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MEASURING SUSTAINABLE DEVELOPMENT

APPLICATION OF THE GENUINE PROGRESS INDEX TO NOVA SCOTIA

GPI AGRICULTURE ACCOUNTS, PART TWO: RESOURCE CAPACITY AND USE: THE VALUE OF AGRICULTURAL BIODIVERSITY

Prepared by:
Jennifer Scott, MES
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EXECUTIVE SUMMARY

"There is no question but that land is alive. All in a life cycle…. To have productivity you have to have life for the breakdown process."
-Kings County poultry farmer

Agricultural production depends on a healthy, fully-functioning ecosystem. In other words, the production of food depends on the services nature provides, such as pest control, nutrient cycling, pollination, waste decomposition, soil formation, nitrogen fixation, bioremediation of toxins, and many others.

Biodiversity is both the diversity of living organisms, and the interactions between those organisms. In order to understand biodiversity and its importance for maintaining ecosystems – including agricultural ecosystems – we need to study those organisms, and ascertain their numbers, their diversity, and their preferred habitats. We also need to understand and value the productive work they do, and how to encourage this work on farms. Biodiversity is the foundation upon which the earth's productive capacity is based. Humankind might be able to produce food with diminished biodiversity, but it would become a progressively more expensive enterprise – both financially and ecologically. Thus when we evaluate progress in agriculture, we must also include evaluations of the state of biodiversity on farms.

To a limited extent, ecosystem services provided freely by earth's biodiversity can be replaced by using purchased inputs of energy, built structures, synthetic fertilizers, pesticides, irrigation systems, and pharmaceuticals. On the one hand, these purchased inputs help to make agriculture more predictable, and may increase short-term yields. On the other hand, some inputs used to replace ecosystem services may be harmful to biodiversity, thus reducing the capacity to generate further ecosystem services. This can create a spiral of increasing needs for inputs, and reduced capacity of agriculture to tap into 'free' services. Depletion of ecosystem services, like any other critical resource, can be self-defeating, expensive, and ultimately reduce long-term net productivity and farm viability.

"Good farmers know … that nature can be an economic ally"
(Berry, 2002:54).

There are a number of indicators of the state of biodiversity on farms. These include indicators of domestic and wild species diversity, genetic diversity, habitat (quantity and quality), and the value of ecosystem services. Here we focus mostly on (1) habitat, and (2) the value of ecosystem services. Habitat is an important indicator because it is relatively easy to measure, compared to listing and counting all of the organisms that live within the habitat. Assessing the value of ecosystem services is more challenging, but it is a critical indicator because it measures the value of *what organisms do*, rather than just measuring *what organisms are present*. It is admittedly a very utilitarian approach to biodiversity, but one that will succinctly indicate its value to agriculture, thus catalysing more immediate action to conserve biodiversity resources.

Habitat

One way to assess the health of agricultural biodiversity is to monitor the homes or habitats of organisms we know are beneficial. In fact extensive agriculture – the kind of agriculture common in Nova Scotia – can create critical and excellent habitat for such organisms. In return, these organisms can be harnessed to provide ecosystem services for the farm – a remarkable symbiotic relationship.

> *"I'm really enjoying the symbiotic relationships that are developing on the farm. We took an abandoned farm and turned it into a place teeming with life. There were no snakes before, no toads, no salamanders, few earthworms. The soil we turn over now is full of earthworms. We see different kinds of birds and more of them now than before."*
>
> *-Hants County specialty vegetable farmer*

Rather than looking at agriculture as an infringement upon wild, natural spaces, farms could be seen as reservoirs of habitat potential. Farmers, as stewards of the land, are providing habitat for thousands of organisms. Because farms are generally collections of crops, livestock, buildings, fields, ponds, streams, patches of trees, and woodland, they are ideal homes for many creatures. Agriculture can even *increase* the diversity of habitat types relative to other land uses, and produce food too. Table 1 summarises the types of land use and farm practices most relevant to biodiversity.

Table 1: Land Use and Farm Practices that Affect Habitat

Land use that affects habitat	NS data?	Habitat effect on beneficial organisms
Area of land in annual crops	Yes	Beneficial organisms are generally less prevalent and less active in annually cropped vs. perennial areas of the farm.
Area of land in perennial crops or pasture (uncultivated)	Partial	While pasture and hayland is generally favoured by many beneficial organisms, high levels of nitrogen (N) fertilization, herbicides, land drainage, and high-intensity grazing are all variables that tend to reduce species diversity on pastures and land growing hay.
Area of land that is not cropped or grazed	Some data, some years	Hedgerows, forest, wetlands and riparian zones are important habitat for predators of pests, including birds as well as a host of other species.

Land Use and Farm Practices that Affect Habitat (continued)

Farm practices that affect habitat	NS data?	Habitat effect on beneficial organisms
Adding fertility to the land	Area fertilized, yes	Increases the activity of soil micro-organisms up to an optimal fertility, then further increases in fertility may decrease their activity.
Raising the pH of acid soils	Area limed, yes	Increases the activity of soil micro-organisms up to an optimal site-dependent pH, then decreases their activity.
Use of synthetic pesticides	Area of pesticide use, yes	Reduces abundance of soil micro-organisms
		Faunal diversity (e.g. arthropods and birds) is negatively affected by organophosphate-based pesticides (used sometimes on livestock and arable crops), and anthelmintics (dewormers used in livestock). The anthelmintics leave residues in livestock dung that adversely affect dung-dwelling invertebrates.
Organic or biological farming	Some data, 2001 only.	Density, abundance, and species diversity of beneficial birds and arthropods are significantly higher in organic or biological systems compared with conventional or integrated systems.
Crop rotation	Difficult to assess.	Monoculture reduces soil organisms species numbers (richness) and may actually increase the organism count (abundance) of the fewer remaining species.
		Diverse crop mix improves bird species diversity
Conservation tillage	Yes	Improves habitat for many soil invertebrates.

Trends in Land Use

In Nova Scotia, the proportion of farm land in annual crops is 11%, almost unchanged in 50 years, while the proportion of land in tame hay or pasture has risen from 10% to 24% in the last 50 years. These proportions are favourable for habitat compared to Canadian averages. The proportion of Canadian farmland in annual crops is between 40% and 45% (up from 32% in 1951), and the proportion of land in tame hay and pasture is about 18%. Within Nova Scotia, the most intensively-farmed county (Kings) has 28% of farm land in annual crops, and 23% of the land in tame hay and pasture (Figure 3).

In Nova Scotia and Kings County, about 8% of the farm land area has 'natural land for pasture.' This portion of the land has remained stable for the years reported (1986 to 2001). Natural land for pasture is a very important habitat on farms, because it has not been cultivated, drained, or treated with synthetic inputs.

The portion of farmland in 'woodland' is reported in census data up to 1986, when it occupied 48% of farm land in Nova Scotia. The *quality* of forested or wooded land habitat is not reported (as indicated by the method of cutting, or diversity of species, for example), making the data difficult to interpret in terms of habitat quality and the value of this habitat for generating ecosystem services.

Trends in Farm Practices

Many studies report reduced habitat quality, species diversity, and ecosystem services as a result of synthetic fertilizer use (particularly rates of nitrogen over 50 kg N/ha) and synthetic pesticide use. Average nitrogen fertilizer use (kg N/ha of cropland) in Nova Scotia in 1990 was below this 'threshold' (Table 2), which indicates that Nova Scotian farms may not be subject to a level of fertilization that would significantly compromise biodiversity. The data *does* show that the increase in N fertilizer use has been continuous over time, with each agricultural census showing higher usage rates. (Unfortunately, average N fertilization rates are not available from Statistics Canada after 1990.) In addition, there will be areas of cropland fertilized at much higher rates of N than the reported average.

In Tables 2, 3 and 4, the areas on NS, Kings County, and PEI farms that are fertilized, sprayed with insecticides and fungicides, and sprayed with herbicides are reported. For the last reporting year (2000), an average of 22% of total farm area was fertilized on NS farms, 36% of total farm area in Kings County (the province's most intensively-farmed county), and 42% of total farm area in PEI. NS farms are also subject to considerably lower levels of pesticide and herbicide application than in PEI, though Kings County pesticide use is approaching PEI levels. This indicates that on average, Nova Scotia farms are subject to a lower amount of synthetic input use than in neighbouring PEI. The higher the percent of total farm area subject to fertilizer and pesticide use, the more likely that habitat and ecosystem services provided by beneficial organisms will be compromised.

Table 2: Intensity of Synthetic Input Use, Nova Scotia Farms, 1970-2000

Year	Mean kg N fertilizer per ha cropland	Area fertilized		Area sprayed with insecticides or fungicides		Area sprayed with herbicides	
		ha	% area of farms	ha	% area of farms	ha	% area of farms
1970	25.0	38,150	7.1	9,971	1.9	15,567	2.9
1980	37.7	88,537	19.0	11,109	2.4	20,863	4.5
1985	41.8	85,042	21.1	12,165	2.9	24,744	5.9
1990	46.1	82,267	20.7	13,466	3.4	22,383	5.6
1995	n/a	88,552	20.7	22,618	5.3	26,621	6.2
2000	n/a	88,376	21.7	28,217	7.0	29,686	7.3

Note: In Tables 2, 3 and 4, data on insecticides and fungicides for 1995 and 2000 are comparable with each other, but not with previous years. Data for 1995 and 2000 are the sum of area sprayed with insecticides and area sprayed with fungicides. Some areas may be sprayed with both, and therefore counted twice. Previous to this, only one question was asked (area sprayed with insecticides or fungicides?), which eliminated double counting. However, the 1995 and 2000 data reflect more accurately the intensity of use. These different reporting requirements and the possibility of double-counting in the 1995 and 2000 data may explain the apparently very sharp increases in reported insecticide and fungicide use for Kings County and PEI between 1990 and 1995.

Table 3: Intensity of Synthetic Input Use, Kings County Farms, 1980-2000

Year	Area fertilized		Area sprayed with insecticides or fungicides		Area sprayed with herbicides	
	ha	% area of farms	ha	% area of farms	ha	% area of farms
1980	22,698	34.0	7,814	11.7	10,154	15.2
1985	21,710	36.0	8,375	13.9	11,582	19.2
1990	17,502	31.0	7,501	13.3	9,074	16.1
1995	20,058	35.7	13,841	24.6	11,689	20.8
2000	19,030	36.2	14,440	27.5	11,173	21.3

Sources: Statistics Canada, 2002; 1997a and b; 1995; 1982.

Table 4: Intensity of Synthetic Input Use, PEI Farms, 1980-2000

Year	Area fertilized		Area sprayed with insecticides or fungicides		Area sprayed with herbicides	
	ha	% area of farms	ha	% area of farms	ha	% area of farms
1980	107,442	37.9	31,984	11.3	81,789	28.9
1985	113,297	41.6	35,039	12.9	85,573	31.4
1990	102,117	39.5	36,161	14.0	73,783	28.5
1995	119,451	45.0	91,267	34.4	91,367	34.5
2000	110,102	42.1	89,808	34.4	92,732	35.5

Sources: Statistics Canada, 2002; 1997a and b; 1995; 1982.

In Table 5, the most recent data for areas fertilized, sprayed with insecticides and fungicides, and sprayed with herbicides are reported for Nova Scotia, Kings County, PEI, and Canada. The proportion of farm area is lower, in each case, when comparing Nova Scotian with Canadian areas. Both Kings County Nova Scotia and PEI have higher input use intensities (as measured by proportion of farm area sprayed and fertilized), most likely because of the intensive nature of farming in these areas and the high proportion of fruits and vegetables grown.

Table 5: Intensity of Synthetic Input Use, NS, Kings Co., PEI, and Canadian Farms, 2000

Location	% area of farms fertilized	% area of farms sprayed with insecticides or fungicides	% area of farms sprayed with herbicides
NS	21.7	7.0	7.3
Kings County	36.2	27.5	21.3
PEI	42.1	34.4	35.5
Canada	35.6	7.1	38.4

Source: Statistics Canada, 2002.

Overall it appears that Nova Scotian farms are being managed in a more intensive manner over time. Substantially higher proportions of farm area fertilized and treated with pesticides, along with a slight recent increase in area used for annual crops indicate a definite increase in intensity. Within Nova Scotia, Kings County is farmed more intensively than average Nova Scotian farms. Nova Scotia is in a fortunate position to be managed much less intensively than Canadian farms in general and PEI farms in particular. From the data available (which is far from complete), it appears that NS farms still offer significant quantity and quality of habitat for beneficial organisms to live, and for beneficial ecosystem services to occur, although trends over time also indicate that these advantages may be increasingly compromised.

Ecosystem Services

Ecosystem services are the services, such as pollination, that organisms provide as they go about their regular business of living. For example, the bee obtains nectar from the flower, and the flower gets pollinated so it can produce fruit. There is usually some element of benefit, for example the plant carries out a process of photosynthesis in order to grow, but at the same time produces oxygen that human beings can breathe. There are a *diversity of functional ecological roles*, and *beneficial ecological interactions* between species. The variety of ecosystem interactions between plants, animals, and micro-organisms maintains the *quality, relative stability,* and *habitability* of the environment by purifying and regulating air, water, and land resources – as well as controlling climate. Ecosystem interactions play a role in the protection of water resources; the formation and protection of soil; the storage and cycling of nutrients; the breakdown and absorption of pollution; the maintenance of ecosystems' equilibrium (including controlling pests); and the recovery of ecosystems from unpredictable events. In addition, ecosystems provide *biological resources*, such as wild food, medicines, and wood products.

Another way to assess the health of biodiversity is to place an economic value on the ecosystem services it provides to agriculture. If society does not explicitly value biodiversity, its services tend to go unnoticed in conventional systems of accounting. In fact, if we rely almost exclusively on economic growth statistics to measure our progress and prosperity, as we currently do, we could irreparably damage our own life-support systems without noticing the damage until it is too late. If, on the other hand, we value ecosystem services explicitly, then we know we are making progress when their value rises over time. If their value diminishes, then society and farmers have an early warning system in place that allows them to take remedial action before it is too late, and before irreversible damage occurs. If ecosystem services are not functioning properly, we know that we are losing our ability to sustain food production in the long run.

Farmers can choose to foster farm environments that allow them to take advantage of ecosystem services. Or alternatively, they can choose to purchase inputs that replace the work done by beneficial organisms, which may produce higher yields in the short term. However, the extra energy (i.e. cost) required to implement these solutions may negate any yield gains that result. Table 6 shows some of the internal (ecosystem-based) and external (fossil fuel-based) choices available when production challenges are encountered. Many farms will use a combination of the two. The advantage of ecosystem-based solutions is that they are a renewable resource, always and indefinitely available for free if sustainably managed, and that they tend to produce a wide range of beneficial side-effects that more specialized synthetic inputs cannot achieve. In fact, fossil fuel-based solutions are based on non-renewable resources, and may produce harmful side-effects (e.g. killing beneficial insects with insecticides).

Table 6: Examples Of 'Internal' Vs. 'External' Solutions To Production Challenges

Production challenge	Internal (ecosystem service) solutions	External (fossil fuel-based) solutions
Water stress - drought	• reduce drying winds and increase shade with hedgerows • increase water holding capacity of soil with soil organic matter and crop residue management	• irrigation using plastic hosing and gas-powered pumps
Water stress - excess	• increase organic matter of soil, which helps soils drain excess moisture • leave ponds and trees where drainage is not ideal • leave wetlands and sufficient forests in place to prevent flooding	• install plastic drain tile
Pest or pathogen control	• provide habitat for beneficial organisms • regulation by competing organisms, predators and parasitoids • optimal levels of fertility • crop rotation • appropriate field size	• use of pest control products
Fertility management	• feed soil life with materials high in organic matter such as crop residues and livestock manure	• application of purchased synthetic fertilizers

As an introduction to the topic of ecological services, Table 7 presents a sample of services provided by beneficial organisms. Many ecological services will not be covered in this table, and many have yet to be discovered. The information presented is meant to demonstrate the wide range of activities in an agro-ecosystem that are possibly being taken for granted.

Table 7: A Sample of Ecological Services Provided by Beneficial Organisms

Soil fertility & nutrient supply	
Service	**Detail**
Nutrient transform-ations	Proteins and related compounds are transformed by soil life to plant-useable nitrates and ammonium compounds. Similarly, sulfate is produced and mineral elements such as iron and manganese are kept relatively insoluble to prevent toxic accumulations.
	Soil micro-organisms mineralize soil organic phosphorous (P) for plants to use. The rate of P mineralization depends on microbial and free phosphatase (enzyme) activity. Phosphatases are produced by micro-organisms, plants, and earthworms. It appears that synthetic P fertilizer may reduce this soil activity, and organic management enhances it.
Yield improvement	In New Zealand, introduction of earthworms produced a 28% improvement in dry matter yield in pastures that previously had no earthworms. In Vermont, pasture production increased up to 25% in pastures with earthworms compared to pastures without earthworms.
	Micro-organisms in soils produce numerous root-stimulating substances that behave as plant hormones and stimulate plant growth. Humus also can stimulate roots to grow longer and have more branches, resulting in larger and healthier plants.
Vesicular arbuscular mycorrhizae help crop productivity	Arbuscular mycorrhizal (VAM) symbiosis is widespread in roots of agricultural plants. It is believed to ameliorate plant mineral nutrition, to enhance water stress tolerance, and to contribute to a better soil aggregate formation, which is important for soil structure and stability and helps prevent erosion. It appears that synthetic pesticides may reduce AM activity, while organic management enhances it. Organic systems had measured increases in AM activity of 30-900% relative to conventionally farmed systems. Preliminary evidence shows positive yield effects of AM fungi.
	Roots that have lots of mycorrhizae are better able to resist fungal diseases, parasitic nematodes, and drought.
Nitrogen fixation	Nitrogen gas in the atmosphere cannot be used directly by crops without the help of rhizobium bacteria and free-fixing bacteria present in the soil.
	Estimated value to US agriculture of $8 billion per year (1997 US funds).
Organic matter decomposition	Significant contribution of soil fauna and flora. Organic matter decomposition prevents unwanted accumulation of residues; releases nutrients for use by plants; and improves soil structural stability. (Without this vital process, food would have to be grown hydroponically – an expensive proposition.)
Soil formation and soil mixing	Earthworms and other invertebrate species bring between 10 and 500 tonnes per ha per year of subsurface soil to the surface, contributing an estimated 1 tonne per ha per year to the fertile topsoil layer. Under agricultural conditions, it takes approximately 500 years to form 25 mm of soil, whereas under forest conditions it takes approximately 1000 years to form the same amount of soil. This enhanced soil formation capacity in US agriculture is valued at $5 billion using a figure of $12 per tonne (1997 US dollars).
Composting –stabilize nutrients, reduce volume of material applied to fields	The major groups of organisms that help convert raw materials to compost are bacteria (excellent decomposers), fungi (highly effective in tackling woody substances), and actinomycetes (technically bacteria – they thrive in aerobic, low moisture conditions).

Regulation of pests and pathogens	
Service	**Detail**
Healthy crops	A diverse biological community in soils is essential to maintaining a healthy environment for plants. There may be over 100,000 different types of organisms living in soils. Of those, only a small number of bacteria, fungi, insects, and nematodes might harm plants in any given year. Diverse populations of soil organisms maintain a system of checks and balances that can keep disease organisms or parasites from becoming major plant problems. Some fungi kill nematodes and others kill insects. Others produce antibiotics that kill bacteria. Protozoa feed on bacteria. Some bacteria feed on harmful insects. Many protozoa, springtails, and mites feed on disease-causing fungi and bacteria. Beneficial organisms, such as the fungus Trichoderma and the bacteria Pseudomonas fluorescens, colonize plant roots and protect them from attack by harmful organisms. Some of these organisms, isolated from soils, are now sold commercially as biological control agents.
Pathogen control	In the process of decomposition, soils render harmless many potential human pathogens in waste and in the remains of dead organisms. Soil organisms produce potent antibiotic compounds, such as penicillin and streptomycin, manufactured by a soil fungus and a soil bacterium, respectively.
	An Australian experiment showed that soils managed organically hosted a higher occurrence of fungi potentially antagonistic to plant pathogens than did conventionally managed soils.
	Earthworms remove plant litter from the soil surface (this can have pest/disease control effects in orchards e.g. apple scab prevention). Apple producers in the Annapolis Valley spend an average of $648-675/ha on apple scab control products (fungicides) – c. 75% of total pest control products expense.
	Earthworms also quickly break down manure in pastures; recycling nutrients, and reducing fly reproduction sites and internal parasite larvae levels in grazing livestock.
Aerial insect pest control	Bats catch an estimated 3,000 insects per night. Swallows catch insects in open areas. Yellow warblers catch all types of insects including those considered to be pests. Dragonflies and damselflies are major predators of mosquitoes and blackflies, which prey on farmers. Downy woodpeckers consume large numbers of insects including corn borers. Flickers eat insects of all types and feast on grasshoppers in late summer.
	In one study, bird predation on insects in US spruce forests is estimated to be worth $180 per ha per year (1997 US funds), or $246.6 per ha per year ($1997 Canadian).
Rodent pest control	Short-eared owls, barred owls, and red-tailed hawks are valuable for controlling rodents
Biocontrol of crop pests	Approximately 99% of pests are controlled by natural enemy species and host plant resistance. Each insect pest has an average of 10-15 natural enemies that help to control it. The estimated value of this biocontrol to US agriculture is $12 billion per year (1997 US funds), or $16.4 billion per year ($1997 Canadian).
	A full-grown ladybird beetle larva can consume about 50 aphids daily. An average female will eat at least 2,400 aphids before she dies.
	Beneficial wasp predators and other natural pest controls may have a value of $561,000 per year to Nova Scotia fruit orchards.
	Anecic earthworm species reduce leaf miner pupae incidence in orchards

Regulation of pests and pathogens (continued)	
Service	**Detail**
Host plant resistance	Genetic traits in crops that help them resist pests and pathogens. An estimate of its value in the US is $8 billion per year (1997 US dollars), or $11 billion per year ($1997 Canadian).
	Species and genetic diversity of crops helps to foster long-term horizontal resistance to pathogens over time if the farmers select and save their own seed.
Disease control	Anecic earthworm species reduce scab pathogens in orchards.
Buffer crops from toxic substances	Humus – the very well decomposed part of organic matter – can surround potentially harmful chemicals and prevent them from causing damage to plants.
Antibact-erial activity	Honeys from different floral sources vary greatly in their antibacterial activity.

Maintenance of water quality and quantity	
Service	**Detail**
Improved water infiltration in soil and erosion prevention	Erosion-prevention effects of the soil biota include improvements in soil aggregation, prevention of surface crust formation, and increase in water infiltration capacity. • Introduction of earthworms produced a 100% improvement in the rate of water infiltration in pastures that previously had no earthworms. • Chemical elimination of earthworms doubled the amount of annual runoff from a 13^0 slope.
Hydrological cycle maintenance	This function of maintaining the water table, slowing percolation of precipitation, filtering wastes before they get to water bodies, water purification, and transpiration is provided by a host of plants and organisms. See Water Capacity and Quality report - forthcoming.
Resistance to drought stress	Species-rich pasture production dropped by 50% during a drought, compared with a 92% drop in production in species-poor pastures in a Minnesota study.
Species indicate health of the environment	In many places, the numbers of amphibians have undergone dramatic reductions during the 1990s. Practices such as draining marshes and meadows, and cutting forests often result in a loss of amphibian habitat. Acid rain and other types of pollution also reduce breeding success. Amphibians live both on land and in water. They have a moist, permeable skin and quickly respond to changes in the quality of air and water. Amphibian populations are excellent indicators of environmental stress and should be monitored with care. Examples of amphibians include frogs, toads, and salamanders.
Degradation of chemical pollutants	Biological treatments, which use microbes and plants to degrade chemical materials, can both decontaminate polluted sites (bioremediation) and purify hazardous wastes in water (biotreatment). Biological methods are often more effective than physical, chemical, and thermal methods because they convert the toxin to a less toxic or inert substance – rather than transferring the pollutant to a different medium. The estimated value of this ecosystem service in the US is $22.5 billion per year (1997 US dollars). A portion of this value occurs on farms where toxic materials in sewage sludge and pesticides are being degraded by soil organisms and plants.

