The Role of Insects in Modified Terrestrial Ecosystems

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In his original proposal Tansley (1935) suggested the term ecosystem to describe the interaction of living things together with their non-living environment. Ecosystems can be erected for varying levels of organisation, but to most it implies a complex of organisms and the physical environment functioning as a community in nature. It is in this context that the role of insects in modified terrestrial ecosystems is discussed in this paper.

The ecosystem is held by many biologists as the concept with which to inspire the direction of ecological research, but despite the fact that the concept and methods for studying ecosystems have been available for some time, it has only been in recent times, that there has been a change from determining the structure of ecosystems towards understanding the function of them. This has been facilitated by more specifically defining the roles of different species of animals in some ecosystems, estimation of their numbers, energetics studies and to a much lesser extent, in depth studies on the factors that regulate them. Theoretically it is a good concept, but from an economic zoological point of view where politics and consumer pressure for " quick solutions " to practical problems dictate research, it provides a fairly impractical approach. The nearest major economic studies have come to using comprehensive ecosystem concepts are on forest or intensive crop ecosystems, which have generally used a single, or at most a few pest species, as their centrepiece.

Ecosystems are characterised by a multiplicity of regulatory mechanisms which limit the numbers of individuals of different species, influence their physiology and behaviour and as a consequence, control the quantities and rates that nutrients and energy move in them. It is important to remember that all ecosystems are open. Although some nutrients are recycled, energy and nutrients continually escape and must be replaced if the system is to continue to function. The pathways of loss and replacement of matter and energy connect ecosystems with each other and consequently it is often difficult to determine the limits of a given ecosystem. The ecosystem is a broad concept, with several conceptional levels, but even within relatively narrowly defined ecosystems the role and importance of particular species varies considerably with changes in soil type and the physical environment. There have been no comprehensive ecosystem studies concluded in New Zealand, because of our pre-occupation with pest research, and a lack of interest in such research in our more academic institutions. It is interesting to note, however, that the study of ecosystems formed the basis of a symposium on " Progress within Pasture and Crop Ecosystems " at the annual conference of the New Zealand Ecological Society in 1965. This symposium included papers by Stockdill (1966), Fenemore (1966), Wood (1966) and Lowe (1966), all pertinent to the role of insects in modified terrestrial ecosystems.

At present the ecosystem concept provides a framework for establishing principles, and hooks on which to hang separate studies which one day may be integrated into a whole. Once the interacting mechanisms which determine the dynamics of the major ecosystems, that man exploits for his own multitudinous purposes, are fully understood then his ability to utilise the earth's biological resources will be infinitely enhanced. The main value of an ecosystem approach, within our current scientific resource must be the co-ordination of data collected for a variety of reasons and a more meaningful understanding of the role of the various organisms.

DEFINITIONS

In this paper I have taken an economic entomologist's licence to broaden the scope of what may be more properly called an insect to include other meso- and macro-invertebrate fauna. A modified terrestrial ecosystem includes any forest, grassland, crop, scrub or "bare" land community modified accidentally or purposefully by man, with greater emphasis being placed on ecosystems knowingly manipulated by man for agricultural use. Most terrestrial ecosystems can be divided for purposes of discussion into a soil and above ground system. Engelmann (1961) suggested this because they have similar trophic level systems and noted that changes in species composition in some soil arthropods are independent of changes in the above ground system. This may be true for systems such as meadows or forests where there are no catastrophic changes in root: shoot ratios or the state of surface litter, but is this true for agro-ecosystems which suffer severe harvest, grazing by stock or, pest depredation? In these simpler, man-made agro-ecosystems a much greater inter-dependence of organisms existing on roots, shoots and litter occurs. Grazing vertebrate herbivores provide a major modifying influence not only on the above ground system, but also on root system and its associated invertebrate, herbivore populations, in pastoral agro-ecosystems.

THE MAJOR MODIFIED TERRESTRIAL ECOSYSTEMS IN NEW ZEALAND

The major modified terrestrial ecosystems in New Zealand (if regions, soil type, climate and other modifying factors are disregarded) can be classified as follows:

(a) *Grassland*

(i) Tussock areas modified by Maori burning or tussock areas induced on forested areas by Maori burning.

(ii) Burnt-over tussock or forest areas improved after European settlement by oversowing with introduced pasture grasses, legumes and fertiliser.

(iii) Grassland or forested areas improved with fertiliser and introduced plants after cultivation.

