Comparative semi-stratified invertebrate diversity study of the Agroforestry Research Trust Forest Garden and Schumacher Native Woodland

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Purpose:

First, to compare the effects of converting pasture land into a highly diversified organic edible forest garden, with the regeneration of farm land into an almost completely unmanaged, planted native oak/ash woodland. Differences were compared by looking at invertebrate biodiversity as well as carbon content of soil.

Secondly, to compare differences of invertebrate biodiversity within the forest garden and between various different patches of plant associations, and determine if anything significant might be said regarding understory plant composition and invertebrate diversity.

Background:

Much of the debate regarding complexity and diversity in ecosystems has centered on the issue of stability and resilience. Since the late 1950's and the publication of Elton's (1958) book The Ecology of Invasions by Animals and Plants and MacArthur's (1955) paper "Fluctuations of Animal Populations, and a Measure of Community Stability", there has been much debate over whether or not complexity in ecological communities begets patterns of stability. There has often been confusion over the meanings and definitions used, as 'stability' in ecological terms has often been used in reference to conditions near equilibrium. This is a convention of convenience, as dealing with non-linear, far from equilibrium systems in mathematics was until recently quite problematic. It does not reflect the real world, however, as many scientists have come to discover.

Complexity is defined here as the combination of *diversity* (measured by either the Shannon index or the Simpson index, in both species richness and equitability of population sizes, as well as *connectance*, or, the diversity of interactions. *Stability*, it is proposed by C.S Holling is, "the ability of the system to return to an equilibrium state after a temporary disturbance." *Resilience*, on the other hand, is, "a measure of the persistence of systems and of their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables."[1] As he points out, stability and resilience are not necessarily twinned, and one can be strong while the other is weak.

There is a strong argument now, stemming from the work of Kevin McCaan as well as Pimm and Drake[2 3 4] which indicates that complexity does indeed increase community stability if there is likewise a diversity in strengths of inter-specific interactions, and if stability is more inclusively defined to include resilience.

Ecology is moving away from the notion of ecosystems as highly balanced loci of equilibrium and stability, and into the idea of ecosystems as complex sets of non equilibrium relationships which derive a satisfactory state of health through a diversity of diversities. Not only is a diversity of species required, but also, it seems, a diversity of interactions and interaction strengths promote communities which are not just adept at responding to disturbance, but which are also able to absorb change in ways which maintain populations and relationships. While this study does not address the question of diversity in interactions and interaction strength, it does demonstrate that there is a significant difference in ground invertebrate taxa diversity between the two sites, which may or may not also be complemented with diversity in interaction strengths.

There is a growing awareness in the UK of the importance of reforestation for carbon emission sequestration, wildlife habitat regeneration, and ecosystem services. However, there is also a well understood need for large proportions of land to be devoted towards food production in striving to address the needs of a large and growing human population. The theory behind edible forest gardening says that if food production is approached from the perspective of whole ecosystem processes - diversity, closed nutrient flows, and inter-taxa relationships - then what emerges is an ecosystem which is self maintaining, self fertilizing, and over-yields useful crops for people, as well as retains and perhaps enhances ecosystem health.

"Any form of nature conservation cannot deny human needs for food. A starting premise is that natural vegetation has and will continue to give way to agricultural development. The urgent emphasis today is for managed development, rather than destructive unplanned expansion. There cannot be total disregard for the natural cornucopia of living material or disregard for the soil fabric. Land is finite. In fact it is less than that, with South Africa alone losing 300 million tons of topsoil annually. This brings to mind the aphorism that there is only about 30 cm of soil between life and death of the planet...the USA is losing topsoil 18 times faster than it's being replaced (Pimentel et al., 1989)...an estimated 17% of the annual fossil energy consumption of the USA is used to supply the country with its food and fibre needs...the energy input for nitrogen fertilizer alone is now greater than the total energy inputs for growing maize in 1945-about a 20-fold increase in the amount of nitrogen fertilizer versus a threefold increase in maize yield (Pimentel et al., 1989). These impacts have a major detrimental effect on soil invertebrates, which are now recognized as being important influences on process-level dynamics in agroecosystems.[5]

