Crop Protection Research Institute

PESTICIDE USE AND BIODIVERSITY CONSERVATION ON FARMS

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Introduction

2010 has been designated the "International Year of Biodiversity" by the United Nations.

The intensification of crop production over the past fifty years is considered one of the major causes of declines in biodiversity measures such as in the populations of certain bird species. Pesticide use is often listed as one of the major factors in agricultural intensification linked to declines in biodiversity. A voluminous literature has appeared on this topic with many field scale studies and comparisons of farms where pesticides are used with farms where they are not used (organic farms). These studies need careful evaluation since, in order to preserve biodiversity, we need to be as certain as possible about which management practices are likely to affect it, and which will likely not [25]. The focus of this paper is to provide an overview of what is known about the relationship between pesticide use on cropland and the conservation of biodiversity on farms.

1.Extent of Biodiversity

The extent and variability of life on Earth is referred to as "biodiversity." Biological diversity, in short "biodiversity", is the variety of all living organisms (or species) within ecosystems. Biodiversity comprises all animals, plants and microorganisms [101] Biodiversity is defined in terms of species richness and population abundance [49]. Estimates of the number of species in the world range from 3 million to 111 million [119].A recent article estimated that 1.5 million species of plants (270,000), fungi (70,000), protozoa (40,000), algae (40,000), and animals (1,080,000) have been named [195]. Of the animals, the largest group consists of insects (720,000) including 300,000 beetles and 420,000 other species. The true total of living species, as distinct from those that have been named and recorded, is hugely uncertain. The current best estimate is that there are roughly 7 million total living species on the planet [195].Of this total, insect species are estimated to total 4 million.

Insects comprise the most diverse and successful group of muticellular organisms on the planet. A majority of the species on earth are insects. Insects have become the dominant component of the known diversity on earth, with 100 million species having ever lived. Insects are the most important group of terrestrial animals, so important that if all were to disappear, humanity probably could not last more than a few months. On land, insects reign and are the chief competitors with humans for the domination of this planet [165].

There are about 20,000 described species of bees. About 3000 earthworm species, grouped into five families, are distributed all over the world. To date, more than 10,000 species of ants have been described.

Soil contains a large number of different organisms, and among its micro-organisms there exist about one million different species of bacteria and about 1.5 million species of fungi [63]. Moreover, soil microbes represent the unseen majority in soil and comprise a large portion of the genetic diversity on Earth. For instance, it has been estimated that one gram of soil contains as many as 10^{10}-10^{11} bacteria, 6,000-50,000 bacteria species, and up to 200 metres fungal hyphae [17]. A handful of soil contains billions of microorganisms. One teaspoon of soil may contain thousands of species, millions of individuals, and a hundred metres of fungal networks. There are typically one billion bacterial cells and about 10,000 different bacterial genomes in one gram of soil.

The loss of biodiversity is accelerating, with 1-10% of the world's species projected to be lost in the next quarter century [119]. Southeast Asia is a region of conservation concern due to heavy losses of its native habitats. This could result in projected losses of 13-85% of biodiversity in the region by 2100 [103].Over 10% of the world's roughly 10,000 bird species are threatened with extinction.

Habitat loss/degradation is the most important threat to biodiversity. The primary causes of habitat loss are agricultural activities (including crop and livestock farming and plantations), extraction activities (mining, fishing, logging, and harvesting), and the development of infrastructure (such as human settlements, industry, roads, dams, and power lines). For the mainland United States, between 25% and 40% of the threats to extinction for native plants stem from the activities of introduced alien invasive plants and animals. In fact, it is likely that on a world scale, the introduction of alien invasive species is second only to habitat destruction as a source of extinction for plants and animals [182].

The ecological consequences of the increasing loss of biodiversity are a current topic because important ecosystem services such as the regulation of crop-eating insect populations by natural enemies, pollination of plants by insects, or decomposition process by soil fauna may be affected.

The population of wild vertebrate species fell by an average of nearly one-third (31%) globally between 1970 and 2006, with the decline especially severe in the tropics(59%). Temperate species populations actually increased on average since 1970, and the steady global decline since that date is accounted for entirely by a sharp fall in the tropics (Figure 1).The increase in wild animal populations in temperate regions may be linked to widespread afforestation of former cropland and pasture[194]. This phenomenon is further explained in Section 5 of this Report (see below).

2. Biodiversity in Crop Fields

The percentage of terrestrial land covered by agriculture (cropland and pasture) has steadily increased to approximately 50% of the habitable land on earth. [15]. Biodiversity and agriculture are indivisibly linked in many countries due to the large surface area occupied by agriculture. In France, agricultural areas represent the majority of the country's surface area (60%);in Britain, 77% of the land is under agricultural production [88] [18].In the EU (EU-25) agricultural land covers 45% of the total land. Over 50% of the conterminous land area of the US is cropped or grazed. Globally, the 5 billion hectares under agricultural management exceeds the area covered by forests and woodlands [94]. As a consequence, a high proportion of the planet's biodiversity now exists on land dedicated to the production of food. Farming is so extensive in some areas that many bird nests inevitably are located on cropland [138].Birds use cropland areas for breeding, foraging, migration stopover, and wintering activities [72]. Lowland farmland provides a breeding or wintering habitat for nearly 120 bird Species of European Conservation Concern, the largest number of such species supported by any habitat.

The total area of cultivated land worldwide increased 466% from 1700 to 1980. There has been a greater expansion of cropland areas since World War II than in the 18th and early 19th centuries combined[185] Conversion of land to agriculture represents a reduction in biodiversity as habitats are lost, natural landscape features are changed and forests are cleared. Through land conversion to agriculture, the original ecosystem is replaced by an unceasing series of constantly occurring interventions such as tilling, planting, harvesting or crop rotation [101]. The conversion of land from natural forests, wetlands, and grasslands to simplified agroecosystems results in a substantial reduction in biodiversity on the converted land and a decrease in habitat for displaced wildlife and plant communities [149]. Habitat structure in fields of annual crops is strikingly ephemeral. Habitat structure breaks down catastrophically during harvest and/or from soil tillage, and the harsh, inhospitable conditions between crops are often not conducive for the overwintering of a diversity of species [114].Microbial biomass can be approximately 40% greater in native grasslands and pastures than in cropped fields.

As noted above, the conversion of land from natural forests, wetlands, and grasslands to simplified agroecosystems results in a substantial reduction in biodiversity on the converted land and a decrease in habitat for displaced wildlife and plant communities. This loss in biodiversity occurs on all farm types including fields farmed without chemicals. A recent Study evaluated ecosystem quality in terms of the percentage of the original pristine situation represented by farm types [32]. Organic farm types represented a loss of 65 to 85% of the pristine ecological quality. Another Study rated a prominent organic farm in Vermont, USA in terms of biodiversity in comparison to a nearby forest on a scale of (-2 to +2). The biodiversity of the forest was rated as

+2 while the organic farm was rated as -1 in terms of biodiversity [15].The negative score reflects the inherent trade-offs between production and ecological functions whereby simply practicing agriculture, even with organic and chemical-free practices, causes disruption of the natural environment[15].

