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ANALYSIS

Impact of production intensity on the ability of the agricultural landscape to generate ecosystem services: an example from Sweden

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Abstract

This paper identifies a number of essential ecosystem services, and estimates their generation by the Swedish agricultural landscape under different production intensities. This is exemplified with data from a low-intensity period (1950s) and a high-intensity one (1990s). The services are described in qualitative and, to the extent possible, quantitative terms, and the ecological functions that support these services are identified. About 20% of Swedish agricultural land has been removed from production during the past 40 years. Production has been strongly intensified with respect to external inputs, and specialized regionally. Local landscape mosaics have been substantially altered, which resulted in a decreased ability of agricultural landscapes to support natural ecosystem components and processes. We argue that all of these changes affect the ability of the landscape to generate ecosystem services. Local, ecological 'goods and services' have largely been replaced by fossil fuel driven technology and the regulation of the system is now driven much more by external factors. However, there is no notable change in the system's ability to assimilate solar energy, measured by net primary production (NPP) and corrected for the cost of production (external inputs considered as foregone NPP). Most of the measures we derive indicate a loss of ecosystem services from the Swedish agricultural landscape. This is tantamount to losing an important form of 'local ecological insurance', and could lead to serious problems in a future with lower access to external resources, or with an altered energy policy.

Keywords: Ecosystem services; Agricultural intensification; Landscape mosaic; Biodiversity; Ecosystem function; Land use; Environmental support system

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1. Introduction

The primary goal of twentieth century agriculture has been to meet the food demands of rapidly increasing populations. The yields increased but at the same time agricultural mechanization made manpower available for other economic sectors such as industry and service. In the industrialized countries, this development has been highly successful. However, this overwhelming success story comes with an ecological price tag of unknown but probably substantial proportions. By converting large regions into agricultural lands, humans have changed the kind and amount of 'ecosystem services' (Daily, 1997) provided by these areas. In many situations, poor agricultural practices or overly intensive production methods severely have depleted the ability of the agricultural landscape to provide services such as maintenance of fertile soils, biotic regulation, nutrient recycling, assimilation of wastes, sequestration of carbon dioxide, and maintenance of genetic information (Vitousek et al., 1986; Pimentel, 1988; Ehrlich and Erlich, 1992; Paoletti et al., 1992; Odum, 1993; Vitousek, 1994; Daily, 1997; Matson et al., 1997).

Sweden, like most of Europe, undertook a major modernization of agricultural practices this century. In the mid 1950s, Swedish agriculture was intensified through accelerated mechanization and increased use of fossil fuel, fertilizers, and pesticides. The rapid structural changes within the Swedish agricultural landscape since the end of the Second World War are documented in official statistics by Statistics Sweden (SCB). These changes, manifested in, for example, increased farm and field size, specialization, and enlargement of the production, have also been described and quantified by analysis of aerial photographs (Ihse and Nordberg, 1984; Ihse and Lewan, 1986; Skånes, 1990; Ihse et al., 1991; Ihse, 1995, 1996). Localized effects on biological diversity related to these changes have been documented (Fogelfors and Steen, 1982; Andersson, 1988; Persson et al., 1989; Bengtsson-Lindsjö et al., 1991; Bernes, 1994; Ahlén and Tjernberg, 1996). However, there has been little or no attempt to quantify changes in the production of ecosystem services as a consequence of this agricultural intensification in Sweden.

In this paper we have identified a number of essential ecosystem services, and estimate their generation by the Swedish agricultural landscape under different production intensities. The word intensification is here used in the sense of the intensity of the use of purchased inputs. Our approach was to analyze agricultural statistics and inventories from the 1950s (pre-intensive agriculture) and 1990s. We have described the services in qualitative and, to the extent possible, quantitative terms, and identified the ecological functions in the different biotopes that support these services.

Our first objective is to elucidate the trade-off between the production of food and the production of other ecosystem services. We also wish to highlight the trade-off between the intensive use of external inputs vs. the landscape's ability to maintain agricultural production when ecosystem services are less compromised.

Finally, we discuss the importance of ecosystem services for the future of Swedish agriculture, and raise questions about what mixes of technology-based and 'ecosystem services-based' practices may provide long-term sustainability.

2. Structural changes in Swedish agriculture, 1950s–1990s

2.1. Regional changes in land use

Agricultural land constituted 7–9% of the total area of Sweden during 1951–1996 (SCB, 1997a). Over 95% of agricultural production takes place in the southern half of the country (Rabinowics, 1992). From 1951 to 1992, about 20% of the agricultural land was removed from production (Fig. 1). Most of this removed area has overgrown with brush or been reforested, but about 10% has been urbanized (64 000 ha from 1960 to 1995, the time period with the most expansive urban development).

Patterns of land use change vary regionally. In the northern and central regions, where forestry predominates, agricultural land has been aban-

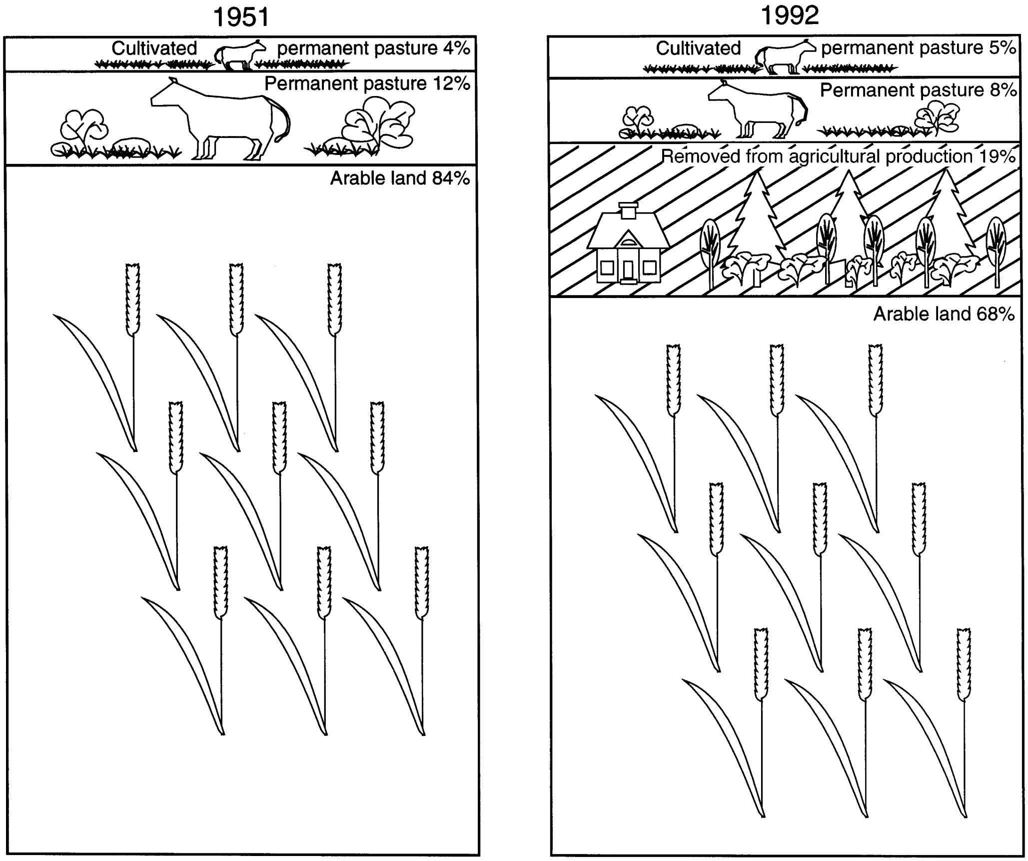

Fig. 1. Land use in the agricultural system (1951 and 1992). Total agricultural area was 4.37×10^6 and 3.56×10^6 ha in 1951 and 1992, respectively. In the statistical records, the definition of pasture and meadow changed during this period. In 1951, permanent pasture and meadow meant land never cultivated, while in 1992 pasture included, among other things, former arable land used as pasture in a permanent manner. Also management practice and grazing pressure differ considerably. In 1944 natural meadow constituted about 5% of the total agricultural land, but in 1989 it was estimated to exist on less then 1% of the land area defined as permanent pasture (data for 1951 and 1992 not available). Sources: (SCB, 1951, 1997b).

doned and the forests extended, whereas in the southern plains production has been greatly intensified, largely at the expense of uncultivated pasture and meadows (Ihse, 1995).