This passage reveals two important concepts. The first is that human needs are not separate from the land, and must be brought into the land conservation equation. Once we recognize that land devoted to food production cannot exist in isolation, and nor can land set aside for conservation purposes, indeed that one always influences the other, we will begin to weave the mentality of respect for other beings with the mentality of respect for our food needs in designing food systems and conservation areas which meet both needs. Respect does not flow uni-directionally. Reciprocity is inherent in respect. Native Americans are often looked to as the leaders in land ethic cosmologies of the western world. What is unique in many of these cosmologies is precisely this perception of our environments as our own care takers. Just as we care for our homes, our environments, we too have to be able to count on our homes and environments to satisfy our needs. Often this reciprocity has devolved into an either/or scenario whereby we are either destroying and demanding of the land, or coveting and conserving.

The second issue that comes out of the above passage is that our current cheap petrochemical induced agribusiness practices are destroying or disrupting vital ecosystem processes associated with invertebrates. Much of the so called native invertebrate diversity contributes substantially to the health of the whole system. Not only are invertebrates crucial for many ecosystem functions, but they are also found in larger abundance than we might think possible. With this in mind a larger question becomes possible. Forest gardening is not dependent on cheap-oil subsidized fertilizers and is not dependent on homogenization of plant diversity and complexity. It is, however, an act of intensive food production. If diversity has a correlation with stability (resistance and resilience) within ecosystems, than it becomes an important question to ask whether or not forest gardening has any comparable effects on biodiversity and the soil food web on par with the reestablishment of native woodlands- a popular and worthwhile task here in the UK, but not one which can directly answer our own food needs. This study seeks to begin answering that question.

Methods:

For the initial spring sampling of May 28th - June 4th 2006 two sites were selected here at Dartington; the almost twelve year old forest garden started by Martin Crawford of the Agroforestry Research Trust, and the Schumacher Woodland. The Schumacher Woodland was chosen for comparison as it is only just slightly older than the forest garden (fifteen years), and was, like the forest garden a field experiencing traditional (intensive) farming practices prior to the reforestation effort. The Schumacher Woodland is representative of woodland restoration efforts in tree composition and spacing. They are approximately the same size (two acres) and both are adjacent to mature secondary growth native woodland. Also, both are adjacent to land currently in pasture or cultivation.

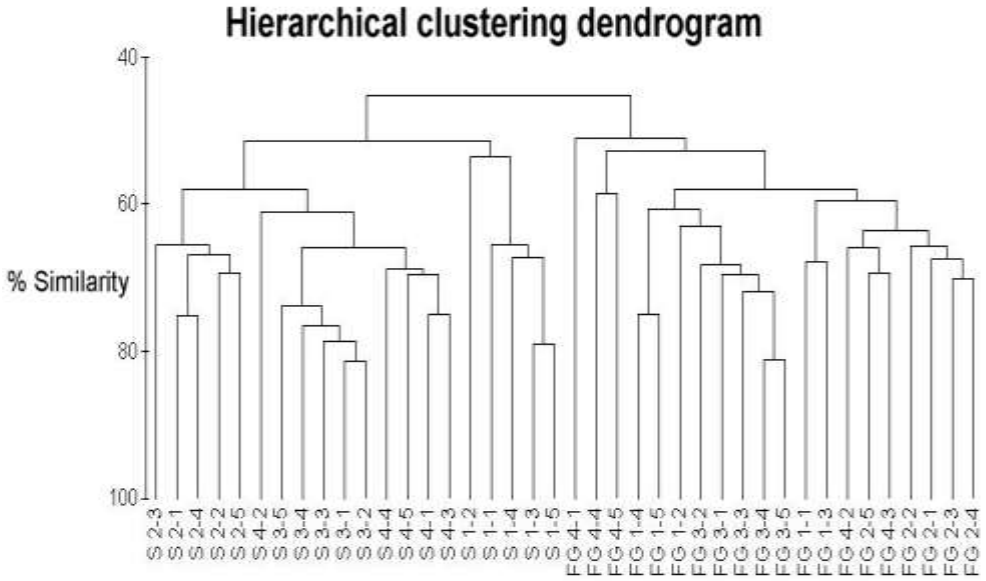
The sites were sampled in the beginning of June in order to attempt to capture a snapshot of peak diversity. The sites were visited by Peter Smithers, entomologist of the University of Plymouth, Department of Biology, and it was determined that the most effective method for sampling invertebrate diversity would be through a method known conventionally as pitfall trapping. Twenty traps each were set in the sites labelled (FG-forest garden) and (S-Woodland), with four groups of five traps in each site. The sampling sites were stratified based on vegetation type within the Forest Garden and the Woodland. Once the sites were stratified, the traps were randomly placed on a transect at least two meters apart. The 'two meter minimum' rule was used in order to keep trap results independent from each other, as suggested in Sutherland, 1996[6]. Plastic drinking cups, approximately 5cm diameter, were set flush into the soil. A solution of 0.1% Propylene phenoxetol dissolved in propan diol which was then made up as a 5% solution in tap water was added. Propylene phenoxetol is a bactericide which slows down decomposition and has the advantage of being non toxic to mammals.