Other Ecological Services Associated with Biodiversity

Service	Detail
Crop and livestock breeding	Use of the richness of breeds and plant varieties to improve agricultural breeds and varieties is valued at $40 billion (1997 US dollars) in the US (equivalent to $55 billion in Canadian dollars).
Exotic germplasm for crop breeding	The United States government estimates that for just two major crops, access to exotic germplasm adds a value of more than $10 billion: -- US$ 3,200 million to the nation's US$ 11,000 million annual soybean production, and about $7,000 million to its $18,000 million annual maize crop (1997 US dollars).
Pollination	Pollination by a host of different organisms (e.g. bees, butterflies, and birds) is estimated to be worth $40 billion to US agriculture per year (1997 US dollars) (equivalent to $55 billion in Canadian dollars), and $1.26 billion per year to Canadian agriculture. Although many major crops are self- or wind pollinated, others require and benefit from insect pollination to increase quality or increase yields.
	In Nova Scotia the value of rented bees required to help pollinate lowbush blueberries is worth $2.7 million annually. The value of wild pollinators' work in this crop has not been estimated.
Wild food	Food gathered from non-cultivated species such as fish, berries, deer, fiddleheads, seaweed, or maple syrup can contribute significantly to our diets. In the US, the value of these wild foods is estimated to be worth $34 billion per year (1997 US dollars). If hunting and seafood is eliminated from the estimate, the estimate is a $0.5 billion per year contribution.
Pharmaceuticals from plants	Estimated value of $20 billion (1997 US dollars) (equivalent to $27.4 billion in Canadian dollars).
Medicinal benefits to livestock	A diversity of vegetation in pastures can be helpful to livestock that selectively graze certain plants for their medicinal benefits and/or mineral concentration. Examples of plants in the Maritimes that have these benefits include mugwort (Artemesia vulgaris), dandelion (Taraxacum officinale), plantain (Plantago lanceolata), wild carrot (Daucus carota), chicory (chichorium intybus), juniper (Juniperus communis), and other conifers.
Maintenance of soil structure	Soil organisms produce sticky substances that help bind soil particles together, stabilizing soil aggregates, thus contributing to good soil structure. A good soil structure increases water filtration into the soil and decreases erosion.
Carbon sequestration	Conversion of cultivated land to productive permanent pastures results in ~ 176 tons of $C0_2$ being removed from the atmosphere and stored in soil, per ha, a significant contribution in an era of climate change that has direct economic value as a credit under the Kyoto Accords.

When the value of 'free' ecosystem services declines, as for example when soil organic matter is depleted, farmers may feel compelled to purchase inputs like synthetic fertilizer to compensate for the lost services, and to supply nutrients artificially. It is therefore important to assess the balance between such purchased inputs and free ecosystem services that can realistically be achieved on farms. Nova Scotian farms could provide leadership in finding that ecological balance, and in identifying thresholds that should not be crossed to avoid irreversibly damaging the capacity of the ecosystem to provide free services.

The value of some ecosystem services has been estimated in this study. Because it is challenging to calculate direct values for these ecosystem services, some hypothetical replacement (restoration) values have been estimated. For a number of different beneficial organisms, we have asked, “what would it cost to replace the work they do?”, or, “what would it cost to replace the organisms if they are depleted?” The final section of this report also poses the specific question, “what would it cost to replace the services of a collection of organisms that filter water in a farm wetland?”. Preliminary and rather crude estimates show that to replace the work done by myriad beneficial organisms on farms would cost Nova Scotians millions of dollars annually. In fact, it would cost the province much more than the value of all food produced on Nova Scotia farms.

When estimating the value of ecosystem services, it is sometimes useful to know what it might cost to *replace* such a service. In some instances it may not be feasible to actually replace a service, but determining a *hypothetical replacement or restoration value* is still instructive. These numbers may have no practical economic reality but rather demonstrate that certain ecological services are, in effect, irreplaceable or *invaluable*.

Ladybird beetles or ladybugs are a well-known beneficial insect with a voracious appetite for common aphid pests. Where natural enemies (including ladybugs) are not disrupted, aphids such as the green peach aphid on potato, and various aphid species in apple orchards seldom increase to densities that cause economic damage. The pest-control work done by ladybugs is estimated to be worth $13.8 million annually on Nova Scotia farms. Their service is more valuable than a pesticide application, because it provides a daily and continuous pest control service, rather than a one-time control. Also, ladybird beetles do not create the health and safety risks associated with spraying a toxic chemical.

Earthworms provide a wide range of valuable and well-documented ecosystem services in agricultural environments. They provide benefits to the structure and productivity of soils, pest and disease control, as well as food for other organisms. Earthworms are like composting facilities, taking in mineral soil and other debris, and churning out a valuable, pH balanced, well-aggregated, nutrient-rich product on which crops thrive. If we had no earthworm castings in the soil, it would cost about $6.2 billion to replace them annually with commercially-produced castings on crop and pasture land (hypothetical restoration value). The value of earthworm soil processing is estimated based on replacing the weight of soil processed (49,000 kg/ha for the lowest estimate) with purchased compost. This would translate into an ecosystem value of at least $3.6 billion per year (hypothetical restoration value).

Green lacewing adults are delicate-looking light green winged insects that are attracted to light. It is hard to imagine that the larval stage of this pretty insect is considered to be a voracious aphid predator. Most of their victims are aphids, but they also control two-spotted spider mites, mealy bugs, mite eggs, leafhoppers, small caterpillars, and thrips. If lacewings (and other predators) were absent from an area where aphids, mites, thrips and small caterpillars are threatening a crop, it would cost $760/ha to replace them (hypothetical restoration value).

The pollination service provided by **bees** is essential in both agricultural and natural ecosystems. Crop pollination is often taken for granted (not valued) until pollinator numbers are reduced or eliminated, leaving farmers with little or no crop. The loss of wild pollinators is mainly caused by two interrelated processes: the destruction of their habitat, and direct poisoning (Kevan et al, 1990). The important contribution of wild bees was nowhere more evident than in southern New Brunswick, when lowbush blueberry crop yields dropped significantly as a result of the decimation of wild bee populations caused by fenitrothion spraying for spruce budworm control from 1969 to 1973. Canadian crops that are dependent on insect pollination include apples, pears, blueberries, strawberries, raspberries, cherries, pumpkins, squash, alfalfa, clover, some types of beans, cucumbers, eggplants, melons and tomatoes. In 1984, the value of this pollination to Canadian crops was estimated at **$1.26-billion** annually. The pollination services provided by honeybees (not including wild bee pollination) amounts to a value of **$2.7 million** for the Nova Scotia lowbush blueberry crop alone. These valuations are direct, not hypothetical replacement values.

Three main types of **parasitic wasps** help to control pests on Nova Scotia farms: braconid, chalcid, and ichneumonid wasps. They are tiny, but useful. Researchers in Nova Scotia have studied these beneficial wasps, because of their potential to help fruit growers reduce pesticide use. **Braconid wasps** parasitize caterpillars, aphids, beetles, flies, and even other wasps. In orchards, they parasitize a number of pests, including leafrollers, codling moth, bark beetles, and aphids. **Chalcid wasps** are very successful parasites of many pests such as aphids, scale insects, moth caterpillars and eggs, and the larvae of some flies and beetles. Parasitization may exceed 50 percent of some pest populations. **Ichneumonid wasps** will attack the larvae of moths, butterflies, beetles, and sawflies, as well as other insects. Chalcid and braconid wasps also attack 'secondary pests' such as the spotted tentiform leafminer (STLM). STLM is not normally controlled with insecticides, because parasites keep population numbers from exceeding economic thresholds. However, should these wasp populations be destroyed through the use of broad-spectrum pesticide application, STLM populations could soar, resulting in continued pesticide reliance. It is challenging to estimate accurately the value of the intricate, graceful, detailed, and deadly work performed by parasitic wasps. If purchased wasps establish as well as native wasps, it would cost about $502,274 to cover Nova Scotia's tree fruit-growing area (hypothetical restoration value). Their actual value to fruit production in Nova Scotia is unknown at this time.

Dr. Rob Smith and colleagues at the Atlantic Food and Horticulture Research Centre in Kentville have been attempting to estimate the value of reduced pesticide use and increased reliance on parasitic insects such as parasitic wasps. They report significant increases in the percentage of growers spraying for key pests in Annapolis Valley orchards, with only marginal savings in percent crop loss. Some of this increase in pesticide use could be due to losses of beneficial organisms in orchards from spraying of broad-spectrum insecticides.

Smith et al. (2001) also report that in 2000 an average hectare of Annapolis Valley orchard received $900 worth of pesticide. In the first year of monitoring, orchards using fewer pesticides and relying on beneficial organisms had 1.8% less fruit damage while using 30% less pesticide (by volume), for a saving of $200/ha. A portion of these savings could be due to the effects of a number of different beneficial organisms working in the orchard. If we multiply the possible benefits of beneficial orchard insects by the area in active fruit production (2,806 ha), benefits could be estimated to be $561,200 per year (direct value). It will be important to monitor the value of progress associated with this initiative.

Beneficial organisms are often undervalued because the work they are doing is not very obvious, they spend most of their time underground (e.g. earthworms), and they are less than half a centimeter long (e.g. parasitic wasps). Society takes their work for granted until they are destroyed or their population plummets, and they can no longer do their critical work.

It is more challenging to devise a value for ecosystem services using direct, compensatory, or avoidance valuations – although some attempts are made. Direct valuation would require properly designed comparisons between crop revenues with and without the beneficial organisms present, an almost impossible task in practice, even though this would likely be the most meaningful economic valuation for farmers. Compensatory valuations are based on expenses incurred for controlling a pest by some other means (e.g. a pesticide) when the natural control mechanisms are no longer in place. Ironically, the compensatory action often exacerbates the situation by harming beneficial organisms, requiring further investments in man-made controls, and a cycle of increased expense and eventual reduced effectiveness. In the United States it was estimated that crop damage due to insect pests rose from 7% to 13% between the 1940s and 1974, despite a tenfold increase in the use of insecticides (Olkowski et al., 1991:96). This declining effectiveness of insecticides may be partially due to the removal of natural controls, and partially due to selection for pests resistant to the insecticides, due to the over-use of those insecticides.

Avoiding the loss of beneficial organisms often involves leaving native flowering plants in crop areas, or allowing for a diverse landscape, which emphasizes again the importance of the earlier discussion on the value of diverse habitats to agriculture. In essence, diverse habitats help to ensure there is a diversity of beneficial organisms that maintain crop productivity, or keep pests in check.

Fortunately, most farmers recognize the value of the work done by beneficial organisms and many will go to great lengths to attract and establish biodiversity. These farmers themselves become one link in the web of biodiversity, by supporting and enhancing its productive functions.

The use of ecosystem services to maintain and increase productivity requires a good knowledge of ecosystem services and how they work. This knowledge may help farmers to reduce purchased synthetic farm inputs, and may therefore create economic incentives for developing knowledge-intensive versus synthetic-intensive agricultural systems. Pest-predator interactions and long-term effects of managing for biodiversity on farms should continue to be thoroughly researched and documented, and farmer innovation in this area rewarded. Ecological habitat management and promotion of beneficial organisms should be the strategies of modern plant protection.

Farmers have a basic choice: they can rely on ecosystem services to help regulate processes on their farms, or they can choose to purchase these services in the form of fossil fuel-based inputs (synthetic fertilizer, pesticides, feed grown with synthetic fertilizer and transported to the farm, machinery, etc). Unfortunately, the purchased option will often have a further negative impact on the very ecosystem services it is replacing, leading to a costly escalation of input expenditures. The potential for increased loss of ecosystem services over time may necessitate an increasing rate of investments in externally-derived control solutions. Alternatively, investing in ecosystem services to regulate farm production will require site-specific knowledge of the farming system, landscape diversification, and a re-integration of livestock and crop farming.

"Farmers are poorly paid for the goods they produce. And for the services they render to conservation, they are not paid at all" (Berry, 2002:54).

In many European countries, farmers are paid to enter into voluntary fixed-term agreements that improve biodiversity habitat on their farms. For example, farmers in the Netherlands – one of the most intensively-farmed areas in Europe – are paid approximately $578 per hectare per year for their efforts to improve farm-level biodiversity. Farmers in environmentally sensitive areas of the UK can be paid about $142 per hectare per year for similar efforts. In Sweden it is recognized that efforts to increase biodiversity on farms also achieves other objectives simultaneously, such as reduction of nutrient losses by runoff, erosion, or leaching.

Agricultural biodiversity cannot be conserved simply by setting aside tracts of uninhabited land; it necessarily involves people. Agricultural diversity can only be maintained in farmers' fields as long as there are societal incentives to encourage appropriate private investments. Diversity is a 'public good' that cannot always be established and promoted through market mechanisms. When food is purchased in the marketplace, it is almost impossible for the consumer to tell whether the food was produced in a way that conserves or degrades biodiversity. One exception is the process of organic certification, which is away to remedy this market imperfection. Organic farmers must follow a set of rules, including maintenance of biodiversity on their farms. In return, consumers pay a premium for food produced on those farms, thus providing the necessary incentive for organic farmers to continue making investments that enhance biodiversity.

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*Needless to say, any errors or misinterpretations, and all viewpoints expressed, are the sole responsibility of the authors and **GPI**Atlantic.*

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LIST OF ABBREVIATIONS

AAFC	Agriculture and Agri-Food Canada
BOD	Biological Oxygen Demand
c	Circa – about
IFP	Integrated Fruit Production
IPM	Integrated Pest Management
N	Nitrogen
NB	New Brunswick
NPK	Nitrogen, Phosphorous, Potassium synthetic fertilizer
NPP	Net Primary Productivity
NS	Nova Scotia
NZ	New Zealand
OECD	Organization for Economic Co-operation and Development
PEI	Prince Edward Island
SA	Solar Aquatics
TSS	Total Suspended Solids
US	United States

THE VALUE OF AGRICULTURAL BIODIVERSITY

1. Introduction

Biodiversity, or diversity of life, refers to the range of different plants, animals, and micro-organisms existing and interacting within an ecosystem. Biodiversity is critically important for agriculture in a number of different ways. Ecosystem functions such as nutrient cycling, pollination, or watershed filtration are a result of the interactions of thousands of organisms. Biodiversity is the source of most of the world's food and fibre products, including the basis for past and future crop and livestock genetic resources. The richness and abundance of biodiversity offers a range of scientific, medicinal, cultural, aesthetic, recreational, and other intangible (and non-monetary) values and services (OECD, 2001:294).

In 1997 researchers in the United States and New Zealand estimated the value of their respective countries' biodiversity (OECD, 2001; Pimentel et al., 1997). The New Zealanders estimated their biodiversity to be worth $223 billion (Canadian 1997$), while their GDP is worth $81.5 billion (Canadian 1997$).[1] There is a recognition in that country that New Zealand's productive systems are underpinned by healthy biodiversity, and primary producers use their 'clean and green' image to appeal to health-conscious customers and tourists. In other words, healthy biodiversity is explicitly valued, and it is used to economic advantage (OECD, 2001:295).

In the United States, the value of biodiversity was estimated by Pimentel et al. (1997) to be $437 billion (Canadian 1997$).[2] When the ecological services related primarily to agriculture were considered, the figure came to $323 billion (Canadian 1997$).[3] The ecological services considered in this estimate were waste decomposition; soil formation; nitrogen fixation; bioremediation of chemicals; crop and livestock breeding; pest biocontrol, host plant resistance; pollination; wild foods; ecotourism; and pharmaceuticals from plants.

Biodiversity is usually analyzed at three different levels: genetic diversity, species diversity, and ecosystem diversity (Atlantic Canada Conservation Data Centre, 2001). *Genetic diversity* is the variation present within a species, i.e. variation between individuals in a species. Genetic diversity is important because it provides the means for agriculture to improve crop and livestock yields and enhances the resistance of crops in the face of disturbance and their resilience in the face of change. For example, an Ethiopian barley variety was crossed with Canadian barley,

[1] 230 billion NZ $1997 = 223 billion Canadian dollars and 84 billion NZ $1997 = 81.5 billion Canadian dollars (based on conversion rate of 1 NZD = 0.97 CAD for 1997 – source www.x-rate.com)
[2] 319 billion US $1997 = 437 billion Canadian dollars (based on conversion rate of 1 USD = 1.37 CAD for 1997 – source www.x-rate.com)
[3] 236 billion US $1997 = 323 billion Canadian dollars (based on conversion rate of 1 USD = 1.37 CAD for 1997 – source www.x-rate.com)

providing the barley crop with protection from specific diseases in Canada and the US (OECD, 2001:296). *Species diversity* can be measured by counting the number of different species within an ecosystem (**species richness),** the number of individuals within each species (**species abundance**), or the relative abundance of a number of species (**species evenness**). One measure is not very informative without the others. Species diversity of soil micro-organisms, insectivorous birds, or plants in a pasture, for example, is of interest to agriculture because of the roles these species perform on the farm. *Ecosystem diversity* describes the landscape and habitat features that 'house' all the species that interact on the farm.

Mollison (1990) suggests that in agriculture, it is important not to focus too much on *numbers* of species, but to appreciate the *diversity of functional ecological roles*, and *beneficial ecological interactions* between species. We not only want to know the *number* of species, but also the *number and quality of interactions (interdependence)* between those species, and the number of *keystone species* (those species that are in some way central to the survival of a host of other species and therefore produce a degree of stability in an ecosystem) (Hawksworth, 1990). Unfortunately we do not yet have adequate data on species richness, species interactions, or prevalence of keystone species for agroecosystems as a whole in Nova Scotia. We should be asking how this complex of living organisms on farms works together to achieve optimal productivity, resistance, resilience, and sustainability over time.

Production: total yield (product 'harvested').
Productivity: Yield per unit of input, in a given unit of time. Inputs can include energy, costs, time, labour, area, nutrients, etc. Productivity is often measured based on the most limiting or expensive input. Ecological measures of productivity are based on minimizing non-renewable inputs and polluting outputs.
Resistance: A measure of the change in productivity in response to a particular intensity of disturbance (e.g. drought, flood, disease etc.).
Resilience: A measure of the rate of productivity recovery after a disturbance.
Sustainability: A measure of the ecological productivity of an agro-ecosystem over a long period of time in order to be able to assess its resistance, and resilience in the face of change.

Ecosystem services are the services, such as pollination, that organisms provide as they go about their regular business of living. For example, the bee obtains nectar from the flower, and the flower gets pollinated so it can produce fruit. There is usually some element of benefit, for example the plant carries out a process of photosynthesis in order to grow, but at the same time produces oxygen that human beings can breathe. There are a *diversity of functional ecological roles*, and *beneficial ecological interactions* between species. The variety of ecosystem interactions between plants, animals, and micro-organisms maintains the *quality, relative stability,* and *habitability* of the environment by purifying and regulating air, water, and land resources – as well as controlling climate. Ecosystem interactions play a role in the protection of water resources; the formation and protection of soil; the storage and cycling of nutrients; the breakdown and absorption of pollution; the maintenance of ecosystems' equilibrium (including controlling pests); and the recovery of ecosystems from unpredictable events. In addition, ecosystems provide *biological resources*, such as wild food, medicines, and wood products. Provision of biological resources is therefore another example of an ecosystem service.

By focusing on the value of ecosystem services to farms, we are highlighting the diversity of function of different organisms, and their beneficial ecological interactions, as Mollison (1990) suggests.

This report begins with a discussion of the possible 'indicators' of biodiversity. Indicators are specific items that are measured to help us determine if we are 'gaining' or 'losing' – making progress or not – over the long term. Existing indicators used by the Organization for Economic Co-operation and Development (OECD) and additional indicators proposed by GPI Atlantic are discussed. This is followed by a section on habitat – what kinds of habitat are important for biodiversity and why. The prevalence of certain kinds of habitat will indicate the health of biodiversity on farms. Another complementary indicator is ecosystem services, discussed in the succeeding section. The final section shows how many different elements and organisms in an ecosystem can help to perform an important ecosystem service: water purification.

2. Indicators of Agricultural Biodiversity

A great deal of important discussion and research has occurred in the last decade in order to try to understand why biodiversity is important, and how it can be monitored. Indicators of agricultural biodiversity proposed by the OECD (2001) will be discussed, followed by an introduction to the indicators used by GPI Atlantic in this study.

2.1 OECD Biodiversity Indicators

The OECD has selected indicators of agricultural biodiversity that focus on the impact of agriculture on biodiversity (Table 1). These include indicators of genetic diversity, species diversity, and ecosystem diversity.

Table 2: OECD Biodiversity Indicators

Biodiversity Level	Type Of Indicator	Indicators
Genetic diversity	Variety	Domesticated crop varieties and livestock breeds • total # of crop varieties and livestock breeds registered and certified for marketing • share of key crop varieties in production for individual crops • share of key livestock breeds in each livestock category • # of national crop varieties and livestock breeds that are endangered • extent of genetic erosion
Species diversity	Quality	Wild species abundance and richness, non-native species - indicators are still being developed

OECD Biodiversity Indicators (continued)

Biodiversity Level	Type Of Indicator	Indicators
Ecosystem diversity	Quantity	Habitat area Intensively farmed area • share of each crop in the total agricultural area (arable and permanent) • share of organic agriculture in the total agricultural area Semi-natural agriculture habitats • share of agriculture land covered by semi-natural habitats (i.e. pasture) Uncultivated natural habitat • net area of aquatic ecosystems converted for agricultural use • area of natural forest converted to agricultural use

Source: Modified from OECD, 2001.

Genetic Diversity

According to the OECD Agri-Environmental Indicators Questionnaire in 1999, the number of crop varieties registered and certified for marketing in Canada rose between 1986 and 1995. The numbers of varieties of oil crops, cereals, root crops, beans and pulses, and forage have risen between 35% and 271% (OECD, 2001). These data do not, however, indicate the genetic diversity of crops *actually being grown*. Loss of genetic diversity in this century is largely the result of the introduction of new varieties of crops, leading to the replacement and loss of traditional, highly-variable crop varieties. In the US, most varieties grown by farmers in the 19th century can no longer be found in commercial agriculture or any US genebank, with 92% of field maize varieties lost, 81% of tomatoes, and 94% of peas (OECD, 2001).

The United Nations Food and Agriculture Organization (FAO) estimates that since 1900, about 75% of the genetic diversity of agricultural crops has been lost (Shand, 1997). "Genetic erosion" refers to the loss of genetic diversity between and within populations of the same species. Nearly all of the 158 countries that submitted background reports for FAO's State of the World Report on Plant Genetic Resources identify genetic erosion as a serious problem.