(iv) Short term pastures with a cropping sequence in the cycle.

(v) Stabilised sand dunes.

(b) *Crop*

(i) Continuous monoculturing. This is a minor land use in New Zealand, but it tends to occur in intensive vegetable cropping areas.

(ii) Arable cropping systems, with or without some pasture in the rotation, but alternating from crop to grassland.

(iii) Orcharding.

(c) *Forest*

(i) Indigenous forests, modified by introduced animals, fire and man's lumbering activities.

(ii) Exotic coniferous forests, planted on indigenous grassland, burnt-over indigenous forests or developed grasslands.

(d) *Urban*

It is significant that a comprehensive study has not been concluded on any of these ecosystems on either an extensive or restricted basis. This paper is mainly concerned with grassland situations and because of the lack of pertinent New Zealand literature is of a general nature.

THE MAJOR ROLES OF ARTHROPODS, ANNELIDS AND MOLLUSCS IN MODIFIED TERRESTRIAL ECOSYSTEMS

The literature suggests that the roles of invertebrates in modified terrestrial ecosystems so long as the changes are not catastrophic, do not differ from natural or undisturbed terrestrial ecosystems, the difference between the two groups of ecosystems being in the degree that the population of each species can express its role. The interactions and roles of organisms in ecosystems can be illustrated in the following way. There are three major biological components; green plants (producers), animals (micro and macro consumers) and microbes (or decomposers) which dissolve organic matter and release vital elements essential to plant growth.

Before spelling out the major roles of insects in modified terrestrial ecosystems and entering into brief discussion on them, several points which bear on this subject, can be made about agro-ecosystems.

1. They are generally much more simplified and often more homogenous in character, due to man's husbandry activities, than naturally occurring ecosystems. Consequently they are more prone to pest and disease epidemics.

2. Agro-ecosystems are much more prone to catastrophic disturbances.

3. They are not the climax community for the habitat, although some systems within the constraints of management may approach this i.e., permanent pasture.

4. Quite often whole trophic levels of consumers are reduced in importance or eliminated.

5. The organic, water and mineral cycles are much better understood than in undisturbed ecosystems, because of man's material interests in them.

6. Community succession inherent in natural systems is largely precluded due to man's management practices.

7. Management may either mask or accentuate the effect of variations in biotic and physical factors which induce minor variations in climax communities.

8. In agricultural areas there is often a sharp change from one ecosystem to another, and frequently agro-ecosystems have a fairly uniform age structure. This also applies to forests. In New Zealand exotic coniferous forests were of a uniform age over expansive areas, but in recent years with improved silvicultural practices, forests of mixed age classes are now being superimposed on them.

9. Because agro-ecosystems are often monocultures of a particular species or variety, they have a limited range of genotype and thus the synchronisation of flowering and growth occurs within a much reduced time span. The vegetation of agro-ecosystems is selected by man, who regulates its composition by management. Man varies plant density by planting, irrigation, application of fertiliser and controls growth by eliminating weeds. This contrasts markedly with natural ecosystems in which the vegetation is the consequence of natural selection.

10. They are not always self-perpetuating.

11. Agro-ecosystems are much more productive than undisturbed ecosystems, which affects the relative size of many invertebrate populations associated with them.

12. Man assumes the most important role of all animals in agro-ecosystems. Odum and Odum (1959) have stated that it is possible to have a sizeable ecosystem containing only producers and decomposers, but almost everywhere, however, the macro-consumers invade sooner or later. A system without animals would be less efficient in time as the rate of energy transfer and speed of nutrient recycling becomes slower.

The "ideal" agro-ecosystems are ones consisting of the producer crop on a man-manipulated basal soil media, or in a pasture ecosystem, a sward with totally beneficial fauna (concerned solely with soil formation, nutrient cycling, the organic cycle and pollination processes), maintained by good agricultural management.

The main roles of "insects" can be summarised as follows:

I. Transport and storage of materials and energy; the interactions between organisms providing the pathways of distribution. These can be labelled as the heterotrophic roles.

(a) Herbivority (on green plants, the primary producers). In modified terrestrial ecosystems because regulatory processes are absent or have been intefered with, many herbivores emerge as pests of some significance. For example, grass grub (*Costelytra zealandica*) on roots, Porina (*Wiseana cervinata*) on foliage, Argentine stem weevil (*Hyperodes bonariensis*) on graminaceous tillers and clover case bearers (*Coleophora* spp.) on seeds.