2.2. Intensity

Harvested yields per hectare increased considerably during the last 40 years. For instance, rotational ley, barley and winter wheat yield increased by 20, 80 and 140%, respectively (L. Ohlander, Dept. of Crop Production Sciences, Swedish University of Agricultural Sciences, personal communication, 1998). The total harvest of cereals has increased by about 85% in spite of an actual reduction (20%) of the area with cereals. Milk production per cow has increased about 200%. However, total Swedish milk output decreased slightly as the total number of milking cows declined approximately 70% (SCB, 1954, 1997b).

These increased yields have mostly been made possible through intensive use of external inputs. Among the most important inputs are direct energy (primarily fossil fuel), nitrogen, and imported fodder, which increased by 110, 190, and 460%, respectively, from 1951 to 1992 (Fig. 2). The corresponding increase in carbohydrates and proteins in the output of products from the agri-

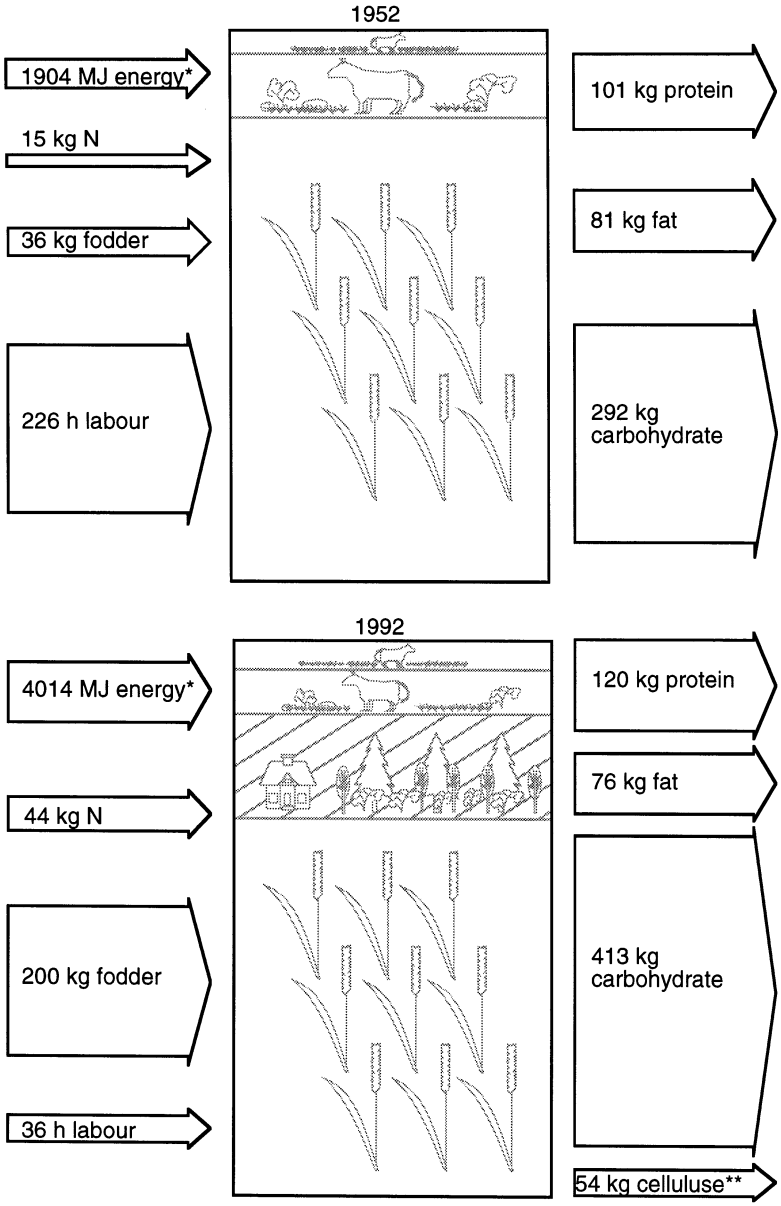

Fig. 2. Inputs to and outputs from the agricultural sector per hectare of agricultural land, in 1951 and 1992. Calculations based on data from Livsmedelsverket (1981, 1996), SCB (1951) and SCB (1997a). *Including energy use for production of electricity. **Calculation based on average Swedish yearly net felling (Håkansson and Steffen, 1994; Skogsstyrelsen, 1997).

cultural sector was 40 and 20%, respectively. Production of fat decreased by 6%. This is a consequence of a shift in the production from e.g. oleiferous plants and rotational ley towards cereals as a conscious attempt to reduce fat content in agricultural products. Moreover, as a consequence of the last 40 years' reforestation, we estimate that the production of lumber on former agricultural land is now 1 345 000 m^3 annually. Perhaps the most striking changes of all are the

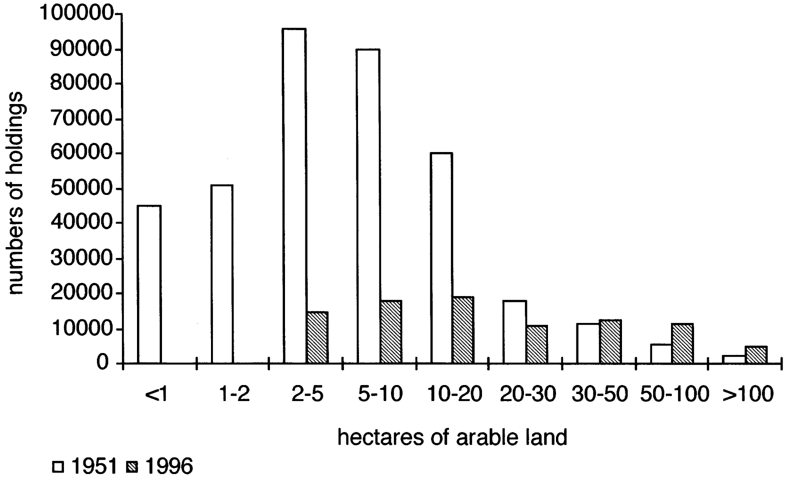

Fig. 3. Numbers of holdings by hectares of arable land. For 1996 no data were available for holdings smaller than 2 hectares, which comprised about 7% of the arable land in 1992 and 3% in 1951. Sources: (SCB, 1951, 1997b).

replacement of 80% of human labor with external inputs and the near-complete disappearance of draft animals. The total number of draft horses in Swedish agriculture in 1951 was approximately 304 000 (SCB, 1951). Draft horses declined to approx. 12 500 in 1991 and were used mostly in small scale forestry (Bernes, 1994; SCB, 1997b).

Intensification is also clearly indicated by the 9-fold increased areal use of pesticides. Only about 5% of the arable land was treated with herbicides in 1951 compared with about 45% in 1994 (Holmström and Lilliehöök, 1951; SCB, 1997b).

