pest at some level, and, when these are maintained below an economic threshold, the control can be deemed successful. As a result, one of the most important effects of a natural enemy may be an unseen non-event, that is, the pest explosion that never happens (Orr, Bambara, & Baker, 1997).

Figure 102, Life is complicated. One natural enemy (a spider) consumes another (a wasp). Orchard food webs are not always simple.

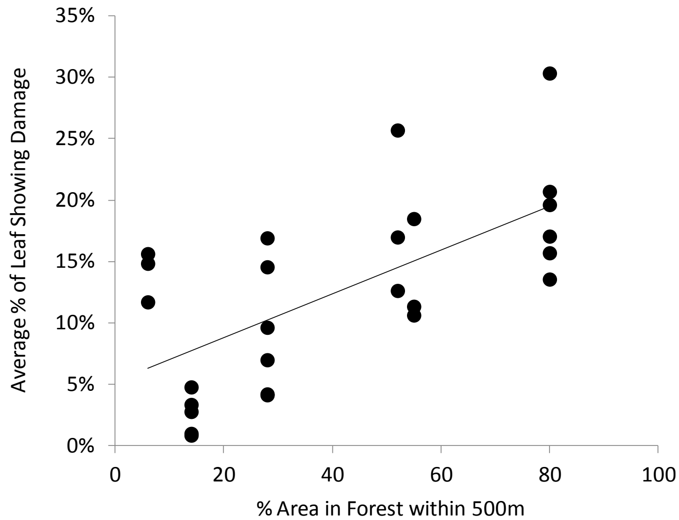

Figure 11. Not only was forested landscape associated with certain beneficials, it was also associated with certain disease and pest damage, as indicated by this relationship between forest area and the average % of leaf damage during July-August scouting.

What does all that say about our ability to study the interaction of low-input apple production with in-orchard habitat management and extra-orchard land use planning? As others including Ron Prokopy have cautioned (Bugg Robert L., 1994; Prokopy, 1994), applied orchard ecology involves cascading relationships. For example, a wild flower strip will only increase spider or wasp abundances if there are source populations of those organisms in the surrounding landscape, if the chemical management of the orchard is such as to allow the build up of in-orchard populations of natural enemies, and if those added habitats don't inadvertently benefit some pest. These relationships are of such complexity that *a priori* knowledge can only provide us with best guesses, and we will always need to caution ourselves that even results borne out in trials may be place (and even time) specific, based upon the suite of interacting ecological factors in a given region, at a given moment.

To me, this all suggests that future work should include both close natural history observations (who's feeding on whom? who lives where?) and trail-and-error learning through adaptive management. We may never know all the details, but we should still try to learn what we can through observations – despite all the complexity, orchard biologists have clearly found agronomically-important, management applicable interactions (e.g., predatory mites and soil nematodes). At the same time, the management relevance of any relationships we think we're seeing need be to test-driven in actual field trials.

Proposed Study: Collaborators and Some General Considerations.

A Network of Collaborating Orchards and Orchardists. The study proposed here is just my current best guess for a way forward. Given the fact that I am not an orchardist and am a rank novice in orchard ecology it should, perhaps, be discarded outright. At the least, any successful research will only derive from collaboration with working orchardists who can help ground the work in both economic and management practicality and who can, furthermore, add their decades of observational experiences. As mentioned earlier, 'conservation biological control' is meant to combine useful orchard management suggestions with those that allow orchards to play a more positive role in regional biodiversity conservation. I believe both goals are valuable; if I come across as being something of a spokesperson for the latter, it is because I am hoping that orchardists can be able spokespeople for the former. The suggestions below are but fodder for a discussion with orchardists and other collaborators

Collaborating Orchards: Low-pesticide Farms. As mentioned above, our own data and those of others do suggest differences between organic and conventional orchards in terms of the magnitude and nature of pest and beneficial populations. While my primary goal is not to compare these two approaches to farming, chemical management regimes (such as, abandoned, organic, ipm, or full conventional) may affect the patterns and relationships in our results and so would need to be treated separately.

I would propose focusing on low-pesticide, but commercial orchards (where 'pesticide' refers to any spray that kills insects, whether organic or conventional. This group has, through its management choice, expressed an interest in working to at least some degree with natural controls, and so might have the most interest in understanding links between land management and those controls. In some cases, this interest extends to a simultaneously held concern for nature conservation, and hence perhaps a sympathy with our dual goals of production and biodiversity conservation.

I think it could also be worthwhile to include a few non-commercial orchards which, other than regular clearing and possible pruning, receive no management. They are unlikely to be commercially relevant, however, they may serve as useful controls that help us better understand the impacts of commercial management on the relationships we're trying to encourage.