(b) Herbivority on decomposer organisms, especially fungi and bacteria.

Springtails and mites are mainly involved in this activity which is of importance as these arthropods can both retard and accelerate the growth of decay organisms.

(c) Symbiotic processes.

(d) Predation.

(e) Parasitism.

(f) Decomposition.

Decomposition, herbivority, predation, parasitism, and to a small extent symbiosis and commensalism, are the principal biological processes responsible for transport and storage of materials and energy. The interactions of organisms engaged in these activities provide the pathways of distribution. These activities provide the momentum necessary to the maintenance of soil formation and nutrient cycling processes. Disturbed ecosystems may or may not operate effectively in this regard and in agro-ecosystems man may be forced to substitute by artificial manipulation. Work of significance has not been conducted in New Zealand to provide a full understanding of the effect of agricultural and silvicultural practices on decomposer populations.

Intensive agriculture invariably interferes with predation and parasitism; important density dependent regulatory processes. Several interesting, but largely unquantified examples of this can be found in New Zealand. Parasites and predators of both porina and grass grub abound around bush margin or relatively undisturbed tussock grassland situations, whereas their numbers and influence on host populations are negligible on previously cultivated, heavily stocked pastures sown with introduced grasses and clovers. One important density dependent regulatory process, intraspecific larval competition appears to be enhanced in *C. zealandica* populations by intensive grassland farming (Kelsey 1951).

II Transport of fruiting bodies, (fungal spores) gametes (pollen) and other animals (phoresy).

(a) Pollination, of leguminous and curcubit crops, fruit trees etc. The role of bees introduced into New Zealand, and the reduced importance of native solitary bees in habitats modified by man, is well understood and will not be enlarged on in this paper.

(b) Spore transfer. Insects and other invertebrates undoubtedly assist the rate of decomposition in all ecosystems by carrying fungal spores on their bodies to new food sources.

(c) Phoresy. This phenomenon is often encountered in New Zealand but the importance of mites transported on Scarabaeids and other large insects is unknown.

III Soil improvement processes

By breaking down organic matter, the litter fauna and microbial flora release minerals, making them available for plant growth. In this process the roles of the microflora and invertebrate fauna are closely related. The combined influence on litter decomposition is far greater than if the microflora operated alone. The animals prepare litter for microbial action, by altering its chemical and physical nature, increasing its surface area, mixing and transporting it into the soil. Most often, decomposition is begun by the microflora, after the plant residues have been wetted, but thereafter the animals hasten the process by breaking up the plant debris. Only a few animals can feed on plant litter in its raw state. Quite obviously succession is important in litter breakdown and its incorporation into soil. It is equally obvious, depending on the amount and length of disturbance, that the role and variety of animals involved in these processes is markedly influenced by agricultural practice. The main soil improvement processes, many of which are not clear-cut and inter-act together are briefly as follows:

(a) Incorporation of wood and other organic debris into soil, i.e. Tasmanian grass grub (*Aphodius tasmaniae*), Porina (*Wiseana* spp.) and lumbricid earthworms in pasture soils.

(b) Humification. Animals are important to humus formation in three ways: by selective decomposition of organic residues, in the transformation of organic residues to humic substances and their effect on soil structure by formation of aggregates.

(c) Translocation of mineral soil to the surface, e.g. Introduced lumbricid worms, *A. tasmaniae*, and the dung beetles *Onthophagus* spp. and *Copris incertus*.

(d) Creation of habitats for smaller soil fauna and micro-organisms by production of better soil tilth.

(e) Pore formation, which results from both tunnelling or burrowing activity and the formation of soil aggregates or crumbs. Pore space aids drainage, soil aeration, CO_2 escape, penetration of roots and movement of other soil animals. Root establishment and the activity of decomposers are favoured by both improved aeration and drainage. Earthworms particularly are most important in this regard, although certain pest species such as *C. zealandica, Wiseana* spp. and *A. tasmaniae* also make contributions in disturbed agro-ecosystems.

(f) Improvement of soil texture, by incorporation of organic matter into the soil, which also results in;

(g) Increase in water holding capacity.

(h) Enhancement of soil structure.

(i) Stabilisation of soils.

(j) Modification of soil pH. Earthworms neutralise carbonic acid in the soil by utilising calcium reserves within their bodies and isopods, millipedes and enchytraeids have a similar mechanism.

