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Review

Effects of Agricultural Pesticides on Decline in Insect Species and Individual Numbers

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Abstract: As agricultural production increases, the use of chemical fertilisers, herbicides, and other synthetic pesticides has equally increased over the years. Inadequate pesticide application description and monitoring has generated a heated debate among governmental organisations, agricultural industries, and conservation organisations about pesticide effects on insect species richness and abundance. This review is therefore aimed at summarizing the decline in insects' species and individual numbers as a result of extensive pesticide utilisation and recommends possible management strategies for its mitigation. This review revealed an average pesticide application of 1.58 kg per ha per year, 0.37 kg per person per year, and 0.79 kg per USD 1000 per year. Insects have experienced a greater species abundance decline than birds, plants, and other organisms, which could pose a significant challenge to global ecosystem management. Although other factors such as urbanisation, deforestation, monoculture, and industrialisation may have contributed to the decline in insect species, the extensive application of agro-chemicals appears to cause the most serious threat. Therefore, the development of sustainable and environmentally friendly management strategies is critical for mitigating insect species' decline.

Keywords: pesticides; biodiversity decline; insect taxa; ecosystem management; sustainability

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1. Introduction

Agricultural production has been under tremendous pressure in recent years to meet the demands of the increasing population growth, globally [1]. The current global population of 8.1 billion, for example, is expected to reach over 9.7 billion by 2050 [2]. As the population grows, so does agricultural production, leading to extensive pesticide trade and application. In 2020, the total pesticide trade reached approximately 7.2 million tonnes of formulated products, with a value of USD 41.1 billion [3]. Farmers are compelled to transition from subsistence farming to large-scale commercial farming. Agricultural production increased in Europe, North America, South America, Africa, and Asia during the twentieth century [4]. As agricultural production increases, the use of pesticides such as herbicides, insecticides, and other agro-chemicals also increases [1,5]. These chemicals are used extensively in agricultural production at both the subsistence and commercial levels around the world [6]. Extensive and indiscriminate pesticide application on a commercial scale affects insect species abundance and non-target organisms by interfering with their growth, development, behaviour, and other metabolic and physiological processes [7]. Some pesticides have been linked to a potential decline in insect species and non-target insects foraging on sprayed crops [8]. The indiscriminate use of pesticides also has a significant impact on microorganisms [9], plants [10], invertebrates [11], amphibians [12], birds [13], and some mammals [14].

Although encroachment on natural habitats has been blamed for insects' species decline, the widespread use of pesticides in agricultural production has been identified as the primary cause of the overall loss of insect species and individual numbers [8]. A previous study found a 76% decline in the population of flying insects and a 78% decline in the number of ground-foraging arthropods, with higher annual losses [15]. Insect decline appears to be much greater than that observed in birds or plants, which could pose a significant challenge to global ecosystem management. For instance, in 71% of butterfly species in Britain, the total number of individuals has decreased over 20 years, compared to birds (54% over 20 years), and plants species (28% over 20 years) [16]. Inadequate pesticide application description and monitoring has sparked a heated debate among governmental organisations, agricultural industries, and conservation organisations about pesticide effects on organisms. Quantitative information on pesticides' impact on insect species decline will aid in the implementation of national and international policy objectives, as well as the reversal of current declines. This is vital for the development of safety management techniques for residual chemicals in agro-food and agricultural environments. This review is therefore aimed at summarizing the decline in insects' species and individual numbers as a result of extensive pesticide utilisation and recommends possible management strategies for its mitigation.

2. Pesticides Usage and Distribution in Agricultural Production

In 2022, the total pesticides used in agriculture was 3.70 million tonnes, representing a 4% increase from 2021, a 13% increase over a decade, and a doubling since 1990 [17]. These pesticides comprise herbicides (47.5%), insecticides (29.5%), fungicides (17.5%), and 5.5% others [17]. Furthermore, 610 chemical compounds containing organochlorin insecticides, which were banned due to resistance and safety concerns, are being replaced with newer chemical products [18]. Although several pesticide products are used, agricultural yield losses are estimated at 37% due to insects (13%), weeds (12%), and diseases [18]. The mode of action of pesticide active ingredients determines their specificity and toxicity, whereas their effectiveness on organisms is largely determined by the dose administered to them. Pesticides such as carbamates, neonicotinoid, organophosphorus, synthetic pyrethroid, and organochlorine are well-known neurotoxins that affect arthropods' nervous systems. As a result, these products are assumed to disrupt the physiology of terrestrial and aquatic arthropods. Herbicides are among the most toxic pesticides to other organisms, particularly insects, because they disrupt their metabolic and reproductive systems. Fungicides are used to treat fungal infections and can also act as antibiotics against certain fungi. However, organomercurial products are considered neurotoxic and toxic to arthropods in several areas. As a result, the active ingredients in most pesticides affect a wide range of taxonomic groups rather than just the target species [18].

Europe and North America account for one-third and one-quarter of the total market, respectively [19,20]. Overall, herbicides are estimated to comprise half of pesticide applications in North America, followed by insecticides (19%), fungicides (13%), and others (22%). Some countries, such as India and South Africa, continue to use DDT and lindane to control mosquito vectors and tsetse flies as needed [21]. The global distribution of pesticide types varies by crop, with corn, soybean, and cotton having the highest herbicide usage (75% in the United States). Orchards predominantly use insecticides, whereas vineyards and vegetables plantations primarily use fungicides [20]. The average pesticide usage worldwide is estimated to be 4.4 kg/ha per year, with agriculture accounting for roughly one-fifth of the Earth's land area [5]. As a result, insect diversity and other ecosystem services are severely threatened [20].

3. Global Pesticide Usage per Agricultural Value

A recent survey conducted in 2022 reported that pesticide usage remains constant at 2.7 million tonnes of products and 1.8 kg/ha per area. Pesticide usage per agricultural capita and value were estimated at 0.69 kg/1000 I$ and 0.37 kg/person, respectively. In 2020, the global pesticide trade was expected to be 7.2 million tonnes of formulated products worth USD 41.1 billion [3]. Despite efforts to regulate pesticide use, average pesticide usage increased by 50% over the last decade compared to the 1990s (Table 1). Crop pesticide use in recent decades has increased from 1.2 to 1.8 kg/ha. A survey conducted over the last three decades revealed an average pesticide application of 1.58 kg per ha per year, 0.37 kg per person per year, and 0.79 kg per 1000 I$ per year [3]. A recent survey showed that Asia had the highest pesticide usage of 3.7 million tonnes in 2020, equivalent to a value of USD 16.1 billion. The total average pesticide usage in Asia is estimated to be 0.6 million tonnes per value of agricultural production, 0.17 kg per person per year, 0.47 kg per 1000 I$ (International Dollars) per year, and 1.17 kg per ha per year [3]. Between the 1990s and the most recent decades, pesticide usage in agriculture in Europe increased by just 3%, most likely due to the strict pesticide control by the European Common Agricultural Policy department. The region has the lowest proportion of pesticide usage compared to other regions. In 2020, Europe pesticide usage per area of cropland was estimated at 1.6 kg/ha, below the world average [22,23]. USA applied cropland pesticides at rates of 2.83 kg per ha per year, 1.17 kg per person per year, and 1.43 kg per 1000 I$ per year per value of agricultural production. In particular, the most recent decade saw a higher application of herbicides (360 to 852 kt), fungicides (93 to 177 kt), and insecticides (159 to 181 kt) per year than previous decades [10,23]. Imports of pesticides in Africa are expected to reach 850 kt in 2020, worth USD 3.1 million. Africa uses 32% herbicides, 33% fungicides, 33% bactericides, and 27% insecticides. In the most recent decade, the region used low volumes of pesticides, with estimates of 0.11 tonne per year, 0.41 kg per ha per year on cropland, 0.11 kg per person per year on capita, and 0.42 kg per 1000 I$ per year for agricultural production value [23]. In 2020, USA utilised the most pesticides globally (408 kt), followed by Brazil (377 kt), China (273 kt), Argentina (241 kt), the Russian Federation (91 kt), Canada (79 kt), France (65 kt), Australia (63 kt), India (61 kt), and Italy (57 kt). Moreover, the countries with the highest pesticide usage on cropland in 2020 were Saint Lucia (20 kg/ha), the Maldives (17 kg/ha), Oman (16 kg/ha), Israel (15 kg/ha), Ecuador (14 kg/ha), Seychelles (12 kg/ha), Japan (12 kg/ha), Belize (11 kg/ha), the Netherlands (11 kg/ha), and the Republic of Korea (10 kg/ha). Pesticide usage appears to be more abundant in industrialised regions than in other regions [22,23].

Table 1. Pesticides used by region and category. Source: [24].

