CHAPTER 3

THE USE OF INVERTEBRATES IN EVALUATING RURAL SUSTAINABILITY

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3.1 Introduction

Producing food in a more sustainable way is the target of most developed and developing countries. Several policies in the last few years have been adopted and could be used to promote sustainability such as:

1) Pesticide reduction (The Netherlands, Denmark, Ontario province in Canada, Sweden have made laws addressed at this target (Pimentel, 1997)).

2) Set aside of farmland in the European Community, United States, etc., to reduce surplus and/or compensate farmer incomes.

3) Promotion of some rules to protect biodiversity in delicate habitats near water captions, water basins and reservoirs, in the protection belt around national and regional parks, etc.

4) Reduction of urban and industrial impact such as reduction of fossil energy based activities, abatement of pollution, recycling, use of alternative low input practices, etc.

In most cases these policies have been promoted as potentially aimed at improving the environment and in most developing and developed countries the rural and natural landscapes are sometimes close to industrial areas or urbanized areas in a complex web.

Can biodiversity in general and of invertebrate species in particular, the most abundant living biota in the planet, be used to monitor change leading to higher sustainability in rural landscapes? In the last few years several theoretical and field studies seem to provide evidence that this may be true.

The landscape is changing and patterns are related both to the recent and the remote past. Some intriguing elements such as large animals (cows, sheep, goats, and pigs) and cereals (wheat, oats, rye, and barley) have their origins from a restricted area, especially the Fertile Crescent, which nowadays is almost desert (Paoletti, 1997). Our lifestyle and rural landscapes are based on these keystones with the addition of few others key plants (potatoes, corn, rice, and sugar beets). All these key species have transformed the structure and shape of our surroundings.

Human population, even if extremely high, is dependent on agricultural production for everyday food and welfare. However, fossil energy is a limited resource in both industrial and developing countries.
Solar energy and the natural environment lend major support to agriculture. But in most countries, especially in the industrial ones, fossil energy based technology, (for example: different pesticides and fertilizers, irrigation, etc.), is responsible for the current high yields. For instance, about 17% of the energy consumed in the USA is linked to agriculture (Pimentel & Pimentel, 1996).

In this chapter we will focus on the invertebrates as a consistent part of biodiversity and as the tool for assessing rural landscapes and improving its sustainability.

To address this possibility we first discuss two points about landscape and sustainability.

3.2 What is Rural Landscape? Large Animals versus Small Animals?

Species assemblages, patterns, and composition have been consistently modified by the transformation from natural to rural landscapes in the past 8,000-12,000 years. For instance, large species of earthworms and ground beetles have been eliminated almost completely from most rural areas (Paolatti, 1998). Large animals, such as ruminants have replaced small vertebrates in range lands, which are now made up of a limited number of grasses. Perennials have been substituted by annuals, basic crops are usually annuals. Forests have been reduced (with their potential perennial trees like oaks and chestnuts in temperate countries or Sago palms and other starchy fruit palms in the tropics). In most transitions from hunter-gatherers to agricultural societies there is a loss of trees bearing fruit etc. to annual, short cycle plants.

Larger grains over small grains. For instance, it has been observed that traditional small grains like millet and sorghum in Africa or quinoa and amaranth in the Andean regions tend to be substituted by the larger cereals such as corn, wheat, or barley (NRC, 1989; BSTID, 1996; Paolatti, 1995). The same trend can be observed in the Mediterranean regions, where small grains such as millet, sorghum, panicum, small legumes such as Lathyrus sp. and vetch or small fruits such as Craetaegus azarolus, Sorbus domestica, Mesepis germanica, etc. tend to be abandoned in favor of larger ones.

In addition, in the original areas of plant domestication; such as for potatoes the Andes; the original, native varieties have been rapidly replaced by the current western varieties. In the Andes of Venezuela, near Merida, for instance, seed potatoes mostly come from The Netherlands. In Ecuador pasture grasses come from Africa. Leguminous pastures in the Amazonas, Venezuela, tend to come from Africa as well. Most original crops are displaced by imported seeds and associated technologies.