Much recent research has documented the benefits of shade-grown coffee for arthropod, bird, and mammal conservation [97].However, even the most diverse rustic shade farms are highly modified compared to natural forest; tropical forest specialists are often missing. For example, one study found only two out of seven forest lizard species in rustic plantations in Costa Rica. The change to the understory is obvious, and the canopy is also dramatically altered. For example, trees and shrubs are thinned to 10% of their original abundance, which substantially reduces plant diversity [168].Shade coffee plantations may sustain a high bird abundance and species richness. However, differences in species composition between forest and shade coffee are significant. Shade coffee may be beneficial for generalist species, but negatively affect forest specialists. In shade coffee plantations, the original bush layer has been replaced by coffee bushes. Few bird species prefer to use coffee bushes for foraging and none feed on coffee beans. Thus, abundance reduction in birds that prefer to forage in the lower and middle strata may be explained by the substitution of native bushes by coffee plants and the reduction in leaf litter because of more open canopy. Shade coffee, like many other anthropogenic perturbations, is detrimental for forest associated species.[183].

3. Agricultural Intensification and Biodiversity

There was a shortage of food, especially cereals, during the Second World War. A consequent desire for self-sufficiency and demand for an increased standard of living after the austerity of the war drove post-war agricultural policy in many countries. In Britain, land drainage grants were introduced. The area of land drained reached a peak of 100,000 hectares per year in the 1970s. 40% of the drainage was carried out for conversion to arable cropping. Declines in bird species occurred as a result of land drainage [46].

In Britain, the Agriculture Act of 1947 introduced financial incentives that encouraged an increase in the amount of machinery used on farms. Farm machinery is capital intensive and its increasing use accelerated the tendency toward large farms. Harvesting was accomplished more quickly and with less wastage [71]. Hedgerows were removed to allow the use of large machinery in arable cropping and because their role in stock control became redundant with the loss of livestock from arable farms. Hedgerows and field margins are important habitats for a range of wildlife [46]. Hedgerows are primary habitats for many species, while others use them as refuges, for example mammals for shelter and some insect species for overwintering. Hedgerows are typically the most important features affecting the number of birds present on UK farmland. Hedgerows in the UK were removed at a consistent rate in 1960-93 to increase farming efficiency [19]. It has been estimated that between one quarter and one third of hedgerows in Britain were removed since 1945, and thus a large proportion of the nesting habitat of many farmland species, in addition to an important source of food, has been lost [81].The area of tilled land in the UK increased by almost one million hectares since the early 1960s [82].

Thus, for several decades it was governmental policy in many countries in Europe to pay farmers to effectively reduce biodiversity by draining wetlands and removing hedges to enlarge fields.

Intensification has occurred at the landscape scale because of the aggregation of intensively managed arable fields together with land consolidation that has resulted in a transformation of formerly complex landscapes to simple ones.

Winter cropping increased at the expense of spring-sown crops over the past 40 years due to the availability of higher-yielding cereal varieties capable of overwintering. In Britain, the percentage of spring-sown wheat and barley declined from over 70% in 1968 to less than 20% in 1998. The increase in autumn tillage changed the composition of weed communities and reduced stubble feeding grounds over winter. The reduction in the presence of winter-stubble is highly significant, as areas of winter-stubble positively influence national trends in breeding and population recovery of key farmland bird species such as skylark and yellowhammer. Modern, efficient combine harvesters leave less wastage and grain remaining in stubbles after harvest, which, when combined with the effects of more efficient weed control, further reduced the availability of food for seed-eating birds and other seed predators over the autumn and winter period [46].The switch from spring to winter-sown cereals may have had particular consequences for seed-eating birds which rely on the weeds and spilt grain provided by stubble fields in the winter. [81].

The high number of species in most ecosystems makes it extremely difficult to measure biodiversity as a whole. However, birds can be a useful indicator of biodiversity in agriculture.

A wealth of evidence points to agricultural intensification as the principal cause of the widespread declines in European farmland bird populations and reductions in abundance and diversity of a host of plant and invertebrate taxa [18].

Many species of farmland bird have shown dramatic declines in both range and population size in northern Europe. Farmland bird populations in Europe have declined by an average of 50% since 1980[194]. In the past 20 years, ten million breeding individuals of ten species of farmland birds have disappeared from the British countryside [74]. Of 28 species primarily associated with farmland in the UK, 24 have shown a contraction in range and 15 out of 18 species showed a decrease in population size between the late 1960s and early 1990s [81] The butterfly fauna of lowland arable UK is becoming the subject of conservation interest. The general reduction in plant diversity in hedge bottoms and grasslands has reduced the range and abundance of food plants for many butterfly species [148]. In Britain and Ireland, it has been suggested that the widespread decline in wildflowers traditionally associated with hay meadows, pasture and hedgerows may have contributed to the decline in British bumble bees [99]. A review of changes in biodiversity on arable farmland in the UK concluded that around half of plant species, a third of insect species and four-fifths of bird species characteristic of farmland have declined [46].

The amount of land devoted to row-crop agriculture in the Midwestern United States increased over the last 50 years, often at the expense of higher quality wildlife habitat. From 1939 through 1972, 30% of north central Iowa's fencerows were removed [144].

In North America the continued decline of grassland breeding birds has been identified as a pending conservation crisis [136]. Grassland birds are one of the most sharply declining groups of birds in North America. Grassland birds experienced a 1.1% per year decline from 1966 to 2002 in the U.S. and a 2.3% per year decline in the southeastern U.S [112]. Since the mid-1800s, it has been estimated that loss of grassland ecosystems in most areas of North America has exceeded 80%. Furthermore, less than 0.1% of tallgrass prairie remains where soils and topography has been conducive to crop production. Consequently, a major factor affecting grassland birds over millions of hectares of the United States is that the modern agricultural landscape now typically offers little or nothing in the way of habitat for grassland birds [159].The clearing of US forests east of the Mississippi River for agriculture precipitated the demise of the passenger pigeon [196].Breeding populations of red-winged blackbirds in Ohio declined by 53% from 1966 through 1996[196].The decrease in the area of non-alfalfa hay likely reduced the availability of quality nesting habitat.

Half of the bumble bee species found historically in Illinois have suffered declines. In Illinois, intensive farming and urban development over the last century have resulted in the loss of most of the state's once vast prairie, forest and wetland habitats. In Illinois, bumble bee richness declines occurred principally between 1940 and 1960, a period that coincided with major agricultural intensification. During that time, farms that grew a variety of crops, including temporary and permanent pastures containing wildflowers, switched to growing corn and soybeans. This conversion resulted in a loss of wildlife habitat within Illinois' agricultural landscape [99].

