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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

EXECUTIVE SUMMARY

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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.
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.

Land Use and Farm Practices that Affect Habitat (continued)

Farm practices that affect habitat	NS data?	Habitat effect on beneficial organisms
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.