Landscapes in industrial countries are a mixture of history, climate, natural ecosystems in a coevolutionary framework. Also the “primary” forest is sometimes a mixture of combinations of plants that have been affected by human intervention. For instance, in the Amazonas the Kayapo Indians or Piaroa actively disseminate seeds of useful “wild” plants trees in the forest (Posey, 1992 and M.G.P. personal observation, July, 1997). This activity is also a form of domestication. Cocona or tiupiro (Solanum sessiliflorum) and similar edible plants are voluntarily disseminated in slash and burn cultivation and in household gardens through human defecation (J. Saliick, personal communication and M.G.P. personal observation). In the European hedgerows seeds are disseminated by bird defecation.

These many processes are involved with animal and crop selection and association. For instance, the dimension of the fields has some links with the animal draft power, the plant associations in pastures with their ruminant animals. The domesticated large animals have consistently shaped the landscapes in most areas around us. For instance trampling, use of fire, erosion, and reduction of woodlands are in most cases linked with this historical option.

3.3 What is Sustainability?

Empirically speaking sustainability is a local concept depending on the mix of environment, economics and peoples in each region. Rather than a definitive set of options sustainability is a flexible target (Conway & Barber, 1990) (Table 1). Over time this theoretical sustainable system should not be degraded but it is difficult to measure, especially in current agroecosystems. In any case, most agricultural based landscapes, lose soil (Pimentel et al. 1995) and species (Paolatti, 1998), and as assumes since the work of Carter and Dale (1974) most civilizations in the past have collapsed due to the poor use of soil and renewable resources. Domestization processes that began the shift to agriculture lead to an incredible transformation of the landscape. Increasing the dimension of the organisms to be cultivated, improving the efficiency of the large, previously wild animals. In this process most mini-livestock (especially terrestrial invertebrates, rodents, amphibians, and reptiles) and semi-domesticated plants disappeared as resources for humans. In the mountains of Friuli Venezia Giulia recollection of wild plants for preparing the dish Pistic was the rule, in the spring up to 52 species were collectively retested. The more productive cereals made these plants become if not an abandoned at least a limited local resource (Paolatti et al. 1995). In the tropics most of the foods come traditionally from perennials and small animals (mini-livestock), so the strongest devastating effect on the forests in tropical Amazonas areas is the adoption of plants and animals coming from the Fertile Crescent (like cows, sheep, or goats). We could expect to promote the domestization process of the small animals once again. But the available knowledge is limited and traditions in food patterns are difficult to change in a short time span, especially for western peoples that progressively have eliminated the small creatures from their diets (Paolatti & Bukkens, 1997). Insects and small animals such as mice were eaten by Greeks and Romans, and even considered a delicacy in some cases (Beavis, 1988), but through Western history this kind of food has been socially banned and relegated to rural or somehow marginal social classes until its almost practical disappearance nowadays. However, in some countries like China this food is still important and there is local consumption of small invertebrates (crustaceans, mollusks, insects) and plants associated with ponds and rice or with silkworm production (Paolatti & Bukkens, 1997; Paolatti 1999a).
Table 1. Comparison of social, economic, and environmental sustainability (from different sources, but especially from Goodland & Pimentel, 1998)

Social Sustainability

Cohesion of community, cultural identity, diversity, solidarity, tolerance, humility, compassion, patience, forbearance, fellowship, cooperation, fraternity, love, pluralism, commonly accepted standard of honesty, laws, discipline, etc. constitute the part of social capital least subject to rigorous measurement, but essential for social sustainability.

This moral capital requires maintenance and replenishment by shared values and equal rights, and by community, religious and cultural interactions. Without such care it depreciates as surely as would physical capital.

Human and social capital, investment in education, health and nutrition of individuals is now accepted as part of economic development, but the creation and maintenance of social capital as needed for social sustainability is not yet adequately recognized.

Economic Sustainability

Economic capital should be stable. The widely accepted definition of economic sustainability is maintenance of capital, or keeping capital intact. The amount consumed in a period must maintain the capital intact because only the interest rather than capital should be consumed.

Economics have rarely been concerned with natural capital (e.g. intact forests, healthy air, stable soil fertility). To the traditional economic criteria of allocation and efficiency must now be added a third, that of scale. The scale criterion would constrain throughput growth - the flow of material and energy (natural capital) from environmental sources to sinks.