4. Positive Aspects of Biodiversity on Cropland

The diversity of species makes vital positive contributions to ecosystem services. For example, biodiversity provides important pollinators, seed dispersers, and pest control agents on which agriculture depends [95]. Micro-organisms (bacteria and fungi) play a central role in maintaining the fertility of the soil, and are therefore crucial to farming. When soil organisms eat, grow and move, they perform essential services for ecosystems, as well as for human society. Within the soil, the decomposition of organic matter is primarily due to microbial activity, these organisms also contributing to the food chain of a great many of the soil fauna. [63]. Wild bees are especially important for cropping systems in which honey bees are inefficient pollinators. Bees derive almost all of their energy and nutrition from flowering plants [106].Insects and spiders contribute significantly to vital ecological functions including pest control and as a food source for wildlife including birds [122].Insects create the biological foundation for all terrestrial ecosystems. They cycle nutrients, pollinate plants, disperse seeds, maintain soil structure and fertility, control populations of other organisms, and provide a major food source for other taxa [165]

In recent decades, there has been a growing awareness of the role of generalist arthropod predators acting as natural enemies of insect pests in agro-ecosystems. Spiders, carabid beetles and staphylinid beetles constitute a major and ecologically important group of generalist arthropod predators, consuming a wide range of prey species, some of which are herbivorous pests of crops.[50]

Earthworms are basically a long digestive system in the shape of a tube. Earthworms play a major role in soil functions like the decomposition of organic matter. Earthworms are burrowing creatures, ingesting soil and expulsing it either at the soil surface or in the space that they have just emptied by soil ingestion. Earthworms ingest soil and leaf tissue to extract nutrients and they excrete casts, or small fecal pellets. They construct galleries through their movements in the soil matrix. Each time they pass through the gallery, they coat its walls with mucus. These galleries may be filled with casts and contribute both to macro-pore formation or eventually microaggregate formation. Earthworms have long been associated with the maintenance of soil fertility through their degradation of organic matter and its incorporation into the soil. These activities are recognized as improving soil structure, aeration and drainage. The elimination of earthworm populations can reduce the water infiltration rate in soil by up to 93%.

Plants are key components of terrestrial ecosystems, providing the primary production upon which food chains are built. Different plant parts may then provide a range of resources for associated fauna. Leaves and stems may be browsed, whereas pollen and nectar provide resources for pollinating insects. In addition to providing food for herbivores, plants have other functions, e.g. by provision of cover, reproduction sites and structure within habitats. Weeds may play some and perhaps all of these roles. A number of insect species are dependent on particular weeds to complete their life cycle. For these insects, weeds are particularly important [33].Weeds can favor natural enemies of insect pests by providing non-host foods such as pollen, nectar, alternative hosts and prey, and shelter. Arable weeds have also been shown to have an important ecological function as a resource for higher trophic groups. Their seeds are found in the diets of farmland birds and are particularly important for over-winter survival [30].

Weeds in crop fields have been shown to have an important ecological function as a food resource. Their seeds are found in the diets of farmland birds and are particularly important for over-winter survival. [30]. Weeds are also important as host species for insects that are eaten by birds [33].Flowering weeds are important as a food source for wild bees. Weeds can favor natural enemies of insect pests by providing non-host foods such as pollen, nectar, alternative hosts and prey, and shelter [6]. In an annual row crop during seedling growth stages and prior to cultivation or other weed mitigation practices, weeds may represent most of the plant biomass present. Weeds therefore may contribute most of the resources and habitat modification for all other organisms in the ecosystem during crop establishment. In dormant herbaceous perennial crops (orchards), weeds may be a major portion of green biomass for several months in winter when the crop is not growing. Weeds in orchards may also be the only green biomass during the winter months. In both of these cases weeds again provide essentially all the resources and habitat modification for part of the year. [188].

Conservation biologists have been focusing on the importance of functional biodiversity rather than "biodiversity for biodiversity's sake for years[97].

5. Negative Aspects of Biodiversity on Cropland

Agrobiodiversity includes pathogens, insects, and plants (weeds) that undermine the productivity and stability of farming [5].

Insect Pests

Throughout history insects have attacked crops and reduced yield or quality.Insects were feeding on plants long before humans began cultivating crops. The fossil record demonstrates that the oldest known insect from 390 million years ago fed on early land plants. Insect species and their host plants evolved together developing intricate relationships for survival and living in equilibrium for millions of years. Of the insect species that feed on plants, 80% are host-specific, that is they feed on plants of only one family or a few closely related families. Humans invented agriculture and formed a partnership with plants only about 10,000 years ago. Wild plants were moved into cultivated fields and orchards and the insects that fed on the wild plants moved in as well

For thousands of years humans accepted insects as part of the normal environment over which they had little or no control. In some cases, insects were handpicked from crops. Historically, large crop losses and human suffering were caused by insects. In 1732, rice fields in West Japan were laid waste by the occurrence of huge numbers of leafhoppers; this infestation alone was responsible for a famine which took a toll of more than 12,000 lives.

Crop Pathogens

Most crop diseases are caused by fungi, which lack chlorophyll and therefore are unable to produce their own carbohydrate food. Consequently, they must feed on other living plants or dead organic matter. Of the 100,000 described species of fungi in the world, approximately 20,000 produce one or more diseases in various plants. Most of these fungi reproduce through the production and distribution of spores. These spores, frequently produced in quantities measured in billions, are spread locally by wind and water or longer distances by high altitude air currents. When spores alight on a susceptible host in an appropriate environment and under conditions of favorable humidity and temperature, they germinate and infect the host plant's tissues. The fungus grows through and between plant cells withdrawing nutrients. The ability of such cells to perform their normal physiological functions is reduced or completely eliminated; as a result, plant growth is reduced or the plant dies. Although the Old Testament contains many references to blights, blasts, smuts, and rusts, there seems to have been little or no effort to control them; such tribulations were accepted as an expression of God's wrath. Severe outbreaks of wheat rust caused crop failures leading to famine that contributed to the downfall of the Roman Empire. During the following two thousand years, little was added to the knowledge of plant diseases. In 1844, a rot of potatoes caused the loss of 25-90% of potato production in the northern US. The rot was first reported in Europe in 1844 and it spread throughout the continent. Irish peasants were almost completely dependent on the potato for their diet and for feed for their farm animals. In 1846 the rot fungus destroyed 100% of the Irish potato crop which led to the deaths of 1.5 million people and emigration of a similar number. Grape powdery mildew had been introduced into France from the US in 1845, and reduced French wine production by 80% by 1854. In 1878 another pathogen of grapes, downy mildew, was introduced into French wine grapes from America and, once again, French wine grape production was greatly reduced. In the early 1900s, yellow sigatoka disease spread to all banana-growing regions of the world reaching Central America in 1934. In less than two years, the disease destroyed more than 22,000 acres of bananas in Honduras and Surinam.

Weeds

Weeds are plants growing where they are not wanted. Weeds compete with crops for moisture, nutrients, sunlight and space thereby resulting in significant crop losses. Weeds deprive crop plants of natural resources. For example, a corn plant requires 368 pounds of water to produce one pound of corn, whereas weeds such as lambsquarters and ragweed use 800 and 950 pounds of water, respectively, to produce a pound of dry matter [216]. One cocklebur may occupy four to eight square feet of soil surface area, thereby reducing the space available for crop growth. When weeds shade crop plants, less sunlight is available for crop production.