Genes from wild relatives of crops are also enormously valuable. Canadian researchers estimate that between 1976 and 1980, wild species contributed $340 million per year in yield and disease resistance to the US farm economy (Shand, 1997).

Canadian agricultural producers and gardeners interested in crop diversity formed a network to grow and exchange endangered and heirloom species of food crops in an attempt to maintain genetic diversity. Numerous varieties of flowers, fruits, herbs, vegetables, trees, shrubs, and grains are being preserved through Seeds of Diversity Canada. Of these food crops, over 1,100 distinct varieties are grown and exchanged by approximately 100 individuals across Canada. Seeds of Diversity Canada began in 1984 as the Heritage Seed Program of the Canadian Organic Growers. (Environment Bureau, Agriculture and Agri-Food Canada, 1997)

Livestock genetic diversity is also threatened (OECD, 2001). In OECD countries, the number of livestock breeds registered for marketing has increased since 1985, largely due to international trade in livestock. However, 16% of livestock breeds used on farms in 1900 are now extinct, and 15% of the remaining breeds are threatened. Globally, these losses are even higher. FAO figures indicate that 50% of livestock breeds have become extinct since 1900 and 43% of remaining breeds are threatened (Shand, 1997). There is very little diversity of breeds used on Canadian livestock farms: 99% of cattle and 96% of hogs raised are from one of three breeds (OECD, 2001:323). No figures are given for poultry. There is somewhat more diversity in sheep and goat breeds raised on Canadian farms: about 60% of the animals raised are from one of three breeds (OECD, 2001:323).

Animal genetic resources include all species, breeds, and strains that are of economic, scientific and cultural interest to humankind for agriculture, now and in the future. Case studies of successful sustainable farm systems often mention farmers who choose livestock breeds to suit the particular farm environment rather than manipulate the environment to suit the breed (Exner et al., 1990: 266-265). For example, availability of a variety of livestock breeds suitable for forage systems rather than high-input concentrate systems is critical to many farms (Murphy, 1998:65).

Centuries of human and natural selection have resulted in genetically diverse breeds within all the major livestock species (Shand, 1997). Breeds that are rare today may carry traits (such as disease resistance, high fertility, good maternal qualities, longevity, and adaptability to changing environmental conditions) which will be of commercial importance in the future. The Finn sheep, for example, was cast aside by commercial breeders decades ago and kept only by Finnish peasants. Today the Finn's fecundity – its ability to produce litters of lambs instead of singles or twins – is widely utilized in the sheep industry (Shand, 1997).

Industrial stocks alone are not an adequate genetic reservoir for the future. These stocks rest on a narrow genetic base, which has been selected solely for maximizing production, not for ecological productivity. Intensive livestock production in the North is characterized not only by genetic uniformity, but also by increasing consolidation in the control and ownership of industrial breeding stock. In the poultry industry, for example, 5 industrial breeders, all owned by transnational corporations, dominate the world industrial egg market. The genetic base for industrial poultry is described by Canadian poultry geneticist Roy Crawford as "exceedingly narrow" and "vulnerable to genetic disaster" (Shand, 1997). 'Genetic disaster' refers to a situation when a disease against which a certain breed has no resistance, kills or harms large numbers of animals because they are all so similar. A more diverse poultry flock might also be harmed by a disease, but each bird might be differentially affected, and some, not at all, because something in their genetic heritage allows them to fight off the disease (this is genetic *resistance*).

Admittedly, counting varieties and breeds is not a perfect indicator of genetic diversity. Many important questions remain unanswered for this indicator: How similar are the breed/varieties in use? How much genetic diversity exists within each breed? How much diversity is conserved outside of recorded commercial channels? Is the 'ownership' of breeds or varieties hindering access to genetic material? Is genetic material concentrated in a few hands, or is it well distributed? What are breeding and development goals – are breeds available that are suited for different climates or farming practices?

Rare Breeds Canada is a national non-profit organization formed to conserve rare, minority, and endangered livestock breeds. Through its Satellite Breeding Network, groups of animals are sent to member farms to establish small breeding populations. Approximately 34 farms are involved in the network, housing approximately 120 of the organization's 700 head of livestock. Participants are typically retired or hobby farmers, who generally retain a portion of the breeding stock to begin their own herd or flock. Livestock breeds involved in the program include Jacob sheep, Canadienne cattle, Canadian horses, donkeys, and various flocks of heritage poultry, geese, and turkeys. (Environment Bureau, Agriculture and Agri-Food Canada, 1997)

The erosion of genetic diversity and the dependence of agricultural production on a relatively small number of varieties and breeds can heighten the risks associated with changes in environmental conditions and susceptibility to pests and disease. We know that greater genetic uniformity has evolved in intensively raised agricultural species of livestock and crops. This has lead to increases in the frequency of 'favourable additive alleles' (desirable growth traits) but also "progressive breakdown of homeostatic regulatory mechanisms" (ability of the crop or livestock to withstand stress) (Notter, 1999). Genetic erosion could impair the potential to raise crop and livestock yields in the future, as genetic material loss is generally irreversible (OECD, 2001: 302).

Species Diversity

Species diversity will be considered below in the GPI indicators, by using habitat quality and diversity as a proxy for species diversity. Some OECD countries, including Canada (McRae et al, 2000) evaluate species diversity in terms of habitat indicators. The reasoning is that better habitat conditions will favour beneficial (non-crop and non-livestock) species diversity on farms. The Netherlands is taking a more detailed approach to species diversity monitoring, tracking plants, birds, butterflies, dragonflies, amphibians, mammals, fish, aquatic macrofauna, and soil fauna. Measurable species within these groups are selected, providing a representative sample of the agro-ecosystem (OECD, 2001:306). Counting species will possibly yield more accurate information than habitat monitoring, but it is more time-consuming and expensive.

If time and resources are limited, detailed monitoring efforts should be targeted to evaluating the *activity* of species (i.e. ecosystem services that they provide) rather than species themselves. This approach is recommended by soil researchers in Canada (Topp & Fox, 2002). Monitoring ecosystem services will immediately highlight the potential beneficial effects of biodiversity on sustainable production, which in itself will be an incentive for farmers to nurture beneficial biological interactions on their farms.

Ecosystem Diversity

The OECD (2001) proposes to evaluate ecosystem diversity based on the quantity of intensively managed, semi-natural, and uncultivated natural areas on farms. It is useful to evaluate the degree of intensively farmed area compared to more natural areas within farms and regions. But ultimately the *effectiveness* of having natural areas on farms will depend on *how* these areas are interspersed with crops, cropping patterns, and other adjoining landscapes (e.g. urban, wetland, industrial). The *effectiveness* might be better assessed by documenting farmers' experiences and monitoring the effect of various ecosystem services on sustainable farm productivity.

There is still some value to assessing 'intensivity' of agricultural land use, as long as it is clear that this does not explain the effectiveness of natural areas in providing ecosystem services. If we follow the OECD example (OECD, 2001), cropland would be considered 'intensive,' hay land and pasture would be 'semi-intensive,' and woodland would be 'natural.' In Table 2 the area and proportion of these land uses on Nova Scotia farms are documented. These will be discussed in more detail later in the report.

Table 3: Average Area and Proportion of Nova Scotia Farmland in Crops, Hay, Pasture, and Woodland

Year	Area in tame hay (ha)	Area in tame pasture (ha)	Area in crops (excluding hay) (ha)	Area in woodland (ha)	Farmland area (ha)	% of farm area in tame hay	% of farm area in tame pasture	% of farm area in crops (excluding hay)	% of farm area in woodland
1951	64,692	62,770	128,529	746,907	1,284,347	5.0	4.9	10.0	58.2
1961	57,664	51,584	75,524	551,553	902,609	6.4	5.7	8.4	61.1
1971	61,738	43,459	36,584	299,604	537,777	11.5	8.1	6.8	55.7
1976	71,988	42,447	39,679	262,579	493,293	14.6	8.6	8.0	53.2
1981	71,105	46,106	41,677	240,842	466,023	15.3	9.9	8.9	51.7
1986	68,399	36,236	41,112	200,799	416,506	16.4	8.7	9.9	48.2
1991	67,478	30,723	38,753	N/A	397,031	17.0	7.7	9.8	N/A
1996	71,264	25,005	39,799	N/A	392,324	18.2	6.4	10.1	N/A
2001	74,915	22,873	44,304	N/A	407,046	18.4	5.6	10.9	N/A

Sources: Statistics Canada, 2002; 1997a; 1997b; 1992; 1987; 1982; 1978; 1973.

2.2 GPI Atlantic Approach to Biodiversity Indicators

GPI Atlantic proposes to use two main indicators of biodiversity: habitat quality, and the value of ecosystem services. Like the OECD, we use habitat as a proxy indicator for species diversity. The most important indicator, however, from the GPI perspective, is to track the value of ecological services offered by biodiversity to farm productivity.

Healthy and flourishing populations of beneficial organisms provide us with ecological services that we take for granted and therefore may not even notice until they are gone. Some examples of ecological services provided by beneficial organisms are pest and disease control; nutrient cycling; pollination; decomposition of wastes; buffering the effects of disturbance; and water purification. A very important ecological service of biological diversity is to provide competition against aggressive species that create harm (i.e. reduce productivity, or induce ill-health) when their populations get out of control.

When ecological services are somehow impaired, they become very expensive to correct or to replace. For example,

- If soil organisms were eliminated, it would be impossible to grow crops in the field. Growing food and feed hydroponically would be a very expensive technological replacement.
- If beneficial pest predators in an orchard are eliminated, the cost of pesticides used to take over the job of controlling pests becomes prohibitively expensive.
- If the beneficial bacterial layer on a crop leaf surface is eliminated, pathogens move in and must be controlled with expensive fungicide applications.
- If we eliminate natural pollination services, beekeepers will have to be hired to replace the lost service.
- If we eliminate natural water purification systems, they must be replaced with expensive water treatment facilities – even if these facilities copy ecological water filtration processes.

Ultimately, we are faced with the prospect of replacing more and more ecological services (normally provided for free) with expensive technological solutions. In the long run, this is not likely to be a sustainable option. By providing appropriate habitat in communities and on farms for beneficial organisms – which carry out ecological services – the question must be asked: how much are we 'giving up' and how much are we 'gaining?' This is a question that researchers are now beginning to tackle in earnest, with the provision of habitat increasingly considered by ecological economists to be an investment rather than simply a cost.

The OECD biodiversity indicators presented above propose to monitor species abundance and species diversity of crops, livestock, wild species, and habitats. This is important work. GPI Atlantic proposes to take a complementary approach to the OECD indicators, in order to (1) clarify which ***habitats and farm practices*** enhance the range of beneficial organisms; (2) highlight and monitor ***ecological services themselves***; (3) find out what the value of those ecological services are and track those values over time; and (4) highlight examples of successful collaboration between farmers and the ecological services offered by biodiversity.

We know we are making genuine progress when

- optimal habitat for beneficial organisms is maintained or enhanced;
- ecological services offered by beneficial organisms (from fungi to forests) and their interactions are maintained (or enhanced) to optimize agricultural productivity and reduce pollution; and
- ecological services do not have to be replaced (due to the loss of biodiversity) with man-made solutions that further reduce ecological services.

In this report we will review the importance of, and trends in, indicators of habitat quantity and quality. Following this, a number of ecological services provided by beneficial organisms will be highlighted, with some preliminary estimates of their value. The final section explores how a number of organisms can work together to perform a vital ecosystem function: turning polluted water into clean water. The value of this alchemical task is higher, the more polluted that water becomes. We look at man-made attempts to mimic this natural process in order to estimate its value. Hopefully these figures will provide some perspective on the value of preventing water resource degradation in the first place.

It is the estimation of the value of biodiversity on Nova Scotia's farmland that makes this study unique and practical. Ecological functions have vital economic value – often hidden – upon which successful agriculture depends. It is important to value the present and potential agricultural biodiversity before it is gone, because only then will we fully realize the expense associated with its loss and take remedial action before it is too late.

3. Habitat for Beneficial Organisms on Farms[4]

"Habitat" is a word used to describe the place and conditions for an organism to live, or to have a home. Whether it is hawks that control rodents, insect-eating birds in orchards, beneficial bacteria and fungi that maintain soil health, or the lowly dung-beetle that takes care of breaking down manure from grazing animals, an important part of land stewardship is to make sure there is adequate habitat for organisms beneficial to the farm. The existence of habitat for species that have a vital role in ensuring crop productivity is therefore a key indicator of food security, farm viability, and genuine progress in agriculture.

A diverse habitat that is important for beneficial organisms can also be directly beneficial to the farm. For example, hedgerows that are important habitat for birds and predatory insects can also help to reduce windspeed over adjacent crops – thereby protecting exposed soil from erosion, or crops from wind damage. Another example is the productivity benefits of multi-species pastures (Tilman, 1997).

The first step in improving habitats on farms is to be aware of the benefits they bring to us. Then we need to understand what kind of habitat is important. The third step is to assess how best to incorporate these habitat requirements into the farm landscape. These three steps are part of a lifelong study for farmers who want to understand what is really happening on their farms. In other words, the study of agricultural habitats can be a pleasurable and challenging learning experience for farmers in addition to having potential productivity benefits.

Rather than looking at agriculture as an infringement upon wild, natural spaces, farms should be seen as reservoirs of habitat potential. Farmers, as stewards of the land, are providing habitat for thousands of organisms. Because farms are generally collections of crops, livestock, buildings,

[4] The valuation component of this section has not yet been completed. Valuation estimates will therefore be included in future updates of this report.

fields, ponds, streams, patches of trees, and woodland, they are ideal homes for many creatures. Agriculture can even *increase* the diversity of habitat types relative to other land uses (OECD, 2001:293), and produce food too. Practices such as 'long rotations,' recycling manure, perennial crops, and planting hedgerows can greatly increase habitat.

On the other hand, the expansion of agricultural production and intensive use of inputs can contribute to the loss of biodiversity (OECD, 2001:293). Monoculture (growing the same crop on the same land several years in a row or in 'short rotations' with other crops), use of synthetic inputs (e.g. pesticides and fertilizers), or wetland drainage, can reduce habitat for beneficial organisms. Many farms will have a combination of 'improved' and 'degraded' habitat.

Habitat and farm practices will be evaluated for their ability to provide adequate living conditions for wild and domesticated species diversity – particularly species beneficial to agriculture.

3.1 Natural, Fertilized, and Cultivated Areas

Habitat can include a home for beneficial *soil* organisms. Most of these organisms prefer a soil that is high in organic matter, with balanced nutrient levels. Compared to uncultivated areas, cultivated fields are generally lower in soil organism species richness and species abundance. Within farms, areas that are *not cropped or cultivated* every year (e.g. pasture, hay, field margins, hedgerows, or wooded areas) will foster greater species diversity than cultivated areas within farms, and are therefore highly valued for their capacity to support biodiversity (OECD, 1997). A study in the UK showed, for example, that the least-disturbed soils in a field complex – permanent grass fields used for grazing cattle and sheep – contained soil invertebrate densities an order of magnitude higher than were found in nearby cereal and oil-seed croplands (Friesen, 1994). Areas left uncut, and untilled for longer periods are particularly important for beneficial arthropod overwintering sites (Pfiffner & Luka, 2000). Pasture soils contain three to four times more earthworms (~2,964,000/ha) than tilled soils (~988,000/ha) (Murphy, 1998). These findings indicate the importance of rotating annual crops with perennial sod crops where possible, which is most often done on farms with grazing livestock.

Studies also show that 'semi-natural' areas within farms (such as field margins and uncropped land) are important habitats for predators of pests, because of their vegetational diversity and density (Hopkins & Hrabe, 2001; Pfiffner & Luka, 2000). For example, Langer (2001) demonstrated that leys that are left uncut the year of establishment are important 'reservoirs' for parasitoids of cereal aphids on organic farms.

> The Swiss government has subsidized farming methods that include the establishment of field margins and semi-natural habitats. One of the objectives of this subsidy is to halt the marked decline of biological diversity in agricultural landscapes. (Pfiffner & Luka, 2000)

Windbreaks and shelterbelts (or hedgerows) are important natural areas on farms that support microclimates favourable to beneficial soil organisms as well as birds and beneficial insects. Predatory insects (the beneficial ones that prey on insect pests) may be particularly dependent on the dense vegetation and deep sod layers of windbreaks and shelterbelts. Numbers of pollinating insects such as bees and butterflies have declined following the destruction of hedgerows and other neglected strips. Herbicide applications can eliminate many pollen- and nectar-producing flowers. In their place appear a few resistant grass and herb species that are of little use to pollinating insects. This is significant, as the estimated economic value of insect pollination to agricultural production in Canada is $1.26 billion[5] per annum (Friesen, 1994).

Fertilization is another farm practice that affects diversity. Grazing and hay areas managed with low levels of nitrogen (< 50 kg N/ha per year), will harbour a higher species diversity of plants and other organisms than highly-fertilized areas (OECD, 1997; Tilman, 1996). The form of nitrogen is also an important consideration. Applying as little as 18 kg/ha of urea to pasture soil can cut earthworm numbers in half (Murphy, 1998:55). Soil acidity below pH 5.6 is generally unfavourable to earthworms.

In the Netherlands, numbers of meadow bird species *increased* in the early 1900s due to increased biomass of soil fauna following initial land fertilization. However, bird populations *declined* in the late 1900s because intensification of agriculture went too far. Intensification caused loss of habitat due to drainage, high fertilization with nitrogen, and increased frequency of mowing and grazing (OECD, 1997: 111).

Kings County Farmers Recognize Non-Monetary Values (Gibson, 1997)

Short-eared owls nest on dykelands in Kings County, Nova Scotia, often in well-established hayfields. New varieties of hay that mature earlier, coupled with the need to get two cuts of hay per season, have made successful nesting difficult. Local naturalists studied the nesting patterns of short-eared owls, and presented the information to farmers who “fully supported” a proposal to avoid cutting hay where the owls are nesting. The farmers “recognized the value of these birds in controlling rodents.” Volunteers monitor over 9,000 acres of dykelands from the roads. When they identify a nest, the farmer is approached for permission to visit the site, and an experienced birder assesses and flags sites that need to be mowed around.

The evidence presented above does not mean that *all* uncultivated and unfertilized areas are more species-rich than cultivated areas. When uncultivated areas are very acidic (which is the case in some areas of Nova Scotia), and a corresponding cultivated area is optimally limed and fertilized, higher species richness and abundance can occur in the cultivated areas (Brady, 1974:115). Therefore, conversion of land to agriculture has the *potential to improve* the status and activity of soil micro-organisms, provided that an optimum level of fertility and cultivation is achieved.

Nevertheless, it is difficult to maintain a persistent population of natural enemies of crop pests within the annual crops themselves, because the pest disappears with the crop when harvested. It is not surprising that attempts to establish new, exotic natural pest enemy organisms into annual cropping systems have been less successful than in more permanent crops such as orchards (Waage, 1990).

[5] The figure quoted by Friesen, 1994 was 1.2 billion, which was converted to $1997 using the Consumer Price Index.

Recently the relationship between diversity and productivity in uncultivated areas has been clarified further by US and European studies. When comparing species-diverse with species-poor permanent hay and pasture land, researchers in the US (Tilman, 1997) and across Europe (Biodepth, n.d.) have found that in species-diverse environments,

- soil carbon sequestration per unit of nitrogen is higher (Kaiser, 1996);
- productivity per unit of soil moisture is higher;
- resistance to stress such as drought is higher;
- year-to-year variation in production is lower;
- leaching loss of nitrogen is lower;
- below-ground root production is higher;
- invasion of weedy species is lower;
- activity of plant parasites and fungal pathogens is lower;
- soil microbial biomass and activity are higher;
- bacterial diversity is higher; and
- mycorrhiza (beneficial root fungi) abundance on roots is higher.

Uncultivated agricultural areas used for hay, pasture, shelterbelts, and even field margins, can contribute significantly to a farm's biodiversity. In turn, this biodiversity can provide significant ecological and productivity benefits, provided the intensity of use (i.e. fertilization and harvest schedule) is not so high as to reduce biodiversity. It is difficult to conclude whether Nova Scotia farms are farmed intensively enough, on average, to reduce the potential benefits from biodiversity. It has been clearly documented that in many parts of Europe's agricultural areas, significant biodiversity losses are now causing alarm (OECD, 2001).

3.2 Farm Landscape Diversity

Numerous surveys indicate that overall species diversity (species richness and species evenness) in agricultural landscapes declines as farmland is used more intensively (Björklund et al., 1999). Hopkins & Hrabe (2001:100) reviewed studies relating birds to farming ecosystems in Europe (see also OECD, 2001:341). Habitat favourable for a diversity of birds on farms includes (1) greater abundance of invertebrates and 'soil life,' (2) structurally diverse landscapes (including diversity of crops), (3) larger, older hedges, and (4) trees integrated into the landscape. Although studies showed 25% more birds are supported on the boundaries of biological (or organic) farms than on paired conventional farms in Britain, it was difficult to determine whether it was the non-use of pesticides, or the more diverse habitats offered on the biological farms, or both, that caused this difference in bird abundance. Other studies in Eastern Europe showed highest bird species diversity near housing (72 species), then meadow and mixed ecosystems (50+ species), followed by pure forest ecosystems (33 species), and then predominantly arable ecosystems (25 species).

Crop rotation can be very effective against pest species that have a narrow host range and a limited dispersal range. Increased diversity on farms not only attracts natural predators of crop pests but provides them with an alternative food source (*i.e.,* pollen and nectar) when crop pests are not abundant (Smallwood, 1996).

Changing the Land's Complexion (DeVore, 1998b).

"Our agricultural system is less diverse than at any time in history and it's paying the price in lost resiliency. Dramatic swings in yields, disease outbreaks that can't be controlled and chemical-resistant pests are just some of the warning signs. Studies are emerging in respected scientific journals that show agriculture needs biological diversity if it is to continue producing food and fibre well into the next century."
In the Red River Valley of Minnesota, "a monocrop-loving disease called *Fusarium graminearum* is wiping out the small grains industry, taking farmers and Main Streets with it.

"It's become clear that diversity is not simply a numbers game: it's also how those plants interact and compete with each other that is key.

"Ideally, scientists worried about lack of biodiversity would like to see a farming system that more closely resembles natural processes; a prairie ecosystem made up of hundreds of species of plants, for example. University of Minnesota ecologist David Tilman's research has shown that increasing diversity in plots of perennial grasses results in more resiliency and biomass productivity. But grain crops can't be produced in such an environment on a large scale -- at least not yet."

"Practical Farmers of Iowa is a pioneer in conducting on-farm research into methods of bringing more diversity back into agricultural systems. Farmers involved with the group are experimenting with using alternative crops in rotations, planting cover crops to build soil between growing seasons and establishing flowering plants near fields to serve as hosts for beneficial insects."

"Recent long-term crop trials in Wisconsin, Minnesota and North Dakota show that diverse rotations not only suppress weeds and disrupt the breeding cycles of insect pests; they can also produce better yields when compared to mono-crop systems reliant on chemical inputs. How much diversity is needed to return ecological health to farm fields? Researchers and farmers aren't sure. What agronomists are certain of is that adding just one or more plants to a one or two-crop system won't accomplish much -- economically, agronomically or ecologically."