On the sink side, this translates into holding waste emissions within the assimilative capacity of the environment without impairing it. On the source side, harvest rates of renewables must be kept within regeneration rates.

Environmental Sustainability

Although ES is needed by humans and originated because of social concerns, ES itself seeks to improve human welfare by protecting the sources of raw materials used for human needs, and ensuring that the sinks for human wastes are not exceeded, in order to prevent harm to humans. Humanity must learn to live within the limitations of the biophysical environment. ES means natural capital must be maintained, both as provider of inputs of sources and as sink for wastes. This means holding the scale of the human economic subsystem to within the biophysical limits of the overall ecosystem on which it depends. ES needs sustainable consumption by a stable population.

Rural landscapes are not an homogeneous assemblage of plants animals and soils but comprise a network of "natural" or modified structures such as field margins, hedgerows, or river and channel banks, woodlots, shelterbelts, woodlands, ponds, marshes, swamps, abandoned fields, gardens, etc. It is not clear but seems a constant that new colonizers, such as the Ancient Romans produced consistent landscape modifications by resettling forested areas, rearing trees, and introducing hedgerows in their rural modified landscape (Fig. 1, Riese Pio X). This was made in Italy but possibly also in other European areas such as in England (Fig. 2). Similar settling of the previously forested landscape was done in the United States and Canada in the last century. This operation and its evolution through the decreased amount of margins create consistent reduction of the small scale fragmentation and decreased presence of the mosaic effect.

![Figure 1](image1.png)

Figure 1. Centuriated area in northeastern Italy (Riese, Pio X, Treviso) showing the still persistent fingerprint of the ancient Roman centuriation on the territory. As in many countries in the last 60 years most landscapes have been severely transformed making larger fields from small ones, reducing trees and hedgerows and decreasing the margin effects.

Looking at the field 'per se' is not the way to measure biodiversity in the rural landscapes. We have to consider the mosaic in different parts. Movement, colonization, and recolonization among the different parts of the landscape are the rule rather than the exception. In many cases different, less disturbed areas, serve as recolonization sources for the more disturbed portions. Hedgerows, shelter belts, undisturbed margins, trees, woodlots, wild vegetation alongside lanes, roads, channels, and ditches can consistently provide sources for field colonization. Perennial crops such as alfalfa, hay, and orchards (low input) especially when covered by living mulches can be important sources for recolonization.
3.4 Methodologies as a Crucial Point for Developing Expert Systems

To assess sustainability consistent tools have to be developed in order to assess change and compare different options in the landscape. One interesting tool is the use of invertebrates. Soil invertebrates have been suggested as key elements for soil formation and plant growth health (Dindal, 1989; Brussaard et al., 1997). Soil biota have been suggested as tools in assessing different impacts and management strategies (Van Straalen, 1997; Paoletti & Bressan, 1996; Paoletti, 1998). Among invertebrates, many other taxa and animal guilds have been suggested as potential tools to assess, above ground, the landscape structure and function, for instance insects (Heliövaara & Väisälä, 1993; Paoletti, 1998, 1999b).

To assess the landscape insects and other terrestrial invertebrates can give an important indication being numerous, relatively known (but not very popular) and present in most situations. To make progress in using invertebrates as potential bioindicators (Paoletti, 1998) a consistent change of tools is required from the manuals to the computer managed expert systems. We expect that computer technology will make large inroads towards a better use of this invertebrate based tool to assess the landscapes around us.

3.4.1 Apple Orchard Assessment (Northern Italy, Near Bolzano)

Rural areas with intensive apple and grape cultivations are associated with some alpine valleys such as Val Tellina, Val di Non, Val Venosta, Val d’Adige in Italy. Intensive conventional apple orchards and vineyards need a quite high input of chemical fertilizers and pesticides, including high amounts of fungicides to control pathogenic fungi (Paoletti, 1997a). Most apple intensive areas have consistent problems with high pesticide input and alternatives such as resistant plants, efficient marketing of new low input varieties, are only at the beginning.