I believe it is also important to work with orchards in a relatively confined geographic region. As alluded to earlier, the ecologies of orchards, as decades-old perennial systems, is hardly simple. Our own work with wild habitats has taught us that plant and animal communities vary even across geographies as apparently small as a single county. As a result, management that hopes to work with natural communities needs to recognize the possibility of relevant geographic variation. Study regions might include, for example, the east bank of the Hudson from northern Dutchess through southern Rensselaer County, and another focal area centered on Ulster County. To be able to say anything meaningful, we will probably need at least ten collaborating, working orchards in any regional grouping.

The General Public: A Second Audience. Clearly, a project such as this has, broadly speaking, at least two audiences. At a certain scale, landscape management is no longer within the control of the orchardist; and the results become most relevant to the land use planning efforts of those in the surrounding community who are interested in supporting ecologically-based forms of local agriculture. In addition, the consumer seems to have a critical role to play in making low-input apple farming economically viable. It is unlikely low-input orchards will be able to produce the spotless apples accessible locally through more intensive spraying and, in some cases, through organic production elsewhere where pest loads are lower. Thus, it will be important to reach that sector of the public who are willing to accept tasty but blemished apples, knowing that they are contributing to a form of orchard management that might also be supporting the biodiversity of their surroundings. For this reason, the research process should also be seen as a story-telling opportunity, that lets the public hear and share in the overall goals of the research. In doing this, the goal should not be to criticize other forms of apple management – it is hardly yet proven that the approach outlined here has regional utility- rather it should be described as an exploration of potentials, while expressing respect for those orchards pursuing other forms of management for very understandable reasons.

Collaboration with Researchers in Other Areas of Orchard Management. As stated earlier, conservation biocontrol is not a stand-alone form of orchard management. Its possibilities will certainly be enhanced by, for example, the planting of pest or disease resistant varieties and other management tools that reduce the need for sprays or other management with non-target effects. This work should thus be done in close contact with orchard researchers with other focuses. It is hoped that some of what we find can complement their efforts and vice versa.

Long-term Monitoring. While a one-year study might provide some initial insights, apple orchard pests and diseases show major year-to-year variation and multi-year work is needed. Any pattern that might seem to hold during one year might be strengthened or completely erased in a subsequent year. For solutions to be useful to orchardists, they need to show net benefits during many, if not all, seasons. While the methods outlined here might get refined over the years, I'd suggest that a minimum of five – ten years of core monitoring is needed, hopefully more. The need for such long-term monitoring is well expressed in the logic behind the National Science Foundation's LTER sites (Redman & Foster, 2008), a network of sites conducting ecological monitoring over decades. A few long-term agricultural monitoring sites also exist and have been informative (e.g. Rothamstead, Rodale); they have focused on primarily on field crops (see MacLellan, 1979; Prokopy, 2003).

Proposed Study: Monitoring Data to be Gathered.

Background Work. As mentioned earlier, it is important to identify invertebrates involved more precisely than the very gross groupings I employed last season – such effort is needed to both understand functional roles and to assay contributions to biodiversity. At the same time, specimen identification can easily require a stifling amount of time and hence resources. I would propose that a first step in this work be time spent determining levels of practical identification for key groups (e.g., moth and caterpillars, wasps, bees, mites, flies, and spiders). The proper level will be determined by a combination of the specialists willing to help, the time and resources available, and the reference materials for identification. Emphasis will be placed on identification that can be applied in the field (e.g., possibly, fly families) or, after some training, by on-site lab perusal (e.g. mites, wasp and spider families?). Having a relatively quick turn around (i.e., all specimens identified by the January following a given field season) will be important for providing meaningful feedback to collaborators and the public and for gauging the effectiveness of methods and experiments.

Describing the Invertebrate Community. Monitoring of the orchard invertebrate community needs to be one cornerstone of any such research. Listening to the advice of others such as Peter Jentsch and based upon my own experiences during the first year, I believe that forms of monitoring based upon direct observation (scouting) or active collection (vacuuming and, in some ways, Malaise Trapping) are most likely to be useful. Although yellow sticky traps and pheromone traps are simple to set up, their catch is highly dependent on visibility and, in the case of pheromones, air flow. I had some traps whose catch far exceeded those of the neighboring traps and, in retrospect, I think that was due to their exposed positions. Furthermore, it is difficult to make use of specimens caught on such traps for the level of taxonomic identification we hope to apply (see below). This in no way implies that such traps are not a valuable part of ipm monitoring, only that they may not be best suited for our purposes.

In this light, I would propose using an array of two-sided malaise traps, run for six hours in each orchard at three points during the season, and located in adjacent wilder habitats, at the orchard edge and near the orchard center (that is, at the point farthest from any edge). Within the orchard itself, I would propose using vacuuming of apple trees and of any experimental plantings to characterize invertebrate communities at three points during the season. Finally, concurrent with the vacuuming, I would propose leaf and fruit scouting intended to collect information on aspects of the apple tree community not understandable through vacuuming. Specifically, such scouting should include monitoring for beneficial thrips, mites (adequate census of mites might require leaf collection and subsequent inspection), syrphid eggs and larvae, lady beetle and lacewing larvae, and various forms of damage.