2.3. Changes in production scale and effects on the landscape

The average size of farms increased from approximately 10 to 31 ha of arable land between 1951 and 1995 (Fig. 3; SCB, 1951, 1997b). Nationwide, field sizes increased by 21% (Ihse et al., 1991) to accommodate the use of larger farm machinery. Even greater changes occurred in the south. For example, between 1947 and 1978, average field size increased from 4.6 to 24 ha on a large property in the south of Sweden (Ihse and Lewan, 1986). Average dairy herd size in Sweden increased from 5 head in 1951 to 28 head by 1996 (SCB, 1951, 1997b). As individual farms have increased in size, numbers of farms and farmers declined.

These changes in production scale have had large effects of the local agricultural landscape. Up until the 1950s Swedish agriculture was largely dependent on local conditions and limited by the landscape's ecological infrastructure, such as soil types and mineralization rates, geographic features such as shade trees and hedgerows, and sunny weather for drying the harvest. By the 1990s many of the connections between natural geographic features and agricultural production had been severed. Local characteristics such as ditches, field islets, small streams and pools of water were leveled out, as they were regarded as obstacles for large scale production (Ihse et al., 1991; Ihse, 1994). These areas are often considered as key biotopes for wild plants and animals, as they are ecological infrastructures which enhance dispersal and provide refugias for nestling and over-wintering.

The changes in the local Swedish agricultural landscape during the last 40 years can be summarized as enlargements of field sizes and decreases in linear elements (such as ditches and field edges), point elements (e.g. tree islands), grasslands, and wetlands (Ihse, 1995, Fig. 4).

2.4. Specialization

Specialization was the net result of agricultural policies that purposefully, through subsidiaries, price regulations, legislation, and extension, enforced a structural change towards industrialized agriculture. These policies were made possible by a large supply of cheap fossil fuel.

One of the more conspicuous changes has been the increasing separation of plant and animal production. Today, 'industrial' farms are dedicated to either crop production or animal husbandry. In 1951, 92% of all holdings kept animals compared with 57% in 1996. Furthermore, different types of production are concentrated in different geographical regions (Fig. 5). One effect of this, besides the increased use of energy for fodder transportation from regions with crop production to regions where animal production is concentrated, is an inefficient use of nutrients. At the national level, more N and P are consumed in agriculture than harvested (Fig. 6) and this excess N and P to some extent depend on the inefficient distribution of nutrients (excess manure which causes environmental problems in regions of high animal production, nutrient deficits with commercial fertilizers in regions of intensive crop production).

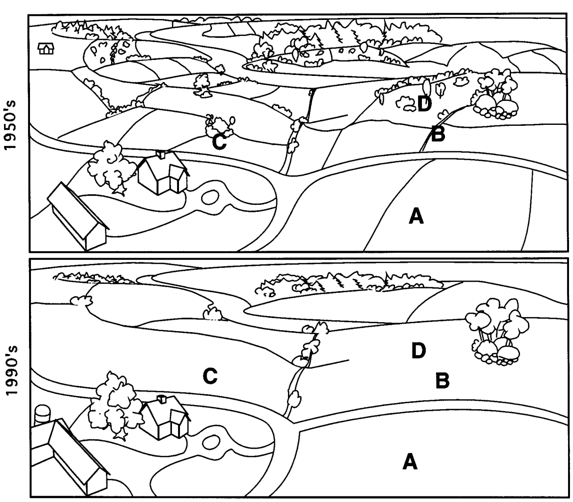

Fig. 4. Illustration of changes in the mosaic of the Swedish agricultural landscape during the last 40 years: (A) enlargement of fields; (B) removal of linear elements; (C) removal of point elements; (D) cultivation of natural grasslands.

3. Changes in the landscape's ability to provide ecosystem services

In this section we describe, first, changes in factors of production which directly impinge upon agriculture, and second, effects of intensification on the 'environmental support system' of the agricultural landscape. The results are summarized in Table 1 and its footnotes, and we refer to them throughout this section.

3.1. Direct production factors

3.1.1. Photosynthetic capacity

Total net primary production (NPP) in the agricultural landscape was about 20% higher in 1990s than in the 1950s (Table 1, footnote 1). During the same period the direct and indirect energy input to the agricultural sector increased nearly 3-fold. If this energy were generated by biomass production rather than oil (a plausible future scenario), this would require 800 additional kg of NPP production per hectare[1] in 1951 and 2400 kg in 1996 or 0.13 (1951) and 0.37 (1996) kg biomass fuel per kg harvested yield. If NPP is corrected for this cost, the 1990s gains essentially disappear (Table 1, footnote 2).

These calculations (biomass energy equivalents of fossil fuel-based external inputs) represent an incomplete estimate of external energy demands by Swedish agriculture, because we do not correct for changes in production efficiencies (at any number of points in the production cycle), nor for differences in energy qualities (e.g. coal vs. oil vs. nuclear vs. solar). Furthermore, we have not accounted for the energy costs of generating the resources ('ecosystem work'), nor have we considered adverse environmental effects of industrial manufacturing/processing or emissions when the external resources are deployed.

[1] Based on area considered as agricultural land in 1951 (4.37×10^6 ha).

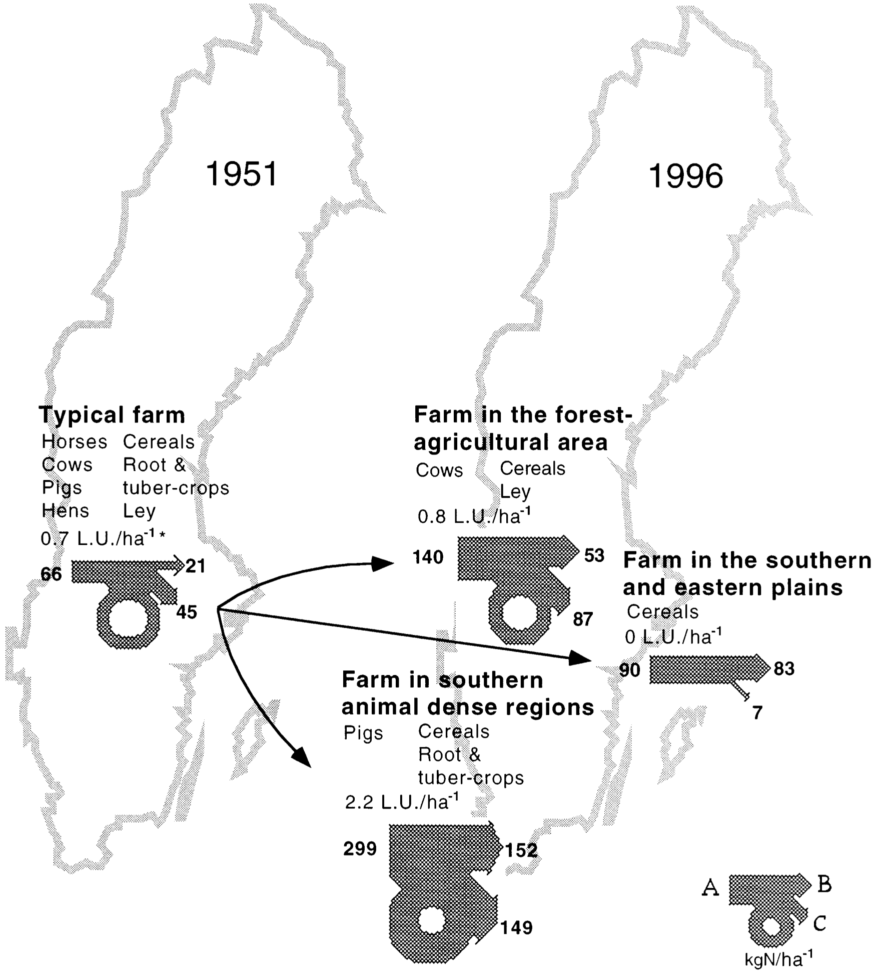

Fig. 5. Illustration of structural changes in Swedish agricultural production and the resultant change in nitrogen flows, exemplified with a typical farm in 1951 and its three corresponding farms 1996. Data for nitrogen flows in 1951 are estimated from the flows on an organic farm in 1990, with equal numbers of livestock units per hectares (Granstedt and Westberg, 1993). Data for farms in 1996 from Naturvårdsverket (1997): (A) supply through fodder, fertilizers, seeds, bacterial fixation and aerial deposition; (B) sale; (C) losses to air and water. Circle equals recycle on farm. *L.U. ha^{-1} = livestock unit per hectare.