Traps were left for eight days, and samples were collected at the end of the eight days. Twice, traps were checked over the course of the eight days, and twice small mammals (mice and shrews) had to be removed from several of the traps in the FG. None, however, were trapped in the woodland. Samples were then preserved in 70 % alcohol and identified at the University of Plymouth. Identification was done to the finest possible resolution, ranging from order (e.g. Diptera, Hymenoptera) to Family (Carabidae, Staphalynidae) to genus (Lasius, Myrmica ants), and even to species in the case of several wood lice taxa.

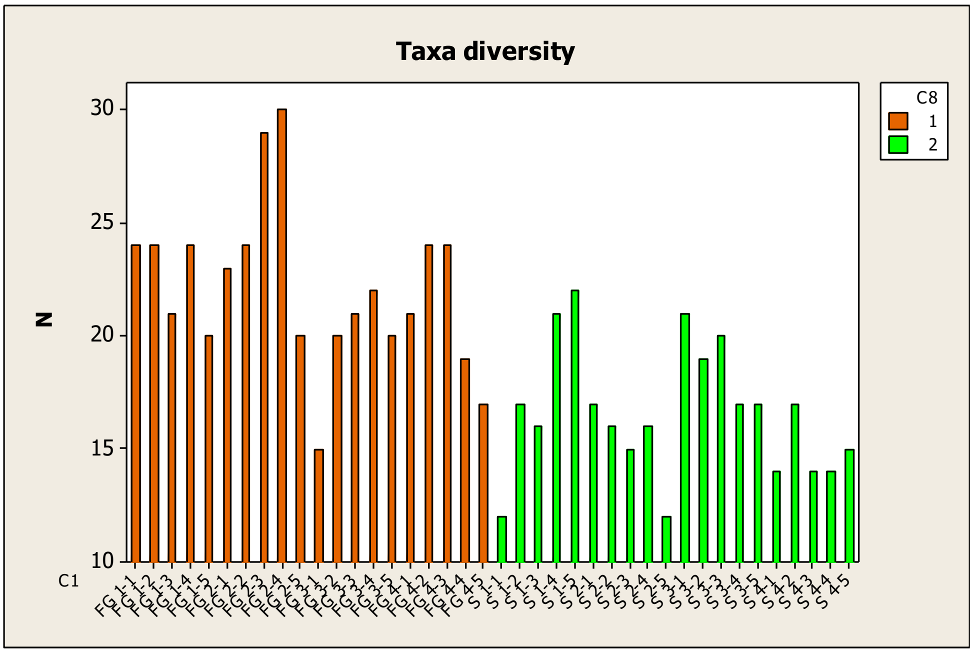
The carbon content analysis was done by first collecting samples of soil (12 from each of the two sites, as well as 4 each from two prospective future forest garden sites nearby) Samples were dried, then weighed before being burned at 400 degrees Celsius for four hours.

Results:

It was determined using Primer 5 multivariate analysis that the two sites had significantly different invertebrate taxa composition. The following hierarchical agglomerative clustering dendrogram visually demonstrates this by giving percentages of similarity between each sample. Notice that the maximum similarity between the two sites is just below 50%. This quite clearly tells us that the two locations are at the time of sampling, supporting rather different compositions of invertebrates. The next question to ask is whether or not one is clearly supporting a higher diversity.