Overwhelming evidence suggests that diverse orchards support a lower crop pest population than monoculture orchards (Altieri, 1990). Orchards with a rich floral undergrowth exhibit lower incidence of insect pests than clean cultivated orchards, mainly because of an increased abundance and efficiency of predators and parasitoids. Smaller blocks of orchards with nearby woody vegetation are generally colonized by a diverse complex of predators early in the season relative to more extensive orchards. Timely colonization is important to reduce pest populations early in the season.

Generally, insects that parasitize crop pests need some source of carbohydrate, such as nectar or aphid honeydew. They may also require protein provided by pollen, bird droppings, or fungi. Many parasitic hymenoptera and syrphid flies feed on nectar of plants from the Apiaceae family (e.g. dill, caraway, wild carrot) and Asteraceae family (e.g. aster, daisy, dandelion), but also on nectar from other sources (e.g. exudates from fruits). Some ladybird beetles (Coccinellids) feed on pollen (NOFA, 1998). According to Altieri (1990:172), the keys to attracting natural pest predators are:

- provide alternative host prey at time of pest-host scarcity;
- make sure there is food (e.g. pollen and nectar) for adult parasitoids and predators;

- provide refuges for overwintering, nesting, and so on; and
- maintain acceptable populations of the pest over extended periods to ensure continued survival of beneficial predator insects.

Attracting natural pest predators is a very complex task. Ultimately successful attraction of beneficial predator organisms to the task of pest control on farms will depend a great deal on knowledge of predator-prey relationships and experience generated at each site in question (Altieri, 1990). Building biological systems to produce optimum yields and pest control is a knowledge-intensive rather than a synthetic input-intensive strategy.

The literature is full of examples of experiments documenting that the diversification of cropping systems often leads to reduced herbivore (crop pest) populations. The published studies suggest that the more diverse the agro-ecosystem and the longer this diversity remains undisturbed, the more internal links develop to promote greater insect stability (Altieri, 1990).

In Europe, practices that cause declines in *plant* species diversity are:
- intensified agricultural land use (i.e. higher crop land to natural land ratio and higher use of synthetic inputs);
- cessation of agricultural use of land (farm abandonment);
- eutrophication of rivers and lakes caused by agricultural inputs;
- loss of pasture land;
- loss of hedgerows and uncropped areas within farms; and
- pesticide use (OECD, 2001).

These same characteristics strongly influence total amounts and species composition of soil organisms in agricultural settings (Björklund et al. , 1999). International studies of keystone organisms such as earthworms, N-fixing bacteria, or mycorrhizal fungi show that reductions in species diversity and functional relationships can profoundly alter biological regulation of decomposition and nutrient availability in the soil (Matson et al., 1997).

3.3 Biological (Organic) vs. Conventional Areas

Some studies cited below are based on a comparative trial (started in 1978) in Switzerland: referred to as the ‘Swiss long-term trial’ (Fleissbach et al., 2000; Mäder et al., 1996; Mäder et al. , 2000; Oberson et al. , 1996; Pfiffner & Luka, 2000; Pfiffner & Mäder, 1997; Pfiffner & Niggli, 1997). This study is valuable because it compares four different farming systems used in Switzerland – two biological (or organic) systems and two conventional systems – while keeping rotations and tillage the same. The two biological systems do not use synthetic fertilizer or pesticides, while the two conventional systems do. The two conventional systems use modern integrated pest management (a variety of pest control methods are used, including careful use of some synthetic pesticides) and receive higher levels of nutrient inputs than the biological systems. One conventional system uses only synthetic fertilizer (treatment M) and the other uses a combination of synthetic fertilizer and manure (treatment C). Treatments are replicated and randomized at one uniform location, allowing for reliable comparisons. Despite the fact that the biological systems received about 70% less input of available nitrogen, and about 50% less input of phosphorous and potassium, the average yields were only reduced by 19-24% in the biological system (Mäder et al., 2000).

Increases in soil organic matter produce substrate for micro-organisms and for earthworms, insects, and other invertebrates, which are, in turn, important for soil structure, water infiltration, nutrient cycling, and ecological productivity. Although many conventional farms have excellent soil organic matter status, and therefore good habitat for soil life, organic or biological farms must *rely on feeding the soil life with organic matter* in order to achieve production goals, as they cannot rely on synthetic fertilizer. Beneficial soil life includes mycorrhizal and other fungi, earthworms, spiders, beetles, and other epigaeic arthropods, as well as bacteria and actinomycetes. For more detail on their benefits, see Table 10.

In biologically managed plots in the Swiss long-term trial, beneficial organisms were much more abundant and diverse than in conventionally managed plots. Earthworm biomass and density were 30 to 80% higher in biological than in conventional systems (Fleissbach et al., 2000). Plots fertilized with synthetic fertilizer only (no compost or manure) had the lowest earthworm biomass and density of all treatments. The total mass of soil micro-organisms in the biological systems was 20–40% higher than in the conventional system with manure, and 60-85% higher than in the conventional system without manure. The *activity* of earthworms and soil micro-organisms was also higher in biologically managed plots (Fleissbach et al., 2000). On average, mycorrhizal colonization of roots was highest in the crops of the unfertilized system, followed by the biological systems. Conventional crops had mycorrhizal colonization levels that were 30% lower than biological systems. Mycorrhizal colonization of grass-clover and vetch-rye crops was much higher than in winter wheat or potatoes on both biological and conventional systems. Investigators discovered that conventionally managed soil actually *suppressed* mycorrhizal symbiosis, even when the soil was inoculated with the beneficial fungi (Fleissbach et al., 2000).

The average density, abundance, and species diversity of epigaeic arthropods (spiders, carabids, and staphylinids) on biological systems was significantly higher than that of conventional systems in the Swiss long-term trial (Mäder et al., 1996). Density was almost twice as high in biological than conventional plots. This finding was repeated in several other European studies (Hopkins & Hrabe, 2001:99) where density, species diversity, total biomass, and bird food species of arthropods were consistently and often significantly greater in biological than conventional fields. All of these variables decreased with increasing distance from the field margins – emphasizing the need for uncropped areas on farms for maintaining in-field invertebrate populations.

Research in Australia (Sivapalan et al., 1993) demonstrated similar results to the European findings. They also showed that *within* the biological field plots, total fungal, bacterial and actinomycete populations were higher in soil with a 10-year history of pasture than soil with a 10-year history of vegetable production. Soil managed organically supported twice the microbial populations and a *wider range* of fungal species than soil managed conventionally. Occurrence of fungi potentially antagonistic to plant pathogens was greater in the organic area. Also, a number of soil-borne plant pathogens found in the conventionally cultivated area were not isolated in the organically managed area. The authors attributed most of the observed differences in soil life to added organic matter in the form of composted manure, as well as the 10-year history of pasture on half of the organic plots.

Birds generally have higher avian diversity and total numbers on biological farms than on conventional farms. Differences are attributed to the higher percentage of land in pasture on biological farms studied, as well as the elimination of synthetic pesticides on organic farms (Freemark & Collins, 1992; Friesen, 1994).

One of the advantages of organic or biological agriculture (in terms of biodiversity) is that it does not allow use of synthetic pesticides. Many of the beneficial organism functions described in the section on ecosystem services are more likely to function well on organic farms or areas of farms where pesticides are not used. Carbamate insecticides have been singled out as particularly harmful because they act on the nervous system of insects, and are also known to affect birds, fish, bees, and mammals (EPA, n.d.). Integrated Pest Management (IPM) can also help to reduce negative side effects of pesticides on beneficial organisms.

3.4 Wetlands

Wetlands are lands that are poorly drained and saturated with water long enough to promote aquatic processes. They occupy a position of transition between water and land, and are able to store and release large quantities of water, buffering surrounding areas from weather extremes (Statistics Canada, 2000). Wetlands include salt marshes, sloughs, peatlands, and swamps. The total area of wetlands in Nova Scotia is estimated to be 1,770 ha, with an additional 1,580 ha classified as peatlands (more than 40 cm depth of peat) (Statistics Canada, 2000). It is unclear how much wetland area exists on Nova Scotia farms.

Salt marshes are a significant type of wetland in Nova Scotia. When a salt marsh is dyked for agriculture, it creates valuable fertile land for farm production. Close to 65% of Atlantic Canada's coastal marshes have been converted to agricultural use (National Wetlands Working Group, 1988). Some wetlands are left in their natural state on farms. Salt marshes, for example, can be used for grazing during midsummer drought, or for collection of mineral-rich salt hay (Purinton & Mountain, 1997).

Altering (draining and dyking) salt marshes in order to grow agricultural crops has consequences for marine production, however. Agricultural annexation of marshland cuts off access to the affected marshes by important bottom-tier foodchain fish species, such as mummichogs (*Fundulus heteroclitus*). In addition, the export of organic matter from the salt marshes – a vital life-support function for the detritus-based food web of estuarine and marine environments – is reduced or eliminated where tidal exchange is restricted or cut off by a tide gate, a flapper valve, or a dyke (Purinton & Mountain, 1997).

3.5 Multiple benefits of habitat[6]

Habitats on farms are important for hosting beneficial organisms. But habitats important for biodiversity can *themselves* provide a multitude of other benefits to farms. One example is the ability of hedgerows (or windbreaks, shelterbelts) to provide wood, wild food, habitat for birds and beneficial insects, as well as reduce wind speed.

There are several on-farm benefits of reduced wind speed (Friesen, 1994; Murphy, 1998). These include:
- protection against wind erosion of soil;
- reduction of crop desiccation which helps plants grow faster (less loss of moisture and shut-down of photosynthesis in the wind to prevent drying);
- reduction of crop lodging and other crop damage;
- maintenance of snow on the ground, which increases winter survival of clovers, winter grains, and other perennial crops;
- shade and shelter for livestock;
- longer growing season due to reduced fluctuations in temperatures on sheltered land; and
- protection of buildings in the winter, therefore reducing energy for heating (a 10-30% energy savings is possible).

Natural features such as hedgerows and forests limit soil loss by reducing surface and subsurface water flow through interception and evapotranspiration. Plant cover impedes water flow and creates barriers to soil movement. The effects can be pronounced, as soils may be a foot deeper on the uphill side of a hedgerow than on the downhill side. The closer hedgerows are to each other, the more they act to inhibit soil erosion. Doubling the distance between hedgerows may result in a 40% increase in erosion (Friesen, 1994).

Small strips of vegetation located between streams and cornfields have been shown to remove a substantial quantity of nitrate-nitrogen from the groundwater that otherwise would have moved into the stream. Similarly, shelterbelts have been demonstrated to limit the water migration of various chemical compounds effectively (Friesen, 1994; Murphy, 1998). Trees such as poplar, for example, can effectively reduce soil residues of atrazine by 50% (Siciliano & Germida, 1998).

In addition to producing salt hay, the marine productivity of salt marshes and associated mud flats is staggering. Rotting material produced by the marsh grasses is used by a wide spectrum of organisms. Dead salt-marsh grass is broken down by bacteria and fungi, producing a natural compost that is consumed by a wide range of organisms (detritivores). Detritivores such as crab larvae provide food for small fish, which in turn provide food for larger fish such as striped bass. These larger fish are in turn consumed by species such as ospreys and humans. Salt marshes provide food as well as important spawning and nursery areas for species crucial to the commercial and recreational fish and shellfish industries. (Purinton & Mountain, 1997)

[6] Much of the information in this section is from Friesen (1994), and Murphy (1998).

Wetlands

- trap sediments, nutrients, and other pollutants, thereby greatly improving water quality;
- reduce the likelihood of flood damage, especially important to agricultural producers;
- help control the rate and volume of runoff;
- buffer shorelines against erosion;
- help maintain and stabilize streamflows over longer periods of time;
- provide spawning grounds and habitat for commercially important fish and shellfish; and
- help preserve biological diversity across the landscape (Natural Resource Conservation Service, 1997).

Similarly, wetlands and ponds are important habitats for a variety of amphibian species. Toads, frogs, and salamanders can help regulate pests because they are voracious consumers of invertebrates (including mosquitoes). These amphibians can be widespread on farmlands if provided with suitable habitat. Retention of wetlands on farms not only maintains habitat, but conserves groundwater resources and provides a measure of protection against drought (Friesen, 1994; Gibson, 1997),which became a major affliction to farms in Nova Scotia in the late '90s.

Multiple benefits of habitat example: Bavarian Hedgerows (Naylor & Erlich, 1997).
In Bavaria, hedgerows are the most diverse woody vegetation, containing some thirty woody species, several of which are insect-pollinated. They serve as a major habitat for herbivorous insects and aphids. These insects support a large number of predators and parasites in their natural setting. At the time when the grain crop is developing in the surrounding fields, these natural enemies are present and control the potential damage of aphids on cereals. As a result, northeast Bavaria is one of the few regions in Germany where spraying pesticides against wheat aphids is not necessary.

On some farms, however, larger machinery has required larger fields; wood from the hedgerows is no longer used for cooking or local woodcraft; and other food sources, such as berries, are no longer collected from the hedgerows. These changes have led to an escalating eradication of hedgerows in recent decades that is disrupting the natural pest-predator balance. Moreover, *the service that hedgerows have provided is largely irreplaceable on a time scale of decades*. It has been shown that because populations of insects in hedgerows are very stable and local, hedgerows that were newly planted in open fields did not contain the full set of herbivores and predators *even after 40 years of growth*.

3.6 Trends

It is possible to track trends in broad land-use categories that may affect habitat on a provincial level. Table 3 provides a summary of different land uses and examples of farm practices that can affect habitat. Some preliminary trends in land use and farm practices, based on Statistics Canada agricultural census information, will be discussed.

National trends in agricultural practices such as increased farm and field size, reduction of uncultivated field boundaries, increased chemical inputs, and lower crop diversity, all point to more ecosystem simplification. All these trends adversely affect habitat quantity and quality for beneficial organisms (Friesen, 1994).

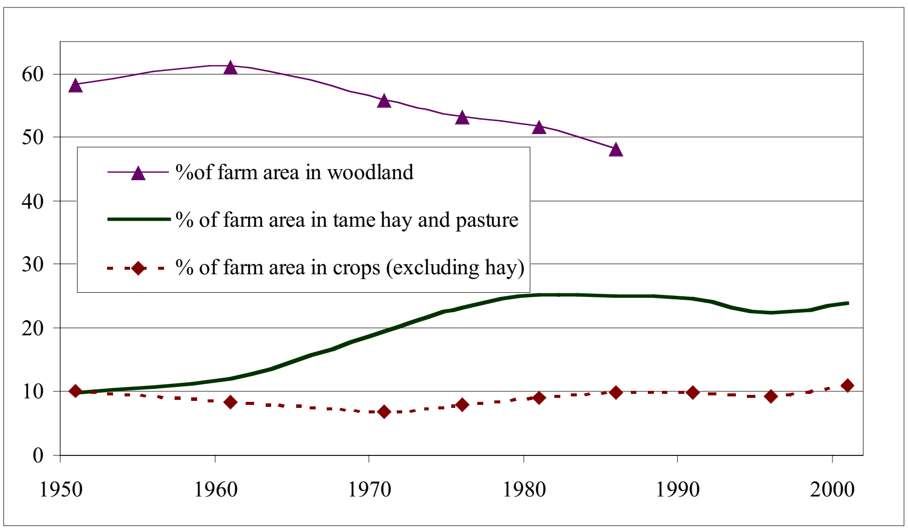
Table 4: Land Use and Farm Practices that Affect Habitat

Land use that affects habitat	NS data?	Habitat effect on beneficial organisms	Reference
Area of land in annual crops	Yes	Beneficial organisms are generally less prevalent and less active in annually cropped vs. perennial areas of the farm.	Hopkins & Hrabe, 2001
Area of land in perennial crops or pasture (uncultivated)	Partial	High levels of nitrogen (N) fertilization, herbicides, land drainage, and high-intensity grazing are all variables that tend to reduce species diversity on pastures and land growing hay.	Hopkins & Hrabe, 2001
Area of land that is not cropped or grazed	Some data, some years	Hedgerows, forest, wetlands and riparian zones are important habitat for predators of pests, including birds as well as a host of other species.	Hopkins & Hrabe, 2001; Pfiffner & Luka, 2000; Langer,2001; OECD, 1997.
Farm practices that affect habitat	**NS data?**	**Habitat effect on beneficial organisms**	**Reference**
Adding fertility to the land	Area fertilized, yes	Increases the activity of soil micro-organisms up to an optimal fertility, then further increases in fertility may decrease their activity.	Brady, 1974; OECD, 1997.
Raising the pH of acid soils	Area limed, yes	Increases the activity of soil micro-organisms up to an optimal site-dependent pH, then decreases their activity.	Brady, 1974; OECD, 1997.
Use of synthetic pesticides	Area of pesticide use, yes	Reduces abundance of soil micro-organisms	Brady, 1974
		Faunal diversity (e.g. arthropods and birds) is negatively affected by organophosphate-based pesticides (used sometimes on livestock and arable crops), and anthelmintics (dewormers used in livestock). The anthelmintics leave residues in livestock dung that adversely affect dung-dwelling invertebrates.	Hopkins & Hrabe, 2001
Organic or biological farming	Some data, 2001 only.	Density, abundance, and species diversity of beneficial birds and arthropods are significantly higher in organic or biological systems compared with conventional or integrated systems.	Fleissbach et al., 2000; Mäder et al., 1996; Hopkins & Hrabe, 2001:99
Crop rotation	Difficult to assess.	Monoculture reduces soil organisms species numbers (richness) and may actually increase the organism count (abundance) of the fewer remaining species.	Brady, 1974 Hopkins & Hrabe, 2001: 100; OECD, 2001:341
		Diverse crop mix improves bird species diversity	
Conservation tillage	Yes	Improves habitat for many soil invertebrates.	OECD, 2001

Land Use

In Nova Scotia, the proportion of farm land in annual crops is 11%, almost unchanged in 50 years, while the proportion of land in tame hay or pasture[7] has risen from 10% to 24% in the last 50 years (Table 2; Figure 1). These proportions are favourable for habitat compared to Canadian averages (Figure 2). The proportion of Canadian farmland in annual crops is between 40% and 45% (up from 32% in 1951), and the proportion of land in tame hay and pasture is only about 18%. Within Nova Scotia, the most intensively-farmed county (Kings) has 28% of farm land in annual crops, and 23% of the land in tame hay and pasture (Figure 3).

Figure 1: Portion of NS Farmland in Woodland, Tame Hay and Pasture, and Annual Crops, 1951-2001



Source: Statistics Canada. 2002; 1997a and b; 1992; 1987; 1982; 1978; 1973.

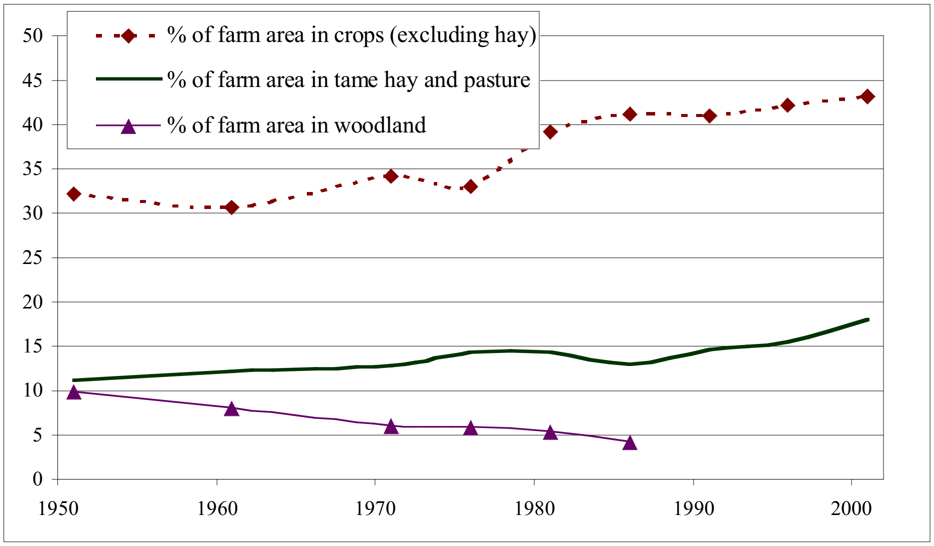
In Nova Scotia and Kings County, about 8% of the farm land area has 'natural land for pasture.' This portion of the land has remained stable for the years reported (1986 to 2001) (Statistics Canada, 2002; 1997a; 1992; 1987). Natural land for pasture is a very important habitat on farms, as explained in the previous section, because it has not been cultivated, drained, or treated with synthetic inputs.

The portion of farmland in 'woodland' is reported in census data up to 1986, when it occupied 48% of farm land in Nova Scotia. The *quality* of forested or wooded land habitat is not reported (as indicated by the method of cutting, or diversity of species, for example), making the data difficult to interpret in terms of habitat quality and the value of this habitat for generating ecosystem services.

[7] Statistics Canada reports area of farm land in tame hay crops, and tame pasture. The agency also has a classification of 'all other land' which could contain 'natural land for pasture'. Tame pasture or 'improved' pasture, is land used for pasture or grazing that has been cultivated, drained, irrigated, fertilized, seeded, or sprayed in recent years. Natural land for pasture has had no such 'improvements' made to it.

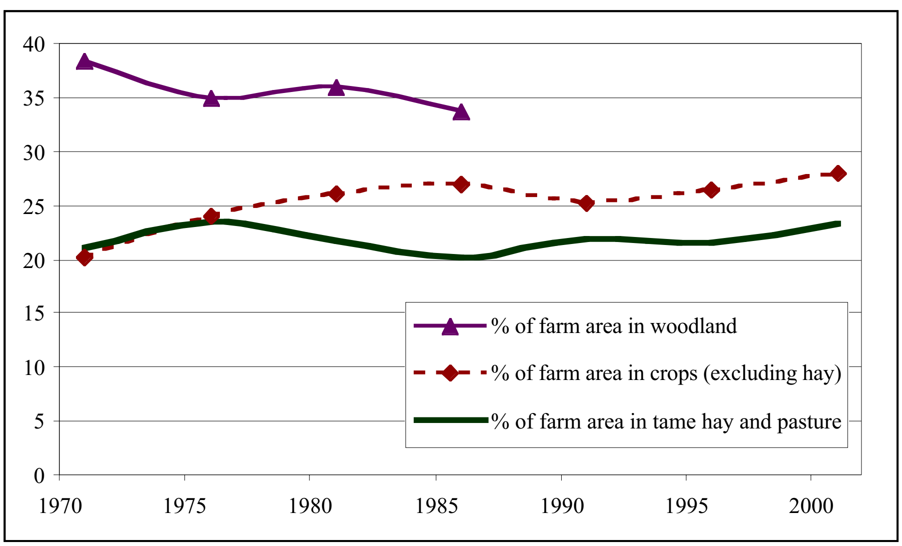
In Nova Scotia, 7% of census farms reported the use of windbreaks or shelterbelts on their farms, and 40% reported the use of 'permanent grass cover' in 2001, up marginally from the 1996 census (Statistics Canada, 2002; 1997a). Both of these are important landscape habitat features for provision of ecosystem services.

Figure 2: Portion of Canadian Farmland in Woodland, Tame Hay and Pasture, and Annual Crops, 1951-2001



Source: Statistics Canada. 2002; 1997b; 1992; 1987; 1982; 1978; 1973.