3.2. Soil fertility

3.2.1. Organic matter and structure

Based on national estimates of a yearly decline of organic matter by about 1 million tonnes in Swedish soils (Lilliesköld and Nilsson, 1997) we calculated the overall decline during the last 40 years, to about 9000 kg ha^{-1} (Table 1, footnote 3). This is due to a dramatic decline in organic matter in organic soils, estimated at between 2000 and 7000 kg C per hectare and year (Lilliesköld and Nilsson, 1997). Organic soils comprised about 400 000 ha in the 1960s and 250 000 ha in the 1990s (Berglund, 1996). Even mineral soils have lost some organic carbon. In mineral soils in field trials in eastern Sweden, containing 1.5% organic carbon, Persson and Kirchmann (1994) reported a continuous reduction of soil carbon over 35 years of cereal production with straw removed. Decreases in soil organic matter mean less substrate for microorganisms and for earthworms, insects, and other invertebrates, which are important for soil structure, infiltration, nutrient cycling etc.

Impaired soil structure, as an effect both of compacting and of diminished soil organic content, is estimated to reduce potential yields from mineral soils in the southern Swedish plains by 10–20% (Håkansson, 1993) (Table 1, footnote 4). Studies also indicate the presence of a permanent hard and thick plow-layer, impairing the permeability for water and roots, in clay soils cultivated with heavy machinery (Rydberg, 1986).

3.2.2. Heavy metals and biological activity

The accumulation of heavy metals in Swedish agricultural soils has increased since the beginning of the century. During this period the concentrations of mercury, cadmium, and lead have increased by 46, 33, and 14%, respectively, mercury primarily from the use of fungicides, cadmium mainly from commercial fertilizers, and lead by aerial deposition (Andersson, 1992). Cadmium is readily assimilated by the crop, and the concentration of cadmium has increased in harvested products (Eriksson et al., 1997) (Table 1, footnote 7). In addition, accumulation of heavy metals also impairs microbial activity, which in turn affects litter decomposition, nutrient cycling, and enzyme activities which ultimately lower production (Witter, 1992). Increased concentration of heavy metals in the soil and in harvest may be one indicator of long-term impairment of an ecosystem service, namely the creation and maintenance of vital soils.

3.3. Water quality

Agricultural use of fertilizers and pesticides has had adverse effects upon water quality in many

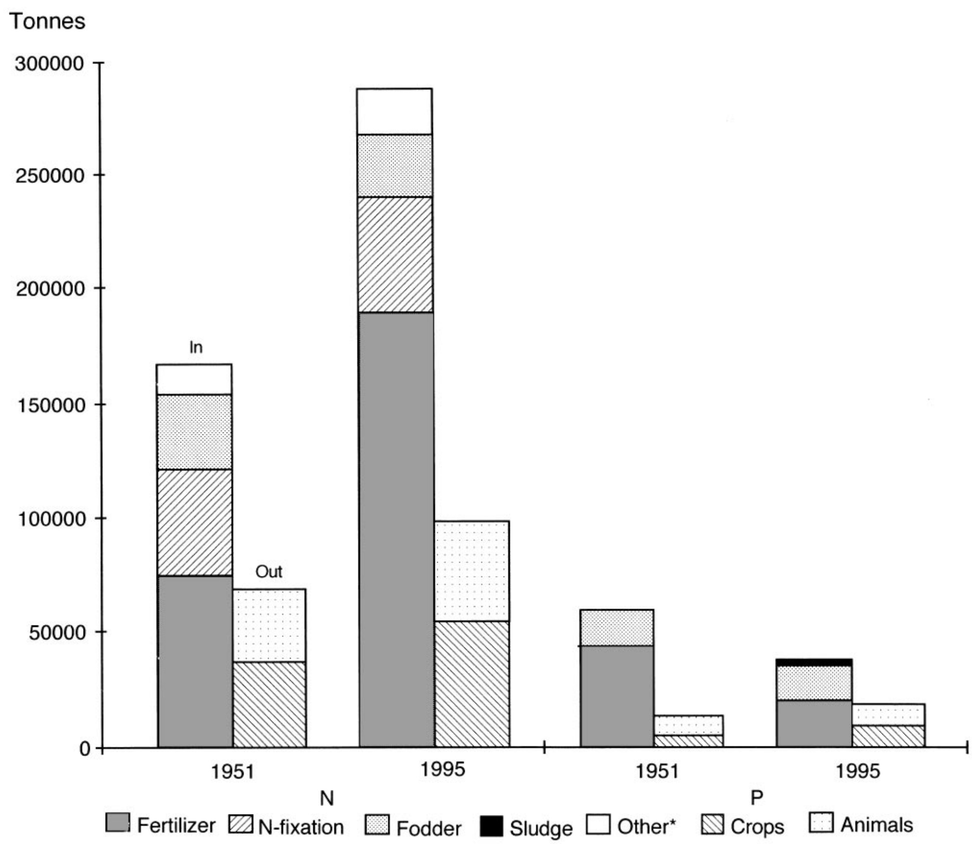

Fig. 6. In- and outflow of nitrogen (N) and phosphorus (P) in the agricultural sector in 1951 and 1995. Sources: SCB (1997c). *Deposition, sludge, cultivation of new land area.

Table 1
Ecosystem services from the agricultural landscape in the 1950s and the 1990s, and estimated changes

Ecosystem service	Measured by:	Agricultural landscape		Change during last 40 years	Footnotes[a]
		Early 1950s	Early 1990s		
Direct production factors					
Net photosynthetic capacity	• Mean annual net primary production (NPP, kg ha^{-1})*	7700	9300	+21%	1
	• Cost corrected (NPP, kg ha^{-1})*	6900	7000	0%	2
Soil fertility	• Average decrease in soil organic carbon	–	–	−9000 kg ha^{-1}*	3
	• Estimated yield loss due to changes in structure and physical quality of the soil	–	–	−10–20%	4
	• Soil loss due to wind erosion	Small	Slightly higher	–	5
	• Potential risk for impairment of soil biological activity due to heavy metals	Low	Low	–	6
	• Total wheat yield, some years, containing above critical conc. of cadmium (%)	0	5–10	–	7
Maintenance of water quality and quantity	• Potential risk of pesticide residues in surface waters in the agricultural landscape (%)	3	23	–	8
	• % of all shallow drinking water wells exceeding 22.1 mg NO_3 l^{-1}	12	13	Not significant	9
	• Changes in water retention and ground water levels in the landscape	–	–	–	10
Nutrient supply	• Kilogram nitrogen fertilizer applied per kg nitrogen in harvest	0.4	0.9	–	11
	• Nitrate leaching (kg ha^{-1})*	10	12	+20%	12
Ecological factors					
Ecological carrying capacity	• Increase in field sizes	–	–	+21%	13
	• Reduction of small un cultivated biotopes	–	–	−50%	14
Maintenance of biologic and genetic information	• Vascular plants extinct since 1950 (% of total extinct in the agricultural landscape)	–	–	60%	15
	• Endangered species in the agricultural landscape (% of total endangered)	No data	44	–	16
Biotic regulation	• Presence of wild pollinators, estimated decline in regions with intensive agriculture	–	–	−60%	17
	• Estimated reduction of the abundance of cereal invertebrates	–	–	−75%	18
Contribution to global climatic regulation					
Emission of greenhouse gases	• Total emission in carbon dioxide equivalents (kg ha^{-1})*	3210	2500	−22%	19