	Herbicides	Fungicides	Insecticides	Others
Africa	30	50	30	10
America	60	10	20	10
Asia	40	30	40	10
Europe	39	45	10	15
Oceania	60	10	20	5

4. Persistence of Residues and Their Bioavailability

Persistence determines how long a toxicant residue can remain on a surface over time. The half-life of persistence is the time it takes for half of the chemical to disappear, which usually occurs when the active ingredient is degraded. Nonetheless, some products, such as endosulfan sulphate, dieldrin, aldicarb sulfoxide, sulfone, and heptachlor epoxide, may remain toxic, affecting species richness and abundance. When some neurotoxic insecticides are applied, they degrade quickly through chemical or biological means. Current pesticides, such as herbicides and fungicides, degrade more easily than previous products, but some of these chemicals are more persistent than insecticides [25]. Presently, it is estimated that 50% of pesticides used have a half-life in either soil or water bodies. Most farmers prefer persistent pesticides because they can remain on plant surfaces for an extended period of time. However, this poses a threat to biodiversity for as long as they remain in the environment. Persistent chemical products with high toxicity, such as 'old' OCs, arsenic insecticides, and copper fungicides, may pose a threat. Chemical residues pose a significant threat to species richness and abundance because pesticide degradation rates decrease when compared to assimilation [25]. For instance, the efficacy of glyphosate requires plants to absorb its residues through their leaves or roots when applied [26]. However, if glyphosate is accidentally spread on the ground, it is absorbed into soil particles and may remain active, threatening other species if not absorbed by the plant. Furthermore, chemical residues such as hydrophobic insecticides, systemic and soluble insecticides, and herbicides leach into the top soil, posing a threat to soil-borne organisms, particularly insects [25,26].

5. Impact of Pesticide Application on Insects' Biodiversity

5.1. Direct Effect

Pesticides are known to be harmful to insects, with direct mortality frequently reported, with non-target insects being the most vulnerable when compared to other insects. These pesticides work directly by disrupting the insect's nervous system or damaging its exoskeleton, causing paralysis and death. Pesticides affect both insects that migrate to sprayed fields and those present during treatments. Pesticides such as malathion, metamidophos, abamectin, acetamiprid, imidacloprid, and acephate are reported to be toxic to both target and non-target insects [27]. Moreover, the direct effects of metamidophos, cartap, and abamectin were found to cause high mortality among a group of insects [27]. Excessive use of insecticides such as organophores, carbamates, and purethroids also reduced hymenopteran and coleopteran populations, which are known to play an important role in food web and crop protection [28]. According to general scientific consensus, pesticides' extreme direct impact has resulted in the decline in most beneficial insects and pollinators. For instance, neonicotinoids increased bee and butterfly mortality while reducing their behaviour and survival [29]. Glyphosate exposure caused changes in bees' gut microbiome, leaving them vulnerable. In the United Kingdom, the direct effects of pesticides reduced butterfly species richness on conventional farms more than on organic farms. Carabid beetles and other non-target insects were more affected by conventional farm management than organic farms [30]. The direct effect of insecticide application affected bugs, wild bees, and moth populations, but not the target pests [30]. In the United Kingdom, organophosphates (42%), carbamates (29%), and pyrethroids (14%) were found to have a direct effect on the species richness and abundance of bees [31]. Pesticides used to control pests in wheat and sunflower fields, such as imidacloprid and clothianidin, resulted in high mortality rates among bumble and wild bees [32]. In France, imidacloprid significantly reduced the diversity of Lepidoptera, bugs, coleopterans, and other species when compared to the target pests [33].

5.1.1. Lepidoptera

Moths and butterflies are known to be vulnerable to habitat loss due to their unique host plant adaptation system [34]. Lepidoptera species are widespread and play important roles in ecosystem services and management [35]. In Belgium, 45 butterfly species declined by nearly 69% as a result of excessive agricultural pesticide use during the twentieth century [36]. In the Netherlands, 11 out of 20 cosmopolitan butterfly species are reported to be declining, while four local species (*Lasiommata megera*, *Gonepteryx rhamni*, *Aglais io*, and *Thymelicus lineola*) are critically endangered [37]. A corresponding report also showed an 85% decline in 733 moth species, with 38% threatened and 34% susceptible in the Netherlands [38]. In Sweden, a report indicated a drastic decline in (45%), endangerment of (22%), and extinct of (159 species) 269 species [39]. In Finland, farmland species experienced a greater decrease in biodiversity (60%) compared to forest species (40%) [40]. A population study in Spain revealed that 66 butterfly species were declining on farmlands, 15 were increasing, and 5 were stable in forest zones [41]. Out of 576 butterfly species in Europe, 71 are endangered and declining [42]. In comparison, cropland butterflies declined the most (19%), followed by wetlands (15%) and forests (14%). The greater decline observed in cropland butterflies could be attributed to the excessive use of pesticides compared to other habitats. This was confirmed by the observation that 80% of butterfly species have declined as a result of pesticide application [43]. According to extensive data from the United Kingdom, 41 cropland butterfly species are on the decline. This was attributed to agricultural expansion and the excessive use of pesticides and chemical fertilisers. There has been no comprehensive study on the trend of insect biodiversity in the United States. Nonetheless, a few studies revealed unstable species populations in Wisconsin and Iowa's prairies and bogs. This was the result of climate change and agricultural intensification [44]. In 2012, agricultural intensification and widespread pesticide use reduced 67 butterfly species to 23. In 2010, the southern part of the state experienced an 80% population decline as a result of agricultural intensification and excessive pesticide use [45]. A detailed data base in Asia shows that the populations of butterfly species are threatened (15–20%) and endangered (80%), with two species on the verge of extinction in Japan [46]. A previous report in Malaysia revealed a 19% reduction in the moth population at Mount Kinabalu due to agricultural intensification and pesticide use (Table 2) [47]. In Great Britain, a previous study showed 28% decrease in larger moth total abundance [34]. Burnet moths also decreased from 117 species to 71, with most of them considered highly endangered in Germany [48]. A previous study in the UK showed a two-third decline in widespread and common macro-moths over 35 years of study [49]. The percentage of common macro-moth species showing a significant decrease was higher (54%) than those showing an increase (22%) in the UK [50]. A similar trend of moths' species abundance and richness decrease has been reported in Scotland (46%) over a 24-year study [51]. A decrease in burnet moths' total abundance was reported in Great Britain (50%) and Scotland (20%) [51].

Table 2. Proportion of declining and threatened species per taxa according to IUCN criteria.

Insect Taxon	Declining (%)	Threatened (%)	Reference
Coleoptera	49	34	[52]
Diptera	25	0.7	[53]
Ephemeroptera	37	27	[54]
Hemiptera	8	n.a	[55]
Hymenoptera	46	44	[56]
Lepidoptera	53	34	[16]
Odonata	37	13	[57]
Orthoptera	49	n.a	[58]
Plecoptera	35	29	[59]
Trichoptera	68	63	[53]

5.1.2. Hymenoptera

Hymenopterans, which include ants, bees, wasps, and other insects, provide important ecosystem services. Bees contribute significantly to pollination, aside from their food, industry, and medicinal products [60]. According to studies conducted in Britain, agricultural intensification and widespread pesticide use have resulted in a significant decline in 18 bee species [59]. Reports from Denmark also revealed 12 extinct inherent species, as well as the native *Bombus distinguendus*, which is currently threatened [61]. In Central Europe, agricultural intensification and widespread pesticide use have resulted in the extinction of 48 out of 60 bee species, 30% of which are endangered [62]. Sweden reported a low crop yield due to insufficient pollination services at Swedish red clover fields, which was associated with a decline in the bee population [62]. Agricultural intensification, chemical fertilisers, and pesticide application have been identified as the primary causes of bee species richness and abundance declines in Sweden [63]. A comparable decline was observed in Europe (46% Bombus species), North America (50% of the 14 bumble bee species), Brazil (63%), Costa Rica (60%) and Finland (23%), China (3–13%), South Africa (29%), and Minnesota

(11 stingless bees) as a result of extensive herbicide application [64]. Historical records from 382 geographical areas in the United States show that 3.5 million out of 6.0 million honey bee populations have declined, representing a 0.9% loss per year, which has been attributed to dichlorodiphenyl-trichloroethane (DDT) and other toxic product application for pest management on croplands [65]. The extensive application of DDT, neonicotinoids, and fipronil are reported to impede bee growth and development, particularly queen performance, resulting in reduced diversity [61]. Aside from bees, hymenopterans such as wasps, ants, and parasitoids have experienced significant biodiversity declines (Table 3). Nonetheless, species like *B. bimaculatus*, *B. impatients*, and *B. rufocinctus* have seen population growth in areas where pesticide use is regulated [61]. As a result, widespread pesticide use must be regulated because it has the potential to increase insect biodiversity.

Table 3. Insects' species status of some insects' taxa and their geographical locations.

Taxon	Abundance	Decline	Location	Reference
Hymenoptera				
Bumble bees	18 species	7 species	England	[66]
Bumble bees	14 species	8 species	Canada	[64]
Bumble bees	60 species	48 species	Central Europe	[67]
Honey bees	6 m colonies	3.5 m colonies	USA	[68]
Wild bees		52% population	Britain	[69]
Wild bees		67% population	Netherlands	[70]
Wild bees		32% population	North America	[68]
Cuckoo wasps		23% population	Finland	[70]
Stingless bees	30 species	11 species	USA	[71]
Orchid bees	24 species	64% species	Brazil	[68]
Parasitic wasps	48 species	23% species	Finland	[70]
Coleoptera				
Ground beetles	419 species	34% species	Belgium, Denmark	[72]
Ground beetles	49 species	16% species	UK	[51]
Ladybird beetles		68% species	USA	[72]
Dung beetles		31% population	Italy	[73]
Saproxylic beetles	436 species	57% species	Europe	[70]
Odonata				
Dragonflies	52 species	65% population	USA	[71]
Odonata species	200 species	57 species	Japan	[72]
Odonata species	155 species	13 species	South Africa	[73]
Plecoptera				
Stoneflies	14 species	5 species	Czech Republic	[74]
Stoneflies	77 species	29% species	USA	[75]
Ephemeroptera				
Mayflies	107 species	43% species	Czech Republic	[76]

5.1.3. Diptera

Hoverflies (Syrphidae) are well-known predators of most major insect pests and are also efficient pollinators. The diversity of this taxon varies significantly across Mediterranean countries, with 249 species reported in Greece [77] and 429 in Spain [78]. A similar trend of findings has been reported in the Netherlands and the United Kingdom [79]. In the Netherlands, a comprehensive study demonstrated an 80% and 44% hoverfly decrease over a 40-year (1982–2021) and 43-year (1979–2021) period, respectively [80]. Of the 303 species of hoverflies in Denmark, a recent report shows that 19% are threatened, 5 critically endangered, 24 endangered, and 26 vulnerable. Moreover, 18 were considered to have an information deficit, 32 as near threatened, and 10 as regionally extinct [81]. In Germany, a 26-year period study of hoverflies (1989–2014) showed 23% decreases in species richness [82]. A recent study from 2008 to 2022 also showed a declining trend in 147 types of hoverflies, compared to an increasing trend in 146 [82]. Although the decline was attributed to the degradation of tree features, loss of diverse habitat, and degradation of small water bodies, extensive pesticide application was considered the most threatening factor, as it causes direct mortality and reduces hoverflies' fitness. Pesticides were reported to destabilise trophic service, hence affecting hoverflies indirectly [81,83].