Natural weed populations in most fields are high enough to cause devastating yield losses in most crops if not controlled by some method [225]. Loss figures of 50-90% are not uncommon for crops grown in natural weed infestations [223] [224].Weeds are different from other pests that pose problems in crop production. Weeds are less transient and less difficult to predict than other crop pests. Weed populations in crop fields are relatively constant while outbreaks of insect and disease pathogens are sporadic.

There are several characteristics that set weeds apart from crop plants. Weeds germinate over a wide range of environmental conditions and have faster rates of development due to high food production efficiency compared to crop plants. These characteristics offer physiological advantages to weeds over crop plants. Weeds typically are able to produce seed before the crop is harvested, are self-pollinated, and have long periods of seed production. Moreover, weed seeds are excellent travelers. Many possess special adaptations such as hooks, wings and spines that aid in their long and short distance spread by wind, water, livestock, human beings or farm equipment.

Two other factors that contribute to the strong competitive nature of weeds include high seed production, leading to high population density and survival in the soil [218]. Weed species re-infest the soil primarily due to the large amounts of seeds produced by a single plant. For instance, seed production of individual redroot pigweed, common ragweed and lambsquarters can be as high as 117,400, 3,380 and 72,450, respectively [219].

The high fecundity of weeds has contributed to the millions of buried weed seeds in a typical acre of cropland in the U.S. In Minnesota, weed seed counts at four different locations in 24 different plots varied from 98 to 3068 weed seeds per square foot of soil six inches deep – that converts to 4 million to 133 million seeds per acre [218]. In western Nebraska, average cropland soil contained 200 million seeds per acre [220]. In a similar Colorado experiment, 122 million weed seeds per acre were present in the upper 25 cm of the soil profile [227]. In California vineyards, counts of 40 million weed seeds per acre have been estimated [217]. In Iowa, the average weed seed counts ranged from 113 million to 613 million seeds per acre [226].

The number of weed seeds that germinate and emerge in any given year is quite low in relation to the total number of seeds present – perhaps only 5-10% of the total seed population [221]. A very high percentage of the total weed seed population in the soil survives from one year to the next. Seed longevity represents a major survival mechanism for weed species; it constitutes a continuing source of emerging weeds in croplands [219]. The seeds of these species can survive in the soil for decades. A typical population of emerged weeds in cropland is approximately 2.5 million weeds per acre.

The struggle for existence between weed and crop plants generally starts at an early stage (seedling stage). Soon after emergence, weeds interact with nearby plants, either with other weeds or crop, and vie for the shared growth resources (light, soil moisture, carbon dioxide, nutrients and space). The mutually adverse effect of weeds and crop that utilize limited resources is called competition. In other words, the competitiveness of a plant is its relative ability to obtain a specific resource. If weeds are able to compete for and utilize a sufficient amount of some growth factor to the detriment of the crop, the result is an adverse impact on crop yield. For most crops, it is critical that fields are kept weed-free during the first four to six weeks after planting to prevent serious yield losses from early season weed competition. The critical period for weed control results from the effects of weed competition not being uniform throughout the year. Rather, yield reduction occurs only during certain, typically brief, stages of crop growth. Weeds must be controlled during this time. Research has shown that soybean fields should be kept weed-free four to six weeks after planting [222]. Any weed emerging in the crop after this initial weed-free period will not compete effectively with soybean and will not affect yield potential due to the soybean canopy, which shades the emerging weeds.

Historically, weeds were removed from fields by hand and with the use of plows. Many fields were kept largely free of weeds; however, millions of workers were required and erosion soil losses were high due to soil disturbance by cultivators

7. Crop Yield Increases and Biodiversity (Land Spared for Nature)

The benefits of agriculture have been immense. Before the dawn of agriculture, the hunter-gatherer lifestyle supported about 4 million people globally. Modern agriculture now feeds 6,500 million people. In the past 40 years, the human population doubled. Global cereal production doubled in the past 40 years, mainly from increased yields [172]. If agricultural-technology development had been frozen in 1961, cropland would have had to increase from its 11% to some 25% of the planetary surface to produce the same amount of food now. Virtually no natural forest would now remain. [170]. Increasing productivity means that less land is needed for crops and can be preserved for Nature [32] Increasing crop yields on productive lands has saved marginal lands from agricultural conversion [94].

Most of the 20th century increases in food production were achieved by increased productivity on cultivated land. Globally, the per capita cropland area decreased by more than half, from around 0.75 ha person^{-1} in 1900 to only 0.35 ha person^{-1} in 1990.[185].

An analysis of 53 tropical countries suggested that the net effect of increasing agricultural yields was to decrease rates of tropical deforestation. The majority of countries (87 out of 96) that increased yields over the 20-year period also reduced their total per capita cropland area. Natural forest area tended to decline in countries where the yield declined or did not increase, whereas forest area fell by a smaller proportion in countries with substantial yield increases [180]. Developed countries with shrinking cropland areas have expanding forests [92].

During the 1990s, gains in forest cover arose from the expansion of natural forests in areas previously under agriculture, mostly in Western Europe and Eastern North America (3.6 million hectares per year globally).[186]. Perhaps the most striking example of the process is from the United States. Within the South, for example, cropland has been increasingly concentrated on areas of high quality land. A "process of natural selection" has led to the concentration of cropland on the better land, and the vacating by agriculture of the poorer land. More generally, large areas of relatively poor land in New England were abandoned as better land in the Mid-West and other parts of the country was opened up. Much of the abandoned land in New England (and in the South) subsequently reverted to forest. The result was that, by 1980, the percentage of the land area of Maine under forest was 90, compared with 74 in the mid-1800s. In New Hampshire, the corresponding figures for these dates were 86 and 50 per cent: in Vermont 76 and 35 per cent [179]. In 1992, US forests covered nearly 300 million hectares, or one-third of all US land and about two-thirds of the area that was covered by forests in the year 1600. After rising about a quarter from 1900 to the 1920s, US cropland has remained steady. While population grew by nearly one-fifth from 1975 to 1992, US cropland and pasture shrank by one percent. [171].

In France, deforestation that reduced forest cover by more than a third over the past 500 years reversed around the turn of the 20th century, and between 1960 and 2005 forest cover increased by approximately a quarter. Satellite imagery and government statistics from Argentina revealed that regions of the Chaco dry forests that developed more intensive and higher food production per unit area had less forest degradation than regions where extensive farming continued. Similarly, in a review of the biodiversity value of oil palm, the authors concluded that potential for management practices that encourage native species on plantations is extremely limited, and thus maximizing yields on smaller land areas is preferable. [187].The Indian forest area has slowly expanded since ~1990, whereas in Vietnam, the turnaround from the same date has been more clearly defined, averaging ~2% per year. Rising crop yield has spared and may well continue to spare land for forests [174].

<u>8. Pesticide Impacts on Biodiversity: Concerns</u>

Concerns have been raised by some organizations that pesticides are a major factor affecting the loss of biodiversity [ ]. Both direct and indirect negative effects of pesticides are cited.