The multivariate analysis was followed up with several two-way statistical analyses of the data. What resulted is a demonstrable difference in diversity (both raw and indexed) with a p value of 0.000. Six statistical analyses made were between the mean values of all twenty samples from the forest garden (1) and the woodland (2), five of which displayed with a 95% confidence interval that the total number of taxa, as well as the Margalef's index, Pielou's evenness index, the Shannon-Wiener index, and the Simpson index are higher in the forest garden than in the woodland. A variety of indices were employed in order to broaden the scope of understanding the two components of diversity; species richness, and equitability. The sixth test (for significance in difference between total numbers of individuals) failed with a p =0.020. Out of curiosity, the numbers were run with a 99.9% confidence interval. Results remained unchanged. Mean sampled species richness was about 33% higher in the forest garden, and mean indexed diversity was approximately 40% higher than the native woodland.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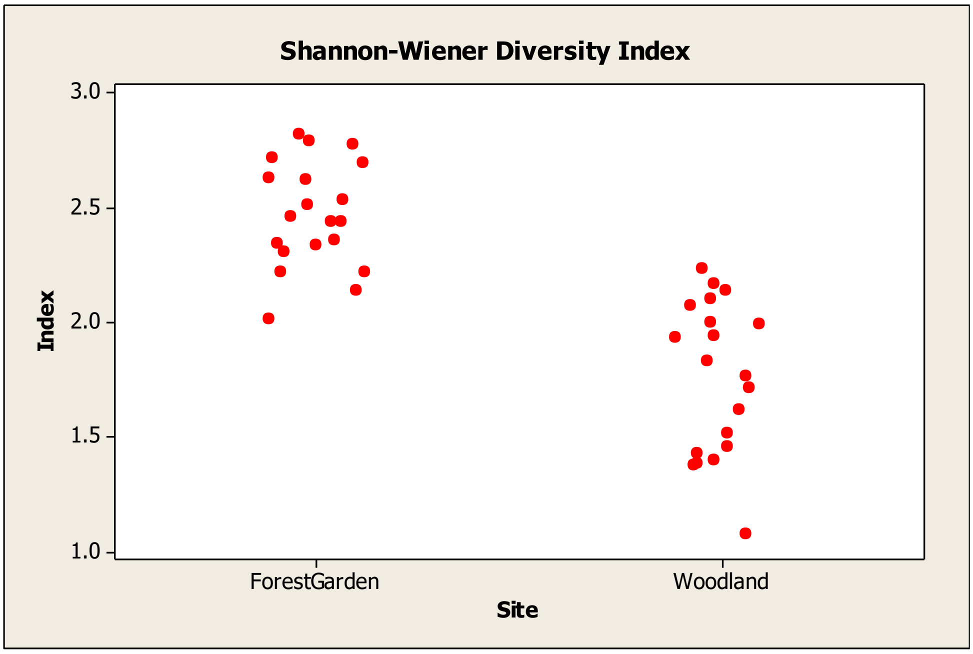
Shannon-Wiener Diversity Index
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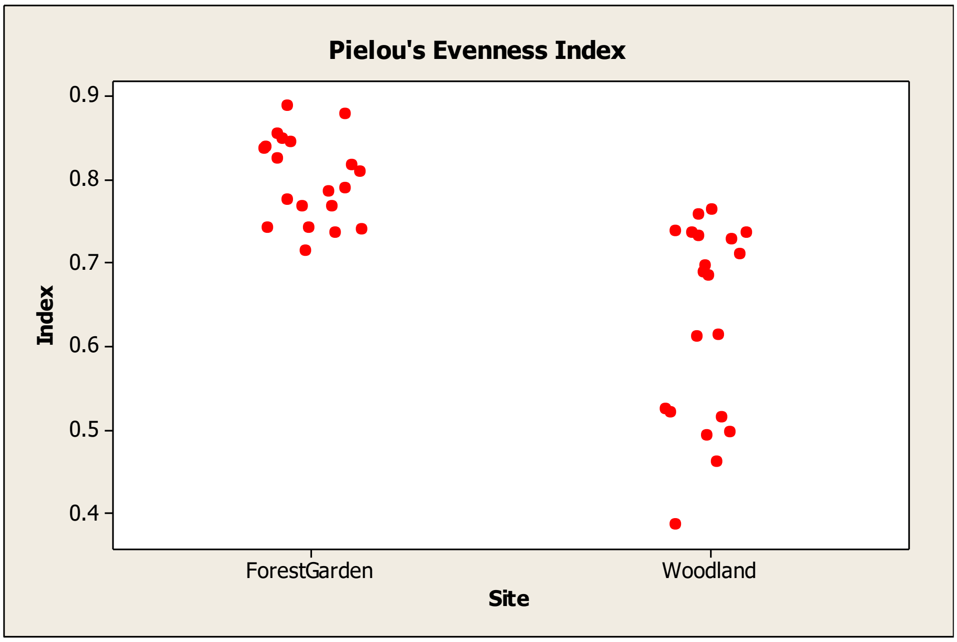