5.1.4. Coleoptera

Coleopterans are biological pest control insects that play a significant role in ecosystem resilience [84]. They also play a significant role in the health of natural and human-modified ecosystems, such as nutrient cycling, seed dispersal, reducing livestock parasites, and promoting plant growth. [85]. The main causes of their biodiversity decline are agricultural intensification and pesticide use. A previous study found that carabids (34%) and xerophilic beetles (50%) were on the decline in Belgium, Denmark, and the Netherlands [86]. Of the 68 carabid species in the United Kingdom, a detailed survey shows 49 in decline, 26 endangered, 8 threatened, and 19 stable. This decline was attributed to urbanisation, agricultural intensification, and extensive pesticide use [70]. According to historical data, 12 species of carabid beetles are threatened in New Zealand, and ladybirds have declined by 68% in the United States and Canada [87]. Studies on the trend of coleopteran species showed a decline in six species in the Czech Republic [88], 19 dung beetle species in the Mediterranean regions of Europe [89], 9 species in Spain [90], 31% dung beetles in Italy [91], 9 Scarabaeidae in France [92], and saproxylic beetles in Europe [93]. Agricultural intensification, urbanisation, wood harvesting, and extensive pesticide application were reported as the main drivers of the decline [89].

5.1.5. Hemiptera

Hemipterans constitute one of the largest insect orders and are the largest among the hemimetabolous insects [77]. At the same study location, a comparative analysis was conducted between two time periods (1963–1967 and 2008–2010). This was investigated to determine the trend of hemipterans' biodiversity, species abundance, and composition. The findings revealed that species biodiversity did not vary significantly, despite some variation in climatic conditions and population abundance. Nonetheless, 14 species declined, while 9 others increased. During the 47-year period, the population decreased from 679 to 231 individuals per site, representing a 66% median population decrease [78]. The decrease in species richness, abundance, and distribution was linked to soil acidification and extensive pesticide use [79].

5.1.6. Orthoptera

A long-term study in Germany on grasshopper and cricket species biodiversity found small variations in species populations and unstable species richness over four decades [94]. Moreover, the study found that the population of bare soil grasshoppers (*Myrmeleotettix maculatus*) decreased while *Tettigonia viridissima* and Phaneroptera falcate species increased slightly. In Germany, only a few species were observed to be declining; however, 50% were highly threatened and vulnerable [90].

5.1.7. Odonata

These are small insect taxa that make a significant contribution to biological pest control and nuisance mosquito management [90]. A previous study found that 118 aquatic insect species were threatened, with Odonata species accounting for 90% [72]. A long-term comprehensive study found that 52 species of dragonflies and damselflies are declining in the United States, 15% of Odonata species are endangered, with two species of damselflies and dragonflies being highly vulnerable to extinction in Europe, and 57 Odonata species are declining in Japan [95].

5.2. Indirect Effects

Toxicants show indirect effects when other organisms become susceptible to the pesticides' active ingredients. Pesticides' indirect effects could be considered as side effects that influence the ecological structure of the affected species rather than the specific mode of action of the various chemicals. Diverse individual toxicants may also have adverse effects on species diversity and their interactions in the ecosystem [96]. Several studies show that most of the pesticides used in agriculture contribute significantly to the decline in insect biodiversity due to side effects on non-target species [5]. Although efforts have been made to classify each type of pesticide and its target organisms, such as birds, plants, insects, and other arthropods, the indirect effects of these pesticides on trophic-level interactions among diverse groups of organisms have not been addressed. For example, some herbicides that were approved through risk assessment for their safety to the environment and other organisms were later discovered to reduce non-target plants that provide food for pollinators and other beneficial insects. As a result, the trophic interactions that underpin biodiversity could be depleted [97].

5.2.1. Herbicides' Indirect Effects

Herbicides and weed management destroy insect host plants, threatening their survival and development [98]. Insects within cultivated fields are reported to be vulnerable to herbicide drift due to the long half-life of these herbicides in the soil [98]. Several studies confirmed the reduction in insect populations as a result of extensive herbicide side effects on host plant populations [99]. This eliminates pollen, nectar, shelter, plant hosts, and pollinator and other insect nesting sites [100,101]. The synergistic effects of 2,4-Dichlorophenoxyacetic acid and other biological agents reduced the insect population due to a higher insecticide lethal dose than what was required for the target weed [102]. Most herbicides are not acutely toxic to other organisms; however, some, such as TCA-sodium, monuron, triazine, and dinitroaniline, have been reported to have an indirect effect on insect biodiversity at higher doses. Dichlobenil (10%) reduced the aphid reproductive rate and population abundance, while 54% of some selected herbicides affected parasitic wasp populations [103]. The antifeedant constituents of simaxine and pronamide inhibited the growth of several phytoghagous insect pests [103]. In Europe, excessive herbicide use has resulted in a decline in insects and other weed species [104]. The synergistic effect of glyphosate and 2, 4-D reduced cricket, ground beetle, and mite populations, while atrazine reduced springtail abundance [105]. Some herbicides may contain little or no direct effect on insects; however, paraquat and terbacil decreased wasp, predatory, and parasitoid species, which indirectly influenced other insect species populations [105]. Previous studies also attributed the decline in carabid beetles to the reduction in food and cover due to herbicide application [104]. It appears that modifying the ecological composition affects the diversity of several insects. Weed control could also indirectly affect insects' larvae, egg-laying, or larval survival [104]. In UK, herbicides' indirect effects are considered a major driver of butterfly and bee decline. An investigation on cereal fields treated with fungicides, herbicides, and insecticides found 13 fewer butterfly species than the 270 on unsprayed fields [105]. In America, the use of genetically modified glyphosate-tolerant corn and glyphosate caused a decline in milkweeds, which consequently led to a decline in the monarch butterfly population [105].

5.2.2. Insecticides' Indirect Effects

Poisoning of Non-Target Insects

Studies have shown a decline in target insect pests and non-target insects as a result of insecticide application. This is because predatory insects may suffer secondary intoxication while feeding on prey that was contaminated with pesticides while still alive. For instance, the spined soldier bug (*Podisus maculiventris*) population was reduced by feeding on diamond moths in a cabbage field treated with imidacloprid [106]. Laboratory and field experimental findings confirmed the poisoning of non-target insects. The lacewing population was reduced when feeding on bollworm larvae treated with azadirachtin [107]. Other experiments also showed a reduction in lacewing lavae when fed lettuce aphids that had been treated with imidacloprid insecticides [67]. Both field and laboratory experiments also showed a high mortality of the ladybug, *Cycloneda sanguinea*, which fed on aphids treated with thiamethoxam, whereas *Pterostichus madidus*, *Nebria brevicollis*, and *P. melanurius* showed significant mortality when feeding on aphids [108]. This is an indication that non-target insects are vulnerable when exposed to poisoned or contaminated preys. Wasp populations were reduced when their larvae fed on an insecticide-sprayed field. Some of these insecticides affect insects' eggs and larvae rather than their adults [108]. The population of non-target mycophagous insects including the ladybeetle, *Phyllobora vigintimaculata*, declined when feeding on plant tissues contaminated with fungi and insecticides. These ladybugs were indirectly poisoned by pathogenic fungi, which grew on treated plants, acting as reservoirs of the applied insecticides. Insects such as the predatory bug, *Orius insidious*, and lacewing, *Chrysoperla carnea*, were affected indirectly by insecticides when feeding on plant sap and extra-floral nectar contaminated with systemic insecticides [109].