(k) Formation of clay-humus colloids which assist nutrient ion retention.

(l) Improvement of nutrient status by breaking down organic matter into smaller particles with greater surface area, thus playing an initial and essential role in the mineralisation of organically fixed nutrients. The role of lumbricid earthworms has been long established in this regard, but Yaacob (1967) has shown that the passage of organic material through *C. zealandica,* also results in an increase in the amounts of mineralised nitrogen in soil.

IV Other benefits

(a) Distribution of soil insecticides and fertilisers down the profile. These roles have been shown by Stockdill (1966) to be affected by *Allolobophora caliginosa* when introduced into grassland previously devoid of Lumbricids.

(b) Indirect control of troublesome species e.g., burial of dung, which breeds flies, by *Onthophagus* spp. and *Copris incertus* in northern areas of New Zealand.

(c) Increased pasture production, as a result of one or more of the above benefits (Stockdill 1966).

V Detrimental roles

Not all " insect " activity in modified terrestrial ecosystems is beneficial from man's point of view. The following problems may arise:

(a) Crop, pasture or pastoral produce losses, due to pest outbreaks favoured by man's monoculturing activities, (Pottinger, 1973) a subject that requires no further expansion in this paper.

(b) Erosion of worm and insect castes by wind and water run-off. The casting activities of *A. tasmaniae* on dry northern hill slopes could be important in this regard and has been pointed to by Pottinger (1968).

(c) Pastures are often opened up, and weed species invade the sward or else a particular species of clover or grass is allowed to dominate with adverse effects on pasture production or stock health.

(d) Water retention of soils is decreased, with subsequent bad effects; namely, less tolerance of the remaining vegetation to droughts, reduced seasonal production and increased erosion potential.

(e) Disease vectors. The role of aphids and leafhoppers in the transmission of viruses in grassland and agricultural crop systems is well documented. In New Zealand the importance of aphids as vectors of crop disease is well known, but their role in the transmission of grassland disease has been largely neglected.

(f) Build up of grass litter in pastures as a result of Argentine stem weevil (*H. bonariensis*) attack on grasses in summer months, probably favours growth of the fungus *Pithomyces chartarum,* and subsequently outbreak of facial eczema in sheep and cattle in northern areas of New Zealand.

It is apparent from this summary, however, that the beneficial roles of insects even in modified terrestrial ecosystems possibly far outweigh their deleterious roles, when these are expressed as conflict to man's material interests.

THE EFFECT OF MAN ON MODIFIED TERRESTRIAL ECOSYSTEMS

If we are to fully appreciate the role of "insects" on modified terrestrial ecosystems then it is important that consideration is given to the effect of man's main agricultural activities on them. Man modifies terrestrial arthropod populations wherever he cultivates, fertilises, drains, irrigates, changes the vegetative cover, grazes animals, burns or discards wastes. Under some situations, such as the addition of organic manure, soil populations are favoured, but generally man's activities have a deleterious effect on numbers and activities of various species.

The main modifying activities with brief comment on some of them are as follows:

1. Fire. Fire has been an integral part of agricultural development in New Zealand. It is still used to a lesser degree today for clearing crop wastes before cultivation, stimulating edible growth on tussock grasslands, and reclamation of scrub and forest land for pasture development. Fire is catastrophic, and its immediate effects are:

(i) Destruction of litter — but not all.

(ii) Destruction of the aerial growth of plants and abrupt termination of the organic cycle.

(iii) Release of plant nutrients, formerly bound in plants and litter in levels comparable to normal applications of fertilisers. This undoubtely favours the transition from scrub to improved grassland whilst the faunal changes essential to maintaining the organic cycle take place.

A study on the effect of fire on fauna during development of grasslands from scrub in New Zealand was made by Miller, Stout and Lee (1955). They found that the immediate effect of burning was to reduce and displace the litter fauna, but not the soil fauna. There was a temporary resurgence of litter fauna accompanied by exploration of atypical niches, followed by extinction of all but a few groups of fauna. Top soil earthworms were eliminated by failure of suitable food supplies but subsoil species survived. Temporary and predatory soil animals were not affected as much as other groups. Survival was proportional to the heat experienced during the fire.