We have assessed, using bioindicators, one organic apple orchard (adopting shallow tillage in the surface and no fertilizer and pesticide input) comparing it with a nearby conventional apple orchard (high input, herbicides, pesticides and chemical fertilizers used) and, as a non-managed reference, one piece of deciduous woodland (Schweigl, 1989; Paoletti et al., 1995). The bioindicator tools used were hand sorted earthworms and macro-invertebrates (operating hand sorting cores 30 x 30 cm, 30 depth with a spade). In addition pitfall traps were adopted. Five site repetitions were performed and almost monthly sampling done.

Both earthworms and some other groups collected by hand sorting gave an important indication of the different input systems (Fig. 3). In particular numbers of the large animal guilds were consistently higher in the organic orchard. In addition sampling with pitfall traps showed that at least carabids have been greatly reduced in the conventional apple orchard (Fig. 4).
In addition to the current input of pesticides (up to 72 kg/ha) in the conventional apple orchard residues of old pesticides have been accumulated, such as DDT metabolites and also arsenic, up to 50 ppm (Schweigl, 1989). Concentrations of these organochloride compounds can be degraded (such as ppDDT, opDDT, and ppDDT) only if a high microbial activity is found in the soil and there is adoption of organic mulching and appropriate incorporation of organic matter into the topsoil. These conditions are present in the organic orchard studied.

Which is the alternative to high input apple orchards? The key problems are pathogenic fungi especially scab and powdery mildew requiring high doses of fungicides. In addition codling moth and a few other Lepidoptera affect these crops requiring insecticides. To reduce this trend scab resistant varieties could be adopted and integrated or organic farming adopted. However to cope with these options clear policies and premiums for supporting organic productions must be implemented and better marketing strategies must be developed.

3.4.2 PEACH ORCHARDS (CENTRAL ITALY, NEAR FORLI)

We assessed, for two years, with the invertebrates, different peach orchards to evaluate the different farming systems (Paoletti et al., 1993). We selected six farms: two organic, two integrated and two conventional peach orchards in one intensive orchard area in the Romagna region in Italy. The organic orchards had minimum pesticide input. In integrated farms only low toxicity chemical pesticides where used under scouting and threshold targets. Different sampling strategies have been adopted, from sweeping to pitfall traps to the entomological umbrella.

Figure 5 shows the species abundance reaction to the different farming strategies, in addition some taxa better than others respond to different farming practices. For instance the isopods, earwigs, and some carabid species singularly respond to the progressively higher farming impact (Fig. 6). Other species such as the spider Oedothorax apicatus react positively to the high input farming in the opposite way when compared to Pachygnatha degeeri (Fig. 7). In this case we could say that these species could be the interesting key biodicators. However, selecting just a few key biodicator species is not the best strategy to compare different environmental impacts because the few key species can disappear or be present just for non expected reasons. It would then be more useful to consider and assess a larger number of species inside one major taxonomic group or of different taxa.

Alternatives to reduce conventional inputs are: living mulches, resistant plants, marketing strategies to promote low input products, appropriate premium policies for low input farming, educational programs for consumers to appreciate products coming from low input farming.
### 3.4.3 COMPARING DIFFERENT ORCHARDS (CENTRAL ITALY)

By reducing the number of taxa investigated as potential bioindicators to the earthworms alone we wanted to see if it was possible to minimize both the time consuming sampling and identification. From the low-plain in the north-east of Italy (Emilia Romagna) we selected and analyzed 64 ecosystems including vineyards and three types of orchards: apple, peach, and kiwi, characterized by different chemical inputs (Paoletti et al. 1998). We desired to assess comparatively these different orchards by using hand sorting of earthworms (cores 30 x 30 cm). There was a significant effect of both crop type and tillage on the biomass and abundance of total earthworms (Fig. 8). Cultivation operations in between the orchards rows reduced earthworm mean biomass by 42% in peach orchards, 36% in apple orchards, 20% in kiwi orchards, and 34% in vineyards. Earthworm mean abundance was reduced by 47%, 37%, 21%, and 64%, respectively. We found a significant, negative regression with copper and zinc content in the soil (Figs. 9, 10); the total earthworm variability explained by copper (expressed as r² in the regression analysis) was 50%.
**Aporrectodea caliginosa** as well as all earthworms were affected by both tillage and chemical treatments. Tillage reduced abundance and biomass by 50–60% in all orchards apart from apple orchards (16% reduction for biomass and 24% for abundance). This species almost disappeared in tilled vineyards (0.85 n/m², 0.25 g/m²) (Fig. 11). It had a negative correlation with copper; for biomass ln y = a - b x 1.5, r² = 0.19, r = 0.44, p < 0.01; for abundance ln y = a - b x 0.5, r² = 0.17, r = 0.37, p < 0.05.