Pathogens in Insect Pollinators

Research shows that extensive and consistent application of insecticides stimulates the incidence of viral diseases and pathogens among insect pollinators. For instance, honey bees that fed on a neonicotinoid- and fipronil-treated field experienced higher pathogen infestation, reducing their population [110]. A variety of insecticide residues are found in flowers, crops, weeds, and trees. Insects that feed on the pollen or nectar of these flowers stimulate detoxifying enzymes in response to the ingested sublethal dose, stressing them [111]. The detoxification mechanism is known to weaken their immune system, leaving them vulnerable to pathogens, parasites, and diseases [88,89]. A previous report showed a significant increase in microsporidian gut parasite *Nosema* infection in honey bees, *Apis mellifera*, when exposed, to sublethal effect [112]. However, the indirect effect of insecticides is reported to be highly dependent on the insect species and type of chemical [113]. For instance, the application of imidacloprid did not show sublethal effects on bumble bee gut microbiome [93]. Honey bees that fed on a thaiamethoxam-treated field had significantly higher mite Varroa sp. and pathogen loads compared to those feeding on the untreated fields, reducing their population [114]. Neocotinoid acetamiprid-treated fields of blueberries increased their vulnerability to pathogens and diseases, which eventually declined their population [115]. In East Anglia, a significantly higher prevalence of Microsporidia parasites in leaf-cutter bees, *Megachile* sp., was observed when they fed on insecticide-treated fields compared to the untreated fields [116]. A report on fungicides also showed a direct effect on fungivorous mites, yet they indirectly reduced the population of predatory mites by exposing them to fungal pathogens [117].

6. Ban on Harmful Pesticides and Alternative Techniques for Agricultural Production

Pesticides pose significant threats to the environment, harming non-target species and threatening biodiversity [118,119]. This has raised a major concern among United Nations agencies and international communities [120]. Banning hazardous pesticides can help to recover insect biodiversity and improve ecosystem services [121]. Although concerns about the potential impact of pesticides on crop yields are raised, previous research in India has shown that sustainable agricultural production strategies, such as integrated pest management and agroecology, significantly increased yield compared to conventional farming strategies [121]. Following the previous national ban of 16 pesticides in 2018, the India national government proposed a ban on 27 pesticides in 2020 [122]. Kerala banned 14 highly hazardous pesticides in 2011, following the 2005 ban on organochlorine insecticides and endosulfan [123]. These efforts demonstrated the potential for safer and more sustainable agricultural practices, which would reduce pesticide threats to plant and insect biodiversity [124]. Moreover, the ban of harmful pesticides in Srilanka [125], India [126], Taiwan [126], Bangladesh [127], and South Korea [128] increased plant and pollinator species richness. Other studies showed that organic farming had five times higher plant biodiversity and 20 times higher insect species richness compared to conventional fields [129]. The EU banned pesticides classified as mutagens, carcinogens, reproductive toxicants, or endocrine disruptors [130]. Similarly, China banned highly hazardous pesticides and revised certain pesticide use regulations for both sellers and users [131]. The Chinese Ministry of Agriculture banned 50 pesticides and further proposed restricting another 30 pesticides [132]. The Brazilian Ministry of Agriculture (MOA), Health Regulatory Agency, and Ministry of Environment incorporated a more protective hazard assessment to ban teratogenic, hormone disrupting, and mutagenic pesticides [133]. Although multiple factors have limited the effectiveness of this regulation, the Brazilian Ministry of Agriculture (MOA) and Health Regulatory Agency managed to ban some pesticides that threaten ecosystem services and the environment [134]. It is recommended that using safer formulations or natural farming strategies could significantly minimise the adverse effects of pesticides on biodiversity [135].

7. Insect Biodiversity Decline and Its Contributing Factors

The decline in insect populations poses a threat to the United Nations Sustainable Development Goal of conserving natural populations and preventing extinctions [136]. Available data indicate a widespread decline in insect biodiversity [124]. For instance, a 50% decline in European grassland butterfly individual numbers was reported in 2011 [124]. Similar trends are observed in well-studied insect groups such as bees and moths. However, anthropogenic modification of global landscapes is presently contributing to insect population decline [137,138], with reduced diversity threatening the sustainability of ecosystem services provided by insects [139]. Climate change, habitat destruction, habitat fragmentation, deterioration of habitat quality, invasive species, pesticide use, and pollution are all contributing to the global biodiversity decline [140]. However, a pan-European long-term study on plant and insect biodiversity identified pesticide use as a major factor in insect species decline [141]. These factors endanger the sustainability of ecosystem services, necessitating immediate action to address these threats and protect insect populations [142]. The combination of these factors leads to habitat loss and degradation, eventually driving insect populations towards decline and extinction [143]. For instance, the blowfly species *Neta chilensis* may have become extinct due to the cumulative effects of multiple stressors [144]. To effectively conserve insects, policies must consider the synergistic effects of these threats. In the Northern Hemisphere, particularly in Europe, changes in insect populations' diversity and abundance have raised concerns about a potential global trend [145]. Geographical areas such as Brazil's Cerrado and Atlantic forests, the Caribbean, Central Chile, and Mesoamerica are considered crucial biodiversity hotspots, due to pesticide use and several other factors [146].

8. Sustainable Management Strategies to Safeguard Insect Biodiversity Declines

The findings of this review have confirmed that extensive use of pesticides has significantly contributed to the decline in insect biodiversity, despite the fact that pesticides play an important role in crop protection. Pesticide applications endanger farmers' health and destabilise the ecosystem by reducing insect biodiversity [73]. In general, biodiversity is a key driver of ecosystem services, which lead to sustainable agricultural management, and thus it must be protected for current and future generations [147]. Although some studies attribute insect biodiversity decline to urbanisation as a result of the increasing global population, the current review clearly shows that the main threat is the wide range of pesticide application due to extensive agricultural production [148]. Therefore, the development of sustainable and environmentally friendly management strategies is critical for mitigating insect biodiversity decline. The approach to conserve insects' biodiversity involves the enforcement of government policies, sustainable farming practices, and crop heterogeneity.

8.1. Organic Agriculture and Integrated Pest Management Strategies

Researchers have explored alternative farming methods to reduce pesticide use while increasing insect species abundance and richness. Organic farming is regarded as a promising alternative, with studies indicating that it can increase species richness by approximately 34% and abundance by around 50% [149]. Organic farming promotes biodiversity by increasing the abundance and variety of plant and insect species [30]. This, in turn, can lead to enhanced biological control, as more predators can help regulate pest populations [150]. A comparison of arthropod populations in various farming systems showed that organic farming had the highest relative density over three seasons. Similarly, a study in Thailand discovered that organic rice fields supported a diverse range of insect species, with a higher proportion of natural enemies (23 species) than pest species (11 species), highlighting organic farming's potential to promote ecological balance [151]. A previous study found that organic fields had a higher relative insect density than conventional fields, indicating potential pesticide-related effects. Moreover, organic farming practices produced the highest Shannon–Wiener index, indicating greater biodiversity [152]. Other studies have found that organic fields promote greater insect richness and abundance [152], whereas pesticide applications can harm certain species, such as spiders and dragonflies [153,154]. Meyling et al. [155] discovered that organic vegetable farming supported a greater diversity of natural enemies. This suggests that reducing pesticide use may increase insect species abundance in open-field ecosystems. Similarly, Reddy and Giraddi [156] discovered that pesticide use patterns influenced insect pest biodiversity in vegetable fields, including cabbage, with the Simpson index higher in sprayed fields compared to unsprayed fields. Cutworms and *P. xylostella* were found to have higher relative densities in cabbage ecosystems, highlighting the effects of pesticide use on insect biodiversity. According to studies on rice and cabbage production systems, organic farming or minimal chemical use (IPM) leads to increased biodiversity [157]. Also, organic rice fields showed increased complexity and changes in community structure under various management practices. This suggests that organic farming has the potential to preserve biodiversity, ecosystem services, and effectively manage pests [152]. As a result, reducing or eliminating chemical use in fields can improve agro-ecosystem diversity while offsetting potential trade-offs and losses and mitigating the environmental damage caused by indiscriminate pesticide application in agriculture.

8.2. Sustainable Farming Practices

Ecological restoration is required to improve habitat connectivity when a degraded ecosystem is unable to restore itself [158]. Sustainable agricultural production plays a major role in biodiversity management and conservation. Result-Oriented Measures that focus on biodiversity fluctuations caused by farmers' management practices have been established, targeting biodiversity restoration [159]. Agricultural sustainability, coupled with innovative technologies, could ensure consistent ecosystem service resilience. This strategy could also contribute to global food security for both the present and future generations [159]. Farmers are expected to increase output while protecting natural resources, biodiversity habitats, and the environment. Unfortunately, a recent survey found that most farmers are unaware of timely insect pest infestations and thus use a variety of management techniques, including indiscriminate pesticide application, which kills non-target insects [1]. These practices disrupt ecosystem services, potentially resulting in a decline in insect biodiversity and the spread of other pests. Thus, crop rotations, intercropping, agroforestry, reduced tillage, and proper pesticide application rates are recommended as ways to ensure sustainable agriculture and stable insect biodiversity. Moreover, strategic development of integrated pest management could reduce the extensive use of toxic pesticides [160].

8.3. Crop Heterogeneity

Mix cropping systems are beneficial to agriculture and biodiversity management, therefore farmers need to be motivated to implement them [161]. Higher biodiversity of insects and other arthropods was reported in crop genetic diversity fields. This was attributed to diverse range of food sources and crop heterogeneity structure. Therefore, strategic implementation of multiple cropping and crop rotation systems could support to sustain insect biodiversity [161]. Landscape conservation, crop rotation, minimal pesticides application, mix cropping, intercropping, and others are among the proposed environmental agricultural practices for biodiversity conservation includes [162].