Pielou's Evenness Index
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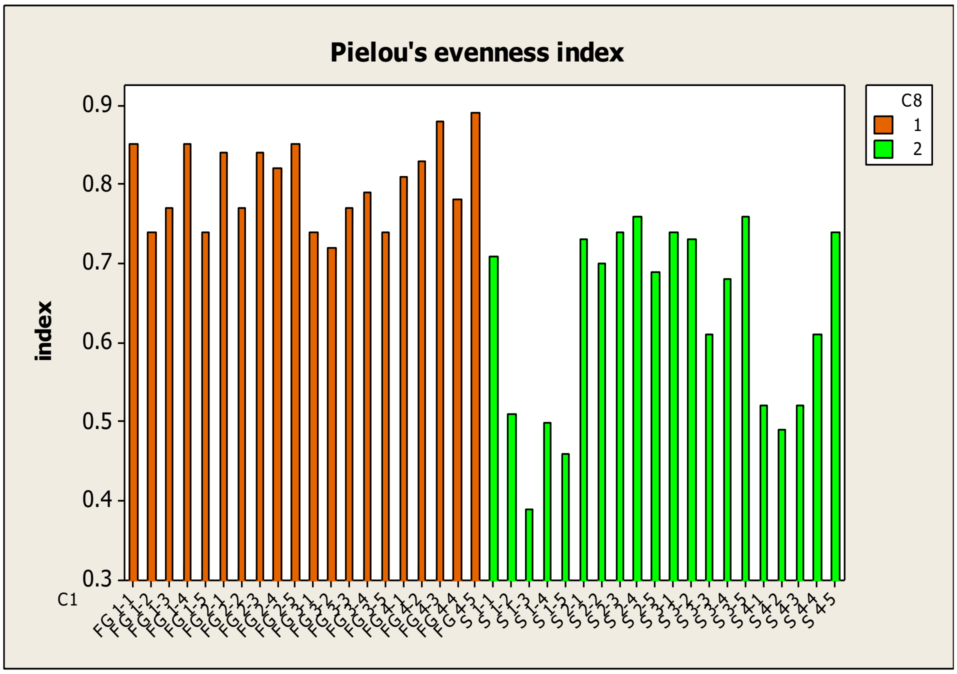
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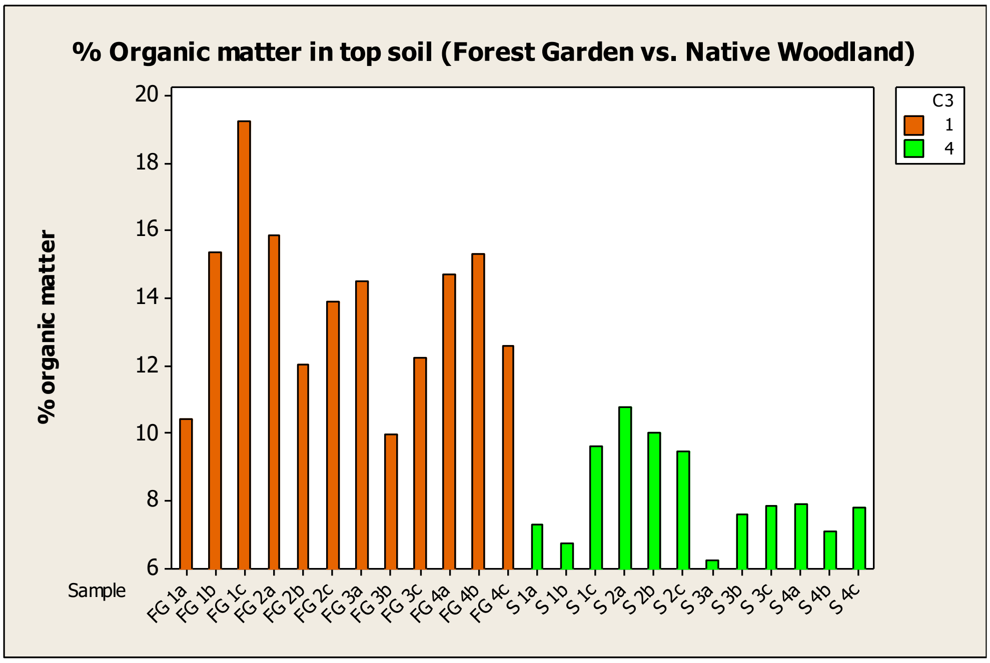
A further statistical analysis of diversity in taxa richness, numbers of individuals, and indexed diversity demonstrated that the semi-stratified samples *within* the forest garden, showed no statistically significant difference. Hence the four predominant understory vegetation types where the traps were set: evergreen Rubus tricolour/Rubus nepalensis, deciduous Mentha suaveolens, dead and down wood with Vinca major and Mentha suaveolens, and mixed understory of Origanum vulgare, Symphytum officinalis, Malva sylvestris, etc. showed no clear difference in supported invertebrate diversity based on this one sampling. Further sampling might draw out greater resolution in attempts to discern in what ways the diversity of the four understory types differ. As well, these four vegetation types, while dominant in the forest garden, are not totally representative of the totality of habitat composition and structure. Further sampling in some of the other microsites of the forest garden, particularly around the pond, and under some of the denser shrubs, might reveal even greater diversity in the forest garden.