**Allolobophora chlorotica** was highly negatively affected by copper treatment, whereas tillage produced no effect for this earthworm’s abundance (ANOVA test, p = 0.36). Biomass was higher in tilled orchards than in untilled ones, even if ANOVA test do not detect such differences as significant (p = 0.15). In this case tillage seemed to increase this earthworm’s biomass and abundance (Fig. 12). The endogeic group as a whole was negatively affected by both tillage and chemical input. Tillage caused a great reduction of 40–60%, except in apple orchards where a modest, not statistically significant increase occurred in tilled orchards (Fig. 13). Vineyards support the lowest number of these organisms. The negative correlation with copper was highly significant.

These different orchards were easily assessed by using earthworm abundance, species dominance, and diversity. In particular tillage and pesticide residues were the key factors that were possible to assess.

**3.4.4 VINEYARDS ASSESSMENT IN SPAIN**

As an illustration of the consequences of recent agricultural transformation on arthropod biodiversity in Mediterranean countries, we can show the preliminary results of a study using pitfall trapping carried out in a transformed vineyard area in Alicante Province (SE Spain) (partial results can be found in Pérez-Martínez, 1997). Present agricultural
landscape in this area is the result of a recent transformation of traditional Mediterranean dry-farming terraced lands (cereal, almond trees, and olive trees) into irrigated vineyards with high chemical input. These modern, intensive farming systems have generated several environmental problems: underground water table exhaustion or salinisation, contamination of waters by fertilizers, etc. Several years after transformation, these high input systems have also been shown to be not economically viable. Thus, many previously transformed fields are now being abandoned, due principally to the high cost of irrigation water, now transported from distant places, and also to marketing problems. EC policy has promoted set-aside as an environmentally sound measure to cope with economical unsustainability. It was the aim of the study to analyze the response of Coleopteran fauna to agricultural intensification and, also, to test if set-aside and reversion of agricultural land to scrub land or forests is really a good strategy for enhancing biodiversity.

As shown in Figure 14a, b, terrestrial Coleopteron abundance and species richness are greatly affected by agricultural transformations, total captures of individuals and species were always lower in intensive vineyards than in traditional almond-tree fields.

However, proximity to natural vegetation areas increases, to a certain extent, terrestrial Coleopteron abundance in vineyards, since captures are progressively lower as field distance to natural areas increases (T6 is in direct contact with natural areas, T7 at a some distance, and T8 at a greater distance). Duelli et al. (1989) found a similar picture in maize fields in Switzerland. Apparently, natural, uncultivated areas serve as reservoirs of arthropods from which agricultural lands can be colonized. So, impoverishment of Coleopteron fauna in agricultural fields would be greater if cultivated fields extended monotonically over large areas, as is the trend nowadays. Small remnants of natural vegetation were generally present in traditional cultivated areas because of irregularities of land relief, small creeks and hills, etc., which were hard to put into cultivation. Present technology allows the removal of these accidents and the enlarging and leveling of vineyard fields also over ancient natural areas.

Figure 13. "Endegeos" earthworms biomass and abundance in different orchards; tillage differences: p = 0.007 for biomass and p = 0.0007 for abundance; difference in crop plant effect: p < 0.0001 for biomass and abundance (Kruskall-Wallis test).