9. Conclusions

This comprehensive review reveals that insects face greater diversity decline within a few decades unless farmers adopt new sustainable agricultural strategies. Although other factors such as urbanisation, deforestation, monoculture, and industrialisation may have contributed to the decline in insect species, extensive pesticide usage appears to be the most serious threat. Apparently, protecting threatened species in natural reserves does not guarantee their survival, as indiscriminate pesticide use and agricultural intensification continue to rise. This is due to most farmers' desire to meet the global food demand as the population grows, so they ignore the risks of pesticides' effects on human health and non-target insects [160]. To mitigate species richness loss, habitat conservation and restoration combined with a significant reduction in agrochemical use in intensive agriculture areas must be prioritised globally. Apparently, excessive application of pesticides does not increase yield and instead contributes to pest resistance, endangers farmer's and consumer's lives, and leads to insects' species decline. Over time, the development of integrated pest management (IPM) in Europe and developing African and Asian countries has increased crop yields. Therefore, developing safety management techniques for residual chemicals in agro-food and agricultural environments, guided by integrated pest and weed management approaches, is the most effective way to increase insect species richness and abundance.

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References

1. Emmerson, M.; Morales, M.B.; Onate, J.J.; Batary, P.; Berendse, F.; Liira, J. How agricultural intensification affects biodiversity and ecosystem services. *Adv. Ecol. Res.* **2016**, *55*, 43–97.
2. Population Reference Bureau (PRB). World Population Data Sheet. 2019. Available online: https://interactives.prb.org/2020-wpds/ (accessed on 7 February 2020).
3. WTO (World Trade Organization). *Trade in Medical Goods in the Context of Tackling COVID-19: Developments in the First Half of 2020*; WTO: Geneva, Switzerland, 2020.
4. Foley, J.A.; DeFries, R.; Asner, G.; Barford, C.; Bonan, G.; Carpenter, S.R. Global consequences of land use. *Science* **2005**, *309*, 570–574. [CrossRef] [PubMed]
5. Raven, P.H.; Wagner, D.L. Agricultural intensification and climate change are rapidly decreasing insect biodiversity. *Proc. Natl. Acad. Sci. USA* **2021**, *118*, 12–25. [CrossRef] [PubMed]
6. Köhler, H.R.; Triebskorn, R. Wildlife ecotoxicology of pesticides: Can we track effects to the population level 300 and beyond? *Science* **2013**, *341*, 759–765. [CrossRef]
7. Fishel, F.M. *Pesticide Effects on Nontarget Organisms*; EDIS PI-85; University of Florida Institute 302 of Food and Agricultural Sciences: Gainesville, FL, USA, 2005.
8. Woodcock, B.A. Impacts of neonicotinoid use on long-term population changes in wild bees in England 311. *Nat. Commun.* **2016**, *7*, 12–45. [CrossRef]
9. Druille, M.; García-Parisi, P.A.; Golluscio, R.A.; Cavagnaro, F.P.; Omacini, M. Repeated annual glyphosate 313 applications may impair beneficial soil microorganisms in temperate grassland. *Agric. Ecosyst. Environ.* **2016**, *230*, 184–190. [CrossRef]
10. Triques, M.C. Assessing single effects of sugarcane pesticides fipronil and 2, 4-D on plants and soil 316 organisms. *Ecotox. Environ. Saf.* **2021**, *208*, 11–16. [CrossRef]
11. Tsvetkov, N.; Samson-Robert, O.; Sood, K.; Patel, H.S.; Malena, D.A.; Gajiwala, P.H.; Maciukiewicz, P.; Fournier, V.; Zayed, A. Chronic exposure to neonicotinoids reduces honey bee health near corn crops. *Science* **2017**, *356*, 1395–1397. [CrossRef]

12. Baker, N.J.; Bancroft, B.A.; Garcia, T.S. A meta-analysis of the effects of pesticides and fertilizers on 322 survival and growth of amphibians. *Sci. Total Environ.* **2013**, *449*, 150–156. [CrossRef] [PubMed]
13. Eng, M.L.; Stutchbury, B.; Morrissey, C.A. A neonicotinoid insecticide reduces fueling and delays migration 324 in songbirds. *Science* **2019**, *365*, 1177–1180. [CrossRef]
14. Prahl, M.; Odorizzi, P.; Gingrich, D.; Muhindo, M.; McIntyre, T.; Budker, R.; Jagannathan, P.; Farrington, L.; Nalubega, M.; Nankya, F.; et al. Exposure to pesticides in utero impacts the fetal immune system and response to vaccination in 326 infancy. *Nat. Commun.* **2021**, *12*, 132–148. [CrossRef] [PubMed]
15. Graf, N.; Battes, K.P.; Cimpean, M.; Dittrich, P.; Entling, M.H.; Link, M.; Scharmüller, A.; Schreiner, V.C.; Szöcs, E.; Schäfer, R.B. Do agricultural pesticides in streams influence riparian spiders? *Sci. Total Environ.* **2019**, *660*, 126–135. [CrossRef] [PubMed]
16. Thomas, J.A.; Telfer, M.G.; Roy, D.B.; Preston, C.D.; Greenwood, J.J.D.; Asher, J.; Fox, R.; Clarke, R.T.; Lawton, J.H. Comparative losses of British butterflies, birds, and plants and the global extinction crisis. *Science* **2004**, *303*, 1879–1881. [CrossRef]
17. FAO. *FAOSTAT: Pesticides Use*; FAO: Rome, Italy, 2024.
18. Prakash, S.; Verma, A.K. Effect of Organophosphorus Pesticide (Chlorpyrifos) on the Haematology of *Heteropneustes fossilis* (Bloch). *Int. J. Fauna Biol. Stud.* **2014**, *1*, 95–98.
19. Baird, D.J.; Van den Brink, P.J. Using biological traits to predict species sensitivity to toxic substances. *Ecotoxicol. Environ. Saf.* **2007**, *67*, 296–301. [CrossRef]
20. Baxter, J.; Cummings, S.P. The degradation of the herbicide bromoxynil and its impact on bacterial diversity in a top soil. *J. Appl. Microbiol.* **2008**, *104*, 1605–1616. [CrossRef]
21. Grondona, S.I.; Lima, M.L.; Massone, H.E.; Miglioranza, K.S.B. Pesticides in aquifers from Latin America and the Caribbean. *Sci. Total Environ.* **2023**, *901*, 16–25. [CrossRef]
22. FAO. *FAOSTAT: Pesticides Trade*; FAO: Rome, Italy, 2022.
23. FAO. *FAOSTAT: Pesticides Use*; FAO: Rome, Italy, 2022.
24. Sánchez-Bayo, F. Impacts of Agricultural Pesticides on Terrestrial Ecosystems, Ecological Impacts of Toxic Chemicals. *Ecol. Impacts Toxic Chem.* **2011**, *2011*, 63–87.
25. Ahmad, R.; Kookana, R.S.; Megharaj, M.; Alston, A.M. Aging reduces the bioavailability of even a weakly sorbed pesticide (carbaryl) in soil. *Environ. Toxicol. Chem.* **2004**, *23*, 2084–2089. [CrossRef] [PubMed]
26. Hill, M.P.; Macfadyen, S.; Nash, M.A. Broad spectrum pesticide application alters natural enemy communities and may facilitate secondary pest outbreaks. *PeerJ* **2017**, *5*, 41–79. [CrossRef]
27. Kannan, M.; Elango, K.; Tamilnayagan, T.; Preetha, S.; Kasivelu, G. Impact of nanomaterials on beneficial insects in agricultural ecosystems. In *Nanotechnology for Food, Agriculture, and Environment*; Springer: Cham, Switzerland, 2020; pp. 379–393.
28. Feber, R.E.; Johnson, P.J.; Firbank, L.G.; Hopkins, A.; Macdonald, D.W. A comparison of butterfly populations on organically and conventionally managed farmland. *J. Zool.* **2007**, *273*, 30–39. [CrossRef]
29. Stuart, A. *Impacts of Pesticides on Biodiversity and the Environment What Do We Now Know?* Pesticide Action Network UK: Brighton, UK, 2021; pp. 1–3.
30. Bengtsson, J.; Ahnström, J.; Weibull, A.C. The effects of organic agriculture on biodiversity and abundance: A meta-analysis. *J. Appl. Ecol.* **2005**, *4*, 2–7. [CrossRef]
31. Fletcher, M.; Barnett, L. Bee pesticide poisoning incidents in the United Kingdom. *Bull. Insectol.* **2003**, *56*, 141–145.
32. Scott-Dupree, C.D.; Conroy, L.; Harris, C.R. Impact of currently used or potentially useful insecticides for canola agroecosystems on *Bombus impatiens* (Hymenoptera: Apidae), *Megachile rotundata* (Hymentoptera: Megachilidae), and *Osmia lignaria* (Hymenoptera: Megachilidae). *J. Econ. Entomol.* **2009**, *102*, 177–182. [CrossRef] [PubMed]
33. Liu, C.Z.; Wang, G.; Yan, L. Effects of imidacloprid on arthropod community structure and its dynamics in alfalfa field. *Chin. J. Appl. Ecol.* **2008**, *18*, 2379–2383.
34. Fox, R. The decline of moths in Great Britain: A review of possible causes. *Insect Conserv. Divers.* **2013**, *6*, 5–19. [CrossRef]
35. Hahn, M.; Schotthöfer, A.; Schmitz, J.; Franke, L.A.; Brühl, C.A. The effects of agrochemicals on Lepidoptera, with a focus on moths, and their pollination service in field margin habitats. *Agric. Ecosyst. Environ.* **2015**, *207*, 153–162. [CrossRef]
36. Maes, D.; Van Dyck, H. Butterfly diversity loss in Flanders (north Belgium): Europe's worst case scenario? *Biol. Conserv.* **2001**, *99*, 263–276. [CrossRef]
37. van Dyck, H.; van Strien, A.J.; Maes, D.; van Swaay, C.A.M. Declines in common, widespread butterflies in a landscape under intense human use. *Conserv. Biol.* **2009**, *23*, 957–965. [CrossRef]
38. Groenendijk, D.; van der Meulen, J. Conservation of moths in The Netherlands: Population trends, distribution patterns and monitoring techniques of day-flying moths. *J. Insect Conserv.* **2004**, *8*, 109–118. [CrossRef]
39. Franzén, M.; Johannesson, M. Predicting extinction risk of butterflies and moths (Macrolepidoptera) from distribution patterns and species characteristics. *J. Insect Conserv.* **2007**, *11*, 367–390. [CrossRef]
40. Kuussaari, M.; Heliölä, J.; Pöyry, J.; Saarinen, K. Contrasting trends of butterfly species preferring seminatural grasslands, field margins and forest edges in northern Europe. *J. Insect Conserv.* **2007**, *11*, 351–366. [CrossRef]
41. Melero, Y.; Stefanescu, C.; Pino, J. General declines in Mediterranean butterflies over the last two decades are modulated by species traits. *Biol. Conserv.* **2016**, *201*, 336–342. [CrossRef]
42. van Swaay, C.; Warren, M.; Lois, G. Biotope use and trends of European butterflies. *J. Insect Conserv.* **2006**, *10*, 189–209. [CrossRef]