Rachel Carson's classic 1963 book *Silent Spring* alerted the public to the toxic side effects of the organochlorine insecticides, such as DDT. Residues of these pesticides were found to persist in the food chain, reaching higher concentrations, and hence having more severe effects, at successive trophic levels. Famously, they were identified as the cause of rapid population decline in birds of prey, such as peregrine falcon and sparrowhawk, through the thinning of eggshells. The offending chemicals have now been phased out in the United Kingdom, USA, and many other countries [74].

It seems generally true that in the developed world, following the withdrawal and changes in use patterns of some insecticides, populations of affected bird species have largely recovered. Most wildlife poisoning events are accidental [141].

Pesticides are now routinely screened for side-effects against non-target invertebrates for the purpose of registration. Current experimental rationale and methods of interpretation comprise three tiers of screening: at the laboratory, semi-field and field levels [105].

Rigorous evaluations are also undertaken for products already on the market when they are re-registered (on average every 5 years). Of the non-target organisms several indicator species are selected whose response to a crop protection product is considered representative for other organism in the same natural community [101].

There is currently little evidence of significant population effects on birds arising from direct effects of insecticides in the UK. Although many species of farmland birds are in decline, the causal factors are difficult to pinpoint and the possible indirect impacts of increasing pesticide use remain unknown for the many species that have exhibited population declines and changes in distribution coincident with agricultural intensification [141].

Some non-target species' populations will be only temporarily affected by insecticides. When a variety of pyrethroids was used in fresh water systems, the population recovery of affected species to pre-treatment levels was noticed within weeks to months after application.

Populations of fish species, dependent on those affected invertebrates for food, also recovered quickly [141].

Long-term field studies in the UK, on a range of arable crops, suggested that there are few adverse long-term effects of pesticides on non-target organisms (including insects, spiders, earthworms and soil microbes). In that study, the application of broad-spectrum insecticides resulted in declines in the numbers of many non-target arthropods, but these usually recovered within the same growing season [141].

Generally, herbicides commonly used in agriculture have a low risk of exposure to birds at levels that are acutely toxic [72]. Direct effects of herbicides on insect species are rare [33]. Modern herbicides made from organic components are reduced to their nontoxic forms soon after application [134].

Concern has also been expressed about the possible toxic effects of herbicides on soil microflora, with subsequent reduction in soil fertility. Herbicides have been shown to both stimulate and inhibit some microbial populations, at least temporarily. But the common mechanisms of herbicidal action in higher plants, such as photosynthesis inhibition and cellulose cell elongation, in general, do not apply to soil microorganisms. Any effects observed so far may be indirect, caused by older, more persistent pesticides that are no longer being used or by unusually high rates of application [127].

There is concern about the potential indirect effects of pesticides, operating through the food chain. Impacts of pesticides on weeds and invertebrates may reduce the availability of food resources, affecting productivity and/or adult survival. Three main mechanisms have been identified through which pesticides may affect food availability for birds: (1) insecticides may deplete or eliminate arthropod food supplies, which are exploited by adults and their dependent young during breeding season and, in so doing, reduce breeding productivity; (2) herbicides may reduce the abundance of, or eliminate, non-crop plants that are hosts for arthropods taken as food by farmland birds during the breeding season, and thereby reduce breeding productivity; (3) herbicides may also deplete or eliminate weed species, which provide either green matter or seeds for herbivorous and granivorous species, respectively, thereby reducing survival of those birds that rely on those food supplies [133]. It remains unclear how important indirect effects of pesticides are in relation to other factors affecting populations of farmland birds [133].

A new suite of more selective pesticides are being developed. These new pesticides are designed to target only certain insect taxa, leaving the remainder of biological communities largely intact. This facilitates combinations of pesticide-imposed disturbances working in concert with biotic factors to regulate insect herbivore populations [21]. For many years, the idea was promoted that natural enemies and insecticides are incompatible. While this is likely to be true for broad-spectrum insecticides such as the organophosphates and carbamates, this is not necessarily the case for newer insecticides that have higher selectivity and a more desirable ecotoxicological profile [59].

Indoxacarb is very effective against lepidopteran (butterfly and moth) larvae but allows most predators and immature wasp parasites which attack these caterpillars to survive. Tebufenozide and methoxyfenozide (insect growth regulators) disrupt the molting process in Lepidoptera but do not affect beneficial insects. Methoxyfenzoide and indoxacarb were not toxic to *Trichogramma* in any assay when applied at field rates.[67]. Benzoylphenylurea IGRs (such as diflubenzuron and teflubenzuron) disrupt chitin synthesis and have a broader spectrum of activity but, because they become active only or mainly after being ingested, direct effects on parasitic wasps (hymenopterans) are minimized. Pyriproxyfen, a pyridine compound developed in the late 1980s, is a juvenile hormone analogue (JHA) that inhibits egg production and metamorphosis. It is active primarily against sucking insects and has little effect on hymenoptera [141].

Many of the newer reduced-risk compounds have translaminar activity, which allows them topically to penetrate leaf tissues and form a reservoir of active ingredient within the leaf. This provides quick knockdown and residual activity against certain foliar-feeding insects that typically feed within or on the underside of leaves. Another practical attribute associated with many of the newer chemistries is their systemic properties that allow them to be applied in diverse ways such as soil drenches, chemigation, in-furrow and subsurface soil applications and seed treatments.[125]. This avoids the use of foliar sprays and the potential for contact with any insect in the plant canopy, pest or beneficial. [115].

Specific herbicides are even being developed to selectively remove only those species whose control in the field margins is advisable on agronomic grounds while promoting the development of ‘good weeds’ [158].

9. Positive Impacts of Pesticides on Biodiversity

The use of pesticides has promoted the adoption of certain agronomic practices that have been extremely beneficial in enhancing biodiversity in crop fields. Millions of acres of cropland in the US and other countries (particularly Latin America) have been converted to reduced-tillage or no-tillage practices. Instead of using tillage equipment to remove weeds from fields before planting, reduced-till/no-till farmers use herbicides which results in considerably less soil disturbance and enhanced biodiversity.

Herbicides are used in large quantities in no-tillage fields because they are the only means of weed control in these systems [123].

Conservation tillage is thought to provide better cover for ground-nesting birds compared to conventional tillage or where tillage is used to control weeds. A recent UK study found that game birds, skylarks and granivorous passerines all occupied a greater proportion of fields established by non-inversion tillage than by plowing in the late winter period. Numbers of earthworms generally increase under reduced tillage systems [46].