Figure 14a, b. Terrestrial Coleoptera captured by means of pitfall traps in different cultivated fields in Alicante province (SE Spain) during autumn 1997. T6, T7 and T8 are placed in intensive, high-input irrigated vineyards; M2, M3 and M4 in traditional, dry-farming almond-tree terraces. In a, total captures per trap; in b, total number of species captured in each field. In order to see the influence on vineyard coleoptera fauna of the distance from natural areas, vineyard experimental fields were placed at different distances from an uncultivated hill covered with semi-arid Mediterranean shrub land. T6 was in contact with natural areas, T7 at a middle distance (ca. 100 m.), and T8 at a greater distance (ca. 300 m). All almond-tree fields were at a middle distance from the closest natural area.
With respect to the consequences of set-aside, in Figure 15a, b, the captures per trap and species richness in cultivated vineyards are shown for different short-time set-aside fields (less than 10 years) and a long-time set-aside field (more than 30 years). As a global trend, set-aside favors Coleopteran abundance and species richness during the first years, total captures passing from 3.87-5.12 individuals/trap in cultivated vineyards to 40.62-100.00 individuals/trap in 5-8 year set-aside fields. Although conditions are not strictly similar, T1-T4 fields can be compared, to a certain extent, with ancient traditional fallow fields (fallow periods of 3, even 5 years were not rare in the region). Dates can be illustrative of the importance of the presence of fallow patches (another reservoir of soil fauna) in maintaining higher arthropod richness in the entire agrolandscape, and of the impacts on arthropod fauna of the permanent, non-fallow cultivation systems typical of modern agriculture.

However, total Coleopteran abundance decreased dramatically in the field abandoned for a long period (more than 30 years) and in a relatively well-developed Mediterranean scrub land (Fig. 15a and b). Here only 6.00 individual/trap and 9 species were captured. It can be deduced that, as succession proceeds and Mediterranean sclerophilous scrub develops, terrestrial Coleoptera, after an initial increase in the first years, become progressively less abundant, reaching even lower values than in intensive vineyards. Similar results were obtained by Schnitter (1994) in Germany.

If we analyze separately the abundances of the two predominant families, Tenebrionidae and Carabidae in the different set-asides, we can have a more detailed picture of the pattern.
of this agro-landscape system (Fig. 16). Both Carabidae and Tenebrionidae increase their abundances with cessation of cultivation, as was shown in Figure 15a and b. In the case of Tenebrionidae, subfamily Pimeliminae, absent from irrigated vineyards, is now well-represented in set-aside fields. This is likely due to the new dry, no-irrigation conditions. However, apparently Carabidae are dominant over Tenebrionidae in set-aside fields placed closer to natural scrub land areas, where there is a more developed plant cover, undoubtly due to the proximity of non-ruderal plant propagules (case of T1 and T3). Greater abundance of Coleoptera in T3 than in T1 can be put in relation to the higher connectivity of T3 to natural areas, since T1 is at a greater distance from scrub lands, and additionally, not connected to them by vegetation-covered field margins. On the contrary, Tenebrionidae, a taxon composed by xerophilous specialists, are more abundant in fields far from natural areas which present a more ruderal (earlier successional stage) and scarce vegetation cover (T2 and T4). Subfamily Pimeliminae, which are even greater desert specialists than subfamily Tenebrioninae, also shows a more acute response to the prevalence of dry conditions, and increase their relative abundance over Tenebrionidae in fields T2 and T4. In advanced successional stages, as represented by field T5, Carabidae are, as expected, more abundant than Tenebrionidae, almost exclusively Tenebrioninae, and almost no members of subfamily Pimeliminae (ratio Tenebr./Pimel. = 7/1). Thus, the relative abundance of Tenebrionidae to Carabidae, and Pimeliminae to Tenebrionidae, seems directly related to the prevalence of arid, poor vegetation cover conditions. Tenebrionidae are favored in the first stages of secondary succession, and Carabidae in more advanced stages when there is a more developed vegetation cover. The value of the ratio Carabidae:Tenebrionidae as bioindicator of arid environmental conditions has also been pointed out by Marcuzzi (1981), de los Santos (1982) and Martin-Cantarín (1994).

It can be deduced from above-mentioned results, than if intensification of agriculture implies a considerable impoverishment of Coleoptera fauna, permanent set-aside at large scale can have the same, or an even worse effect. However, set-aside of small fields, intermingled and well connected with productive lands, would enhance the richness of Coleoptera communities in cultivated fields. An even greater enrichment would be attained with the combination of fallow fields (that is, short-time set-aside of no more than 5-8 years), natural areas, and non-intensive productive fields, i.e., the kind of complex mosaic present in the traditional landscape.

3.5 References