43. van Swaay, C.; Cuttelod, A.; Collins, S.; Maes, D.; Munguira, M.L.P.; Šašić, M. *European Red List of Butterflies*; Publications Office of the European Union: Luxembourg, 2010.
44. Swengel, S.R.; Swengel, A.B. Assessing abundance patterns of specialized bog butterflies over 12 years in northern Wisconsin USA. *J. Insect Conserv.* **2015**, *19*, 293–304. [CrossRef]
45. Breed, G.A.; Stichter, S.; Crone, E.E. Climate-driven changes in northeastern US butterfly communities. *Nat. Clim. Chang.* **2012**, *3*, 142. [CrossRef]
46. Nakamura, Y. Conservation of butterflies in Japan: Status, actions and strategy. *J. Insect Conserv.* **2011**, *1*, 5–22. [CrossRef]
47. Chen, I.C.; Hill, J.K.; Shiu, H.J.; Holloway, J.D.; Benedick, S.; Chey, V.K. Asymmetric boundary shifts of tropical montane Lepidoptera over four decades of climate warming. *Glob. Ecol. Biogeogr.* **2011**, *20*, 34–45. [CrossRef]
48. Habel, J.C.; Segerer, A.; Ulrich, W.; Torchyk, O.; Weisser, W.W.; Schmitt, T. Butterfly community shifts over two centuries. *Conserv. Biol.* **2016**, *30*, 754–762. [CrossRef]
49. Conrad, K.F.; Warren, M.S.; Fox, R.; Parsons, M.S.; Woiwod, I.P. Rapid declines of common, widespread British moths provide evidence of an insect biodiversity crisis. *Biol. Conserv.* **2006**, *132*, 279–291. [CrossRef]
50. Conrad, K.F.; Woiwod, I.P.; Parsons, M.; Fox, R.; Warren, M.S. Long-term population trends in widespread British moths. *J. Insect Conserv.* **2006**, *8*, 119–136. [CrossRef]
51. Dennis, E.B.; Brereton, T.M.; Morgan, B.J.T.; Fox, R.; Shortall, C.R.; Prescott, T.; Foster, S. Trends and indicators for quantifying moth abundance and occupancy in Scotland. *J. Insect Conserv.* **2019**, *23*, 369–380. [CrossRef]
52. Gallai, N.; Salles, J.M.; Settele, J.; Vaissiere, B.E. Economic valuation of the vulnerability of world agriculture confronted with pollinator decline. *Ecol. Econ.* **2009**, *68*, 810–821. [CrossRef]
53. Cameron, S.A.; Lozier, J.D.; Strange, J.P.; Koch, J.B.; Cordes, N.; Solter, L.F. Patterns of widespread decline in North American bumble bees. *Proc. Natl. Acad. Sci. USA* **2011**, *108*, 662–667. [CrossRef] [PubMed]
54. Goulson, D.; Hanley, M.E.; Darvill, B.; Ellis, J.S.; Knight, M.E. Causes of rarity in bumblebees. *Biol. Conserv.* **2005**, *122*, 1–8. [CrossRef]
55. Dupont, Y.L.; Damgaard, C.; Simonsen, V. Quantitative historical change in bumblebee (*Bombus* spp.) assemblages of red clover fields. *PLoS ONE* **2011**, *6*, 25–27. [CrossRef] [PubMed]
56. Kosior, A.; Celary, W.; Olejniczak, P.; Fijal, J.; Król, W.; Solarz, W. The decline of the bumble bees and cuckoo bees (Hymenoptera: Apidae: Bombini) of Western and Central Europe. *Oryx* **2007**, *41*, 79–88. [CrossRef]
57. Bommarco, R.; Lundin, O.; Smith, H.G.; Rundlöf, M. Drastic historic shifts in bumble-bee community composition in Sweden. *Proc. R. Soc. B Biol. Sci.* **2012**, *279*, 309–315. [CrossRef]
58. Ceballos, G.; Ehrlich, P.R. Mammal population losses and the extinction crisis. *Science* **2002**, *296*, 904–907. [CrossRef]
59. Bommarco, R.; Kleijn, D.; Potts, S.G. Ecological intensification: Harnessing ecosystem services for food security. *Trend. Ecol. Evol.* **2013**, *28*, 230–238. [CrossRef]
60. New, T.R. *Hymenoptera and Conservation*; Wiley Blackwell: Hoboken, NJ, USA, 2012; 232p.
61. Ellis, J. The honey bee crisis. *Outlooks Pest Manag.* **2012**, *23*, 35–40. [CrossRef]
62. Ellis, J.D.; Evans, J.D.; Pettis, J. Colony losses, managed colony population decline, and Colony Collapse Disorder in the United States. *J. Apic. Res.* **2010**, *49*, 134–136. [CrossRef]
63. Anderson, K.E.; Sheehan, T.H.; Eckholm, B.J.; Mott, B.M.; DeGrandi-Hoffman, G. An emerging paradigm of colony health: Microbial balance of the honey bee and hive (*Apis mellifera*). *Insectes Soc.* **2011**, *58*, 431–444. [CrossRef]
64. Johnson, R.M.; Dahlgren, L.; Siegfried, B.D.; Ellis, M.D. Acaricide, fungicide and drug interactions in honey bees (*Apis mellifera*). *PLoS ONE* **2013**, *8*, 40–52. [CrossRef]
65. Williams, G.R.; Troxler, A.; Retschnig, G.; Roth, K.; Yañez, O.; Shutler, D.; Neumann, P.; Gauthier, L. Neonicotinoid pesticides severely affect honey bee queens. *Sci. Rep.* **2015**, *5*, 14621. [CrossRef]
66. Thorp, R.W.; Shepherd, M.D. Profile: Subgenus Bombus. In *Red List of Pollinator Insects of North America*; Shepherd, M.D., Vaughan, D.M., Black, S.H., Eds.; The Xerces Society for Invertebrate Conservation: Portland, OR, USA, 2005.
67. Brandt, A.; Hohnheiser, B.; Sgolastra, F.; Bosch, J.; Meixner, M.D.; Büchler, R. Immunosuppression response to the neonicotinoid insecticide thiacloprid in females and males of the red mason bee *Osmia bicornis* L. *Sci. Rep.* **2020**, *10*, 4670. [CrossRef]
68. Paukkunen, J.; Poyry, J.; Kuussaari, M. Species traits explain long-term population trends of Finnish cuckoo wasps (Hymenoptera: Chrysididae). *Insect Conserv. Divers.* **2018**, *11*, 58–71. [CrossRef]
69. Cooling, M.; Hoffmann, B.D. Here today, gone tomorrow: Declines and local extinctions of invasive ant populations in the absence of intervention. *Biol. Invasions* **2015**, *17*, 3351–3357. [CrossRef]
70. Brown, P.M.; Roy, H.E. Native ladybird decline caused by the invasive harlequin ladybird *Harmonia axyridis*: Evidence from a long-term field study. *Insect Conserv. Divers.* **2018**, *3*, 230–239. [CrossRef]
71. Ball-Damerow, J.E.; M'Gonigle, L.K.; Resh, V.H. Changes in occurrence, richness, and biological traits of dragonflies and damselflies (Odonata) in California and Nevada over the past century. *Biodivers. Conserv.* **2014**, *23*, 2107–2126. [CrossRef]
72. Futahashi, R. Diversity of UV reflection patterns in Odonata. *Front. Ecol. Evol.* **2020**, *8*, 201–215. [CrossRef]
73. Tierno de Figueroa, J.M.; López-Rodríguez, M.J.; Lorenz, A.; Graf, W.; Schmidt-Kloiber, A.; Hering, D. Vulnerable taxa of European Plecoptera (Insecta) in the context of climate change. *Biodivers. Conserv.* **2010**, *19*, 1269–1277. [CrossRef]
74. McCafferty, P.W.; Lenat, D.R.; Jacobus, L.M.; Meyer, M.D. The mayflies (Ephemeroptera) of the Southeastern United States. *Trans. Am. Entomol. Soc.* **2010**, *136*, 221–233. [CrossRef]