The structural diversity of the plant residues in non-inversion tillage systems supports a wide variety of surface invertebrates and insects including carabid beetles and spiders. Reduced intensity from cultivations in non-inversion tillage increase invertebrate populations allowing a build-up in populations from year to year. Under non-inversion tillage systems, minimal disturbance of the soil, combined with a consistent supply of crop residue as a food source, encouraged deep burrowing earthworms. An increase in tillage buries earthworm food sources and destroys burrows therefore reducing earthworm numbers. Cover provided by the crop residue, along with weed seeds and waste grain for food, and less soil disturbance from fewer field operations allows non-inversion tillage to be of greater benefit to wildlife. Overwintered stubble provides an important winter food source for seed-eating birds and the planting of spring-sown crops after overwintering stubbles can provide birds with important nesting habitats. The crop residue provides insects with a protective environment to live and feed and this in turn allows birds and other mammals to feed on these insects [47].

Reduced tillage provides better wildlife habitat because crop residue provides cover and fewer nests are destroyed by farm machinery. Bird surveys were conducted in reduced-tillage and conventional tillage fields in the Texas Panhandle. Eastern meadowlarks, longspurs, and savannah sparrows were more common in reduced-tillage (sorghum and wheat stubble) fields than in conventionally tilled (plowed) fields. Bird diversity was greater in reduced-tillage fields than in conventionally tilled fields in summer. Reduced-tillage agriculture for sorghum and wheat farming is being encouraged in the southern Great Plains as a means of improving the attractiveness of agricultural land to many bird species [116].

Advantages of no-till agriculture compared to tilled organic and conventional fields include an increase in pest predators (mainly carabids and staphlinids) by six-fold in number. These pest predators hide under the vegetation on the surface. They are also protected from many bird predators. Large earthworm numbers increase by up to 6-fold. Bird territories and bird nests increase from 3-100-fold. Small mammals are more abundant in no-tilled fields [120].

A beneficial effect of no-till management was in increasing predatory ant species richness on the no-till plot compared to traditional till so exerting better control of herbivorous pests. Herbicides did not affect diversity or abundance of ants. Herbicides have a minimal effect in the short term on the most surface-active fauna in wheat fields and conservation farming results in a more abundant and diverse soil fauna compared to traditionally tilled fields [135].

Research in the prairie pothole region of Manitoba showed duck production to be 3.8 times greater on no-till small grain farms than on conventional farms. There were two reasons why. Undisturbed stubble expanded the nesting habitat, thus permitting more total nests. The increase in habitat also allowed ducks to disperse their nests, which may have hindered predators or buffered their impact by increasing the availability of alternate prey [138].

In an Iowa study, researchers found eight species of birds nesting in no-till crop fields, with the greatest species diversity in fields with corn residue. Nest densities in no-till fields were about seven times those in conventionally tilled fields. Fall tillage, a common farming practice, has contributed to wildlife population declines. Negative effects on wildlife from fall tillage are generally greatest with moldboard plowing [138].Twelve bird species, with an average density of 36 nests/100 hectares, nested in no-tillage fields; only three species, with an average of 4 nests/100 hectares, nested in tilled fields. The study suggests that no-tillage cornfields and soybean fields are used by more avian species and at greater nesting densities than are tilled fields.

Ecologists have tended to favor minimal tillage over conventional tillage because of the serious negative impacts of mechanical tillage on some avian populations in recent years. The use of surface tillage implements frequently kills or injures nesting birds and small mammals; densities of waterfowl nests on untilled land may be 12 times those on tilled croplands and can yield 16 times as many ducklings [158].

Tillage causes major changes in the habitat for all soil-inhabiting organisms. The use of herbicides has led to decreased use of tillage for weed control. Increased survival of insects has been noted for several species. [188].

10. Importance of Adjacent Habitats for Biodiversity

Landscape diversity is positively associated with on-farm biodiversity. Surrounding landscapes may be as or more important than within-field management practices for determining pest suppression potential in agricultural systems [91].

Crop field margins support a high diversity of plant species. Field margins also provide a habitat for numerous invertebrates, a food resource for mammals, and a refuge for beneficial parasitoids and predators. Margins provide resources for birds and bees, and may be the only source of nectar and pollen in arable landscapes through much of the season. [157]. In a review of 79 studies, investigators quantified biodiversity (usually species richness) associated with 18 specific agricultural practices. The strategy most often correlated with the conservation of wild biodiversity was the maintenance of adjacent hedgerows, windbreaks or woodlots [10].

The landscape surrounding agricultural fields is an essential resource for maintaining parasitoid abundance and biodiversity. In addition to providing a parasitoid refuge, hedgerows and native ecosystems provide a source of flowers, nectar, and other factors that can help enhance both the numbers and species richness of parasitoids [43]. Non-crop habitats are favorable habitats for natural enemies and act as source habitats from which the agricultural fields are invaded. Non-crop habitats play an essential role in the conservation of biodiversity in agricultural landscapes and highlight the ecological significance of these habitats for natural enemies that have the potential to suppress pest populations. All field cropping systems are ephemeral habitats that are subject to frequent and intensive disturbances. Predators are forced to emigrate upon crop senescence or harvesting. [28]. Crop habitats are hostile environments for many species and biodiversity is concentrated in more stable non-crop habitats and field edges. Many species occurring in intensively managed cropping systems must be able to move between non-crop habitats and fields at critical times, such as harvest, and colonize fields at the start of the growing season in order to be effective control agents. The dominant theme that emerges from the terrestrial insect ecology literature is that many, if not most, of the predatory insects that are potential natural enemies in annual crop systems migrate cyclically between fields and surrounding permanent habitats (hedgerows, woodlots, and other field boundaries) [114]. The vast majority of predators overwinter in the field margins and disperse into the crop in the spring. [6].

Bumblebees apparently perceive their surroundings over large distances. They seem to require a sufficient supply of food plants at a regional and not at a local level [107].

Non-crop habitats such as field margins, fallows, hedgerows and wood lots are relatively undisturbed and temporally permanent areas that hold a substantial proportion of the biodiversity in agricultural landscapes [68].In the UK, The Boarded Barns study reported that 80-85% of biodiversity on any farm existed in the field margins and hedgerows. What was in the cropped area was of little overall significance for biodiversity [120].

From 1983 to 2001, of 27 bird species associated with farmland habitat in Denmark, five declined , 10 showed stable trends and 12 increased [53].At present more than 60% of the Danish land surface is cultivated, of which 60% is devoted to cereal production, and a shift has occurred from spring- to autumn-sown crops. However, despite all these changes, in general Danish farmland birds have shown neither the same contractions of range nor the dramatic declines in abundance that have occurred among the same species in the UK. The majority of farmland species in Denmark were stable or increased, including several of the seed-eating birds showing the most serious declines in the UK (e.g. skylark, tree sparrow, linnet, bullfinch, corn bunting and reed bunting) [53].

The Danish agricultural landscape is relatively rich in non-crop habitats, particularly field margins, headlands, wetlands, and hedgerows. The Danish landscape is particularly rich in small woodlands, which support high bird densities. Farmland bird populations in Denmark have been maintained at similar or higher levels than those of the early 1980s [53].

Even though biodiversity has important ecological functions at the farm scale, it is nevertheless possible to decrease biodiversity levels very substantially in crop fields while maintaining the productivity and resilience of agroecosystems due to the biodiversity contribution of the surrounding landscape [36].