Figure 3: Portion of Kings County Farmland in Woodland, Tame Hay and Pasture, and Annual Crops, 1971-2001



Source: Statistics Canada. 2002; 1997a; 1992; 1987; 1982; 1978; 1973.

Farm Practices

Many studies discussed in sections 3.1 and 3.3 report reduced habitat quality, species diversity, and ecosystem services as a result of synthetic fertilizer use (particularly rates of nitrogen over 50 kg N/ha) and synthetic pesticide use. Average nitrogen fertilizer use (kg N/ha of cropland) in Nova Scotia in 1990 was below this 'threshold' (Table 4), which indicates that Nova Scotian farms may not be subject to a level of fertilization that would significantly compromise biodiversity. The data *does* show that the increase in N fertilizer use has been continuous over time, with each agricultural census showing higher usage rates. (Unfortunately, average N fertilization rates are not available from Statistics Canada after 1990.) In addition, there will be areas of cropland fertilized at much higher rates of N than the average.

Table 5: Intensity of Synthetic Input Use, Nova Scotia Farms, 1970-2000

Year	Mean kg N fertilizer per ha cropland	Area fertilized		Area sprayed with insecticides or fungicides		Area sprayed with herbicides	
		ha	% area of farms	ha	% area of farms	ha	% area of farms
1970	25.0	38,150	7.1	9,971	1.9	15,567	2.9
1980	37.7	88,537	19.0	11,109	2.4	20,863	4.5
1985	41.8	85,042	21.1	12,165	2.9	24,744	5.9
1990	46.1	82,267	20.7	13,466	3.4	22,383	5.6
1995	n/a	88,552	20.7	22,618	5.3	26,621	6.2
2000	n/a	88,376	21.7	28,217	7.0	29,686	7.3

Note: In Tables 4, 5 and 6, data on insecticides and fungicides for 1995 and 2000 are comparable with each other, but not with previous years. Data for 1995 and 2000 are the sum of area sprayed with insecticides and area sprayed with fungicides. Some areas may be sprayed with both, and therefore counted twice. Previous to this, only one question was asked (area sprayed with insecticides or fungicides?), which eliminated double counting. However, the 1995 and 2000 data reflect more accurately the intensity of use. These different reporting requirements and the possibility of double-counting in the 1995 and 2000 data may explain the apparently very sharp increases in reported insecticide and fungicide use for Kings County and PEI between 1990 and 1995 indicated in Tables 5 and 6 below. Fertilizer per ha is reported in Statistics Canada, 1995. Human Activity and the Environment 1994. These data are not updated in Statistics Canada, 2000. Human Activity and the Environment 2000.[8]

Sources: Statistics Canada, 2002; 1997a and b; 1995; 1982.

In Tables 4, 5 and 6, the areas on NS, Kings County, and PEI farms that are fertilized, sprayed with insecticides and fungicides, and sprayed with herbicides are reported. For the last reporting year (2000), an average of 22% of total farm area was fertilized on NS farms, 36% of total farm area in Kings County (the province's most intensively-farmed county), and 42% of total farm area in PEI. NS farms are also subject to considerably lower levels of pesticide and herbicide application than in PEI, though Kings County pesticide use is approaching PEI levels. This

[8] GPI Atlantic recommends that data for the rate of N fertilizer application continue to be reported.

indicates that on average, Nova Scotia farms are subject to a lower amount of synthetic input use than in neighbouring PEI. The higher the percent of total farm area subject to fertilizer and pesticide use, the more likely that habitat and ecosystem services provided by beneficial organisms will be compromised.

Table 6: Intensity of Synthetic Input Use, Kings County Farms, 1980-2000

Year	Area fertilized		Area sprayed with insecticides or fungicides		Area sprayed with herbicides	
	ha	% area of farms	ha	% area of farms	ha	% area of farms
1980	22,698	34.0	7,814	11.7	10,154	15.2
1985	21,710	36.0	8,375	13.9	11,582	19.2
1990	17,502	31.0	7,501	13.3	9,074	16.1
1995	20,058	35.7	13,841	24.6	11,689	20.8
2000	19,030	36.2	14,440	27.5	11,173	21.3

Sources: Statistics Canada, 2002; 1997a and b; 1995; 1982.

Table 7: Intensity of Synthetic Input Use, PEI Farms, 1980-2000

Year	Area fertilized		Area sprayed with insecticides or fungicides		Area sprayed with herbicides	
	ha	% area of farms	ha	% area of farms	ha	% area of farms
1980	107,442	37.9	31,984	11.3	81,789	28.9
1985	113,297	41.6	35,039	12.9	85,573	31.4
1990	102,117	39.5	36,161	14.0	73,783	28.5
1995	119,451	45.0	91,267	34.4	91,367	34.5
2000	110,102	42.1	89,808	34.4	92,732	35.5

Sources: Statistics Canada, 2002; 1997a and b; 1995; 1982.

In Table 7, the most recent data for areas fertilized, sprayed with insecticides and fungicides, and sprayed with herbicides are reported for Nova Scotia, Kings County, PEI, and Canada. The proportion of farm area is lower, in each case, when comparing Nova Scotian with Canadian areas. Both Kings County Nova Scotia and PEI have higher input use intensities (as measured by proportion of farm area sprayed and fertilized), most likely because of the intensive nature of farming in these areas and the high proportion of fruits and vegetables grown. The trend towards ever-increasing areas fertilized and treated with pesticides is a signal that the ecological services provided by biodiversity (discussed in the next section) may be increasingly compromised.

Table 8: Intensity of Synthetic Input Use, NS, Kings Co., PEI, and Canadian Farms, 2000

Location	% area of farms fertilized	% area of farms sprayed with insecticides or fungicides	% area of farms sprayed with herbicides
NS	21.7	7.0	7.3
Kings County	36.2	27.5	21.3
PEI	42.1	34.4	35.5
Canada	35.6	7.1	38.4

Source: Statistics Canada, 2002.

These data should be combined with rates of use information, which is presently unavailable, to determine more accurately the trends in intensity of farming over time. It is important to know the amount of a nutrient or an active ingredient used, and how benign or toxic these materials might be relative to each other. It is also difficult to know how accurate agriculture census information is, given that it is based on answers to a questionnaire rather than empirical evidence. Data for amounts of synthetic inputs sold to farms within the province would be required to double-check the figures from Census questionnaires. Repeated attempts to obtain pesticide sales data from the Nova Scotia Department of Environment and Labour have failed.

According to recent agricultural censuses, Nova Scotia farmers are using predominantly conventional tillage practices (71% of area prepared for seeding) (Table 8). This is a much higher percentage than the national average of 41% of area prepared for seeding. This is possibly due to the fact that minimum till and no-till work best on light-textured soils, so areas of Nova Scotia with heavier-textured soils are not managed with these methods. Reduced tillage may provide better habitat for some soil organisms. However, it is still unclear whether the increased use of herbicides in reduced tillage systems will cancel out any habitat benefits of leaving the soil relatively undisturbed.

Table 9: Tillage Practices Use on NS and Canadian Farms

Tillage practice	% of area prepared for seeding		
	Nova Scotia farms		Canadian farms
	1996	2001	2001
Conventional tillage (incorporates most crop residues into the soil)	77	71	41
Minimum tillage (tillage retaining most crop residue on the soil surface)	20	20	30
No-till or zero till seeding	3	8	30

Note: Figures in each column may not add up to 100% due to rounding.

Source: Statistics Canada, 2002; 1997a.

Overall it appears that Nova Scotian farms are being managed in a more intensive manner over time. Substantially higher proportions of farm area fertilized and treated with pesticides, along with a slight recent increase in area used for annual crops indicate a definite increase in intensity.

Within Nova Scotia, Kings County is farmed more intensively than average Nova Scotian farms. Nova Scotia is in a fortunate position to be managed much less intensively than Canadian farms in general and PEI farms in particular. From the data available (which is far from complete), it appears that NS farms still offer significant quantity and quality of habitat for beneficial organisms to live, and for beneficial ecosystem services to occur, although trends over time also indicate that these advantages may be increasingly compromised.

4. Ecological Services Provided by Beneficial Organisms

Ecosystem services are the services, such as pollination, that organisms provide as they go about their regular business of living. For example, the bee obtains nectar from the flower, and the flower gets pollinated so it can produce fruit. There is usually some element of benefit, for example the plant carries out a process of photosynthesis in order to grow, but at the same time produces oxygen that human beings can breathe. There are a *diversity of functional ecological roles*, and *beneficial ecological interactions* between species. The variety of ecosystem interactions between plants, animals, and micro-organisms maintains the *quality, relative stability,* and *habitability* of the environment by purifying and regulating air, water, and land resources – as well as controlling climate. Ecosystem interactions play a role in the protection of water resources; the formation and protection of soil; the storage and cycling of nutrients; the breakdown and absorption of pollution; the maintenance of ecosystems' equilibrium (including controlling pests); and the recovery of ecosystems from unpredictable events. In addition, ecosystems provide *biological resources*, such as wild food, medicines, and wood products.

A Swedish study demonstrated that ecological goods and services provided by biodiversity on farms have largely been replaced by fossil fuel-based technology (Björkland et al., 1999). In the 1950s, regulation of Swedish agricultural systems was carried out mostly by landscape-based ecosystem services, and in the 1990s, the system was driven largely by external (purchased) factors. The two systems were compared: net primary production (NPP, a measure of yield) was higher for the more modern system, but when the NPP was corrected to account for the purchased inputs used in the modern system, production gains over the 40 year period were cancelled out by the increased energy required to produce those gains. Not only is this lack of *net* gain concealed by conventional accounting mechanisms based on *gross* domestic product, but the increased farmer expenditures and energy and input usage are *added* to the economic growth statistics, and thus misleadingly counted as contributions to economic progress and prosperity. Compared with 1950s agriculture, the modern system uses less land more intensively (higher use of purchased inputs), many diverse landscape features have been removed, and farms are more specialized regionally, so that livestock operations are concentrated in one area, and crop farms are concentrated in another.

Overly intensive modern production methods severely depleted the ability of the agricultural landscape to provide services such as maintenance of fertile soils, biotic regulation (pollination and pest control), nutrient recycling, assimilation of wastes, and maintenance of genetic information. Biotic regulation alone is estimated to have declined by 60% in the case of wild pollinators, and 75% in the case of invertebrate activity (Björkland et al., 1999).

Swedish agriculture in the 1950s was more dependent on the landscape's ecological infrastructure, partly because transportation of goods and services was less of an option than in the 1990s. More labour and draft power was required in the 1950s, manure from livestock was essential for maintenance of healthy soil life, and landscape characteristics (ditches, field islets, wetlands, small streams, hedgerows, pools of water) were key habitat for beneficial organisms and other wildlife. Much of this 'ecological infrastructure' was dismantled over time. (Björkland et al., 1999)

This Swedish study is informative because it demonstrates that farmers can choose to foster farm environments that allow them to take advantage of ecosystem services, which may yield less. Or alternatively, they can choose to purchase inputs that replace the work done by beneficial organisms. However, the extra energy (i.e. cost) required to implement these solutions may negate any yield gains that result. Table 9 shows some of the internal (ecosystem-based) and external (fossil fuel-based) choices available when production challenges are encountered. Many farms will use a combination of the two. The advantage of ecosystem-based solutions is that they are a renewable resource, always and indefinitely available for free if sustainably managed, and that they tend to produce a wide range of beneficial side-effects that more specialized synthetic inputs cannot achieve. In fact, fossil fuel-based solutions are based on non-renewable resources, and may produce harmful side-effects (e.g. killing beneficial insects with insecticides) (Björkland et al., 1999).

Table 10: Examples Of 'Internal' Vs. 'External' Solutions To Production Challenges

Production challenge	Internal (ecosystem service) solutions	External (fossil fuel-based) solutions
Water stress - drought	- reduce drying winds and increase shade with hedgerows - increase water holding capacity of soil with soil organic matter and crop residue management	- irrigation using plastic hosing and gas-powered pumps
Water stress - excess	- increase organic matter of soil, which helps soils drain excess moisture - leave ponds and trees where drainage is not ideal - leave wetlands and sufficient forests in place to prevent flooding	- install plastic drain tile
Pest or pathogen control	- provide habitat for beneficial organisms - regulation by competing organisms, predators and parasitoids - optimal levels of fertility - crop rotation - appropriate field size	- use of pest control products
Fertility management	- feed soil life with materials high in organic matter such as crop residues and livestock manure	- application of purchased synthetic fertilizers

As an introduction to the topic of ecological services, Table 10 presents a sample of services provided by beneficial organisms. Many ecological services will not be covered in this table, and many have yet to be discovered. The information presented is meant to demonstrate the wide range of activities in an agro-ecosystem that are possibly being taken for granted.

Table 11: A Sample of Ecological Services Provided by Beneficial Organisms

Soil fertility & nutrient supply		
Service	**Detail**	**Reported by**
Nutrient transform-ations	Proteins and related compounds are transformed by soil life to plant-useable nitrates and ammonium compounds. Similarly, sulfate is produced and mineral elements such as iron and manganese are kept relatively insoluble to prevent toxic accumulations.	Brady, 1974: 135
	Soil micro-organisms mineralize soil organic phosphorous (P) for plants to use. The rate of P mineralization depends on microbial and free phosphatase (enzyme) activity. Phosphatases are produced by micro-organisms, plants, and earthworms. It appears that synthetic P fertilizer may reduce this soil activity, and organic management enhances it.	Oberson et al., 1996
Yield improvement	In New Zealand, introduction of earthworms produced a 28% improvement in dry matter yield in pastures that previously had no earthworms. In Vermont, pasture production increased up to 25% in pastures with earthworms compared to pastures without earthworms.	Lee, 1990; Murphy, 1998
	Micro-organisms in soils produce numerous root-stimulating substances that behave as plant hormones and stimulate plant growth. Humus also can stimulate roots to grow longer and have more branches, resulting in larger and healthier plants.	Magdoff & van Es, 2000
Vesicular arbuscular mycorrhizae help crop productivity	Arbuscular mycorrhizal (VAM) symbiosis is widespread in roots of agricultural plants. It is believed to ameliorate plant mineral nutrition, to enhance water stress tolerance, and to contribute to a better soil aggregate formation, which is important for soil structure and stability and helps prevent erosion. It appears that synthetic pesticides may reduce AM activity, while organic management enhances it. Organic systems had measured increases in AM activity of 30-900% relative to conventionally farmed systems. Preliminary evidence shows positive yield effects of AM fungi.	Mäder et al., 2000
	Roots that have lots of mycorrhizae are better able to resist fungal diseases, parasitic nematodes, and drought.	Magdoff & van Es, 2000
Nitrogen fixation	Nitrogen gas in the atmosphere cannot be used directly by crops without the help of rhizobium bacteria and free-fixing bacteria present in the soil.	Brady, 1974: 135
	Estimated value to US agriculture of $8 billion per year (1997 US funds).	Pimentel et al.,1997
Organic matter decomposition	Significant contribution of soil fauna and flora. Organic matter decomposition prevents unwanted accumulation of residues; releases nutrients for use by plants; and improves soil structural stability. (Without this vital process, food would have to be grown hydroponically – an expensive proposition.)	Brady, 1974: 135

Soil fertility & nutrient supply (continued)		
Service	**Detail**	**Reported by**
Soil formation and soil mixing	Earthworms and other invertebrate species bring between 10 and 500 tonnes per ha per year of subsurface soil to the surface, contributing an estimated 1 tonne per ha per year to the fertile topsoil layer. Under agricultural conditions, it takes approximately 500 years to form 25 mm of soil, whereas under forest conditions it takes approximately 1000 years to form the same amount of soil. This enhanced soil formation capacity in US agriculture is valued at $5 billion using a figure of $12 per tonne (1997 US dollars).	Pimentel et al., 1997
Composting –stabilize nutrients, reduce volume of material applied to fields	The major groups of organisms that help convert raw materials to compost are bacteria (excellent decomposers), fungi (highly effective in tackling woody substances), and actinomycetes (technically bacteria – they thrive in aerobic, low moisture conditions).	Rynk, n.d.:12

Regulation of pests and pathogens		
Service	**Detail**	**Reported by**
Healthy crops	A diverse biological community in soils is essential to maintaining a healthy environment for plants. There may be over 100,000 different types of organisms living in soils. Of those, only a small number of bacteria, fungi, insects, and nematodes might harm plants in any given year. Diverse populations of soil organisms maintain a system of checks and balances that can keep disease organisms or parasites from becoming major plant problems. Some fungi kill nematodes and others kill insects. Others produce antibiotics that kill bacteria. Protozoa feed on bacteria. Some bacteria feed on harmful insects. Many protozoa, springtails, and mites feed on disease-causing fungi and bacteria. Beneficial organisms, such as the fungus Trichoderma and the bacteria Pseudomonas fluorescens, colonize plant roots and protect them from attack by harmful organisms. Some of these organisms, isolated from soils, are now sold commercially as biological control agents.	Magdoff & van Es, 2000: 20.

Regulation of pests and pathogens (continued)		
Service	**Detail**	**Reported by**
Pathogen control	In the process of decomposition, soils render harmless many potential human pathogens in waste and in the remains of dead organisms. Soil organisms produce potent antibiotic compounds, such as penicillin and streptomycin, manufactured by a soil fungus and a soil bacterium, respectively.	Daily et al., 1997: 121
	An Australian experiment showed that soils managed organically hosted a higher occurrence of fungi potentially antagonistic to plant pathogens than did conventionally managed soils.	Sivapalan, 1993.
	Earthworms remove plant litter from the soil surface (this can have pest/disease control effects in orchards e.g. apple scab prevention). Apple producers in the Annapolis Valley spend an average of $648-675/ha on apple scab control products (fungicides) – c. 75% of total pest control products expense.	Smith et al., 2001
	Earthworms also quickly break down manure in pastures; recycling nutrients, and reducing fly reproduction sites and internal parasite larvae levels in grazing livestock.	Murphy, 1998
Aerial insect pest control	Bats catch an estimated 3,000 insects per night. Swallows catch insects in open areas. Yellow warblers catch all types of insects including those considered to be pests. Dragonflies and damselflies are major predators of mosquitoes and blackflies, which prey on farmers. Downy woodpeckers consume large numbers of insects including corn borers. Flickers eat insects of all types and feast on grasshoppers in late summer.	Gibson, 1997
	In one study, bird predation on insects in US spruce forests is estimated to be worth $180 per ha per year (1997 US funds), or $246.6 per ha per year ($1997 Canadian).	Pimentel et al., 1997
Rodent pest control	Short-eared owls, barred owls, and red-tailed hawks are valuable for controlling rodents	Gibson, 1997
Biocontrol of crop pests	Approximately 99% of pests are controlled by natural enemy species and host plant resistance. Each insect pest has an average of 10-15 natural enemies that help to control it. The estimated value of this biocontrol to US agriculture is $12 billion per year (1997 US funds), or $16.4 billion per year ($1997 Canadian).	Pimentel et al., 1997
	A full-grown ladybird beetle larva can consume about 50 aphids daily. An average female will eat at least 2,400 aphids before she dies.	See section 4.2
	Beneficial wasp predators and other natural pest controls may have a value of $561,000 per year to Nova Scotia fruit orchards.	See section 4.6
	Anecic earthworm species reduce leaf miner pupae incidence in orchards	Pfiffner & Mäder, 1997
Host plant resistance	Genetic traits in crops that help them resist pests and pathogens. An estimate of its value in the US is $8 billion per year (1997 US dollars), or $11 billion per year ($1997 Canadian).	Pimentel et al., 1997
	Species and genetic diversity of crops helps to foster long-term horizontal resistance to pathogens over time if the farmers select and save their own seed.	Robinson, 1996

Regulation of pests and pathogens (continued)		
Service	**Detail**	**Reported by**
Disease control	Anecic earthworm species reduce scab pathogens in orchards.	Pfiffner & Mäder, 1997
Buffer crops from toxic substances	Humus – the very well decomposed part of organic matter – can surround potentially harmful chemicals and prevent them from causing damage to plants.	Magdoff & van Es, 2000
Antibact-erial activity	Honeys from different floral sources vary greatly in their antibacterial activity.	McCarthy, 1995: 342

Maintenance of water quality and quantity		
Service	**Detail**	**Reported by**
Improved water infiltration in soil and erosion prevention	Erosion-prevention effects of the soil biota include improvements in soil aggregation, prevention of surface crust formation, and increase in water infiltration capacity. • Introduction of earthworms produced a 100% improvement in the rate of water infiltration in pastures that previously had no earthworms. • Chemical elimination of earthworms doubled the amount of annual runoff from a 13^0 slope.	 Lee, 1990 Lal, 1990
Hydrological cycle maintenance	This function of maintaining the water table, slowing percolation of precipitation, filtering wastes before they get to water bodies, water purification, and transpiration is provided by a host of plants and organisms. See Water Capacity and Quality report - forthcoming.	
Resistance to drought stress	Species-rich pasture production dropped by 50% during a drought, compared with a 92% drop in production in species-poor pastures in a Minnesota study.	Tilman, 1997.
Species indicate health of the environment	In many places, the numbers of amphibians have undergone dramatic reductions during the 1990s. Practices such as draining marshes and meadows, and cutting forests often result in a loss of amphibian habitat. Acid rain and other types of pollution also reduce breeding success. Amphibians live both on land and in water. They have a moist, permeable skin and quickly respond to changes in the quality of air and water. Amphibian populations are excellent indicators of environmental stress and should be monitored with care. Examples of amphibians include frogs, toads, and salamanders.	Gibson, 1997
Degradation of chemical pollutants	Biological treatments, which use microbes and plants to degrade chemical materials, can both decontaminate polluted sites (bioremediation) and purify hazardous wastes in water (biotreatment). Biological methods are often more effective than physical, chemical, and thermal methods because they convert the toxin to a less toxic or inert substance – rather than transferring the pollutant to a different medium. The estimated value of this ecosystem service in the US is $22.5 billion per year (1997 US dollars). A portion of this value occurs on farms where toxic materials in sewage sludge and pesticides are being degraded by soil organisms and plants.	Pimentel et al., 1997

Other Ecological Services Associated with Biodiversity

Service	**Detail**	**Reported by**
Crop and livestock breeding	Use of the richness of breeds and plant varieties to improve agricultural breeds and varieties is valued at $40 billion (1997 US dollars) in the US (equivalent to $55 billion in Canadian dollars).	Pimentel et al., 1997
Exotic germplasm for crop breeding	The United States government estimates that for just two major crops, access to exotic germplasm adds a value of more than $10 billion: -- US$ 3,200 million to the nation's US$ 11,000 million annual soybean production, and about $7,000 million to its $18,000 million annual maize crop (1997 US dollars).	Shand, 1997
Pollination	Pollination by a host of different organisms (e.g. bees, butterflies, and birds) is estimated to be worth $40 billion to US agriculture per year (1997 US dollars) (equivalent to $55 billion in Canadian dollars), and $1.26 billion per year to Canadian agriculture. Although many major crops are self- or wind pollinated, others require and benefit from insect pollination to increase quality or increase yields.	Pimentel et al., 1997; Friesen, 1994
	In Nova Scotia the value of rented bees required to help pollinate lowbush blueberries is worth $2.7 million annually. The value of wild pollinators' work in this crop has not been estimated.	See section 4.6
Wild food	Food gathered from non-cultivated species such as fish, berries, deer, fiddleheads, seaweed, or maple syrup can contribute significantly to our diets. In the US, the value of these wild foods is estimated to be worth $34 billion per year (1997 US dollars). If hunting and seafood is eliminated from the estimate, the estimate is a $0.5 billion per year contribution.	Pimentel et al., 1997
Pharmaceuticals from plants	Estimated value of $20 billion (1997 US dollars) (equivalent to $27.4 billion in Canadian dollars).	Pimentel et al., 1997
Medicinal benefits to livestock	A diversity of vegetation in pastures can be helpful to livestock that selectively graze certain plants for their medicinal benefits and/or mineral concentration. Examples of plants in the Maritimes that have these benefits include mugwort (Artemesia vulgaris), dandelion (Taraxacum officinale), plantain (Plantago lanceolata), wild carrot (Daucus carota), chicory (chichorium intybus), juniper (Juniperus communis), and other conifers.	Duval, 1994; Lampkin, 1990; Murphy, 1998
Maintenance of soil structure	Soil organisms produce sticky substances that help bind soil particles together, stabilizing soil aggregates, thus contributing to good soil structure. A good soil structure increases water filtration into the soil and decreases erosion.	Magdoff & van Es, 2000
Carbon sequestration	Conversion of cultivated land to productive permanent pastures results in ~ 176 tons of $C0_2$ being removed from the atmosphere and stored in soil, per ha, a significant contribution in an era of climate change that has direct economic value as a credit under the Kyoto Accords.	Murphy, 1998

In this section, beneficial organisms are considered in more detail. Several beneficial organisms are highlighted here, with the aim of adding new ones in future updates of this report. Commonly known beneficial predatory insects such as ladybird beetles, and common green lacewings are included along with lesser known parasitoid insects such as braconid, chalcid, and ichneumonid wasps. Other beneficial functions include pollination by bees, or soil mixing/aeration by earthworms. The information presented for each organism is based on three very utilitarian questions:

- What are the ecosystem services performed?
- What is the estimated value of those services?
- What conditions does the organism need to thrive/decline, and are these conditions currently being met?