Directly Assessing the Activities of Beneficials: Pollinators. As was done during the past season, visual counts of pollinators on apple blossoms should be conducted. Understanding the role of any habitat manipulation in pollinator conservation is important. Such counts should also be done at least three times during the season on wild flowers within and adjacent to the orchard and, as we did in the autumn of 2014, flower abundance 'in the neighborhood' should also be indexed at least three times during the season. Given the resources available for bee identification and concern about native bee conservation, it may also be appropriate to periodically capture bees for identification if the malaise trapping does not do an adequate job of this. Bees are one of the most heavily studied of orchard beneficials. This means there are both ample resources available for their study and for comparison and that much has already been learned. The final amount of effort devoted to pollinators will be determined, in part, by consultation with those working in the field; there is no point in repeating what has already been done (although, based on such consultation, even our sketchy work last season seemed to have held some useful surprises).

Directly Assessing the Activities of Beneficials: Time-lapse Photography of Sentinel Cards. We experimented with this technique during 2014. It involves placing 'cards' to which Codling Moth eggs or other pest life stages are attached and then using photography to monitor predation. While it involves the review of a mind-numbing number of photographs, it seems to provide information barely accessible in other ways. For example, pit trapping has often been used to survey for ground predators, but our work and the more intensive work (Grieshop et al., 2012) suggest such traps do a poor job of representing who's doing the work. 'Bait' obviously needs to be carefully chosen and its positioning should be as natural as possible (e.g., perhaps Codling Moth bait cards should be placed on the tree rather than the ground). Freeze-killed Codling Moth eggs (and freeze-dried meal worms) proved practical last season, and should be repeated. Additional, baits might be interesting, but the effort and facilities needed for raising such bait can be discouraging.

Figure 12. A recently-emerged tentiform leafminer beside its tent. These leaf pests were rare in all but one orchard.

Directly Assessing the Activities of Beneficials: Caterpillar Parasitism. Wasp and fly parasitism of caterpillars is clearly an important form of biocontrol in orchards. Aside from some time spent inspecting the tents of tentiform leafminers (Fig. 14), little effort was devoted to this in 2014. Elegant studies involving the placement of lab-raised caterpillars in the field and their subsequent monitoring for parasitism (Sarvary et al., 2010) have been conducted. However, again, these involve substantial efforts to provide the 'bait' caterpillars. Instead, I would suggest using the detailed apple pest caterpillar identification materials available (Chapman & Lienk, 1971) coupled with the relatively inexpensive caterpillar rearing techniques of people like David Wagner to field collect caterpillars from trees and then raise them to gauge parasitism rates and, if possible, identify parasites. During at least one period during the season, tree beating could be used to gather caterpillars, these live specimens could then be sorted according to kind, and that each kind of caterpillar from each orchard be raised and monitored for parasitism. This will be a relatively large effort, but seems crucial for linking aspects of the biodiversity at large with control aspects.

Directly Assessing the Activities of Beneficials: Placing Bird Netting on Trees. As alluded to earlier, birds have long been recognized as potentially important components of orchard pest control. It is also possible to test their importance in ways largely impossible with other purported natural enemies. Bird netting is already widely used in the small fruit industry, and has been applied to the study of bird effects in coffee plantations (for example, Johnson, Kellermann, & Stercho, 2010) and, occasionally, in orchards (Mols & Visser, 2002). The idea is conceptually simple: a tree is enclosed in netting whose mesh is small enough to exclude all birds (but no invertebrates) and then insect populations and damage on enclosed trees is compared to that of unenclosed trees. Such study obviously has some large 'up-front' costs (i.e., netting the trees) but then the monitoring is relatively straightforward, involving nothing more than the standard vacuuming and scouting already described above. Because of those large up-front costs, we probably could not undertake this work on all collaborating orchards, but even three trees on three orchards should indicate the general magnitude of any avian effect under regional conditions. Such study of bird effects might be supplemented by following McLellan's (MacLellan, 1958) techniques of looking at Codling Moth cocoon predation: corrugated cardboard trunk bands attracted metamorphosing Codling Moths and, during the winter, McLellan monitored woodpecker predation on these bands. In Spring, he was also able to assess cocoon parasitism rates.

Harvest Assessment. Assessing harvest is a key component of this work. The size and quality of the product needs to be indexed. Based in part on last year's work, I would purpose at least four different indices: apple seed number – a useful indicator of pollination, even if not always correlated with apple size; apple weight at maturity; apple grade and damage levels at maturity; and 'apple survivorship'. The last index was not attempted last season and needs some explanation. Starting post thinning, I would purpose marking and following 10 apples on at least six trees per orchard (three at the edge, three in the center). The twigs next to a fruit or fruit cluster would be flagged so that the fate of that fruit, while on the tree, could be followed. Fallen fruits would be tallied and new fruits tagged to insure that sample size was maintained across the season. This would allow us to get an estimate of unintended fruit fall. By harvest, we would have an estimate of apple survivorship or the percentage of apples which persisted on the tree. This is an important component of the apple harvest that was not assessed in 2014.