production areas in Sweden. With the increased use of fertilizers, leaching to adjacent ecosystems has also risen (Table 1, footnote 12). Increases in nutrient leaching from agriculture typically elevate loading rates to downstream ecosystems (Lowrance and Groffman, 1987). Leached nutrients which accumulate in dissolved and particulate forms in rivers and lakes may affect these ecosystems for long periods, depending upon residence times and recycling rates. In groundwater, which may have very long turnover times, increased nutrients from leaching tend to appear decades after the fact. In shallow drinking water wells, nitrate is found at about same extent as in the 1950s (Table 1, footnote 9). However, today about three percent of the deeper drilled wells have concentrations exceeding 22.1 mg nitrate l^{-1} (Sveriges Geologiska Undersökning, 1994). The highest concentrations have been found in agricultural areas in southern Sweden.

Pesticides have been detected in Swedish surface waters since the inception of their use (Torstensson, 1994). There is a potential risk for residues in streams and rivers even with careful use, and we assume that this risk is related to the areal extent of application (Table 1, footnote 8). The highest concentrations of pesticide residues are measured during spraying season. In an inventory undertaken in areas of intensive agriculture in southern Sweden during 1988–1990, pesticide residues were found in 46% of the investigated streams, and low concentrations were found in streams in agricultural areas throughout the year. Agricultural pesticide residues have also been found in three out of 56 water samples from exposed municipal water supplies in an inventory in 1988 (Sandberg and Erlandsson, 1990).

Short-term impairment and potential risk of long-term effects on ecosystem services by pesticide residues in surface and ground water are obvious. Aquatic organisms may be affected by pesticides at very low levels (Muirhead-Thomson, 1987; Graney et al., 1990), and pesticides found in drinking water raise special concern for cancer and other problems caused by 'estrogen mimics' even at low levels of exposure (Colburn et al., 1996).

3.4. Nutrient supply

The ratios of N and P fertilizer inputs to the N and P outputs in harvest were calculated as an index of the reliance of agriculture on external (off-the-farm) nutrients (Table 1, footnote 11). If this ratio is 1, we assume that crop production is wholly dependent upon external nutrients; if the ratio is less, the balance is made up by mineralization of soil organic matter, bacterial fixation of nitrogen from air, or was supplied through recycling of manure (and thus we count it as an ecosystem service). A high ratio of input of fertilizer to output of nutrients in harvest does not necessarily indicate that the agricultural landscape is unable to generate and recycle nutrients: but it does mean that this ability may be underutilized. Likewise, a low ratio may indicate non-sustainable use of nutrients if they are not recycled.

In 1951, commercial fertilizers provided about 43% of the nitrogen in the total harvest; the remaining 57% was balanced on the farm. In 1995, the nitrogen in the harvest was more or less equal to purchased fertilizers, and additional nitrogen was supplied through manure, bacterial fixation, atmospheric deposition, and mineralization (Fig. 6). For phosphorus, the reverse is true. In 1951, P input–harvested output was nearly 200%, declining to about 70% of the output in 1996 as farmers cut back on the application of phosphate. Surplus phosphorus is to a larger extent retained in the soil than is nitrogen and this accumulation of phosphorus has led to an improvement of the phosphorus state in the soils since the 1950s (Mattson, 1997).

An increase in nitrate leaching of about 20% (Table 1, footnote 12) was calculated by use of simulation models which estimate N leaching at the field scale (Johnsson and Hoffman, 1997). This result has been confirmed in field trials at similar scale (compilation by B. Lindén in Jordbruksverket (1996)). There is a large discrepancy between this figure and the 2-fold increase of surplus N in the total Swedish agricultural sector (Fig. 6). Because nitrogen retention in the soil is unlikely to have increased with time (Clarholm, 1997), this disparity implies a large increase in N losses by run-off from manure storages, by emission of ammonia during storage and spreading or by denitrification, or else that leaching may be underestimated.

3.5. Ecological factors

3.5.1. Habitat and ecological carrying capacity

A landscape mosaic manifests physical complexity, which includes field sizes, amount of edges, habitat diversity, and the presence of wetland areas. It is a characteristic of the landscape which in itself is not an ecosystem service, but contributes to these services, to the extent that habitat complexity is related to ecological carrying capacity. Carrying capacity comprises not only the amount of biomass present, but also the numbers of populations, species, functional ecological roles, and dynamics in the landscape.

It is estimated that half of all vascular plant and mammal species, and one fifth of the bird species nesting in Sweden, live entirely or partly in the agricultural landscape (Bernes, 1994). Most wildlife existing here use the edges and corridors among the agricultural fields, foraging on flowers and seeds of wild plants or on prey species, rather than on the cultivated crop itself (Gärdenfors, 1996). Thus it follows that biodiversity will diminish as landscape complexity decreases. At the subfield scale, the increase of monoculture agricultural production results in a decline in microhabitat diversity, which also reduces the diversity of organisms (Carroll et al., 1990). Larger areas of harvested biomass mean less habitat for wild plants and animals.

Small uncultivated biotopes, e.g. clumps of trees or ditches in a plowed field, were common in the 1950s but were largely eliminated by the 1990s. Based on the studies of Ihse and Lewan (1986), Skånes (1990), Ihse et al. (1991) and Ihse (1995) we estimate this reduction, as an average for all Swedish agricultural land, at about 50% (Table 1, footnote 14). These 'islands' in the agricultural landscape provide vital refugia for wild plants and animals and form corridors and connectivity, that enhance dispersal and reduce the risk of genetic depletion (Ihse, 1994). Between 50 and 80% of the wild plants in the agricultural landscape are to be found in these increasingly rare habitats (Bertelsen et al., 1995).

Ecologically, grasslands are the most important habitat in the Swedish agricultural landscape (Ihse, 1995). Old, uncultivated meadows and pastures, especially those with sparse tree and bush vegetation, are the landscape's most species-rich biotopes. This is true for large organisms, such as plants, mammals and large insects as well as for small organisms living on detritus in the soil (Schnürer et al., 1985; Bernes, 1994). More than 90% of these areas have disappeared (mostly grown into forest) in the last century (Skånes, 1990). In 1950, some 9000 ha of agricultural land consisted of old meadows in Halland in southern Sweden; today, only 100 ha (1%) remain (Georgson, 1997).

In the 1990s landscape, road edges and ditches, where the vegetation is cut annually, are the only remaining habitats that are similar to the old meadows. Such landscape elements are essential refuges for the meadow plant species and many herbaceous plants are only present there. They are also important for beetles, butterflies, other pollinators, etc. The total length of linear elements such as road edges and ditches has decreased by 30–50% since the beginning of the 1950s but is nevertheless considerably larger than the remaining natural meadows (Bernes, 1994; Ihse, 1995).