Soil organic matter content

As a follow up to the invertebrate study, there was an organic content soil analysis conducted in both the woodland and the forest garden, as well as in neighbouring pasture land and mowed lawn, which displayed interesting, and statistically significant results as well. A one-way ANOVA test of the four sites demonstrates that there is a difference in the four sites. A second test of just the woodland and the forest garden show a difference with a 99.9% confidence interval. In fact the soils of the woodland were on average, lower in organic content than the lawn, and the forest garden was just below the pasture.

Pasture:	15.739% (average of four samples)
Forest Garden:	13.856% (average of 12 samples)
Lawn:	10.926% (average of 4 samples)
Native Woodland:	8.220% (average of 12 samples)



[A note on the % organic content. Martin has had professional soil analyses done, and has found the current organic content to be 8.8% for the forest garden. Why these numbers figure so much higher is probably due to a different sampling method. It is likely that I took my samples from the upper layer of the top soil, whereas his samples included more soil from below. The actual percentages are irrelevant *for the purposes of comparison*. All of the samples I took were to the same depth using the same implement. By this method, the forest garden showed nearly 69% higher organic content than the woodland.]

Conclusions and thoughts for future research:

Both in raw numbers of taxa, and in indexed diversity the forest garden seems to support a more robust population of invertebrates. While plant diversity has not always been shown in previous studies to be directly correlated with invertebrate diversity, in the case of this study it seems plausible. The density of the undergrowth as well, likely leading to consistently higher temperatures and humidity, may be contributing factors to a more robust and diversified invertebrate population. Thirdly, the soil in the forest garden contains a higher organic content than that of the woodland. Nothing in this small study indicates that a woodland regenerated via plantings of uniform aged native trees of only a couple species can compete with the forest gardening process in supporting native invertebrates in south Devon. Both the increased diversity of invertebrates, as well as a robust and healthy soil profile, significantly more so than the soil of the Schumacher woodland, lends credence to the idea that we, as human actors in a larger play, can indeed affect change in ways which yield positive results for the whole. However, this study is a mere snapshot of a vastly more complex set of comparisons, and would need to be followed up with more sampling through the seasons, in order to generate a more robust data set.