<u>Proposed Study: Exploring In-orchard Habitat Management Techniques.</u>

One ultimate goal of this work is to provide useful suggestions to orchardists regarding in-orchard habitat management (Fig. 15). As the referenced works with wild flower strips, ground covers, and other forms of in-orchard habitat management have shown, there is certainly value in knowing as much as one can about who's feeding upon whom and the habitat requirements of both pest and beneficial. These can give you some best guesses as to what plantings might influence pest numbers (for example, one would be barking up the wrong tree to plant flower strips so as to support beneficial wasps for the control of Plum Curculio, see Fig. 16, a species that apparently does not have significant wasp enemies). However, even with some understanding of ecological relationships, experimentation will be needed for testing our best guesses. For example, one study of orchard ground covers (Mathews, Bottrell, & Brown, 2004) showed that certain covers markedly increased the populations of Codling Moth natural enemies but that physical structure of the cover was such that Codling Moth larvae could apparently largely evade those enemies.

I would thus suggest that, simultaneous to any orchard monitoring, but at sites initially somewhat removed from it, efforts be made to establish and monitor at least one habitat management technique. The specific technique should be determined in close consultation with the orchardists to insure, at the least, it practicality. Given the benefits sometimes reported for peripheral wild flower strips, the relative ease of establishing them, and their relative lack of interference with immediate orchard management (vs. for example, ground cover manipulation), I would propose the experimental installation of a standardized (for the purpose of comparisons) wildflower strip.

Figure 135. The yellow of a brassica cover crop shows through an orchard. Adjacent flowers like this might be part of a conservation biological control program.

The literature (e.g. Lee-Mader, Hopwood, Morandin, Vaughan, & Black, 2014) provides useful starting points for the designing of such a strip. For example, it should contain a variety of flowering plants so that, across the growing season, there is a relatively constant source of nectar and pollen for flower feeders (being not just pollinators, but natural enemies such as flower flies and wasps). As part of major, current efforts at pollinator conservation, organizations such as Xerces have created region-specific plant mixes. Recalling the biodiversity conservation is one of our dual goals, the use of native plants should be maximized so that they have the potential to also provide food for native herbivores. Potentially and if easily incorporated, one might consider including native plants that, while not major nectar producers, do host a diversity of native insects (e.g., some native grasses). At the same time, since these strips are not meant as trap crops, care should be taken avoid using plants that are known secondary hosts for apple pests or diseases (Fig. 17). I would suggest working with NRCS/Xerces to determine the most practical plant mix – they have nationwide experience in creating and installing wild flower strips that are practical in agricultural situations. Insect populations in these strips should be monitored by regular vacuuming.

Cover crops are another form of in-orchard management already being utilized by some orchardists. These should be monitored at least through pollinator observations and vacuuming. Sharing amongst

Figure 146. The nemesis - Plum Curculio - on the surface of a young apple. Plum Curculio were widespread across the orchards.

orchardists and input from the likes of NRCS/Xerces might even suggest alternative plantings although, obviously, flower production is not the sole agricultural goal of cover cropping.

Proposed Study: Information Exchange

This process has the best chance of coming up with something that is useful to orchardists and conservationists alike if it is an on-going dialogue. Monitoring and analyses techniques should be chosen so that, whenever possible, results are available if not during a given growing season then before the next one. These should be shared in an accessible way and, ideally, at least one get-together amongst collaborators (perhaps in conjunction with a larger meeting such as NOFA) should occur between each season. At such meetings, the results of the past season and ideas for the next season should be discussed. While one value of long-term monitoring is the repetition of unchanging, standardized monitoring techniques, this will need to balanced against each orchard's need for management flexibility and any evidence of scientist stupidity that become apparent with repetition.

Figure 157. One orchardist's joy is another's headache. This abundance of wild flowers attracted numerous bees, but, the literature suggests, may have also created nutrient competition and pest habitat.