When estimating the value of ecosystem services, it is sometimes useful to know what it might cost to *replace* such a service. In some instances it may not be feasible to actually replace a service, but determining a *hypothetical replacement or restoration value* is still instructive. These numbers may have no practical economic reality but rather demonstrate that certain ecological services are, in effect, irreplaceable or *invaluable*.

4.2 Ladybird Beetles

Ladybird beetles belong to the beetle family Coccinellidae, which means ‘little sphere.’ There are more than 350 species in North America. In Nova Scotia, the seven-spotted lady beetle (C7) is the most common species.

- What are the ecosystem services performed?

Both adults and larvae are fierce predators and are best known for their appetite for aphids. According to Bishop et al. (1997), a full-grown larva can consume about 50 aphids daily. An average female will eat at least 2,400 aphids before she dies.

Where natural enemies (including lady beetles) are not disrupted, aphids such as the green peach aphid on potato and various aphid species in apple orchards seldom increase to densities that cause economic damage.[9]

- What is the estimated value of those services?

The exact economic worth of the crop protection service provided by ladybeetles is difficult to estimate because it would be challenging to set up a comparison control excluding these insects. In one case where crop plants were caged to exclude lady beetles, aphid populations quickly increased to destroy them (WWF Canada, 1999).

If lady beetles were absent from an area, the replacement cost (hypothetical restoration value) would be approximately $34 per hectare, just to purchase the insects.[10] More commonly,

[9] Javorek, S., personal communication.

farmers will take compensatory action when aphids get out of control, and use a pesticide application to compensate for the loss of predatory insects (compensatory value). Pesticide sprays may cost about the same per hectare as purchasing lady beetles, but will do nothing to re-establish a long-term balance between predators and pests (i.e. the capacity for biocontrol). If all populations of lady beetles (and other aphid predators) on Nova Scotia farms were absent, the cost of trying to keep aphid populations under control would likely be significantly higher than $34 per hectare. Using this figure for now, however, we can estimate that lady beetles are providing a service worth at least $13.8 million annually to the control of aphids and other pests on farms.[11]

The naturally-adapted predators will be more effective than purchased insects, because many purchased insects will be lost due to shipping stress and lack of adaptation to the environment in which they are introduced. Their service is more valuable than a pesticide application, because it provides a daily and continuous pest control service, rather than a one-time control. Also, ladybird beetles do not create the health and safety risks associated with spraying a toxic chemical.

Table 12: Ladybird Beetle Species, Functions, And Price

Species	Functions	Price
Seven-spotted lady beetle (Coccinella septempunctata)	This species is most common in Nova Scotia. One to two generations occur annually. The adults and larvae feed on aphids, mites, small caterpillars, aphid honeydew and, when food is scarce, each other (Bishop et al., 1997). Each larva can consume 500 to 1000 green peach aphids during its 2-4 weeks of growth.	2 gallons of lady beetles can cover an area 4-8 ha: $214.00 (NIC, 2001).
Pink spotted lady beetle (Coleomegilla maculata)	These are a particularly voracious predator of the Colorado potato beetle (CPB). Both adults and larvae eat eggs, and the larvae will eat CPB larvae, green peach aphid (GPA) nymphs and adults, and European corn borer eggs. The adults will also feed on nectar, pollen, fungal spores, and GPA honeydew (Pavlista, n.d.).	250 eggs and 50 adults: $76.95 (NIC, 2001).

- What conditions does the organism need to thrive/decline?

Ladybird beetles are sensitive to pesticides intended to kill crop pests. Since ladybird beetles have one or two generations a summer (Bishop et al., 1997), and aphids can produce a new generation every week (WWF Canada, 1999), pest populations can quickly get out of control when predator populations such as ladybird beetles are killed or set-back by pesticide applications. In this regard, increased use of pesticides (see Tables 4-7 above) are a cause for concern.

[10] $214 for 2 gallons of lady beetles, which is likely to cover about 6 ha. This would not include shipping costs, application costs, or costs associated with lady beetles that fly away. $214/6 ha = $36. This is equal to $34 ($1997).
[11] The total area of Nova Scotia farms in 2001 was 407,046 hectares. The area of forested and Christmas tree land is included, because aphids would affect them as well. 407,046 ha * $34 = $13,839,564.

Ladybird beetles benefit from the maintenance of field and landscape diversity. Nearby shrubs, trees, 'weeds' and leaf litter are important overwintering habitat (Bishop et al., 1997; Pavlista, n.d.). This habitat also supports populations of alternative ladybird beetle prey (food sources) such as thrips and mites. Because adult ladybird beetles react very quickly to the absence of prey by migrating (Corbet, 1997), these non-pest insects are an important part of the whole system. An increase in prey diversity ensures that predator densities will remain high even after reductions of specific agricultural pests (Coderre, 1988). Both non-pest prey and beneficial predators require a diversity of habitats within a given landscape (Maredia et al., 1992). Ladybird beetles also benefit from pollen and nectar flowers in the crop area, such as dandelions, wild carrot, and yarrow (Ellis & Bradley, 1996).

4.3 Earthworms

Earthworms provide a wide range of valuable and well-documented ecosystem services in agricultural environments. They provide benefits to the structure and productivity of soils, pest and disease control, as well as food for other organisms.

- What are the ecosystem services performed?

Earthworms provide essential benefits to the structure and productivity of agricultural soils (Table 12). They can produce earthworm castings at a rate of about 20 tonnes per ha per year for crop land and 56 tonnes per ha for pasture land (Murphy, 1998). Another source estimates that earthworms produce up to 33 tonnes of castings per ha per year (WWF Canada, 1999). Earthworms are like composting facilities, taking in mineral soil and other debris, and churning out a valuable, pH balanced, well-aggregated, nutrient-rich product on which crops thrive.

Table 13: Value of Earthworm Benefits

Ecosystem benefits of earthworms	Hypothetical restoration value/ha/yr ($1997)	Hypothetical value to all NS crop and pasture land[12]
Fertilizer producing benefits Earthworms produce 56 tonnes of castings per hectare of pasture and 20 tonnes per ha of crop land per year. Earthworm casts, compared to the top 15 cm of soil, contain five times more nitrate-N, twice as much calcium, three times more magnesium, seven times more phosphorous, and 11 times more potassium. Pasture production can be 25 to 28% higher with earthworm presence than with no earthworm presence (Murphy, 1998; Lee, 1990).	$63,280/ha of pasture land $22,600/ha of crop land[13]	$ 6.2 billion/yr restoration valuation

[12] Pasture and crop land in Nova Scotia consist of 22,873 ha tame pasture + 32,867 ha natural pasture + 119,219 ha crop land = 174,959 ha (Statistics Canada, 2002). Per hectare figures are multiplied by 174,959 ha to reach the figures in this column, or a re separated into pasture land and crop land.
[13] Jolly Farmer Products Inc. in Northampton NB sells worm castings for $231/45 cubic foot bag. A cubic foot of worm castings weighs about 10 lbs, which gives us 450 lbs * 0.454 = 204.3 kg. $231/204.3 kg = $1.13/kg.

Value of Earthworm Benefits (continued)

Ecosystem benefits of earthworms	Hypothetical restoration value/ha/yr ($1997)	Hypothetical value to all NS crop and pasture land
Soil composting benefits "The earthworm gut is like a miniature composting tube that mixes, conditions, and inoculates plant residues." - Neutralize soil pH - Stimulate beneficial soil organisms, e.g. nitrogen fixing bacteria - Provide ideal rooting environment **Creation of porosity and aggregate stability in the soil** - Increases plant growth - Reduces soil erosion - Increases the soil's ability to absorb and hold water **Soil mixing** - Brings minerals upward in the soil profile and makes - plant nutrients more available	$20,580 to $222,180[14] ecosystem service	$3.6 to 38.9 billion/yr ecosystem service
Pest/disease control Earthworms remove plant litter from the soil surface (this can have pest/disease control effects in orchards e.g. apple scab prevention). Apple producers in the Annapolis Valley spend an average of $648-675/ha on apple scab control products (fungicides) – c. 75% of total pest control products expense (Smith et al., 2001). Earthworms also quickly break down manure in pastures; recycling nutrients, and reducing fly reproduction sites and internal parasite larvae levels in grazing livestock (Murphy, 1998).	To be determined	To be determined
Food source for other species such as birds, toads and snakes	To be determined	To be determined

Earthworms stimulate microbial populations. Free-living nitrogen-fixing bacteria are more numerous around the sides of the earthworm burrows. The mucous, enzymes, and calcium lining of the burrows are excellent sources of nutrients for microbial populations, as well as ideal rooting environments (Brown, 1995).

Earthworms producing 56 tonnes/ha/year of castings in pasture land generate $63,280 worth of castings (56,000 kg * $1.13/kg) for a total of $3.5 billion in Nova Scotia farm pastures ($63,280* 55,740 ha) annually (replacement value). Similarly, earthworms producing 20 tonnes/ha/year of castings in crop land generate $22,600 worth of castings (20,000 kg * $1.13/kg) for a total of $2.7 billion in Nova Scotia farm cropland ($22,600* 119,219 ha) annually (replacement value). These prices do not include shipping or spreading costs.

[14] Estimates of the amount of soil processed by worms range from 49 to 1,008 tonnes per ha (WWF Canada, 1999). The average of those two figures is 529 tonnes per ha. Since earthworms perform many of the same functions as a composting operation, the value of 529 tonnes of compost is used as a proxy value for the work they do. Jolly Farmer Products Inc. in Northampton NB sells compost for $60/45 cubic foot bag. A cubic foot of compost weighs about 7 lbs, which equals 143 kg (315 lbs * 0.454). The value of earthworm work is estimated to be $0.42/kg ($60/143 kg), multiplied by the amount of compost generated per ha (529,000 kg) = $222,180/ha. Using the lowest estimate of worm soil processing capacity (because many soils in Nova Scotia are acidic), produces a value of $20,580/ha (49,000 kg * $0.42/kg).

Earthworms also play a role in pest and disease control, for example in orchards (Smith et al., 2001) and in pasturing livestock (Murphy, 1998).

- What is the estimated value of those services?

Estimates of the value of earthworm castings, and earthworm soil processing are presented in Table 12. If we had no earthworm castings in the soil, it would cost about $6.2 billion to replace them annually with commercially-produced castings on crop and pasture land (hypothetical restoration value). The value of earthworm soil processing is estimated based on replacing the weight of soil processed (49,000 kg/ha for the lowest estimate) with purchased compost. This would translate into an ecosystem value of at least $3.6 billion per year (hypothetical restoration value). There are additional services earthworms provide that have not yet been valued, such as disease prevention in orchards, or provision of a food source for other organisms.

Obviously all of these values far exceed the value of agricultural production in the province. If we compared the productivity on land with and without earthworms, and estimated the difference in value of production between the two systems (direct valuation), we would get much smaller figures for the value of earthworm work. If we put a value on the fertilizer and tillage necessary to compensate for lack of earthworms, that would be a compensatory valuationthat would still be much smaller than values presented in Table 12. Avoidance values, the amount of money spent to avoid earthworm losses in the first place (such as liming, adding organic matter, or forgoing a fungicide application), would also be lower. These will all be determined in later updates of this report. For now it is instructive to have an estimate of the hypothetical replacement value of the extraordinarily valuable services earthworms provide, so that it is quite clear why they are so important to soil productivity and agricultural production.

- What conditions does the organism need to thrive/decline?

The primary habitat requirement for earthworms is a good supply of organic matter in the soil to act as a food source. Other conditions that earthworms prefer, and that enable them to thrive, are listed in Table 13. Of course there is some variation among different earthworm species in terms of preferred habitat conditions that y will not be dealt with here.

In 1999 the World Wildlife Fund (Canada) (WWF Canada, 1999: 39-40) prepared a review of the effects of pesticides on earthworms. Pesticides affect earthworms directly as toxins, or indirectly by changing their habitat food sources. In general, earthworms are better off in environments where pesticide use is minimized or eliminated. Parts of the WWF Canada review are reproduced below.

"It is known that fumigants, fungicides, insecticides and vermicides are toxic to earthworms, while herbicides pose less of a threat. Although differences in sensitivity exist among earthworm species, earthworms such as Lumbricus terrestris are very sensitive to toxic chemicals. ... Surface activity makes [Lumbricus terrestris] particularly prone to exposure from chemicals applied to vegetation and to granular pesticide formulations [Ebing et al., 1985; Edwards and Lofty, 1977]. The overall effects of pesticides on non-target organisms such as earthworms can be categorized as follows: (a) reduction of numbers, (b) alteration of habitat with species

reduction, (c) changes in behaviour, (d) growth changes, (e) altered reproduction, (f) changes in food quality and quantity, (g) resistance, (h) disease susceptibility and (i) biological magnification" (Pimental, 1971).

"… Few data exist regarding the toxicity of fungicides for earthworms. It is clear that benzamidazols are very toxic for earthworms; in grasslands and orchards, drastic reductions in earthworm population were observed after spraying with benomyl and thiophanate-methyl [Canters et al., 1990; Stringer & Wright, 1973; Stringer & Lyons, 1974]. Leaf litter was no longer completely decomposed. In orchards with a program of moderate benomyl treatment, all earthworm species were found to have decreased in number after two years, and two species (L. terrestris and Allobophora chlorotica) disappeared completely [Canters et al., 1990]. Earthworm populations generally took from two to three years to recover, depending on species."

"Carbamate insecticides, such as carbaryl, carbofuran and propoxur, are strongly toxic to earthworms [Canters et al., 1990; Kring, 1969]. When carbaryl was applied on grassland (2.5 to 4.5 kilograms per hectare), population reductions of earthworms were observed. With applications of 4.5 kilograms per hectare, almost complete elimination of the population occurred. Agents such as carbaryl and carbofuran also cause sublethal side effects" [Canters et al., 1990).

In light of this evidence, the increased use and intensity of synthetic fertilizers, pesticides, and herbicides in Nova Scotia and PEI in the last 30 years, as noted in Tables 4-7 above, is serious cause for concern, as is the average 23 kg/ha/year loss of soil organic carbon in the Maritimes.

Table 14: Preferred Habitat Conditions for Earthworms

Preferred Habitat	Comments
Soils high in organic matter	Organic matter is a food source for earthworms
Soils covered with crop residues	Residues help reduce fluctuations in temperature and moisture; they are a food source as well as an insulator.
Perennial crops (e.g. pasture)	Perennial crops require less soil disturbance than annual crops
Soils approaching neutral pH	Soils with a pH below 5.6 are generally unfavourable to earthworms. As some fertilizers are acid-forming, the application of fertilizers can reduce earthworm abundance and species richness. As little as 45 kg/ha of urea can halve earthworm abundance.
Fine-textured clay, organic, and clay loam soils	Earthworms are generally less abundant in sandy soils.
Pesticide-free land versus land where pesticides have been applied	Applying herbicides (especially 2,4-D), insecticides (especially those used against cutworms and corn earworms), and fungicides, can drastically reduce earthworm numbers.

Source: WWF Canada (1999); Murphy, 1998.

4.4 Green Lacewings

The common green lacewing, *Chrysoperla carnea* (Stephens), is a well-known predatory insect species. The adults are delicate-looking light green winged insects that are attracted to light. It is hard to imagine that the larval stage of this pretty insect is considered to be a voracious aphid predator.

- What are the ecosystem services performed?

Green lacewings are often the first predators to appear in the spring, making them very important in suppression of early season aphid populations (Bishop et al., 1997). The larvae are less than a centimetre long, but have spiny-looking backs and large, curved, pincer-like jaws which are used to grasp other insects. Larvae feed by sucking body fluids out of their prey. They will consume between 20 and several hundred victims per day. Most of their victims are aphids, but they also control two-spotted spider mites, mealy bugs, mite eggs, leafhoppers, small caterpillars, and thrips (Bishop et al., 1997). Adults feed on nectar, pollen and aphid honeydew (Pavlista, n.d.).

- What is the estimated value of those services?

Lacewing eggs can be purchased. One supplier suggests that 2,000 eggs valued at $38 (2001 Canadian dollars) will cover an area about 500 m^2 (NIC, 2001). That works out to $760/ha for lacewing eggs. If lacewings (and other predators) were absent from an area where aphids, mites, thrips and small caterpillars are threatening a crop, it would cost $760/ha to replace them (hypothetical restoration value). Again, this is a crude valuation for the fine balance between insect species achieved in a natural setting. Other ways of valuing lacewings would be to compare the productivity of similar areas with and without lacewings (direct value), or to estimate the value of pesticide products necessary to protect a crop due to the absence of control species (compensatory valuation). It would also be possible to figure out any expense associated with avoiding the loss of lacewings in the first place (avoidance value), or the cost of attracting them to an area and keeping them there.

- What conditions does the organism need to thrive/decline?

Aphid predators are often difficult to use for crop pest control (outside of greenhouses) because they tend to "skim the top off whatever local aphid population is largest, and then, because they can feed on so many different species of aphids, move on to find a more abundant colony elsewhere" (Olkowski et al., 1991). A much better strategy is to encourage native pest predators by allowing a diverse array of flowering plants in the crop area. The goal is to have something flowering at all times because many predators (and parasitoids) of aphids are dependent on obtaining nectar and pollen for egg laying (Olkowski et al., 1991). The diversity of plants is also important because they host a number of different aphid species, which will increase the chance that predators such as lacewings will stay in the crop area. It is possible to attract lacewings by planting (or leaving) pollen and nectar flowers throughout the crop area. Lacewings also need water, so it is important in drought conditions to have areas where they can drink (Ellis & Bradley, 1996).

4.5 Bees (pollinators)

The pollination service provided by bees is essential in both agricultural and natural ecosystems. In the broadest sense, bees can be classified as managed (honey bees and leafcutting bees) or wild (Andrenid bees, Anthophorid bees, bumble bees, Colletid bees, Halictid bees, Megachilid bees, Mellittid bees, Osmiine bees and Xylocopid bees). Crop pollination is often taken for granted (not valued) until pollinator numbers are reduced or eliminated, leaving farmers with little or no crop. The loss of wild pollinators is mainly caused by two interrelated processes: the destruction of their habitat, and direct poisoning (Kevan et al, 1990). The important contribution of wild bees was nowhere more evident than in southern New Brunswick, when lowbush blueberry crop yields dropped significantly as a result of the decimation of wild bee populations caused by fenitrothion spraying for spruce budworm control from 1969 to 1973 (Kevan, 1978).

In the Maritimes, honey bees are routinely rented by blueberry growers and orchardists to supplement native pollinators. 'Bringing in the bees' is thought to be easier than designing the crop system for optimum native bee pollination. With recent honeybee declines due to winter conditions or mite infestations, the cost of ordering in pollination services has gone up, sparking new interest in native pollinators.

- What are the ecosystem services performed?

Canadian crops that are dependent on insect pollination include apples, pears, blueberries, strawberries, raspberries, cherries, pumpkins, squash, alfalfa, clover, some types of beans, cucumbers, eggplants, melons and tomatoes (Kevan et al., 1990). Honeybees and wild pollinator species also help crops such as canola, sunflower, soybean, and ginseng, which do not *need* external pollinators, but can achieve higher yields with the help of pollinators (Stubbs & Drummond, 1997; McCarthy & Scott-Dupree, 1997; Erickson et al., 1978).

- What is the estimated value of those services?

In 1984, the value of this pollination to Canadian crops was estimated at **$1.26-billion** annually. In the United States, the economic value of honeybees as crop pollinators has been estimated to outweigh their value as producers of honey and other bee products by as much as twenty times (Winston & Scott, 1984).

To buy a new hive of bees costs $120, according to New Brunswick chief apiary inspector, Paul Vautour. To rent a hive of bees for a season of pollination costs between $65 and $70, although in 2001 the price was up 5-10 dollars because of poor bee overwintering (Scott, 2001). Honey bee stocking rates range from 2 to 11 hives per hectare of blueberries, and there were 7,291 hectares of blueberries being grown in Nova Scotia for harvest in 2001 (Statistics Canada, 2002). This amounts to a value of **$2.7 million** for pollination services for the lowbush blueberry crop alone[15] (direct value).

[15] In 2001, 7,291 ha of blueberry producing area in Nova Scotia, requiring about 5 hives per ha, equals 36,455 hives. At $75/hive, the blueberry producers are paying approximately $2,734,125 per year for pollination services.

- What conditions does the organism need to thrive/decline?

Native bees require nesting and foraging habitat. Weather conditions, competition, pests, disease, and toxins in their environment also affect bee abundance. While weather is to a large extent beyond our power to manipulate, factors that farmers *can* control are discussed below.

The loss of foraging habitat within agricultural landscapes is a major factor that contributes to declines in native bee fauna, causing farmers to become more dependent on (rented) honeybees for pollination of crops (Johansen, 1977). For example, in a study comparing 18 lowbush blueberry agroecosystems in New Brunswick, a strong positive relationship was found between the percentage of the study area covered by flowering plants and native bee abundance (Javorek 2001a). Furthermore, when flowering plant populations were separated into habitat-linked populations, floral availability was unevenly distributed, both spatially and temporally, throughout the landscape. These habitat-linked floral assemblages resulted in the need for native bee populations not only to exploit a changing array of forage plants, but also to switch between several habitats over the course of individual or colonial life spans.