Numerous surveys indicate declines in species richness and evenness due both to intensification of the agriculture and to removal of grasslands and meadows from production (Hald and Kjølholt, 1985; Aebischer and Potts, 1990; Ingelög et al., 1991; Svensson, 1992; Freemark and Csizy, 1993; Bernes, 1994; Ihse, 1995). The number of plant species in natural grasslands is reduced by approximately 50% when fertilizers are introduced and the composition of species may also be altered by domination of nitrophiles (Fogelfors and Steen, 1982; Bengtsson-Lindsjö et al., 1991). In documented cases in Sweden, former natural meadows and pastures which were allowed to revert to woodland lost about 40–60% of their plant species, with herbs most affected (Fogelfors and Steen, 1982; Aronsson, 1991). Inventories on Danish farms show that both the seed bank and amount of germinating wild plants have decreased considerably since the 1960s (Bertelsen et al., 1995). This is evident in Sweden as well (Gummesson, 1987).

As much as 30% of the vascular plants, 60% of the birds, and 70% of the amphibians are endangered (classification according to The International Union for Conservation of Nature and Natural Resources, IUCN) in the Swedish agricultural landscape of today (Bernes, 1994). Approximately 60% of all plants reported as extinct since 1850 purportedly went extinct during the last 40 years (Table 1, footnotes 15 and 16).

Total amount and species composition of soil organisms in agricultural land is strongly influenced by agricultural practices such as land use, tillage, pesticide use, soil compaction, crop rotation, etc. A reduction of the total amount of soil organism biomass affects the biological activity in the soil, and international studies of keystone organisms such as earthworms, N-fixing bacterias, mycorrhizal fungi, etc. show that reduction of the species diversity may profoundly alter the biological regulation of decomposition and nutrient availability in the soil (Matson et al., 1997).

Swedish long-term field trials have been used to study influence of agricultural management on soil organisms, e.g. microarthropods, enchytraeids, nematodes (Andrén and Lagerlöf, 1983), earthworms (Lofs-Holmin, 1982, 1983), fungi, bacteria, and protozoa (Schnürer et al., 1985). Often a certain management practice may produce more than one effect, but the effects may be divided into two kinds, one affecting the food supply and the other the physicochemical environment of the soil. Generally, management practices that increase soil organic matter favor soil organisms. Mineral fertilizers stimulate plant production and thus the amount of available food, but may occasionally be harmful. Pesticides can be directly toxic or produce secondary effects, such as changes in food supply or growth inhibition on juvenile earthworms (Andrén and Lagerlöf, 1983; Lofs-Holmin, 1982). Unfortunately, almost no documentation exists in Sweden of overall changes in amount and diversity of soil organisms due to the alteration of agricultural management since the 1950s.

3.5.2. Pollination

Bees are recognized among the most important pollinators (Kevan et al., 1990), and about 20 of the Swedish agricultural and horticultural crops demand or are improved by bees (estimate based on Corbet et al., 1991). The areal extension of horticultural plants pollinated by insects was 6400 ha in 1996 and its economical value approximately US$95 000 000 (calculation based on SCB (1998a) and SCB (1998b)). The economically most important agricultural crops pollinated by insects are clover (*Trifolium* spp.) used in rotational ley and rapeseed (*Brassica* spp.). The areal extent of these crops is 72 920 ha and the economic value approximately US$29 000 000 (the areal extent and the value of pollination in rotational ley estimated by the cultivation of clover seed; Lindahl-Larsson, 1996).

Major losses of managed and wild pollinators have been reported in regions with industrial agriculture (e.g. Banaszak, 1983, 1992; Nabhan and Buchmann, 1997). The loss of wild pollinators is mainly caused by two interrelated processes: the destruction of habitats by altering the mosaic structure of the landscape, and direct poisoning of pollinators by insecticides (Kevan et al., 1990).

There are no Swedish studies of changes in wild pollinators due to the large scale changes in the agricultural landscape since the 1950s, but in regions with simplified agricultural landscapes, the decline has been estimated to be about 60% (Table 1, footnote 17).

The decrease in the diversity of cultivated species has also been a factor in the declines in abundance of wild pollinators. In Sweden, cropping changes have resulted in large reductions in cultivation of clover (*Trifolium* spp) for seed, and the cultivation of buckwheat (*Polygonum fagopyrum* Mnch.) and rapeseed (*Brassica* spp). It has been reported that the halving of rapeseed cultivation in 1996 and 1997 resulted in a 25–30% reduction of the honey harvest in the southern Sweden, and presumably also in reduction of the density of wild pollinators (J. Stark, Department of Entomology, Swedish Agricultural University, personal communication).

3.5.3. Biotic regulation—invertebrate soil fauna

Aebischer and Potts (1990) showed that the density of invertebrates in the agricultural landscape in England dropped by half from 1970 to

1989. The decline was a result of decreases across a wide range of taxa, from agricultural pests such as aphids, to beneficial insects such as spiders and rove beetles. The authors estimated the decline since the introduction of pesticides to be about 75% of the original densities. There are few quantitative assessments of changes in the numbers of invertebrates in Sweden, but even if the pesticide use in England has been more frequent than in Sweden, it is reasonable to assume that the trend has been similar (Table 1, footnote 18).

The causes of the decline in the invertebrate fauna are complex, but include structural changes in the landscape which diminish the amount of host species, presence of overwintering refugia, and total amount and quality of food. A key problem is the use of pesticide that affects soil fauna indirectly by reducing their food base, and directly by poisoning (Dennis and Fry, 1992; Ehnström, 1994).

3.5.4. Wildlife

The ability of the landscape to support small game, such as partridge, pheasant, and hare, is dependent on habitat diversity and presence of forage sources during the whole year (Frylestam, 1985; Rands, 1985). The number of partridge has decreased drastically in the Swedish agricultural landscape since the 1950s (SCB, 1983; Dahlgren, 1987). This was largely a consequence of applying broad-spectrum herbicides that indirectly reduced the insect food available to chicks, as well as a decline in suitable nesting sites (Dahlgren, 1987; Chiverton, 1991). Further, the size of the fields is decisive: the bigger the fields, the fewer the game animals. An area divided into small (opposed to large) fields has more total field edge, and therefore more habitat that can support wild flora and fauna (Ihse and Nordberg, 1984, Table 1, footnote 13).

3.6. Contribution to global gas regulation

The Swedish agricultural landscape is a net source of carbon (Lilliesköld and Nilsson, 1997). Most of the emission of carbon dioxide comes from the cultivation of peat soils (Table 1, footnote 19). Over the last 40 years, the emission has decreased due to a nearly 50% reduction of the area of peat soils under cultivation. Those soils have also been under cultivation for long times and have therefore probably lower CO_2 fluxes now than in the 1950s. Under current management practices, Swedish organic soils emit $1-1.5 \times 10^6$ ton C annually, while mineral soils sequester 0.3×10^6 ton C (Lilliesköld and Nilsson, 1997).

Methane emission from the agricultural sector is largely related to the number of cattle, and because the stocks of cattle are lower today than 40 years ago, methane discharges have also decreased (Table 1, footnote 19). The emission of nitrous oxide has increased during the last 40 years as a result of increased N applied as fertilizer (Table 1, footnote 19). The emission of this gas is, however, also related to moisture conditions and biological activity in the soils (Moss, 1992; Jarvis and Pain, 1994; Naturvårdsverket, 1995).

A decline in the emission of greenhouse gases from the agricultural landscape will have a positive influence on the ability of the global life-support system to maintain climatic conditions that are favorable to humans. This is a desirable management goal to the extent that it is compatible with food production.