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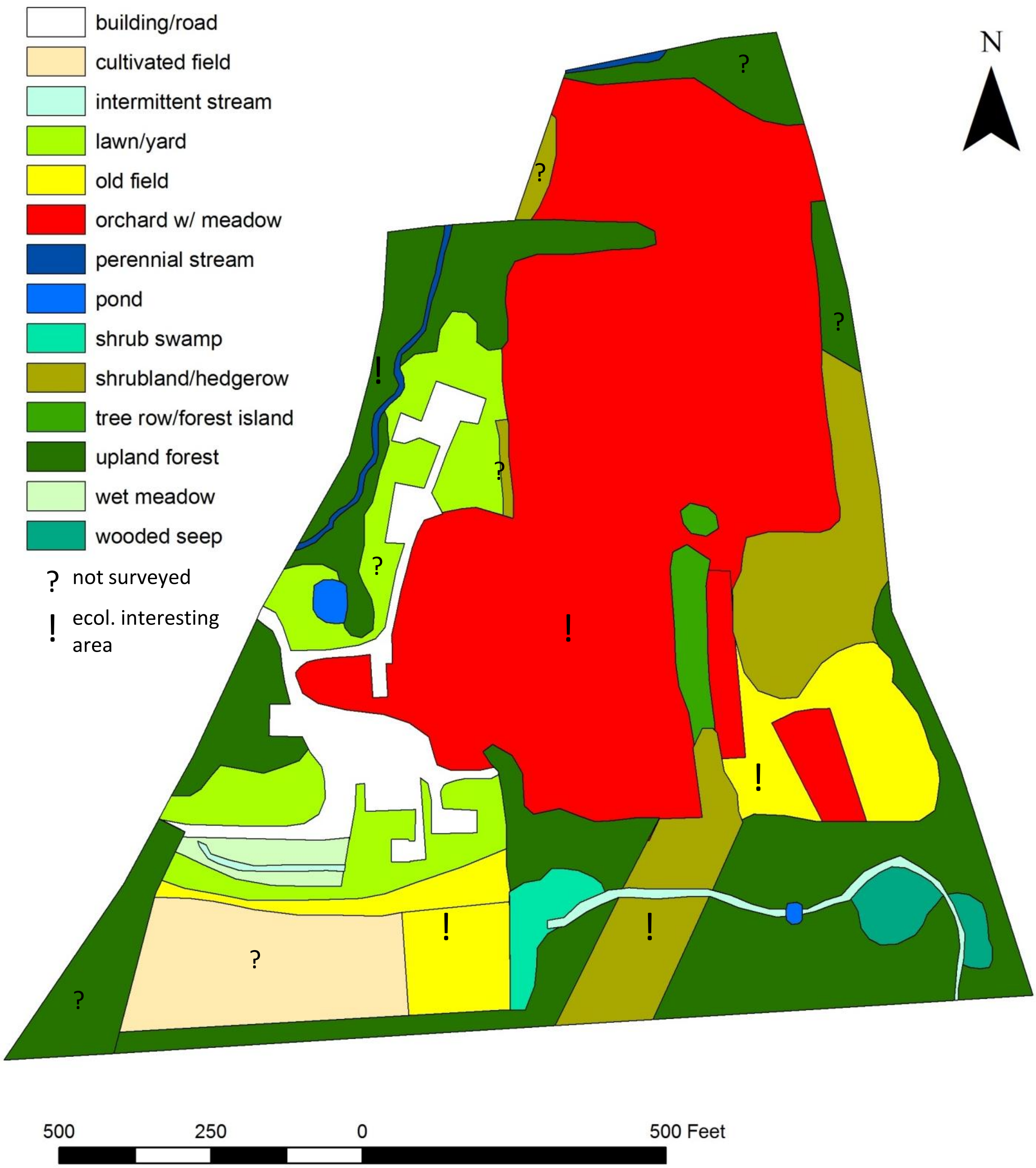
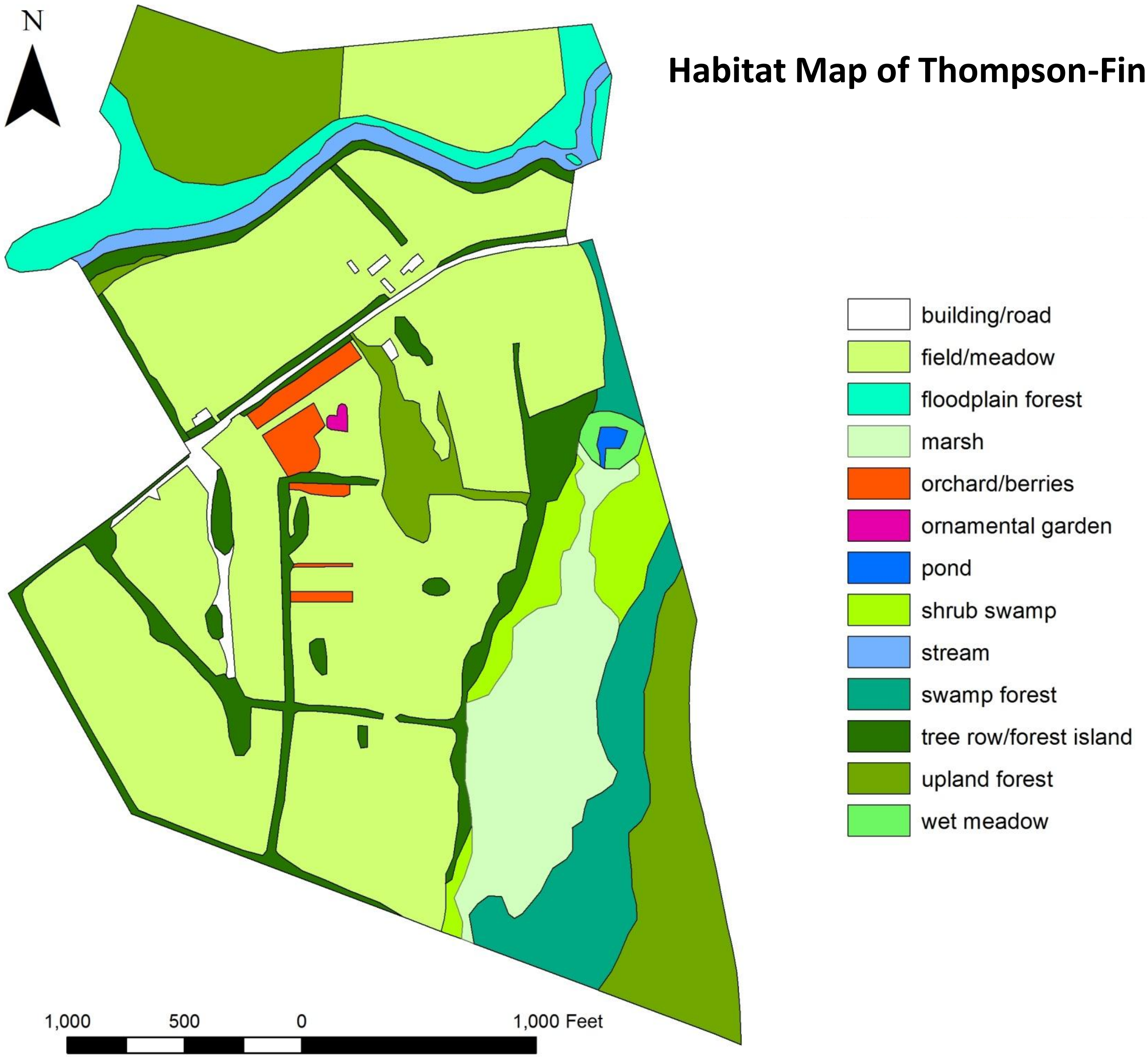
APPENDIX