Questions of reliability could be raised regarding the limitations of the study to only one method of invertebrate trapping. Equally, the difference in certain taxa could be regarded as an effect of difference in mobility due to difference in temperature, humidity, habitat structure (i.e.: taxa move about more in less nutrient rich soils and/or in grass dominated understories). Also, the large numbers of spiders and ants in the woodland is quite interesting and could be a result of unknown processes going on, which are also affecting numbers of other invertebrates sampled. As well, the site of the native woodland may have been more actively tilled prior to woodland regeneration than the site where the forest garden now exists. This would contribute to a more crippled soil profile, and perhaps lower biodiversity. However, the site of the woodland is on two sides, adjacent to relatively intact mature native woodland, whereas the site of the forest garden is predominantly adjacent to woodland of introduced conifers. All of the site contextualization's are important in questioning how much this one study can tell us.

At the very least, what this study intimates is that the often assumed thesis which perpetuates the nature myth, that whatever we touch in nature we destroy or diminish, seems in this instance refuted. Indeed, this study is but one tiny view to a much more miraculous and incomprehensible whole. However, it demonstrated to myself and others at Dartington (against considerable scepticism) that forest gardening *can* contribute to human needs while not diminishing the possibilities for ecosystem health and diversity. In fact, in some cases it may well increase them. It would be useful if this study was followed up with inquires into the aforementioned diversities of interactions and interaction strengths. It is still uncertain whether or not a highly diversified forest garden can be considered stable *and* resilient, due to complexity. As there are no mature temperate climate forest gardens, these questions may not be answerable anytime in the near future, if ever. Holling describes ways of measuring relative amounts of resilience and stability, but he notes that these measurements require, "immense amounts of knowledge of a system, and it is unlikely that we shall often have all that is necessary."[7]

As we are all actors and participants, not there and later, but rather here and now, we can only continue with our cultivation of knowledge and hope for an inclusive whole wisdom to emerge. Taxonomic counts cannot provide this alone. Our feelings and intuitions of how we can most skilfully act must be heeded *as we go*. Linking what little bits of knowledge we do have with wider ecological understandings can help inform these intuitions.

Making meaning of the data

A reductionist understanding of the complexity of interactions between plant species, herbivores and predatory arthropods soon becomes untenable when dealing with even just a handful of variables. Calculations of a simple ecosystem of two plant species, six herbivore species, and six predatory species has 91 potential two-way and 36 potential three-way ecological interactions.[8] An 'organism' such as Martin's forest garden, with close to 500 plant species, and close to 80 identified taxa of invertebrates precludes the possibility of understandings limited to reductionist methodologies. Martin noted to me at one time that forest gardening, 'defies [quantitative] science in its complexity.' I would agree. The question then becomes, in what ways can we understand and make meaning of a vastly complex ecosystem such as the forest garden?

While counting how many mites and how many spiders fell into the small, semi-randomly distributed plastic cups in the forest garden won't tell us much about the whole health of the garden, and although the combinations of interspecific interactions are vastly complex, these reductions and taxonomic identifications do provide an opening of awareness as to general trends, and processes which may or may not be going on in the garden. Knowledge of these overlooked critters also draws the gardener further into relationship with the more-than-human community of life. Some background research on ecological functions of the more abundant taxa show some interesting trends in comparing the forest garden with the woodland.

Mites (Acari) are important grazers of bacteria and fungi, shred organic matter, and play key predator roles.[9] Mites were found four times (542:139) more abundantly in the forest garden than the native woodland.

Beetles (Colyoptera) are variously scavengers and predators, but predominantly herbivores. Carabids are well known as playing important roles in pest regulation, dissemination of insect viruses, and as specialist hunters. Staphalinids (rove beetles) are typically small predators and scavengers. The Curculionids include some historically well known 'pest' species, and many other weevil species can be economic problems.[10]

With the exception of the Caribidae family (47/96) there were overwhelmingly more beetles found in the forest garden versus the woodland: Staphyalynidae (250/166), Curculionidae (48/23), Ptilidae (91/14), Chrysomelidae (17/3). As well, there were several families which were low in abundance in both locations: Cantharidae (1/1), Elateridae (1/1) Scarabidae (1/1), and Silphidae (3/5), Nitidulidae (4/1), Pslaphidae (0/1)