A number of agricultural pest species are associated with these habitats, such as aphids, herbivorous flies and beetles [68]
In the Midwestern USA, most woody field margins have been removed because they occupied valuable farmland and are thought to be a supply of weed seeds.[65]

11. Organic Farm Comparisons

Organic production methods are utilized on only a very small percentage of the world's cropland. However, a large number of studies have compared the impacts on biodiversity between organic and conventional farms. These comparisons should clarify the impact of farm chemical use on biodiversity since the defining characteristic of organic farming is the non-use of synthetic chemical pesticides and inorganic fertilizers.

Most of these studies compare pairs of organic and conventional farm fields in the same region. Not all studies found positive effects of organic agriculture and some species showed even negative responses. A meta-analysis of the effects of organic agriculture on biodiversity showed that although organic farming is usually associated with greater species richness and abundance, results are highly variable and frequently contradictory. Therefore, the efficiency of organic farming as an overall key for protecting biodiversity in arable areas has lately become questioned [64].

A recent critique of these paired studies is that they do not account for differences in the landscapes surrounding the fields and farms. A problem with biodiversity studies in the agricultural landscape is that both management and landscape features are likely to affect diversity. It is therefore necessary to control for landscape features when comparing the effect of farm management [60].On average, the positive effects on biodiversity are not as strong as previously understood from studies that have not contrasted paired farms within landscapes, perhaps because organic farms are sited in a biased sample of landscapes.[34]. In Sweden, studies show that the distribution of organic farms is skewed towards agricultural districts with more extensive farming activity that, as a consequence, are likely to contain more heterogeneous agricultural landscapes [155]. Interpretation of these results is complicated by the possibility that organic farms may be predisposed to support higher biological diversity if they have greater habitat heterogeneity compared to other farms [90].

In general, organic farms are located in more diverse landscapes with more woodlots and hedgerows. Sympathetic hedgerow and field boundary management is also likely to positively influence certain bird species by providing better shelter and nesting habitat, as well as increased food resources [18].A significant proportion of the enhanced bird abundance on organic farms may be attributed primarily to an increase in the quality and quantity of non-cropped habitats and boundaries [18]. Landscape characteristics such as the proportion of arable land and semi-natural grassland, and field margin and hedge lengths, rather than farm management appear to be the important drivers of bird abundance. This is in accordance with two recent large-scale studies, which also indicated little support for organic farms having higher densities of birds. [34][147] In some studies, larger areas of spring cereals on organic farms seemed to be the only cause for higher bird densities. [117].[113]

It is impossible to draw any inferences on the likely impacts of the absence of pesticides and artificial fertilizers on the bird populations of organic farms given the sometimes large differences in hedgerow structure and cropping regimes between farm types.[81].

Landscape structure is important for the species richness of carabids. The diversity of arthropods in agroecosystems is affected much less by management practices than by landscape features. The results clearly demonstrate that surrounding grassland can act as a source of diversity for farmland carabids by offering refuges and corridors for beetles dispersing between and across fields [22]. A comparison of cereal farms managed either organically or conventionally showed that the mode of farming had a small effect on the species richness of carabids relative to landscape effect [22].

The relationships of ground-dwelling spiders to landscape features and to organic agriculture were studied in twelve pairs of organic vs. conventional fields of winter wheat. Organic agriculture did not increase the number of spider species. Animal communities depend on both local conditions and features of the surrounding landscapes. Most spider species that are typically found in crops during summer emigrate from treated fields and overwinter predominantly in non-crop habitats. The pairs of organic and conventional fields were selected to be as similar as possible in all respects other than management [77].

A Swedish Study of butterflies paired the farms so that the landscape heterogeneity did not differ significantly between farms within pairs. The conclusion was that in a mosaic landscape, butterflies are unlikely to respond significantly to organic farming. There were no differences between organic and conventional farms. The study showed that other factors in the agricultural landscape than the farming system *per se* seem to be of importance for butterfly diversity. The alternative methods used in organic farming, for example a long and diverse crop rotation scheme with a high proportion of grass-clover leys and nitrogen-fixating crops, might in itself promote butterfly diversity and abundance by increasing the amount of temporary food sources[148]. Butterflies did not respond to organic farming in the mosaic landscape of central Sweden [56].

Overall, it has been found that other aspects of agricultural practice, such as crop type and the location of the farms assessed in the studies, tend to be more significant than the differences in the farming practices themselves [46]. As a result, the conclusion is that it is the landscape surrounding the farm that determines the on-farm level of biodiversity and not the farming practice *per se*. Organic farms differ not only in agrochemical use but also have smaller fields, more non-crop habitats, more frequent crop rotations and larger, wider and more sympathetically managed hedges than conventional farms. Such habitat differences may explain differences in biodiversity [19] [56] [74].

Studies of organic farms that report on higher populations of bacteria (a microbial biomass 10-26% greater), carabid beetles, and earthworms generally attribute the increase to the significant use of manure [18] [39].

In the Boarded Barns study, small mammal activity variables included wood mice, bank voles, and common shrews. Based on trapping, activity and diversity was identical between organic and conventional farming [120].

What is consistently higher on organic farms is the number of individuals and mass of weeds because non-chemical weed control methods are less effective than herbicides [72][63]. Studies have shown more than six times more weeds in organic fields than in fields treated with herbicides [14]. At both English and Danish locations, about five times as much weed biomass, 2.4-5.3 times greater weed density, significantly greater species diversity and about 1.8 times greater weed cover have been observed in organically cultivated fields of cereals.[63].

As a result of more weeds, some studies find more beneficial insects (predators, bees) on organic farms. The high floral diversity in organic fields may increase the provision of larval host plants and adult nectar resources for flower-visiting insects, and thus contribute to higher densities of butterflies and bumblebees in organic fields. [34]. However, even with more bees on organic farms, levels of pollination are the same [111].

The presence of more predators on organic farms does not necessarily translate into effective biological control of pest organisms. Contrary to expectation, researchers found no difference in natural pest control between the two farming systems. There was no difference in overall parasitism rate in the whole-farm networks [31].The expectation that cereal aphid abundance should be lower in organic than in conventional fields due to better functioning of biological control was not confirmed in a research trial. Parasitism was not higher in organic than conventional fields [96].

While predator densities were generally highest in organic potato fields, these fields also had the highest densities of the two most injurious insect pests, the green peach aphid and the Colorado potato beetle [40]. Thus, a dramatic increase in predator densities did not lead to lower pest densities [40].Organic Brassicas have been produced in south coastal British Columbia since 1996. Despite a seemingly abundant fauna of natural enemies, crop rotation, and conservation of non-crop habitat surrounding the fields, the crops routinely experience aphid outbreaks requiring multiple applications of insecticidal soap sprays [66].

Researchers tested the effect of farming practices in Swiss organic and conventional vineyards. Organic farming promoted neither diversity nor abundance at any trophic level. Beneficial effects of organic farming on species richness have mostly been observed in annual crops or grasslands where disturbance intensities by management practices are particularly high. Perennial crops, such as fruit orchards or vineyards, are generally less disturbed in comparison to annual crops. Thus, the response of diversity to organic farming may not be the same in perennial compared to annual systems because disturbance intensity differs in these two systems [110].