Habitat Maps of the Seven Collaborating Orchards. These are based upon aerial photographs and at least a pair of field visits. While more time would be needed for precise habitat maps, these images give a general indication of the habitats contained within the properties of these orchards**.**

Habitat Map of Breezy Hill Orchard

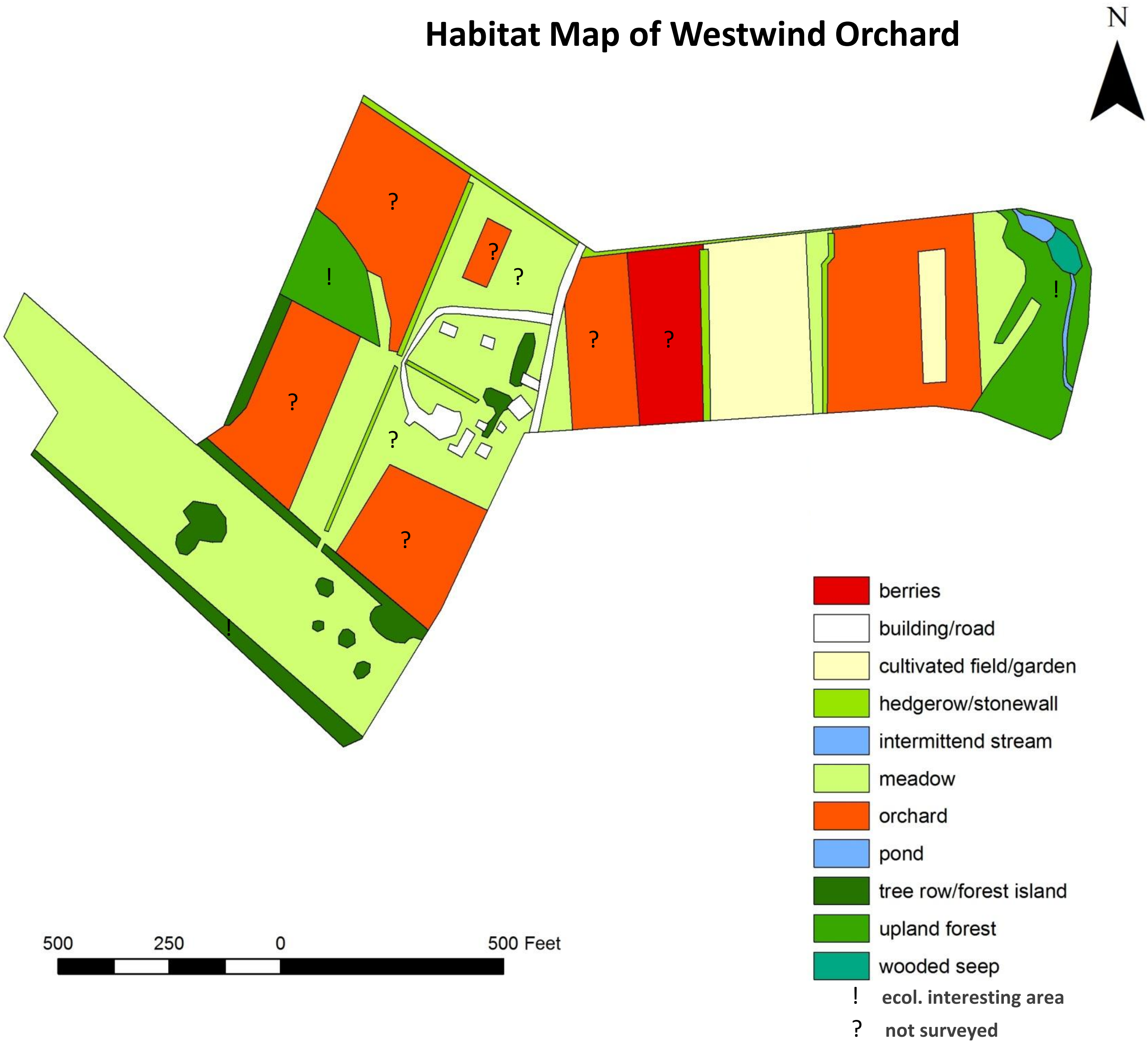


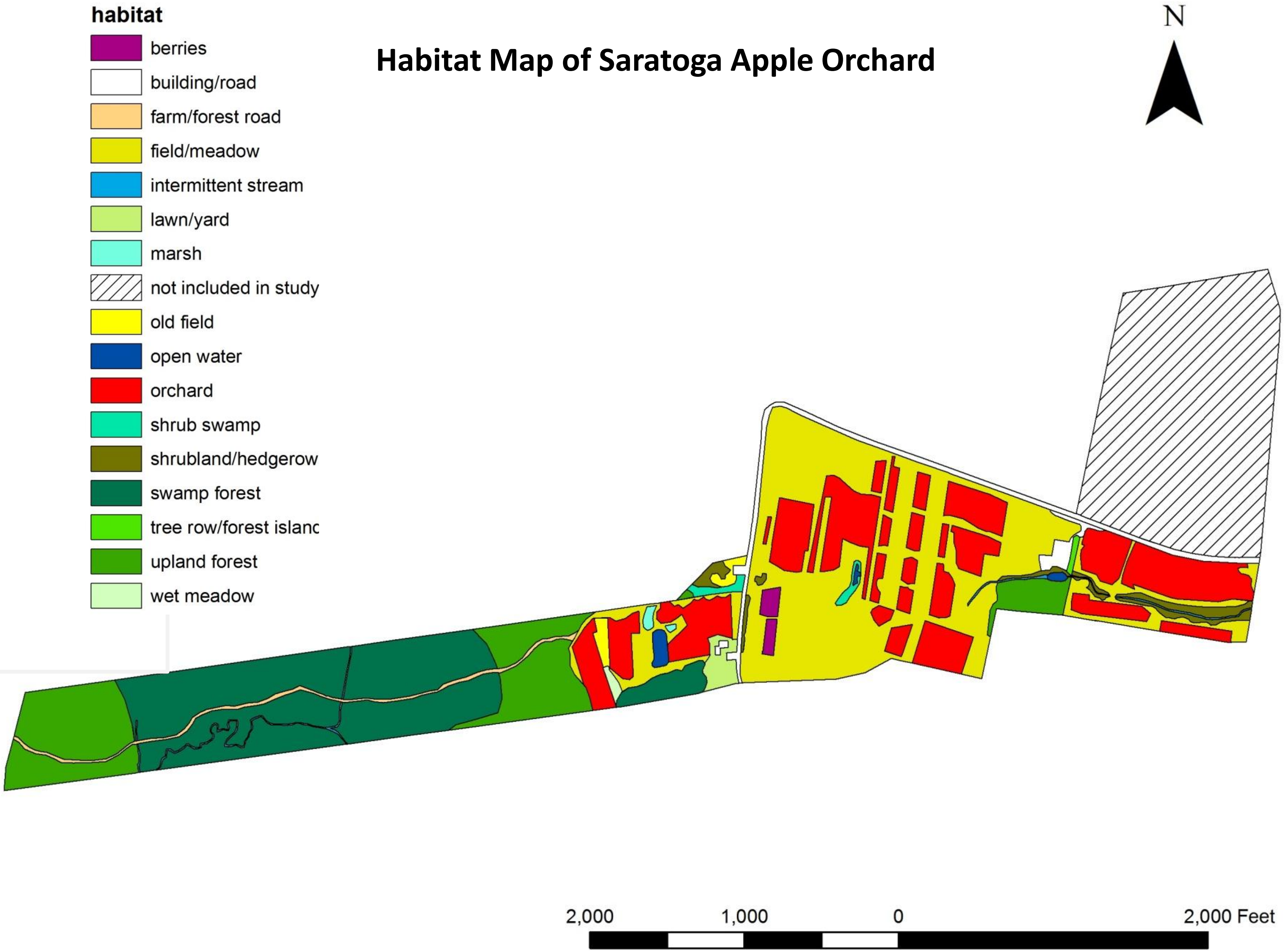
Habitat Map of Thompson-Finch Farm