Hymenoptera order is perhaps the most beneficial order of arthropods to humans. The suborder Apocrita (wasps, ants, and bees) in particular contribute to the processes of insect predation/parastism, flower pollination, and in the case of ants (formicidae) can be vital in nutrient recycling and plant dispersal.[11]

Numbers of Hymenoptera individuals trapped in the forest garden nearly doubled those found in the native woodland (121/68) with the exception of ants, which were identified to genus and were significantly more abundant in the woodland (920/106). (It should be noted that approximately two-thirds of the 920 ants trapped in the woodland came from only three adjacent traps.) Predator insects need flower nectar as energy source while searching for prey or hosts. As they only have biting or sucking mouthparts they need easily accessible nectar ie: Apiaceae, Asteraceae, and some of the Lamiaceae, and they need them throughout the season[12] The emphasis made by forest gardeners to 'keep' pest predators in the garden by abundantly planting these families could account for the doubling of non-ant hymenoptera in the forest garden.

Diptera order is enormous and generalizations about the ecology must be taken, as just that. However, the vast majority of dipterids are 'beneficial to the function of ecosystems as pollinators, parasites, and predators, and vital to the processes of decomposition and nutrient recycling.' As with the Hymenoptera, there was nearly a two-fold difference in abundance of Diptera individuals between the forest garden and the woodland (56/28).[13]

Spiders are well known predators of other invertebrates (mostly insects), however their role in the ecology of pest control and limitation is not yet well understood. Some studies have been done which have indeed linked the importance of the spider assemblage in agroecosystems. An experiment conducted with four $70m^2$ plots, demonstrated the effect spiders can have on keeping pest insect densities down. By adding mulch and floral diversity (flowering buckwheat) to two of the plots, and by increasing the complexity of the system (even just marginally) they showed increases in spider populations with reciprocal decreases in insect densities. "Studies of energy flow and the movement of labelled materials through food webs indicate that spiders are major components of the predatory fauna, and more importantly, that spiders capture a substantial fraction of the insects in the trophic levels beneath them."[14]

Spiders were trapped in far greater abundance in the woodland than the forest garden. The relative populations of various families of spiders in the forest garden versus the woodland include: Linyphiidae (Money Spider) (24/85), Opiliones (Harvestmen) (15/61), Strip Spider (0/8), Theriidae (Comb footed spider) (1/1), Thoricsidae (Crab Spider) (0/1), Lycosidae (Wolf Spider) (40/98), and Zoridae (Ghost spider) (0/2). Spiders like grass hay mulch better than leaf and bark mulch.[15] As the understory of the woodland was more dominated by grass species than was the understory of the forest garden, this could be a possible reason why there was higher spider abundance in the woodland than in the forest garden.

Collembola (Springtails) are extremely abundant in soil and leaf litter, and can contribute as much as 33% of total soil fauna respiration in early successional ecosystems.[16] Collembolan faecal pellets number in the millions/m2 and become available to plants slowly as microbes break them down. Much of the composition of these pellets comes from collembola grazing of fungal hyphae, which at certain threshold densities can actually stimulate growth of the symbiont plants of the fungi[17]. By creating faecal pellets, Collembola increase surface area and availability for further decomposition by microbes and fungi. It should be noted that this effect is more pronounced in systems which are polluted or highly acidic, and whereby other decomposers such as earthworms are absent.[18]

As well, springtails contribute to available food supply for other predatory invertebrates such as generalist Opiliones (harvestman spiders), hunting spiders, pseudoscorpions, and ants (Dejean 1985; Foster 1970; Holldobler and Wilson 1990; Johnson and Wellington 1980a,b; Schlegel and Bauer 1994 in Hopkin, 1997)[19] Also, several Staphylinid and Carabid beetle species are known to specialize in hunting springtail, and have evolved highly efficient trap mechanisms. Springtails in the woodland outnumbered those of the forest garden (845/169). It seems plausible that the high numbers of the springtails, carabids, and spiders in the woodland may have a connection.

* at Schumacher College in 2006, Dartington, Totnes, Devon, TQ9 6EA. This article is an edited version of Justin's full research paper, available at
https://www.agroforestry.co.uk/product/homing-in-wisdom-knowledge-and-practice-in-temperate-forest-gardening-pdf-version-via-email/

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