In general, nesting habitat differs from foraging habitat. Bumble bees fly from their woodland nesting sites to forage on crops or wild flowers. Soil-nesting bees such as Andrinids, Colletids and Halictids nest within blueberry fields or on dirt roadways that traverse them, and forage along field margins when blueberry is not in bloom. As such, both floral and habitat diversity must be considered important for the conservation of native bees within agroecosystems. The herbicide Velpar (Hexazinone) is widely employed by blueberry growers to create “clean” conditions by destroying weedy plants in and surrounding fields. In addition to lowering floral abundance, herbicide application has changed the traditional multi-floristic composition of blueberry fields to relatively few Velpar-tolerant species that can further limit the foraging options for wild bees. Researchers at AAFC, Kentville, are now encouraging blueberry growers to maintain floral enclaves within agroecosystems to enhance wild bee abundance.

On many crops, wild bees are more efficient pollinators than their managed counterparts. For example, Bumble bees pollinate over six lowbush blueberry flowers in the same time it takes for a honey bee to pollinate a single flower. A honey bee would have to visit a blueberry flower four times in order to deposit the same amount of pollen as a single visit by a digger bee (*Andrena* spp.) (Javorek, 2001b). The ability of many wild bees to forage in marginal weather conditions further enhances their value as crop pollinators.

Competition with rented honeybees may also be contributing to lower native bee populations (MacKenzie & Winston, 1984; Buchmann, 1996; Sugden, 1996). The various disadvantages of honeybees have led a growing number of researchers to suggest that native bees could play a larger role in crop pollination, and that measures should be taken to conserve and enhance their numbers. Protection from pesticides would certainly be at the head of the list of such measures because, in general, native bees are more susceptible to pesticides than honeybees (Johansen, 1977). Researchers in the United States estimate that pollination losses attributable to pesticides account for 10 per cent of the value of pollinated crops and have a yearly cost of $200-million (U.S.). Recovery times for bee populations reduced by pesticide applications can range from one to 10 years, although two dozen studies have indicated periods of five years or more (Kevan & Plowright, 1989).

Parker et al. (1987) stressed the negative consequences of relying so heavily on honey bees and cited many crops that may benefit from the investigation of alternative pollinators. This avenue of inquiry has led to the development of the Blue Orchard bee (*Osmia lignaria*) for the pollination of apples in the United States and western Canada. In the Atlantic region, S. Javorek (AAFC) is developing guidelines on how to increase populations of some of the naturally-occurring Osmiine species (*Osmia atriventris*, *O. tersula* and *O. bucephala*) for blueberry, cranberry, and apple pollination (Javorek, 1998, Javorek, *pers. comm.*).

The rising demand for pollination of lowbush blueberries in eastern Canada facilitated research aimed at testing the feasibility of the alfalfa leafcutting bee (*Megachile rotundata*) as a second managed pollinator of this crop. Leafcutting bees demonstrated the ability to provide excellent blueberry pollination, while displaying many positive attributes such as restricted flight range, high floral constancy, and gentle nature (Javorek, 1996). Despite this, an incomplete understanding of leafcutting bee management retarded the expanded use of this bee within the blueberry industry. Recent advancements in Maritime-specific leafcutting bee management protocols, developed by AAFC, Kentville, have led to excellent pollination on a consistent basis. Given this success, there is a renewed interest in the expanded use of this bee for blueberry pollination.

Pollination of Maritime crops will increasingly depend on a diversified pollination strategy that includes both managed and wild bees.

4.6 Wasps (parasitoids)

Three main types of parasitic wasps help to control pests on Nova Scotia farms: braconid (*Braconidae*), chalcid (*Chalcidoidea*), and ichneumonid (*Ichneumonidae*) wasps (Bishop et al., 1997). They are tiny, but useful. Researchers in Nova Scotia have studied these beneficial wasps, because of their potential to help fruit growers reduce pesticide use in a management protocol known as Integrated Fruit Production (Smith et al., 2001).

- What are the ecosystem services performed?

Bishop et al., 1997, describe the benefits of these special wasps. Braconid wasps parasitize caterpillars, aphids, beetles, flies, and even other wasps. In orchards, they parasitize a number of pests, including leafrollers, codling moth, bark beetles, and aphids. Chalcid wasps are very successful parasites of many pests such as aphids, scale insects, moth caterpillars and eggs, and the larvae of some flies and beetles. Parasitization may exceed 50 percent of some pest populations. Ichneumonid wasps will attack the larvae of moths, butterflies, beetles, and sawflies, as well as other insects. According to Bishop et al. (1997), "female wasps deposit eggs inside their host insects. The long ovipositor allows them to inject eggs directly into larvae hidden inside rolled leaves, plant stems, or even beneath tree bark. Wasp larvae develop inside the host, then pupate in or on the dead body."

According to Trombley et al. (2000), chalcid and braconid wasps also attack ‘secondary pests’ such as the spotted tentiform leafminer (STLM). STLMs are regulated by a combination of braconid and chalcid species in Nova Scotia apple orchards. STLM is not normally controlled with insecticides, because parasites keep population numbers from exceeding economic thresholds. “However, should [braconid or] chalcid populations be destroyed through the use of broad-spectrum pesticide application, STLM populations could soar, resulting in continued pesticide reliance” (Trombley et al., 2000). Parasitism rates of 40%+ and 30% for braconid and chalcid wasps, respectively, have been documented in Nova Scotia.

In experiments comparing chalcid and braconid parasitism of STLM, parasitism was similar or better in achieving pest control in orchard blocks under integrated fruit production (IFP) management than were pesticides in achieving the same results in conventional orchards. IFP is an attempt to achieve pest control equal to that of conventional orchard practices, while relying less on pesticides and more on parasites, predators, and pathogens. (Trombley et al., 2000).

- What is the estimated value of those services?

It is challenging to estimate accurately the value of the intricate, graceful, detailed, and deadly work performed by parasitic wasps. There are several braconid species native to Nova Scotia, and some braconids are available as commercial biological controls (eg. Apanteles). There is a large number of species in the chalcid wasp family, and many are present in Nova Scotia. Most chalcid wasps are parasites of insects injurious to crops; a few injure crops. Some beneficial species (eg. Trichogramma) are available commercially (Bishop et al., 1997).

The parasitic wasps available commercially cost between $130 and $250 to cover one hectare (NIC, 2001). In 2001, 2,806 hectares of tree fruits were reported on Nova Scotia farms (Statistics Canada, 2002). If purchased wasps establish as well as native wasps, it would cost about $502,274 to cover the tree fruit-growing area (hypothetical restoration value).[16] Their actual value to fruit production in Nova Scotia is unknown at this time.

Dr. Rob Smith and colleagues at the Atlantic Food and Horticulture Research Centre in Kentville have been attempting to estimate the value of reduced pesticide use and increased reliance on parasitic insects such as parasitic wasps (Smith et al., 2001). They report significant increases in the percentage of growers spraying for key pests in Annapolis Valley orchards, with only marginal savings in percent crop loss (Table 14). Some of this increase in pesticide use could be due to losses of beneficial organisms in orchards from spraying of broad-spectrum insecticides (Trombley et al., 2000).

Smith et al. (2001) also report that in 2000 an average hectare of Annapolis Valley orchard received $900 worth of pesticide. In the first year of monitoring, orchards using fewer pesticides and relying on beneficial organisms had 1.8% less fruit damage while using 30% less pesticide (by volume), for a saving of $200/ha. A portion of these savings could be due to the effects of a number of different beneficial organisms working in the orchard. If we multiply the possible

[16] The average of $130 and $250 is $190. This figure is converted to $1997 using the NS CPI: $179. 2,806 ha * $179 = $502,274.

benefits of beneficial orchard insects by the area in active fruit production (2,806 ha), benefits could be estimated to be $561,200 per year (direct value). It will be important to monitor the value of progress associated with this initiative.

Table 15: Percentage of Annapolis Valley Growers Applying Insecticides for Key Pests

Pest	% of growers spraying		% crop loss to all pests	
	1983	2000	1983	2000
Apple maggot	76	90	3.9	3.0
Coddling moth	58	87		
Stinging bugs	41	52		
European red mite	40	48		
Winter moth	35	32		
Rosy apple aphid	34	77		

Source: Smith et al. (2001).

Smith et al. (2001) also report that in 2000 an average hectare of Annapolis Valley orchard received $900 worth of pesticide. In the first year of monitoring, orchards using fewer pesticides and relying on beneficial organisms had 1.8% less fruit damage while using 30% less pesticide (by volume), for a saving of $200/ha. A portion of these savings could be due to the effects of a number of different beneficial organisms working in the orchard. If we multiply the possible benefits of beneficial orchard insects by the area in active fruit production (2,806 ha), benefits could be estimated to be $561,200 per year (direct value). It will be important to monitor the value of progress associated with this initiative.

- What conditions does the organism need to thrive/decline?

Chalcid wasps depend on pest populations. An increase in parasitism occurs with a rise in pest populations. When pest numbers decline, so does the level of parasitism. Both populations maintain a balance by remaining between upper and lower limits. This prevents pest outbreaks, as well as complete extinction of pest species (Trombley et al., 2000).

4.7 Conclusions – Ecological Services Provided by Beneficial Organisms

Beneficial organisms are often undervalued because the work they are doing is not very obvious, they spend most of their time underground (e.g. earthworms), and they are less than half a centimeter long (e.g. parasitic wasps). Society takes their work for granted until they are destroyed or their population plummets, and they can no longer do their critical work.

We have made a few preliminary estimates of the worth of these organisms, using mostly hypothetical restoration valuation. Replacing a beneficial organism with a purchased one is most often used in greenhouses, and will be much less successful in a field situation. One common example of replacing beneficial organisms (such as wild pollinators) in decline, is the use of honeybees for pollination.

It is more challenging to devise a value for ecosystem services using direct, compensatory, or avoidance valuations – although some attempts are made. Direct valuation would require properly designed comparisons between crop revenues with and without the beneficial organisms present, an almost impossible task in practice, even though this would likely be the most meaningful economic valuation for farmers. Compensatory valuations are based on expenses incurred for controlling a pest by some other means (e.g. a pesticide) when the natural control mechanisms are no longer in place. Ironically, the compensatory action often exacerbates the situation by harming beneficial organisms, requiring further investments in man-made controls, and a cycle of increased expense and eventual reduced effectiveness. In the United States it was estimated that crop damage due to insect pests rose from 7% to 13% between the 1940s and 1974, despite a tenfold increase in the use of insecticides (Olkowski et al., 1991:96). This declining effectiveness of insecticides may be partially due to the removal of natural controls, and partially due to selection for pests resistant to the insecticides, due to the over-use of those insecticides.

Avoiding the loss of beneficial organisms often involves leaving native flowering plants in crop areas, or allowing for a diverse landscape, which emphasizes again the importance of the earlier discussion on the value of diverse habitats to agriculture. In essence, diverse habitats help to ensure there is a diversity of beneficial organisms that maintain crop productivity, or keep pests in check.

5. Water Remediation

5.1 Introduction

Modern intensive agriculture concentrates nutrients, manure, and other potential pollutants beyond the capacity of the land to absorb the excess. Run-off can contain inorganic N and P as well as organic and inorganic contaminants. Livestock wastes are also potential sources of pathogenic organisms. Erosion from tilled fields can lead to siltation and degradation of streams and rivers.

To this point, we have examined the functions of beneficial organisms as if they functioned independently. But this section provides an opportunity to explore how a number of organisms can work together to perform a vital ecosystem function: in this case, turning polluted water into clean water. The economic value of this alchemical task is higher, the more polluted water becomes. We look at man-made attempts to mimic this natural process in order to estimate its value. Hopefully these figures will provide some perspective on the value of preventing water resource degradation in the first place, and on the synergistic interplay among different organisms that is the product of healthy biodiversity in agriculture.

There are two ways to prevent the water degradation that results from agricultural practices. The first way is to de-intensify agriculture. This involves redistributing livestock more evenly with crop production, ensuring a better balance between livestock and the land on which their manure is spread, and ensuring that input use per hectare is reduced to the point that excesses (i.e. pollution) are not occurring.

In the meantime, there are heavy costs associated with the second option for dealing with water degradation caused by agriculture, -- namely cleaning up the mess at some point between the source of the pollution and the water it has the potential to affect. This option is usually more expensive than preventing it from happening in the first place. Luckily some natural features in our landscape, such as riparian zones, wetlands, and forests, can help to clean and absorb agricultural pollutants. Some trees such as Poplars can even absorb and neutralize widely used and persistent herbicides such as atrazine.[17]

Three points need to be made about natural remediative capacity. First, just because wetlands and forests can absorb pollutants does not mean that we need to be careless about producing those pollutants. Natural remediative capacity has limits, and by overloading wetlands and forests with pollutants, we will seriously undermine their health and diversity (Green, 1994). Wetlands, for example, may absorb excess nutrients from a farm for a few years, then reach their limit, and release them all at once, seriously undermining the aquatic ecosystem and its productivity (see review by Moerman and Muirhead, 1994).

The second point is that as agriculture has become more intensified, many features in the rural landscape that are able to buffer its effects have been removed or changed, compounding the problem.

The third point is that it is expensive to replicate this natural remediative capacity, whether it is constructed in a greenhouse (as in the case of solar aquatics) or constructed in the landscape (as in the case of constructed wetlands). Nevertheless, this possibility is a fascinating, knowledge-intensive experiment worth exploring. It also has the potential to increase our awareness and respect for nature’s own buffering capacities.

There are a number of different options for water remediation. Some examples are

- Constructed wetlands and ponds
- Solar aquatics (SA)
- Natural wetlands
- Zeolites (a basalt with the ability to absorb nutrients and pollutants)
- Forests
- Riparian zones

Two of these options are reviewed below with the goal of reviewing them all in future updates of this report. Here we will focus on the ability of solar aquatics and wetlands to process wastewater. Although some examples from sewage treatment are included here, the same techniques can be used for cleaning water polluted by agricultural practices.

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[17] It is reported that after 80 days, only 29% of labelled atrazine remained in poplar planted soil compared with 79% in unplanted soil (Siciliano & Germida(1998).

5.2 Constructed wetlands and ponds[18]

Constructed wetlands and ponds have been found to be as effective as conventional wastewater treatment in cleaning agricultural runoff and wastewater (Petersen, 1998).

The constructed wetlands will vary according to the site and wastewater contents that need to be processed. Typically a series of ponds and shallow wet areas are constructed so that the wastewater flows through several stages before it is released to the environment at large. It is important to have a long 'residence time' in the system, allowing for sludge to settle, and the water to be processed by a number of different plant and bacterial populations. Plants selected can determine which processes occur. Emergent macrophytes (plants that emerge from the surface of the water) can influence bacterial community structure and physiological function (Grayston et al., 1998). Free-floating and submerged macrophytes have been employed for 'water polishing,' reducing the residual nutrient concentration after bacterial oxidation of contaminants (Peterson, 1998; East, 1994). As well, all these types of plants provide surfaces for bacterial colonization, allowing for more efficient degradation.

Contaminants are removed from water in constructed wetlands through several processes. Chemical and physical mechanisms include redox reactions, photolysis and hydrolysis, volatilization, sedimentation, and adsorption. Biological effects include bacterial oxidation of organic matter and metals sequestration. Nitrogen can be removed from the system entirely through denitrification (Reuter et al., 1992). Sediment and particles settle to the bottom or adhere to the gravel medium or plant surfaces.

Phosphorous (P) tends to be removed from the water stream through adsorption to sedimenting particles or direct sedimentation with some incorporation into plant material (Cooke, 1992). This has been found to lead to a reduction in the ability of the wetland to act as P sink over time. It could be that a periodic harvest of plant material would refresh this capacity but others have found that harvesting mature plants can lead to an even greater decrease in treatment capacity (Uusi-Kämpä et al., 2000).

Table 16: Contaminants, Typical Loading and *Desired* Removal Rates in Constructed Wetlands

Contaminant	Typical loading (Mg/L)	Desired removal rates
BOD	150	>80%
Ammonia N	25	>90%
Phosphorous	10	>80%

Source: Adapted from Peterson, 1998.

[18] Much of the information in this section is from "The use of natural and constructed wetlands for the remediation of agricultural wastes." Prepared by Paul Cushing. Student website: http://is.dal.ca/~dp/new/cushingst.html.

Reports in the literature have shown that pollutant removal efficiencies in natural wetlands are site specific and may vary as a function of wetland hydrology, soil type, and nature of plant cover (Moerman and Muirhead, 1994).

Table 17: Actual Average Removal Rates from the North American Wetland Treatment System Database[19]

	Surface flow			Subsurface flow		
Contaminant[20]	**In (mg/l)**	**Out (mg/l)**	**Removal rate**	**In (mg/l)**	**Out (mg/l)**	**Removal rate**
BOD	29.2	7.9	73%	27.5	9.8	64%
Ammonia N	5.3	2.2	59%	6.0	3.9	35%
Phosphorous	4.4	1.6	67%	3.9	3.6	8%

Example: Gordon and Joyce Jackson, Hillbrook Farm, Clarence, Nova Scotia[21]

Gordon and Joyce Jackson knew they had a problem with manure runoff from their 150 head dairy herd (70 milking) ending up in the Leonard Brook, near Clarence, Nova Scotia. As a result, they built an elaborate wastewater management system that mimics the functions of a natural wetland. Although this installation will not 'turn a profit,' in the long run it may reduce farm costs, and the ecological costs associated with water pollution.

Planning for the project started in early 1999, and the system was in place by late 2000. A pond and four irregularly-shaped 'wetlands' were created in the hillside, with wastewater from the dairy barn and runoff from the manure pile flowing into it. The first receiving pond is designed to overflow into the first wetland, which can overflow into the second wetland, and then the third and fourth. The second, third and fourth wetlands all have pits that can be dug out to remove sludge and sediment every five to ten years.

Advantages of the wetland include its water purification function. The spillway from the last wetland releases water clean enough to flow into the Leonard Brook safely. Also, it provides habitat for wildlife and will help to modify peaks and troughs in precipitation.

Some plants found in North American wetlands (Neralla et al., 1999)

* Sagittaria latifolia (arrowhead)
* Phragmites australis (common reed)
* Scirpus acutus (bullrush)
* Typha latifolia (cattail)
* Typha angustifolia (narrow-leaved cattail)
* Juncus roemerianu (black needlerush)
* Acer rubrum (red maple)
* Quercus sp (oak)
* Cyperus alternifolius (umbrella flat sedge)

[19] The database includes information from 178 sites in 35 American states and Canadian provinces. (Adapted from Anonymous, 1994).
[20] Future updates of this report should include removal of pathogens in water.
[21] The information for this example is from Crocker (2000).

Costs associated with constructed wetlands

In one study, construction costs of $985,500 ($1997) and 12 ha of land were required to treat 3,785 m^3/day of municipal wastewater.[22] This translates into $260/ m^3 per day of capacity (985,500 / 3,785). Another study of four constructed wetlands[23] reports a cost of $81-334 / m^3 per day of capacity, compared to $1,572 – 1,965 / m^3 per day of capacity for a conventional treatment system. The only annual operation and maintenance costs reported were for a 4.8 ha wetland, which amounted to $1.22 / m^3 per day of capacity.

5.3 Solar Aquatics (SA)

The solar aquatics plant in Bear River,[24] Nova Scotia, has the capacity to treat 15,000 gallons (56,700 L) of sewage per day. This would be equivalent to the sewage produced by about 100 homes. The Solar Aquatics Process is a proprietary technology developed by Ecological Engineering Associates (EEA) of Marion, Massachusetts. Annapolis County purchased the rights to use the technology through Environmental Design and Management (EDM).

The advantages of solar aquatics treatment over conventional sewage treatment include:

- reduction in the size of some of the physical unit processes;
- plants used in the SA process remove some elements in the waste stream that are not removed by more conventional microbiological processes;
- removal of the elements mentioned reduces the need to use chemicals in the treatment system; and
- SA does not necessarily do a better job of treating the sewage than some of the more conventional systems, it does it for less expense, and using fewer pesticides.

Three SA plants will be described here. One is in Bear River, Nova Scotia, another is an ice-cream waste processing plant in Vermont, and the third is a plant that serves '330 person units' in a community in Scotland.

22 Gersberg et al (1984) report a construction cost of $450,000 US, $1984 and 12 ha of land to treat 3,785 m^3/day of municipal wastewater. 450,000 * 1.5 (US converted to Canadian) = 675,000 *1.46 (conversion to $1997) = $985,500 ($1997).

23 Annual operation and maintenance of a 4.8 ha created wetland receiving 284 m^3 per day of oxidation pond effluent cost $0.46/ m^3 in 1981. The four case studies gave variable results. Construction costs for the three wetlands ranged from $170-$41 per m^3/day of capacity. For the test hyacinth project, the unit cost was $110 per m^3/day. By comparison, typical secondary treatment capital costs range from $800-$1000 m^3/day (reported in Crites and Minges 1987). 170 * 1.5 (conversion to Canadian dollars) = 255 * 1.31 (conversion from 1987 to 1997 dollars) = 334. Similar formulas were used to convert $41 to $81 ($1997 Canadian); $800 to $1572 ($1997 Canadian); $1000 to $1965 ($1997 Canadian); and $0.46 to $0.69 * 1.77 (conversion from 1981 to 1997 dollars) = 1.22 ($1997 Canadian).

24 The description of the Bear River Solar Aquatics facility is available at http://www.annapoliscounty.ns.ca/solaraqu.htm

Bear River, Canada

The Bear River plant cost up to $400,000 to design and build in 1995. Annual operating and maintenance costs are $40,000[25] ($1997). As the operators become more experienced, the annual operating cost will go down to $25,000, which is equivalent to $250/household served. Generally SA plants operate at about $200/household per year. Therefore the cost summary is $4,000/household initial capital start-up, with a $250/year operating expense, to treat 56,700 L per year of sewage from 100 homes. If the plant lasts 40 years, that would equal about a thousand dollars per year in capital costs, plus an estimated average annual operating cost of $32,000. This works out to $33,000/year ÷ 56,700 L (or 56.7 cubic meters) = $582/m^3 per year.

The Bear River plant treats human sewage and features nine 'Unit Processes.' The final products are released into Bear River, or composted. The nine processes are:

- Screening to remove gross solids.
- Grit removal, i.e. separation of inorganic solids such as sand.
- Bioaugmentation, in which activated sludge is recirculated and bacteria are added.
- Solids grinding to break up gross solids that are not removed on the screens.
- Biological treatment in the solar tanks. There are four rows of solar tanks, each row containing three tanks that contain sewage, bacteria, plants, snails, and other aquatic life forms. Digestion and absorption of organic materials by various life forms in the tanks occurs here.
- Biological treatment in the solar pond (three stages). Solar ponds contain different species than the solar tanks. *A variety of different microbiological life forms* are required to remove the different organic compounds dissolved and suspended in the sewage at this point in the process.
- Sedimentation. In the clarifier, much of the suspended solids settle out of the fluid. The solids, called activated sludge, are diverted either to the bioaugmentation unit or the sludge digester.
- Disinfection. The sewage effluent discharged contains bacteria, and is therefore put through a UV treatment to disinfect it.
- Activated sludge treatment. Any sludge put through this treatment has its organic material consumed by bacteria in an oxygen-rich environment. The dried sludge remains, looks and feels like damp coffee grounds, and is composted.