2. Cultivation. Like fire cultivation has catastrophic effects, completely eliminating the surface fauna, initially reducing the soil fauna, but eradicating even this if the cultivation is continued. Mortality is either due to burial or mechanical damage. Subsequent to cultivation phytophagous species (pests) often build up on the crop. A set of studies conducted by Barratt (1967), Luxton (1967), Dutch (1967) and Stout & Dutch (1967) at Pukekohe showed that pore space and animal populations were markedly reduced by cultivation compared with grassland soils. Earthworm and some insect populations were high under pasture but had totally disappeared from the cropping area. After two years of cropping, earthworms had been reduced to one twelfth of nearby pasture populations. Only transient springtail species survived in the soil after 30 years of cropping; after two years, a single mite and one springtail species survived. In the permanent pasture area, insect and mite counts were high with a diversity of species present, whereas in one year old pasture sown after 50 years of cropping a typical grassland fauna had not fully established. One species of springtail and various aphids had established well, but the total number and diversity of mite species was low. These results agree with those of Sheals (1956). It is easily concluded that arable ecosystems have a much poorer fauna than uncultivated areas.

Implements affect soil fauna in different ways, mouldboard ploughing favours survival more than surface working implements. Kain & Atkinson (1970) have demonstrated the benefits of reducing grass grub populations by cultivating when the grubs are in the pupal stage, whilst McLennan & Pottinger (in press) have demonstrated that surface working of grassland in autumn can result in 78 percent mortality as a result of mechanical damage. Additionally, the number of cultivations may or may not be important. Dixon (1974) suggests six cultivations over a six week period is essential to control soldier fly whilst, Cumberland *et al* (1974) found that as little as one cultivation can be adequate.

Beside mechanical injury and straight burial, cultivation exposes soil animals to predation, frost action and dessication.

3. Stock Treading and grazing. Heavy stocking even for short periods of time can result in consolidation of soil, and compaction of the surface soil, so that accumulating CO_2 in the soil and a reduced O_2 supply result in increased soil animal mortality. East & Pottinger (1972, 1975) have indicated that mob stocking of sheep on irrigated pastures reduced grass grubs by 20-30 percent. In contrast to this effect Kelsey (pers. comm.) suggested grazing of pastures oversown with barley to " catch " the eggs of Argentine stem weevil (*H. bonariensis*), as a means of controlling this pest, and as a consequence has indicated a means by which the surface fauna in modified terrestrial ecosystems can be removed.

4. Fertiliser applications. The influence of these is generally indirect if applied at acceptable rates apart from the adverse effect of sulphate of ammonia on worms. Fertilisers (like irrigation water) by stimulating plant growth and bacterial activity stimulate a richer fauna and in some situations induce a sward more tolerant to pest attack.

5. Changes in vegetative cover. Changes in sward composition at a species level can cause marked changes in the phytophagous feeders but probably do not influence changes in the decomposer mite and springtail populations as much as over or under grazing. Overgrazing removes more from the organic cycle and therefore must rely on greater farmer inputs of inorganic fertilisers to compensate. Overall, one suspects that heavily stocked pasture systems would have lower pest, carnivore and decomposer populations than moderately or undergrazed swards, but definitive work on these aspects has not been concluded in New Zealand. Undergrazed swards return more organic matter to the soil and probably support a more diverse fauna. Under acid conditions there would be

less springtail and greater mite activity and accumulation of a surface litter; whereas in more neutral soils springtail populations and a thinner litter should prevail.

An important way in which populations can be checked is by the use of resistant plants — something which is reasonably well developed for use against crop pests, but is only in process of development for use against pasture insects in this country (Farrell & Sweney 1972 and 1974, Farrell *et al* 1974 and Kain & Atkinson 1975).

6. Irrigation. Well regulated watering by promoting plant growth must promote a richer and bigger soil fauna. Research by Kain (pers. comm.) has revealed that grass grub populations fluctuate in response to moisture level; the prepupa-pupal phase being sensitive to excessive soil moisture and the early larval instars to soil drying. This indicates the possible use of water to regulate insect populations as distinct from stimulation of plant growth.

7. Farm wastes. No work has been conducted in New Zealand on the effect that dairy shed effluent has on grass production, but in Europe dung applications have been shown to increase coprophagous, saprophagous and their dependent species (Morris 1922, 1927).

8. Introduced biological control agents. A variety of parasites and predators have been introduced to control crop and pasture pests in New Zealand. These are well known (Given, 1967 and Valentine, 1975) and will not be considered further in this paper.