75. Jinguji, H.; Thuyet, D.; Ueda, T.; Watanabe, H. Effect of imidacloprid and fipronil pesticide application on *Sympetrum infuscatum* (Libellulidae: Odonata) larvae and adults. *Paddy Water Environ.* **2013**, *11*, 277–284. [CrossRef]
76. Houghton, D.C.; Holzenthal, R.W. Historical and contemporary biological diversity of Minnesota caddisflies: A case study of landscape-level species loss and trophic composition shift. *J. N. Am. Benthol. Soc.* **2010**, *29*, 480–495. [CrossRef]
77. Brooks, D.R.; Bater, J.E.; Clark, S.J.; Monteith, D.T.; Andrews, C.; Corbett, S.J. Large carabid beetle declines in a United Kingdom monitoring network increases evidence for a widespread loss in insect biodiversity. *J. Appl. Ecol.* **2012**, *49*, 1009–1019. [CrossRef]
78. McGuinness, C.A. Carabid beetle (Coleoptera: Carabidae) conservation in New Zealand. *J. Insect Conserv.* **2007**, *11*, 31–41. [CrossRef]
79. Turin, H.; Den Boer, P.J. Changes in the distribution of carabid beetles in The Netherlands since II. Isolation of habitats and long-term time trends in the occurence of carabid species with different powers of dispersal (Coleoptera, Carabidae). *Biol. Conserv.* **1988**, *44*, 179–200. [CrossRef]
80. Barendregt, A.; Zeegers, T.; van Steenis, W.; Jongejans, E. Forest hoverfly community collapse: Abundance and species richness drop over four decades. *Insect Conserv. Divers.* **2022**, *15*, 510–521. [CrossRef]
81. Andersen, E.E.; Dons Henriksen, J.; Lykke Corfixen, N.; Garn, A.-K.; Leus, K.; Lees, C. *Moving from Assessment to Conservation Planning for Hoverflies in Denmark*; IUCN SSC Conservation Planning Specialist Group: Apple Valley, MN, USA, 2022; pp. 5–8.
82. Hallmann, C.A.; Ssymank, A.; Sorg, M.; de Kroon, H.; Jongejans, E. Insect biomass decline scaled to species diversity: General patterns derived from a hoverfly community. *Proc. Natl. Acad. Sci. USA* **2021**, *118*, 200–255. [CrossRef]
83. Reemer, M.; Smit, J.T.; Zeegers, T. Basisrapport voor de Rode Lijst Zweefvliegen. *EIS Kenniscentrum Insecten. EIS* **2024**, *20*, 2–3.
84. Harmon, J.P.; Stephens, E.; Losey, J. The decline of native coccinellids (Coleoptera: Coccinellidae) in the United States and Canada. *J. Insect Conserv.* **2007**, *11*, 85–94. [CrossRef]
85. Barretto, J.W.; Cultid-Medina, C.A.; Escobar, F. Annual abundance and population structure of two dung beetle species in a human-modified landscape. *Insect.* **2019**, *10*, 12–20. [CrossRef]
86. Wheeler, A.G.; Hoebeke, E.R. Rise and fall of an immigrant lady beetle: Is *Coccinella undecimpunctata* L. (Coleoptera: Coccinellidae) still present in North America? *Proc. Entomol. Soc. Wash.* **2008**, *110*, 817–823. [CrossRef]
87. Sato, S.; Dixon, A.F. Effect of intraguild predation on the survival and development of three species of aphidophagous ladybirds: Consequences for invasive species. *Agric. For. Entomol.* **2004**, *1*, 21–24. [CrossRef]
88. Lumaret, J.-P. *Atlas des Coléopteres Scara-Béides Laparosticti de France*; Secrétariat Faune Flore/MNHN: Paris, France, 1990.
89. Lobo, J.M.; Lumaret, J.-P.; Jay-Robert, P. Diversity, distinctiveness and conservation status of the Mediterranean coastal dung beetle assemblage in the Regional Natural Park of the Camargue (France). *Divers. Dist.* **2001**, *7*, 257–270. [CrossRef]
90. Stefanescu, C.; Aguado, L.O.; Asís, J.D.; Baños-Picón, L.; Cerdá, X.; García, M.A.M. Diversidad de insectos polinizadores en la peninsula ibérica. *Ecosistemas Rev. Cietifica Tec. Ecol. Medio Ambiente* **2018**, *27*, 9–22.
91. Clausnitzer, V.; Kalkman, V.J.; Ram, M.; Collen, B.; Baillie, J.E.M.; Bedjanič, M. Odonata enter the biodiversity crisis debate: The first global assessment of an insect group. *Biol. Conserv.* **2009**, *142*, 1864–1869. [CrossRef]
92. Schuch, S.; Wesche, K.; Schaefer, M. Long-term decline in the abundance of leafhoppers and planthoppers (Auchenorrhyncha) in Central European protected dry grasslands. *Biol. Conserv.* **2012**, *149*, 75–83. [CrossRef]
93. Nieto, A.; Alexander, K.N. *The Status and Conservation of Saproxylic Beetles in Europe*; University of Alicante: Alicante, Spain, 2010.
94. DeWalt, R.E.; Favret, C.; Webb, D.W. Just how imperiled are aquatic insects? A case study of stoneflies (Plecoptera) in Illinois. *Ann. Entomol. Soc. Am.* **2005**, *98*, 941–950. [CrossRef]
95. Nakanishi, K.; Nishida, T.; Kon, M.; Sawada, H. Effects of environmental factors on the species composition of aquatic insects in irrigation ponds. *Entomol. Sci.* **2014**, *17*, 251–261. [CrossRef]
96. Bernhardt, E.S.; Rosi, E.J.; Gessner, M.O. Synthetic chemicals as agents of global change. *Front. Ecol. Environ.* **2017**, *15*, 84–90. [CrossRef]
97. Habel, J.C.; Samways, M.J.; Schmitt, T. Mitigating the precipitous decline of terrestrial European insects: Requirements for a new strategy. *Biodivers. Conserv.* **2019**, *28*, 1343–1360. [CrossRef]
98. Gianessi, L.P. The increasing importance of herbicides in worldwide crop production. *Pest Manag. Sci.* **2013**, *69*, 1099–1105. [CrossRef] [PubMed]
99. Sharma, A.; Jha, P.; Reddy, G.V.P. Multidimensional relationships of herbicides with insect-crop food webs. *Sci. Total Environ.* **2018**, *643*, 1522–1532. [CrossRef] [PubMed]
100. Zattara, E.E.; Aizen, M.A. Worldwide occurrence records suggest a global decline in bee species richness. *One Earth* **2021**, *4*, 114–123. [CrossRef]
101. Rands, S.A.; Whitney, H.M. Field margins, foraging distances and their impacts on nesting pollinator success. *PLoS ONE* **2011**, *6*, 2–5. [CrossRef]
102. Kampfraath, A.A.; Giesen, D.; van Gestel, C.A.M.; Le Lann, C. Pesticide stress on plants negatively affects parasitoid fitness through a bypass of their phytophage hosts. *Ecotoxicology* **2017**, *26*, 383–395. [CrossRef]
103. Norris, R.F.; Kogan, M. Interactions between weeds, arthropod pests, and their natural enemies in managed ecosystems. *Weed Sci.* **2000**, *48*, 94–158. [CrossRef]
104. Holland, J.M.; Luff, M.L. The effects of agricultural practices on Carabidae in temperate agroecosystems. *Integr. Pest Manag. Rev.* **2000**, *5*, 109–129. [CrossRef]