Findhorn, Scotland [26]

The treatment facility, built in 1995, is considered to be state of the art and cost effective. It is in a 10 x 30m greenhouse with a four-step built ecosystem for processing the waste of 330 'person equivalents.' This facility is therefore likely to be slightly larger than the Bear River '100 household' facility. The four steps are:
1) Anaerobic primary. This stage occurs in a tank outside the greenhouse, and it promotes the growth of *anaerobic and facultative bacterial populations.* Its purpose is to strip odours.

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[25] It is not clear if this includes depreciation.
[26] The description of this facility is available at www.findhorn.org and http://dx.gaia.org/dx1.html#LM.

2) Aerobic reactors. The four aerobic tanks have diaphragm aerators and contain plant species with large root masses on floating plant racking. The BOD and TSS will be reduced at this stage and ammonia nitrified. The primary function of the *plants* is to provide favourable environments for *enhanced microbial activity*. Secondary functions include nutrient removal, metal sequestering, pathogen destruction, and some control of gas exchanges.
3) The clarifiers. This process settles solids, which are returned to the anaerobic primary (#1).
4) Ecological fluidized beds. Wastewater flows through well-aerated beds, which provides a reduction in BOD, TSS, and nitrification. The fluidized beds are planted, and *benthic animals graze the surface.*

The objective of this treatment is to reduce levels of BOD, ammonia, total nitrogen, fecal coliform, and solids.

Ben and Jerry's, Vermont, USA [27]

This SA treatment greenhouse has been in operation since 1989, and processes dairy waste from an ice cream plant in Waterbury, Vermont. Ice cream processing waste is fed to a variety of *plants and animals*, then the food energy is channelled into useful products such as flowers, fish, or compost. The facility is housed in an 8 x 24 m plastic greenhouse. In the greenhouse, three treatment trains purify the wastewater. Each train is made up of five tanks and six marshes. The influent is pumped through translucent acrylic tanks to allow it to be exposed to sunlight, which activates *bacteria* and *microscopic plants* to 'eat' the nutrients present in the ice cream waste.

Algae cling to the sides of the tanks where they can get sunlight for photosynthesis. *Microscopic bacteria* feed on the *algae* and ice cream waste, and *large vegetation* floats on top of the water. *Snails, protozoa and fish (tilapia)* increase the diversity in the secondary tanks and provide important sludge digestion functions. *The higher order of aquatic plants* provides a surface where microbes flourish.

The influent flows through each train from the tanks to the marshes. Air lift pumps recycle a portion of the liquid back to the first tank to inoculate the fresh waste with a rich, *biologically diverse* 'soup.' The final tank is designed for clarification before water flows into the marshes. Undigested solids, which have settled to the bottom of this tank, are pumped out of the greenhouse to be dried and composted.

From the tanks, the water flows into a series of constructed 'tidal' wetlands and engineered marshes. Tidal marsh ecosystems are diverse and prolific environments. The first two sets of marsh tanks mimic a diverse and prolific tidal marsh ecosystem. Every 20 minutes the 'tide' changes with water levels rising and falling on either side of the constructed marsh.

The marshes allow the water to pass through a variety of media, each populated with a *unique ecosystem of purifying organisms*. *Grasses, sedges, rushes, and perennial plants* have been carefully selected to scrub macro- and micronutrients from the waste stream and to increase

[27] The description of the plant is provided by Shawna Henderson, ABRI Sustainable Design, who visited the site.

media porosity. The water flows through an anaerobic marsh of sand and gravel until it spills into the final marsh sumps. The processed water is then sampled, measured, and pumped out of the system.

This system has been proven to be an effective method of cleaning waste water, and reducing various waste indicators to levels below those accepted for conventional waste treatment without using chlorine or other pesticides.

The purpose of providing this detail on the solar aquatics waste water process is to demonstrate the range of applications of this technology, and the energy and costs involved in order to replicate what happens in natural systems. The construction of a SA facility can serve as a replacement cost estimate for wetlands that are changed or degraded by human activity.

Costs and Benefits

Preliminary estimates of costs to build and run a SA plant or constructed wetland are summarized in Table 17.

Table 18: Construction and Operation Costs for Wastewater Treatment Options

	Wastewater capacity (m^3/day)	Construction cost ($1997)	Operation and maintenance ($1997)
		Per m^3/day capacity	
Bear River Solar Aquatics Plant	56.6	7,054[28]	4.42
Constructed wetland[29]	3,785	260	?
Constructed wetlands[30]	various	81-334	1.22
Conventional treatment system	?	1,572 – 1,965	?

There is a cost associated with the concentration of both livestock animals and 'adult person equivalent' units, because their wastes can not be naturally 'digested' by the land around them, therefore requiring expensive treatment facilities, or resulting in costs associated with nutrient accumulation and losses, pathogenic build-up, and water contamination. It is important to circulate as much 'waste' as possible into beneficial processes, such as growing agricultural products using aged or composted livestock manure. Turning waste into a resource results in double benefits of pollution prevention and reduced remediation costs.

Constructed wetlands, solar aquatics plants and other natural features such as forests, natural wetlands, and riparian zones all help to reduce pollution from agricultural sources. Our willingness to pay for such systems will increase as our store of clean water declines.

[28] Figures are calculated as follows: 56,700 L/day capacity /1000 L/ m^3 = 56.7 m^3. The $400,000 design and build cost / 56.6 m^3 per day results in a $7,054 cost / m^3 per day capacity. Likewise, an operating budget of $25,000/56.6 m^3 per day results in a $4.42 cost / m^3 per day capacity
[29] Gersberg et al (1984)
[30] Crites and Minges (1987)

6. Conclusions

While the evidence presented in this study is almost entirely from scientific sources, many farmers, through their direct experience, have a profound understanding of the value of biodiversity, and the ecosystem services it provides to agriculture. Here are a few examples, from interviews with Kings County farmers:

"There is no question but that land is alive. All in a life cycle…. To have productivity you have to have life for the breakdown process."
-Kings County poultry farmer (Campbell, 1994).

(Organic matter is incorporated into the soil routinely. Plant health, weed, insect, and bird life are all used as indicators of soil quality.) "It's been a modest, slow process, with noticeable improvement."
- Kings County mixed farmer (Scott et al., 2000).

"There are an increasing variety of insect-eating organisms including ladybird beetles, various birds, and bats along with a decline in mosquitoes and slugs over the last three years."
- Kings County mixed farmer (Scott et al., 2000).

"I'm really enjoying the symbiotic relationships that are developing on the farm. We took an abandoned farm and turned it into a place teeming with life. There were no snakes before, no toads, no salamanders, few earthworms. The soil we turn over is full of earthworms. We see different kinds of birds and more of them now than before."
-Hants County specialty vegetable farmer, 2002

Biodiversity is both the diversity of living organisms, and the interactions between those organisms. In order to understand biodiversity and its importance for maintaining ecosystems – including agroecosystems – we need to study those organisms, and ascertain their numbers, their diversity, and their preferred habitats. We also need to understand and value the productive work these organisms do and how to encourage this work on farms. Biodiversity is the foundation upon which the earth's productive capacity is based. Humankind might be able to produce food with diminished biodiversity, but it would progressively become a more financially and ecologically expensive enterprise. Thus when we evaluate the progress achieved in agriculture, we must also include evaluations of the state of biodiversity on farms.

"Good farmers know … that nature can be an economic ally" (Berry, 2002:54).

There are a number of proposed indicators of the state of biodiversity on farms. These include indicators of domestic and wild species diversity; genetic diversity; habitat (quantity and quality); and the value of ecosystem services. Here we have focussed mostly on (1) habitat, and (2) the value of ecosystem services. Habitat is an important indicator because it is relatively easy to measure compared to listing and counting all of the organisms that live within the habitat.

Assessing the value of ecosystem services is more challenging, but it is a critical indicator because it measures the value of *what organisms do*, rather than just measuring *what organisms are present*. It is admittedly a very utilitarian approach to biodiversity, but one that is capable of indicating its value to agriculture, thus acting as a catalyst toward more immediate action to conserve biodiversity resources.

Habitat monitoring on farms currently occurs only at a very basic level and should be improved. Information on areas of crops, pasture, hay, and woodland indicates that on average, Nova Scotia farms hold a great deal of potentially beneficial habitats relative to average figures for Canadian farms as a whole. Habitats should be examined more closely in order to assess their quality.

The value of some ecosystem services has been estimated in this study. Since it is challenging to calculate the direct values for these ecosystem services, some hypothetical replacement (restoration) values have been estimated. For a number of different beneficial organisms, we have asked, "what would it cost to replace the work they do?", or, "what would it cost to replace the organisms if they are depleted?" The final section of the study also posed the question, "what would it cost to replace the services of a collection of organisms that filter water in a farm wetland?" Preliminary and rather crude estimates show that to replace the work done by myriad beneficial organisms on farms would cost Nova Scotians millions of dollars annually. In fact, it would cost the province much more than the value of all food produced on Nova Scotia farms.

Fortunately, most farmers recognize the value of the work done by beneficial organisms and many will go to great lengths to attract and establish biodiversity. These farmers themselves become one link in the web of biodiversity, by supporting and enhancing its productive functions.
Many of the lessons learned and observations made about biodiversity come from farmers, ecologists, and agricultural scientists. Some of these lessons are summarized below.

Environmental benefits

The environmental benefits stemming from ecological agriculture are multidimensional (OECD, 1997: 104). One of the most important environmental benefits of biodiversity is its capacity for ecological regulation. Increased biotic diversity usually reduces the chances that one or two organisms dominate, which could cause them to become pests or pathogens rather than just one of many competing species. Generally speaking, healthy species diversity and an even distribution of species indicates a less disturbed ecosystem. This is true for pasture species, insects, or intestinal flora in people or livestock. Indiscriminate use of pesticides or antibiotics can kill pests and pathogens as well as their competitors, leading to high rebound populations of more aggressively reproducing species (Exner et al., 1990; Altieri, 1990; Levy, 1998; Pfiffner & Niggli, 1996). The value of this regulation service has not yet been estimated for Nova Scotia farms.

A Swedish study has demonstrated that the energy-intensive agricultural system of the 1990s is dependent on technology and external energy to protect the production of harvest from climate change, pests, or diseases. Such perturbations are, in ecologically-based systems, often buffered by internal biological feedbacks. Although an ecological system may have a lower gross harvestable *production* in the short term, its *productivity* in terms of *net* primary production is equivalent to a modern intensive system, and may be greater in the longer term (Björklund et al., 1999).

Further, intensive specialized agriculture, with heavy reliance on monocultures of a few cultivars that have uniform response to a particular plant pathogen, is more vulnerable to plant disease epidemics than are more diverse agricultural systems (Robinson, 1996).

The authors of the Swedish study (Björklund et al., 1999) attempted to quantify the value of ecological services on Swedish farms by comparing a farming system that relies on internal ecological services with. an 'intensive' system that relies largely on purchased technology for maintaining and protecting production. This study was a comprehensive attempt to analyze the value of ecological services in farming systems. The authors concluded that although the value of ecological services is equivalent to the value of the technology purchased to replace those ecological services, the longer- term costs of the purchased technology were not included in the cost analysis. This makes the replacement technology unsustainable in the long run, because of its reliance on non-renewable energy and its creation of toxic waste.

The authors recommend that agriculture be organized to take advantage of ecological services – making sure to enhance landscape habitat features that favour diversity and activity of beneficial organisms. They consider this strategy a form of 'ecological insurance' upon which farms of the future may need to draw. Reducing reliance on external inputs "without jeopardizing agricultural productivity will…increase our reliance on local ecosystem services." Their specific recommendations for rebuilding ecological insurance include:

- Reconstruct the landscape to re-introduce smaller fields, forests, and open water.
- Increase the variety of cultivated crops (genetic variety within as well as between species).
- Shorten linkages and feedbacks within farms, between farms, and between farms and consumers, in order to cycle resources such as crop residues, animal manure, and food wastes more effectively, – as well as to reduce the energy needed for transportation. (This would require the re-integration of livestock and crop farming).
- Reduce the use of purchased fertilizers, providing incentives for more sustainable management methods for manure. This would make animal manure more valuable.

The main environmental benefits stem from the existence of *extensive* agriculture, rather than from farm abandonment or farm intensification. Extensive agriculture to the Europeans means using fewer synthetic inputs such as fertilizers and pesticides; adding N inputs of less than 50 kg N/ha per year); relying less on imported feed for livestock; and reducing livestock stocking densities (OECD, 1997).

Knowledge-intensive approach

The use of ecosystem services to maintain and increase productivity requires a thorough knowledge of ecosystem services and how they work. This knowledge may help farmers to reduce purchased synthetic farm inputs, and may therefore create economic incentives for developing knowledge-intensive versus synthetic-intensive agricultural systems. Pest-predator interactions and long-term effects of managing for biodiversity on farms should continue to be carefully researched and documented, and farmer innovation in this area rewarded. "Ecological habitat management and promotion of beneficial organisms should be the strategies of modern plant protection" (Pfiffner & Niggli, 1996).

Farmers have a basic choice: they can rely on ecosystem services to help regulate processes on their farms, or they can choose to purchase these services in the form of fossil fuel-based inputs (synthetic fertilizer, pesticides, feed grown with synthetic fertilizer and transported to the farm, machinery, etc) (Björklund et al., 1999). Unfortunately, the purchased option will often have a further negative impact on the very ecosystem services it is replacing, leading to a costly escalation of input expenditures. The potential for increased loss of ecosystem services over time may necessitate an increasing rate of investments in externally-derived control solutions. Alternatively, investing in ecosystem services to regulate farm production will require site-specific knowledge of the farming system, landscape diversification, and a re-integration of livestock and crop farming.

Policy and research considerations

Many authors point out that we need to find a middle ground between very intensive agriculture, and abandonment of agriculture altogether – both of which contribute to loss of biodiversity. Less intensive farms, or parts of farms, contribute to enhanced habitat for many organisms, along with the resulting ecosystem services these organisms provide. The challenge for policy makers is to support management methods that encourage the ecosystem services provided by rich biodiversity to complement agricultural productivity (OECD, 2001; Kiley-Worthington, 1993).

It is recommended that if monitoring resources are limited, biodiversity monitoring should focus on the value of ecosystem services. The **value** of uncultivated areas within the farm; the **value** of pest-predator activities; the **value** of soil organisms; and the **value** of wetlands should be made explicit in farming circles. In assessing value, it is not the numbers of organisms that count so much as the interactions among the organisms, the balance between organisms, and their activity. On that basis, farmers who manage their farms to enhance overall biodiversity should be appropriately recognized for the societal service they are providing.

"Farmers are poorly paid for the goods they produce. And for the services they render to conservation, they are not paid at all" (Berry, 2002:54).

In many European countries, farmers are paid to enter into voluntary fixed term agreements that improve biodiversity habitat on their farms. For example, farmers in the Netherlands – one of the most intensively-farmed areas in Europe – are paid approximately $578/ha per year for their efforts to improve farm-level biodiversity.[31] Farmers in environmentally sensitive areas of the

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[31] 885.08 Netherland guilders paid in 1996 is equivalent to $567 Canadian dollars (based on the exchange rate on April 30.02). $567 in 1996 is equivalent to $578 in 1997 based on the Nova Scotia CPI.

UK can be paid about $142 /ha per year for similar efforts[32] (OECD, 1997). In Sweden it is recognized that efforts to increase biodiversity on farms also achieve other objectives simultaneously, such as reduction of N and P losses by runoff, erosion, or leaching.

Gollin & Smale (1998) argue that "agricultural diversity cannot be conserved simply by setting aside tracts of uninhabited land; it necessarily involves people…. [A]gricultural diversity can only be maintained in farmers' fields as long as incentives are appropriate." they write. "Diversity is a 'public good' that can't always be established and promoted via the market." When food is purchased in the marketplace, it is generally impossible for the consumer to tell whether the food was produced in a way that conserves or degrades biodiveristy. By contrast /organic certification is one way to remedy this market imperfection. Organic farmers must follow a set of rules – including maintenance of biodiversity on their farms. In return, consumers pay a premium for food produced on those farms.

[32] 66 UK pounds in 1996 is equivalent to $139 Canadian dollars (based on the exchange rate in 1996 1 UK pound = 2.1 $Canadian). $139 in 1996 is equivalent to $142 in 1997 based on the Nova Scotia CPI.

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8. Glossary

Arable: Land that is used to produce crops, usually involving tillage.
Arthropod: Invertebrates that have a jointed body and limbs with a hard shell.
Biodiversity or biological diversity: Global variety of species and ecosystems and the ecological processes of which they are part, covering three components: genetic, species, and ecosystem diversity.
Biological farms: Farms managed to enhance productivity and soil quality without the use of synthetic pesticides or fertilizers. Often composted manure and nitrogen-fixing legumes are the basis of the fertility program.
Biological oxygen demand (BOD): The amount of oxygen required by microbes to mineralize organic compounds; a measure of the organic loading of water.
Biotic regulation: An ecosystem service in which organisms such as bees help with pollination, or such as ground beetles help with pest control. A variety of organisms perform 'jobs' that (even by their existence as a competitor for resources) exert inhibitory or helpful effects on other organisms, thus having an overall regulatory effect.
Carbon sequestration (carbon sink): Biochemical process by which atmospheric carbon is absorbed by living organisms, including trees, soil micro-organisms, and crops, and involving the storage of carbon in soils with the potential to reduce atmospheric carbon dioxide levels.
Conservation tillage: A tillage system that creates a suitable soil environment for growing a crop and that conserves soil, water, and energy resources mainly through the reduction in the intensity of tillage, and retention of crop residues.
Conventional farms: Farms that may use biological methods (See Biological farms) but also have the option to use synthetic fertilizers and pesticides.
Denitrification: The principal loss mechanism of oxidized N from wetlands. NO_3^- is converted to N_2 gas under anaerobic conditions by heterotrophic bacteria.
Ecosystem service: Any service provided by life forms, such as water purification (by cattails or bacteria) or nutrient cycling by soil micro-organisms.
Emergent macrophytes: These are plants rooted in the sediment and extending through the water surface to the atmosphere, effectively linking the air and sediment. This creates an oxic environment near the plant roots and rhizomes allowing aerobic bacteria to degrade organic compounds in the sediment. Included in this category are cattails (Typha spp.), bulrushes (Scirpus spp.), and common reeds (Phragmites spp.)
Epigaeic: Living near the surface of the soil.
Eutrophication The result of high levels nutrients in water. Algae and plants growth is stimulated and decomposition of the extra plant material leads anoxic water. With no oxygen, fish, invertebrates, protists and many bacteria will die and the water body will stay lifeless.
Extensive agriculture: Extensive agriculture (to the Europeans) involves using fewer synthetic inputs such as fertilizer and pesticides; adding N inputs of less than 50 kg N/ha per year to land; relying less on imported feed for livestock; and reducing livestock stocking densities. **Intensive agriculture** involves using more synthetic inputs such as fertilizer and pesticides; adding N inputs of more than 50 kg N/ha per year to land; relying more on imported feed for livestock; and increasing livestock stocking densities. Both are relative terms.

Genetic erosion: The loss of genetic diversity between and within populations of the same species.
Humus: The very well decomposed part of the soil organic matter.
Integrated Fruit Production (IFP): IFP is an attempt to achieve pest control equal to that of conventional orchard practices, while relying less on pesticides and more on parasites, predators and pathogens.
Integrated Pest Management (IPM) or Integrated Farm System: Control of pests using a combination of techniques such as crop rotation, cultivation, and biological and chemical pest controls.
Invertebrates: Animals lacking a spinal column, e.g. earthworms.
Keystone species: Those species that are in some way central to the survival of a host of other species and therefore produce a degree of stability in an ecosystem. A coyote is an example of a keystone species in canyons. The coyote keeps the size of the populations of other predatory mammals, such as raccoons, in check. When the coyote is not present, population of these smaller predators explodes, leading to the extinction of other breeding birds or small mammals.
Ley: An area on a farm that may be grazed by livestock, but it is not a permanent pasture as it is rotated with other crops.
Monoculture: Production of the same annual crop in the same field year after year.
Mycorrhizal relationship: The mutually beneficial relationship that develops between plant roots of most crops and fungi. The fungi help plants obtain water and phosphorous by acting as an extension of the root system and in return receive energy-containing chemical nutrients from the plant.
Nitrogen fixation: The conversion of free nitrogen in the atmosphere to nitrogen combined with other elements; specifically regarding soils, the assimilation of atmospheric nitrogen from the soil air by soil organisms to produce nitrogen compounds that eventually become available to plants.
Opportunity cost: These are the losses incurred from not being able to take advantage of the best alternative use of an asset. Wetlands can require significant land area, land which could perhaps be more profitably used for crops or livestock. Countering the lost revenue are the non-monetary benefits derived from the water treatment in a wetland.
Organic farming: A system of farming employing biological methods of fertilization and pest control as substitutes for synthetically created fertilizers and pesticides.
Parasite: Parasites consume parts of their prey rather than the whole.
Parasitoid: A group of insects that lay their eggs in or near other insects. The larval parasitoid then develops inside its host, killing it. It is estimated that parasitoids account for about 25% of the world's species.
Pasture: Grasses, legumes, and/or other herbage used or suitable for the grazing of animals.
Pathogen: A causative agent (bacterial, fungal, or viral) of disease.
Pest: Any organism that is annoying to mankind.
Pesticide: Chemical that kills or controls pests; mainly includes herbicide, insecticide, and fungicide.
Precautionary principle: The principle of precautionary action has four parts. (i) People have a duty to take anticipatory action to prevent harm; (ii) the burden of proof of harmlessness of a new technology, process, activity, or chemical lies with the proponents of the technology, not with the general public; (iii) before using a technology, process, or chemical, or starting a new activity, people have an obligation to examine a 'full range of alternatives'; (iv) decisions

applying the precautionary principle must be 'open, informed, and democratic' and 'must include affected parties.'[33]
Predators: Predators kill their prey.
Productivity: Yield per unit input, in a given unit of time. Inputs can include energy, costs, time, labour, area, nutrients, etc. Productivity is often measured based on the most limiting or expensive input. Ecological measures of productivity are based on minimizing non-renewable inputs and polluting outputs.
Resilience: A measure of the rate of productivity recovery after a disturbance.
Resistance: A measure of the change in productivity in response to a particular intensity of disturbance (e.g. drought, flood etc.).
Semi-natural: This is a term used often in European studies. It refers to managed meadows and managed woodlands. The **meadows** are minimally managed hayland or pasture. They generally receive no synthetic fertilizer or pesticides. Manure may be used, as well as lime. The areas are generally grazed once or mowed once per year.
Sod: A dense covering over the entire land surface comprised of a mixture of grasses, legumes and other herbs. Usually all land classified as pasture and hay can be assumed to have a sod cover.
Soil cover: Vegetation, including crops, and crop residues on the surface of the soil.
Soil organic matter: Carbon-containing material in the soil that derives from living organisms.
Soil quality: It encompasses two distinct, but related parts. *Inherent quality*, or the innate properties of soil such as those that lead to soil formation; and *dynamic quality*, covering the main degradation processes (physical, chemical and biological) and farm management practices.
Species diversity: The number of different species within an ecosystem (**species richness),** the number of individuals within each species (**species abundance**), or the relative abundance of a number of species (**species evenness**).
Sustainability: A measure of the ecological productivity of an agro-ecosystem over a long period of time in order to be able to assess its resistance, and resilience in the face of change.

[33] from Rachel's Environment and Health Weekly, Feb. 1998.