9. Bee management and activity. The activity of many native solitary bees has been curtailed by elimination or modification of the indigenous habitat although *Leioproctus fulvescens* appears to have been favoured by the array of composite weed species inhabiting our pasture lands. An equally great impact has been made in New Zealand by the introduction of the honeybee and bumble bees (either to ensure natural regeneration of swards or enhance small seeds crop yields). Recently alkali and leaf cutter bees have been introduced in an attempt to enhance pollination of lucerne seed production, but their impact is still being assessed.

10. Agricultural chemicals particularly insecticides. This is an area on which considerable overseas, but little New Zealand information is available. Kelsey and Arlidge (1968) reported on the adverse effects of isobenzan on plants, pasture fauna and as a consequence of reduced animal activity, increased soil bulk density. Grass grub and porina populations were eliminated and springtail, fly, mite, Hemiptera and worm populations dramatically reduced. Their paper serves as an illustration of the worst effects on beneficial organisms, which follow applications of insecticides.

More recently Martin (1973) has initiated more comprehensive trials to assess the effect of commonly used pasture insecticides at commercial rates on non-pest pasture fauna. His preliminary results indicated no pasture yield differences between control and his four treatments, which may reflect measurement over too short a period, or restriction of treatments to a single early winter application. To summarise, he found that:

Fensulfothion reduced nematodes by 57 percent and retarded populations for at least 18 months.

Carbofuran reduced worm populations by 42 percent (Control = $800/m^2$) and suggested that decomposition of worms, by encouraging free living nematode populations, may have counteracted this material's known nematicidal effects.

Both fenitrothion and fensulfothion reduced populations of several species of Collembola.

The soil aphid *Aploneura lentisci* was reduced by all treatments except fenitrothion, but fenitrothion (and carbofuran) reduced surface dwelling species of aphids.

DDT did not appear to have any significant immediate effect on the fauna.

The question arises from Martin's work however, as to how applicable these results are to other pasture types, soil types or climatic zones. The absence of slugs, porina, grass grub, and millipedes suggest that these results may not be typical of large areas of New Zealand. Comparison is difficult because so little is known about the fauna of New Zealand's exotic or native grasslands. Martin's work serves to illustrate; that understanding of the effects of insecticides on grassland insects is a complex study, and there is a need to achieve a much better understanding than is available at present.

GENERAL SUMMARY ON THE ROLE OF FAUNA IN DIVERGENT AGRO-ECOSYSTEMS

In crop ecosystems, simplification and catastrophic interference by man results in reduction to all but the primary trophic level of plants, transient animals, a few specialist decomposers and phytophagous pest species which affect the plants by direct feeding or transmission of disease (viruses in particular). Because a significant part of most crops are harvested, only the residues (if not burnt) and the root systems remain to sustain a limited decomposer population or to build a higher level of organic matter in the soil. Apart from the pest herbivores and their carnivores which have adapted to the crop monocultures, the secondary and tertiary trophic levels are largely eliminated.

In both short term pastures and crop ecosystems the beneficial role of soil animals is severely restricted or eliminated and the systems can only be maintained by cultivation, fire, addition of fertilisers and water management. The main role of insects in these systems are as pests or biological regulators of pest populations.

In long term pastures, however, if the grazing pressures are not too intense a more stable situation approaching the self-sustaining natural meadow land and undisturbed grasslands prevails. There is still a need to maintain pasture vigour by regular application of lime and other inorganic fertilisers, and it is only in rangeland situations that man's removal of organic matter from the system is low enough to allow this practice to be negated. Because there is some return of litter and animal excrement and less disturbance of the soil, populations of soil animals, their diversity and the roles they play are considerably greater. Improved grasslands have markedly increased mite, springtail, earthworm and macro-arthropod populations over other agro-ecosystems in New Zealand. While there may be greater diversity of species in natural grassland, the total numbers or biomass is considerably less.

Increased use of nitrogenous fertilisers or soil nitrogen by use of clovers in swards favours earthworm populations and because of this soil formation processes are enhanced in comparison with natural grasslands.

Soil animals are important in the maintenance of soil fertility and stimulation of plant growth. An ideal agro-ecosystem would be a self-perpetuating one, but because energy stored in the crop is distributed elsewhere the more man extracts organic matter from the system, the more intense his husbandry activities must be to make good his losses.

It may be concluded that in an agro-ecosystem man is of greater importance than insects or any other major faunal group — with the possible exception of earthworms!

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