There are usually higher counts of pest organisms on organic farms. Lack of effective biological control of insect pests and higher weed biomass result in lower yields on organic farms. A recent comparison indicated that yields for organic cereals in the UK may be as low as 50% of that of a 'matched' conventional farm [85]. [24].

Mechanical weed control is an alternative to herbicide treatment. If, however, these management practices reduce populations of generalist arthropod predators and cause a release of pest insects, the overall benefit may be questionable. First, arthropods can be killed directly by mechanical damage or by burying. Second, habitat disturbance may cause arthropods to disperse from the field shortly after cultivation. Cultivation may cause 'indirect effects' through habitat deterioration, by altering microhabitats, removing essential microhabitats for reproduction or other life-history processes, removing plant cover and thereby increasing predation risk [50].

Some aspects of organic farming may detrimental to bird species that are limited by winter seed availability. Once harvesting is completed, it is general practice for farmers on organic farms to plough in the stubbles to prevent an over-winter weed burden, making this resource unavailable to birds [137]

Some studies have reported on the negative impact on birds of tillage practices on organic farms. Mechanical weed control is frequently used in organic farming, and tillage has been shown to cause high mortality amongst the eggs and young of skylarks.
[63]. On organic farms, the survival of ground-nesting birds can be reduced because of usage of mechanical weeding methods instead of herbicides [117].As the breeding period of Lapwings

coincides with numerous sowing and weeding activities, the latter mainly on organic farms, the hatching success of their brood may be severely affected by these activities. With such activities more frequent and varied on organic farms, the impact on reproductive performance is also likely to be greater. As a result, overall hatching success might therefore be lower on organic farms [75].

A Dutch study compared organic and conventional farms where the surrounding landscape features and soil type were similar for both, thus minimizing influences other than farm management. The study showed that the higher frequency of soil-disturbing activities on organic farms results in greater nest failure rates of ground-nesting birds. This study provides strong indications that while organic farming attracts higher densities of Lapwings compared with conventional farming, nest success may in fact be lower due to higher rates of mechanical disturbance [75].

One study reported a lower abundance of earthworms in organic arable fields. Although the reasons for these differences are unclear, excessive tillage can have a serious negative impact on earthworm populations [18].

In contrast to previous studies of crop visitation by wild bees, a New Jersey Study did not find negative effects of conventional farming or natural habitat loss. In the study system, organic and conventional farms differed little in field size, crop diversity and weedy flower diversity, unlike some systems where organic farms have smaller fields with greater crop and weed diversity. Such variables may be more important than organic vs. conventional farming practices [152].

In a Danish study of organic farms, 38% fewer spiders were caught in the plowed area. Plowing caused significant direct mortality of carabids (27%). Weed harrowing caused significant direct mortality of spiders [162][50].

Bird use of organic sites does not necessarily mean greater reproductive success. Within crop fields, tillage practices can disturb or destroy nests; organic sites have more tillage passes, increasing the likelihood that nests within the crop field would be disrupted. If birds are attracted preferentially to organic fields, and tillage destroys their nests, the organic fields could be functioning as an ecological trap [72].

A comparative study of the abundance of breeding birds and wintering birds was carried out over the period 2005-2007 in conventionally and organically managed arable fields in Northern Germany. The diversity of farmland bird species was not affected by farming system (conventional/organic) neither during the breeding season nor during the non-breeding period. As in this study, none of the small number of comparable studies available in this area indicates positive effect of organic farming on the diversity of breeding bird species. Organic cropping usually requires mechanical weed control (harrowing, hoeing), which might negatively affect ground-breeding birds [73].

To design cropping systems for the Midwestern US that promote earthworm populations and thereby improve their sustainability, studies have found that reducing tillage is the most important factor. Consequently, grain farmers who want to increase earthworm numbers to improve sustainability should lower tillage options as opposed to omitting pesticides [160].

One concern among ecologists is that if non-chemical weed control methods become more effective, there may be less weed biomass on organic farms in the future. Some organic fields may contain almost as few non-crop flora as some conventional fields, in part as a result of the development of new, increasingly effective methods of non-chemical weed control. It is also possible that high premiums for organic produce may encourage a minority of farmers to adopt organic management purely for financial reasons [18].

Thus any farming mode that maintains margins and hedgerows is likely to be as good as any organic field and the effects of pesticide application on the cropped area of little significance [120].

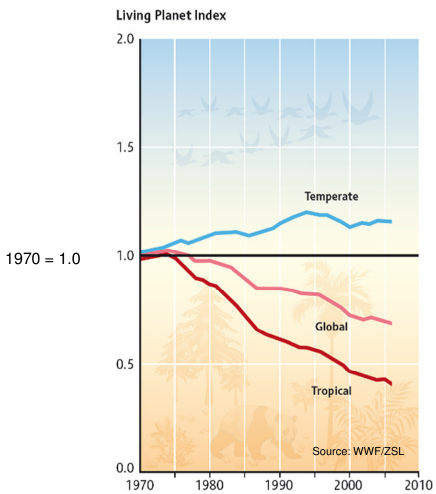
The interest in organic cropping of spring cereals has decreased substantially in Finland. One evident reason for the transition back to conventional farming has been the increased weed infestation and particularly problems with perennial weeds. In general, noxious species like *Avena fatua* and *Galium spurium* have become more frequent during the last ten years [163].

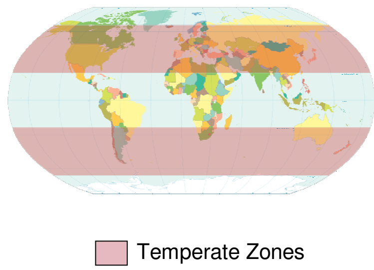
12. Conclusions

Synthetic chemical pesticides are used judiciously on millions of cropland acres around the world each year to reduce the populations of biological organisms which would otherwise significantly lower crop yields. Direct negative effects of pesticides on non-target biological organisms are minor and short-lived. In the world's crop fields, beneficial biological organisms provide their essential ecosystem services even though the acres are treated with pesticides. Crops are pollinated by bees; predators and parasitoids control a majority of crop pests. Declines in biodiversity associated with agriculture are largely the result of habitat destruction and alteration from a natural form to a managed farm. This habitat alteration and loss of biodiversity occurs on crop fields that are managed both with and without chemical pesticide use. Research has shown that it is not the management practice on crop fields that is the major determining factor on cropland biodiversity levels, but rather the characteristics of surrounding areas – hedgerows, woodlands, etc.

Pesticide use has actually been beneficial for biodiversity conservation around the globe since resulting higher crop yields have meant that fewer acres have needed conversion from a natural state. Herbicides have made it possible for farmers to reduce tillage operations on crop fields which has resulted in enhanced biodiversity. Many of the negative concerns about the impacts of pesticides on biodiversity have decreased due to the introduction of pesticides with great selectivity.

Figure 1: Global Living Planet Index





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