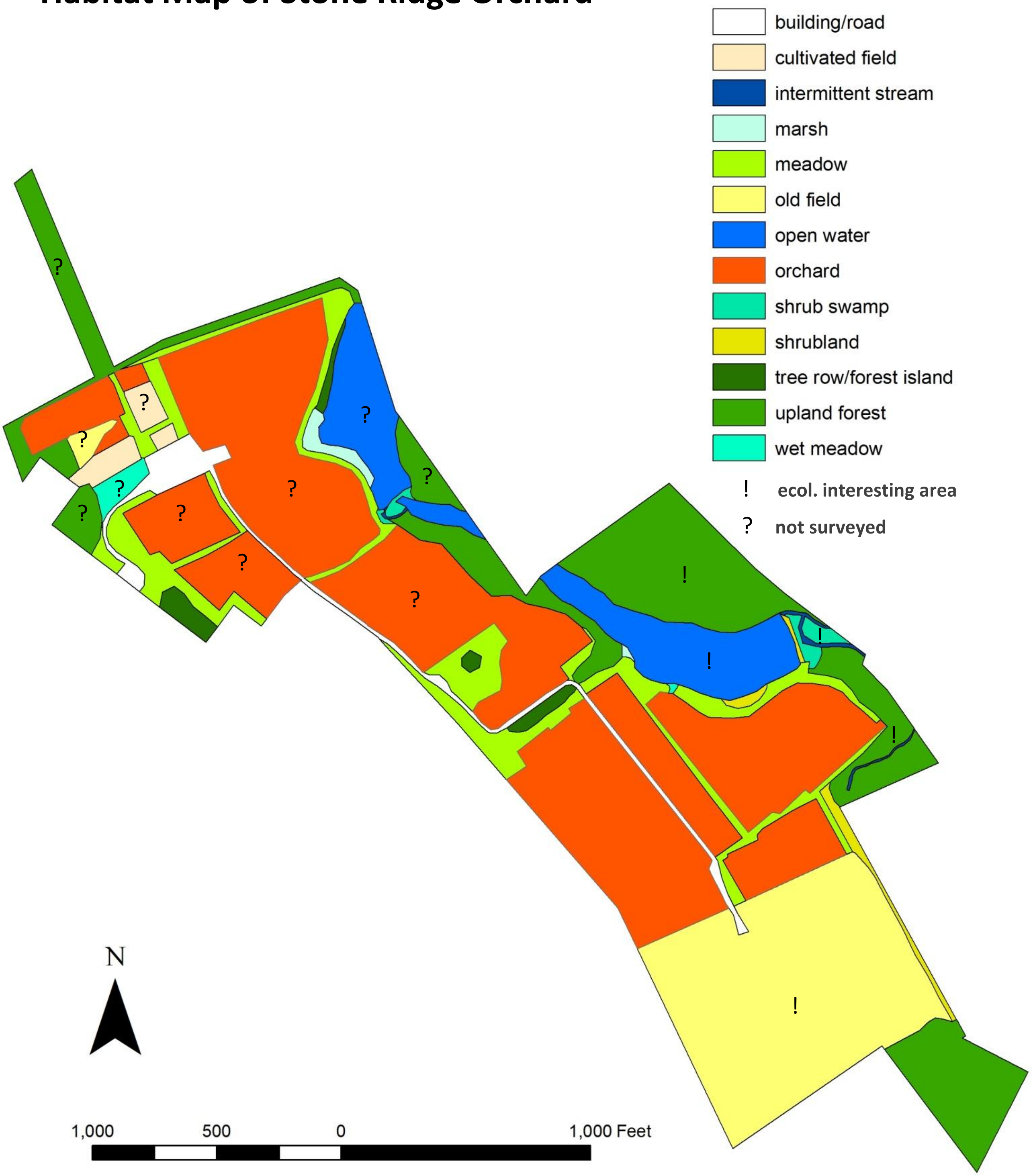
Habitat Map of Threshold Farm

Habitat Map of Westwind Orchard




Habitat Map of Saratoga Apple Orchard
habitat
berries
building/road
farm/forest road
field/meadow
intermittent stream
lawn/yard
marsh
not included in study
old field
open water
orchard
shrub swamp
shrubland/hedgerow
swamp forest
tree row/forest islanc
upland forest
wet meadow
N
2,000
1,000
0
2,000 Feet

Habitat Map of Stone Ridge Orchard



Habitat Map of Fishkill Farm