3.7. Important, unassessed ecosystem services

Some kinds of ecosystem services go largely unassessed, particularly in human-dominated landscapes; we draw attention to these as challenges for future study. For example, the capacity to absorb environmental perturbation in Swedish agriculture is increasingly performed by imported, rather than on-farm, goods and services.

A general feature of agricultural systems with large amounts of external inputs is that much of the storage of information and system regulation originates outside the system. In low input systems, the information is mainly stored endogenously (in genetic information in species, in the stored biomass, in landscape formation, in local management practices, etc.) and regulation takes place largely in the form of internal interactions.

The intensive system is dependent on technology and external energy to protect the production of harvest from climatic changes, pest epidemics, animal and plant disease, etc. such perturbations are, in the low input systems, often buffered by internal biological feedbacks, although net harvestable production is lower as well. For example, experiments in grasslands show that ecosystem productivity (a key function) can recover from drought disturbance in proportion to the number of species (Tilman, 1996). Further, modern agriculture, with its 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. A recent example is the blackleg epidemic in Canadian rapeseed, discussed by Juska et al. (1997).

4. Discussion

During the past 40 years, local resources such as on-farm human and draft animal labor, as well as land in uses other than cultivation, have been largely replaced by fossil fuel, machinery, pesticides, fertilizers, and other fossil fuel driven technology. If we account for these external inputs in the same production 'currency' (NPP), and consider them as a cost of production (in terms of foregone NPP), then the apparent increase in productivity in the 1990s vanishes. This suggests that the magnitude of demand for ecosystem services in agricultural production does not change, whether they are generated locally, or generated elsewhere and imported to the system in the form of external inputs.

It is beyond the scope of this study to assess the impacts of modern Swedish agriculture on all of the ecosystems whence the input resources are generated. Ideally, a complete picture of the demand of ecosystem services by any economic sector would include these impacts as well. Clearly there are serious consequences, at local, regional, and global scales, of the emissions associated with oil extraction, phosphate mining, transportation over long distances, production of fertilizers and pesticides, etc. In a strictly accountable world, these adverse environmental impacts would be the responsibility of the resource consumers, but the distance between resource generation and consumption results in delayed or severed feedback. Borgström-Hansson and Wackernagel (this issue) refer to this as a 'disembedding' of resource consumption from associated environmental costs.

The face and fabric of the Swedish agricultural landscape have been altered as a result of intensification. Not only are farms larger, they are specialized and regionalized now, which means that many demands can only be met by efficient transportation systems (highways, shipping, air), all of which are energy intensive, as well. In the short-term, this system will pay off, particularly as international trade agreements open up new markets.

However, at this point it is unreasonable to assume that the supply of external resources is unlimited, or that the ability of the biosphere to assimilate the waste products of their use cannot be exceeded. How would a planning board for the future of Swedish agriculture best proceed? We argue that conserving the basis of ecosystem services in the agricultural landscape provides an important form of 'ecological insurance' upon which farms in the future may need to draw.

One form that this 'insurance' should take is to increase the ability of the landscape to provide ecosystem services, such as retention of water and nutrients, soil formation, stabilization of microclimate, maintenance of genetic information, and biotic regulation. In fact, reducing the amount of external inputs without jeopardizing agricultural productivity will, of necessity, increase our reliance on local ecosystem services. In this light, maintenance, and in many cases reconstruction, of the landscape mosaic will be exceedingly important. In the physical landscape, this means that restoration of physical complexity, such as the presence of open water, ditches, field islets, forest and field edges, etc. will be necessary in many agricultural areas. Other factors that are critical to maintenance of local vitality also include an increase (from present conditions) in complexity in the variety of cultivated crops (including genetic variety within as well as between species).

Another aspect of local 'ecological insurance' is to reconstruct and shorten the feedbacks and linkages on farms, and between farms and consumers, to better internalize the cycling of resources in the system (Tilman 1998). For example, animal husbandry and crop production have been separated over the last four decades. These two production branches must be closely integrated to safeguard the service of nutrient recycling, minimize nutrient leaching, maintain physical and biological landscape complexity, and reduce the energy cost for transportation of fodder and food.

At the individual farm scale, poor management of animal manure causes substantial nutrient leaching. However, from our analysis at the national scale (Fig. 6), the excess of nutrients used in agriculture, in relation to nutrients in the total harvest (particularly nitrogen), is likely to be an important non-point source flux of N to other ecosystems, as evidenced by eutrophied lakes and coastal waters. A reduction in the use of purchased fertilizers would provide incentive for more sustainable management methods for manure as it would make human and animal manure more valuable, and as long as we do not change our consumption patterns radically, the total amount of manure produced will not decrease. The reconstruction of tighter, on-farm nutrient cycles should have a cascading, positive effect on a larger scale as well, i.e., the reduction of non-point source eutrophication.

5. Conclusion

Future Swedish agriculture, and agriculture in general, will require a mix of externally and locally based ecosystem-derived services and technology; but in all likelihood, the ratio of external to internal inputs will have to decline. Decisions of optimal use of external inputs will need to be informed by careful assessments of resource (both renewable and non-renewable) consumption and availability, as well as the direct and indirect cost of their use, from both a local and a global perspective. This implies analytical tools capable of identifying, assessing and comparing resources with different qualities. This suite of approaches will likely be developed from economic analyses, energy analyses, and other techniques such as calculation of 'ecological footprints' (Rees and Wackernagel, 1994; Odum, 1996; Costanza et al., 1997; Daily, 1997; Pimentel et al., 1997).

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Appendix A. Footnotes to Table 1

A1. Table A

Net primary production in kilogram per hectare of agricultural land (1951 and 1996)

	Share of total area		Economic yield (kg dry matter, ha^{-1})		Conversion factor[b]	NPP	
	1951	1996[a]	1951	1996		1951	1996
Annual crops[c]	0.41	0.35	1900	3300	1.5	1169	1733
Rotational ley on arable land[d]	0.36	0.25	5600	6700	2.0	4032	3350
Fallow	0.04	0.06	0	0	–	0	0
Reforestation and other land use[e]	0.03	0.18	0	0	–	390	2340
Meadow, permanent Pasture[e,f]	0.16	0.13	1400	1400	–	2080	1690
Willow	0	0.01	–	12 000	1.5	0	180
Development	0	0.02	–	0	–	0	0
Total (kg ha^{-1})	–	–	–	–	–	7671	9293

[a]Figures from 1996 and 1992 to include holdings less than 2 ha (SCB, 1951, 1997b).
[b]Conversion factor for calculation of NPP from economic yield (kg NPP/kg yield) based on Pettersson (1987).
[c]Economic yield of barley; mean of 10 years.
[d]Economic yield; mean of 10 years.
[e]Estimated average NPP for Swedish permanent grasslands, 13 000 kg ha^{-1}. Based on review by Pettersson (1987).
[f]Economic yield based on figure for meadow hay 1951.

A2. Table B

Estimation of NPP requirement for the generation of energy in external inputs by biomass production, based on energy analysis of the agricultural sector in 1951 and 1996

Net purchased (ha^{-1})[a]	MJ $unit^{-1}$*	1951		1996	
		Quantity	MJ	Quantity	MJ
Machinery (kg)[b]	78	4	273	19	1499
Direct energy[c]	–	–	1904	–	4014
N-fertilizer (kg)	88	15	792	44	3872
P-fertilizer (kg)	26	10	260	5	130
K-fertilizer (kg)	10	12	120	10	100
Calcium oxide (kg)	1	34	34	41	41
Pesticide (kg)[d]	419	–	14	0.3	126
Imported animal feed (kg)[e]	21	36	756	200	4200
Labor (h)	3	226	678	36	108
Total	–	–	**4831**	–	**14089**
Requirement of NPP to generate equal amount of energy by biomass production (kg ha^{-1})[a,f]	–	810	–	2350	–

*Data from Pimentel (1993), no corrections made for changes in energy use for production between the years.

[a]Hectare based on the size of the agricultural land 1951.

[b]Total numbers of tractors and harvesters × mean weight of tractors (2 ton (1951) and 4 ton (1996)) tractor longevity (10 years).

[c]Including electricity, which is corrected for production cost (Uhlin, 1997).

[d]Estimate for 1951 based on size of treated area compared with 1996.

[e]Considered as maize.

[f]Calculated with assumption of 12 MJ kg^{-1} biomass (estimate for metabolisable energy in grassland based on Frame (1992) and NPP = 2 × economic yield, based on Pettersson (1987).

A3. Annual carbon reduction is estimated at 1 million ton (Lilliesköld and Nilsson, 1997). (1 million ton C $year^{-1}$ × 40 years)/4.37 million ha agricultural land = 9200 kg C ha^{-1}

A4. Estimate based on field trials in the southern Swedish plain dedicated to intensive cereal production (Håkansson, 1993).

A5. Wind erosion is a problem on light soils in the southern part of Sweden and on the eastern islands. Only about 35 000 ha are estimated to be affected (Mattsson, 1984). The problem has increased due to the mechanization of agriculture and the large scale cultivation of cereals.

A6. Critical levels relative to background values, which possibly will affect microorganism populations or microbial processes in soils, have at present only been established for copper (Cu), nickel (Ni), and zinc (Zn) and are four, ten and three times the background values, respectively (Witter, 1992). These elements increased by less than 10% in Swedish soils since beginning of the century (Andersson, 1992). Regional variations are large, however.

A7. During the 1990s, 5–10% of total wheat harvest has, at least in some years, exceeded the critical limit of 100 μg cadmium kg^{-1} set by the Swedish mill industry (Eriksson et al., 1997). There are no reports on cadmium concentration in crops from the 1950s, but since the beginning of the century, the concentration of cadmium in the plow-layer has increased by 33%, mainly due to phosphorus fertilizer and atmospheric deposition (Andersson, 1992). We assume that such high concentrations of cadmium in harvested crops were rare in the 1950s.

A8. 1990s: Estimate based on the % of samples with pesticide residues, of a total of 170 surface water sampling sites (838 samples) in 14 of the 24 Swedish counties, 1988–1990 (Lundberg et al., 1995). 1950s: Estimate based on above cited study normalized to the area treated with pesticide. (23% of samples with residues/30% of arable land treated (1994)) × 4% of agricultural land treated (1951) = 3% risk.

A9. 1950s: inventory of 1100 wells (Sveriges Geologiska Undersökning, 1994); 1990s: Aastrup et al. (1995).

A10. The supply of ground water in Sweden has so far, due to a climate with precipitation exceeding evapotranspiration on a yearly basis, not been seen as a problem. However, reduction of wetlands change the water retention in the landscape, but this change mainly took place before 1950 (Thunberg, 1982; Löfroth, 1991).

A11. Table C
Nitrogen and phosphorous in fertilizer/nitrogen and phosphorous harvest[a]

	1951	1995/96
In		
N-fertilizer (ton)	64 000	192 300
P-fertilizer (ton)	45 000	21 300
Out		
N-harvest (ton)	150 074	218 637
P-harvest (ton)	24 060	34 670
N in/N out	0.43	0.88
P in/P out	1.87	0.61

[a]Calculation based on data from SCB (1951, 1997b), Eriksson et al. (1972).

A12. Calculated annual loading was 45 000 and 53 000 ton in 1951 and 1995, respectively (Johnsson and Hoffman, 1997).

A13. Estimate based on data from a limited selection of fields in the middle and south of Sweden, 1973/74–1987/88 (Ihse et al., 1991).

A14. Interpretation of aerial photographs from 20 sites of between 500 and 2000 ha in the southern and middle of Sweden from 1940s to 1980s showed that linear elements had diminished by about 30–50% and point objects by about 50% (Ihse, 1995). Skånes (1990) estimated the reduction of linear elements at 28% and the decrease in length of field edges at almost 60% in an area of 5 km^2 on the west coast of Sweden during the same time period.

A15. Percentage of total species extinct in the agricultural landscape since 1850, estimate based on when last seen in Sweden (Svensson, 1991; Georgson, 1997).

A16. Table D
Endangered species in the agricultural landscape, total numbers of endangered species in Sweden (%)[a]

	Total no. of spp. in Sweden	Total no. of endangered spp.	Endangered spp. in agricultural landscape (%)
Vascular plants	2000	445	69
Moss	1000	241	22
Lichens	2000	238	35
Mushrooms	3000	528	33
Mammals	66	23	35
Birds	245	91	26
Reptiles, amphibians	19	13	69
Invertebrates	35 000	1876	46
Total (flora/fauna)	–	–	42/45

[a]Sources: (Svensson, 1992; Ehnström et al., 1993; Ahlén et al., 1996; Ahlén and Tjernberg, 1996).

A17. Estimated decline in areas with more than 70% of the land under cultivation (J. Stark, Department of Entomology, Swedish University of Agricultural Sciences, personal communication, 1998).

A18. Estimate based on a British inventory during 1970–1989 (Aebischer and Potts, 1990).

A19. Table E
Crude calculation of emission of greenhouse gases due to agricultural production per hectares of agricultural land*

Item	kg CO_2 equivalents (ha*, year)$^{-1}$		Footnotes
	1950s	1990s	
Decomposition of organic matter	2000	1300	1
Direct use of fossil fuel	100	180	2
Methane from animal metabolism	820	480	3
N_2O from denitrification	290	540	4
Total emission	3210	2500	–

*Area considered as agricultural land in 1951.

1. Calculation based on an annual emission of 2.61 and 10.44 ton C ha^{-1} from peat soil and 1 and 1.5 ton C ha^{-1} from gyttja soils with rotational ley and with other crops, respectively (W. Johansson, Department of Soil Science, Swedish University of Agricultural Sciences, personal communication, 1998). In 1962 the cultivated organic soils extended about 400 000 ha, of which about 11% were gyttja soils (W. Johansson, personal communication, 1998). We assume that the extension of organic soils was about the same in the beginning of the 1950s. In 1996 the organic soils comprised about 250 000 ha (Berglund, 1996). We assume that the gyttja soils comprised the same share as 1962. The share of area with rotational ley was 43 and 36% in 1951 and 1996, respectively. The calculated total amount of CO_2 emissions from Swedish agriculture in 1951 and 1996 was 2.6 and 1.7 million tons, respectively.

2. CO_2 emission from direct use of fossil fuel (emission of 66 g CO_2 MJ^{-1} during combustion).

3. Calculation based on data for animal CH_4 emission from Moss (1992) and a GWP_{100} (Global Warming Potential, in perspective of 100 years) of 24.5 CO_2 equivalents (Naturvårdsverket, 1995). We have calculated the total amount of animal CH_4 emission from agriculture in 1951 and 1996 to be 145 000 and 84 000 tons, respectively.

4. Calculation based on data from Jarvis and Pain (1994) and Pain et al. (1990). The ratio of N_2 to N_2O in denitrifying materials was assumed to be 3:1, and 10% of fertilizer N and 20% of mineral N in manure (after disposal of slurry) was assumed to be lost through denitrification. The GWP_{100} was 320 CO_2 equivalents (Naturvårdsverket, 1995). We estimated the total amount of N_2O emission through denitrification in 1951 and 1995 at 3900 and 7400 tons, respectively, from Swedish agriculture.

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