105. Pleasants, J.M.; Oberhauser, K.S. Milkweed loss in agricultural fields because of herbicide use: Effect on the monarch butterfly population. *Insect Conserv. Divers.* **2013**, *6*, 135–144. [CrossRef]
106. Resende-Silva, G.A.; Turchen, L.M.; Guedes, R.N.C.; Cutler, G.C. Imidacloprid soil drenches affect weight and functional response of spined soldier bug (Hemiptera: Pentatomidae). *J. Econ. Entomol.* **2019**, *112*, 558–564. [CrossRef] [PubMed]
107. Qi, B.; Gordon, G.; Gimme, W. Effects of neem-fed prey on the predacious insects *Harmonia conformis* (Boisduval) (Coleoptera; Coccinellidae) and *Mallada signatus* (Schneider) (Neuroptera: Chrysopidae). *Biol. Control* **2001**, *22*, 185–190. [CrossRef]
108. Scarpellini, J.R.; Andrade, D.J.d. The effect of insecticides on the lady beetle *Cycloneda sanguinea* L. (Coleoptera, Coccinellidae) and on the aphid *Aphis gossypii* Glover (Hemiptera, Aphididae) on cotton plants [Efeito de inseticidas sobrea *joaninha Cycloneda sanguinea* L. (Coleoptera, Coccinellidae) e sobre o pulgao *Aphis gossypii* Glover (Hemiptera, Aphididae) em algodoeiro]. *Arq. Inst. Biol.* **2011**, *78*, 393–399.
109. Gontijo, P.C.; Moscardini, V.F.; Michaud, J.P.; Carvalho, G.A. Non-target effects of two sunflower seed treatments on *Orius insidiosus* (Hemiptera: Anthocoridae). *Pest Manag. Sci.* **2015**, *71*, 515–522. [CrossRef] [PubMed]
110. Sánchez-Bayo, F.; Goulson, D.; Pennacchio, F.; Nazzi, F.; Goka, K.; Desneux, N. Are bee diseases linked to pesticides?—A brief review. *Environ. Int.* **2016**, *89*, 7–11. [CrossRef] [PubMed]
111. Tong, L.; Nieh, J.C.; Tosi, S. Combined nutritional stress and a new systemic pesticide (flupyradifurone, Sivanto®) reduce bee survival, food consumption, flight success, and thermoregulation. *Chemosphere* **2019**, *237*, 124408. [CrossRef] [PubMed]
112. Pettis, J.; van Engelsdorp, D.; Johnson, J.; Dively, G. Pesticide exposure in honey bees results in increased levels of the gut pathogen Nosema. *Naturwissenschaften Sci. Nat.* **2012**, *99*, 153–158. [CrossRef]
113. Rothman, J.A.; Russell, K.A.; Leger, L.; McFrederick, Q.S.; Graystock, P. The direct and indirect effects of environmental toxicants on the health of bumblebees and their microbiomes: Impact of toxicants on bumblebee health. *Proc. R. Soc. B* **2020**, *287*, 20200980. [CrossRef]
114. Alburaki, M.; Boutin, S.; Mercier, P.-L.; Loublier, Y.; Chagnon, M.; Derome, N. Neonicotinoid-coated *Zea mays* seeds indirectly affect honeybee performance and pathogen susceptibility in field trials. *PLoS ONE* **2015**, *10*, 12–15. [CrossRef]
115. Chandler, A.J.; Drummond, F.A.; Drummond, F.A.; Collins, J.A.; Lund, J.; Alnajjar, G. Exposure of the common eastern bumble bee, *Bombus impatiens* (Cresson), to sub-lethal doses of acetamiprid and propiconazole in wild blueberry. *J. Agric. Urban Entomol.* **2020**, *36*, 1–23. [CrossRef]
116. Herrick, N.J.; Cloyd, R.A. Direct and indirect effects of pesticides on the insidious flower bug (Hemiptera: Anthocoridae) under laboratory conditions. *J. Econ. Entomol.* **2017**, *110*, 931–940. [CrossRef] [PubMed]
117. Pozzebon, A.; Borgo, M.; Duso, C. The effects of fungicides on non-target mites can be mediated by plant pathogens. *Chemosphere* **2010**, *79*, 8–17. [CrossRef] [PubMed]
118. Potts, S.G.; Imperatriz Fonseca, V.; Ngo, H.T.; Biesmeijer, J.C.; Breeze, T.D.; Dicks, L.; Garibaldi, L.A.; Hill, R.; Settele, J.; Vanbergen, A.J. *Summary for Policymakers of the Assessment Report of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services on Pollinators, Pollination and Food Production*; IPBES: Bonn, Germany, 2016; Available online: https://ri.conicet.gov.ar/handle/11336/130568 (accessed on 4 February 2016).
119. World Health Organization. *The WHO Recommended Classification of Pesticides by Hazard and Guidelines to Classification 2019*; World Health Organization: Geneva, Switzerland, 2019; Available online: https://apps.who.int/iris/bitstream/handle/10665/332193/9789240005662-eng.pdf (accessed on 1 May 2020).
120. United Nations Environment Programme: Bees, Bans and Broad-Spectrum Pesticides. 2021. Available online: https://www.unep.org/news-and-stories/story/bees-bans-and-broad-spectrum-pesticides (accessed on 20 May 2021).
121. Birthal, P.; Sharma, O.; Kumar, S. Economics of integrated pest management: Evidences and issues. *Indian J. Agric. Econ.* **2000**, *55*, 644–659.
122. Ministry of Agriculture and Farmers Welfare. *The Gazette of India: Extraordinary*; PART II—Section 3—Sub-section (ii), No. 1351; Government of India: New Delhi, India, 2020; Available online: http://egazette.nic.in/WriteReadData/2020/219423.Pdf (accessed on 31 October 2023).
123. Bonvoisin, T.; Utyasheva, L.; Knipe, D.; Gunnell, D.; Eddleston, M. Suicide by pesticide poisoning in India: A review of pesticide regulations and their impact on suicide trends. *BMC Public Health* **2020**, *20*, 2–5. [CrossRef]
124. Government of Kerala. Substitutes for Pesticides Banned by Govt of Kerala Vide G.O. (MS) No. 116/2011/Agri Dated 7-5-2011. 2011. Available online: https://keralaagriculture.gov.in/wp-content/uploads/2019/01/go_and_circular/GO_MS_116_B.pdf (accessed on 16 May 2012).
125. Gunnell, D.; Fernando, R.; Hewagama, M.; Priyangika, W.D.; Konradsen, F.; Eddleston, M. The impact of pesticide regulations on suicide in Sri Lanka. *Int. J. Epidemiol.* **2007**, *36*, 1235–1242. [CrossRef]
126. Chang, S.S.; Lin, C.Y.; Lee, M.B.; Shen, L.J.; Gunnell, D.; Eddleston, M. The early impact of paraquat ban on suicide in Taiwan. *Clin. Toxicol.* **2021**, *6*, 131–135. [CrossRef]
127. Chowdhury, F.R.; Dewan, G.; Verma, V.R.; Knipe, D.W.; Isha, I.T.; Faiz, M.A.; Gunnell, D.J.; Eddleston, M. Bans of WHO Class I Pesticides in Bangladesh-suicide prevention without hampering agricultural output. *Int. J. Epidemiol.* **2018**, *47*, 175–184. [CrossRef] [PubMed]
128. Cha, E.S.; Chang, S.S.; Gunnell, D.; Eddleston, M.; Khang, Y.H.; Lee, W.J. Impact of paraquat regulation on suicide in South Korea. *Int. J. Epidemiol.* **2016**, *45*, 470–479. [CrossRef] [PubMed]

129. Krauss, J.; Gallenberger, I.; Steffan-Dewenter, I. Decreased functional diversity and biological pest control in conventional compared to organic crop fields. *PLoS ONE* **2011**, *6*, 5–9. [CrossRef]
130. European Parliament, Council of the European Union. Council Regulation 1107/2009. In: Concerning the Placing of Plant Protection Products on the Market and Repealing Council Directives 79/117/EEC and 91/414/EEC. 2009. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32009R1107 (accessed on 24 November 2009).
131. US Department of Agriculture. China: China Releases Regulations on Pesticide Management. Foreign Agricultural Service. 2017. Available online: https://www.fas.usda.gov/data/china-china-releases-regulations-pesticide-management (accessed on 28 April 2017).
132. Food and Agriculture Organization of the United Nations. *Progress in Pesticide Risk Assessment and Phasing-Out of Highly Hazardous Pesticides in Asia*; Food and Agriculture Organization of the United Nations: Bangkok, Thailand, 2015; Available online: http://www.fao.org/3/a-i4362e.pdf (accessed on 1 January 2015).
133. Pelaez, V.; da Silva, L.R.; Araujo, E.B. Regulation of pesticides: A comparative analysis. *Sci. Public Policy* **2013**, *40*, 644–656. [CrossRef]
134. Agência Nacional De Vigilância Sanitária (ANVISA). Regularização de Produtos—Agrotóxicos. Monografias Excluídas. Available online: http://portal.anvisa.gov.br/registros-e-autorizacoes/agrotoxicos/produtos/monografia-de-agrotoxicos/excluidas (accessed on 25 June 2018).
135. Hole, D.; Perkins, A.J.; Wilson, J.D.; Alexander, I.H.; Grice, P.V.; Evans, A.D. Does organic farming benefit biodiversity? *Biol. Cons.* **2005**, *122*, 113–130. [CrossRef]
136. United Nations. THE 17 GOALS | Sustainable Development. 2015. Available online: https://sdgs.un.org/goals (accessed on 3 March 2022).
137. van Swaay, C.; van Strien, A.; Harpke, A.; Fontaine, B.; Stefanescu, C.; Roy, D.; Kühn, E.; Õunap, E.; Švitra, G.; Prokofev, I.; et al. The European grassland butterfly indicator: 1990±2011. *EEA Tech. Rep.* **2013**, *11*, 1–34.
138. Seibold, S.; Gossner, M.M.; Simons, N.K.; Blüthgen, N.; Müller, J.; Ambarlı, D.; Ammer, C.; Bauhus, J.; Fischer, M.; Habel, J.C.; et al. Arthropod decline in grasslands and forests is associated with landscape-level drivers. *Nature* **2019**, *7*, 5–12. [CrossRef]
139. Noriega, J.A.; March-Salas, M.; Castillo, S.; García-Q, H.; Hortal, J.; Santos, A.M. Human perturbations reduce dung beetle diversity and dung removal ecosystem function. *Biotropica* **2021**, *53*, 753–766. [CrossRef]
140. Feldhaar, H.; Otti, O. Pollutants and their interaction with diseases of social Hymenoptera. *Insects* **2020**, *11*, 153. [CrossRef] [PubMed]
141. Geiger, F.; Bengtsson, J.; Berendse, F.; Weisser, W.W.; Emmerson, M.; Morales, M.B.; Ceryngier, P.; Liira, J.; Tscharntke, T.; Winqvist, C.; et al. Persistent negative effects of pesticides on biodiversity and biological control potential on European farmland. *Basic Appl. Ecol.* **2010**, *11*, 97–105. [CrossRef]
142. Fletcher Jr, R.J.; Didham, R.K.; Banks-Leite, C.; Barlow, J.; Ewers, R.M.; Rosindell, J.; Holt, R.D.; Gonzalez, A.; Pardini, R.; Damschen, E.I.; et al. Is habitat fragmentation good for biodiversity? *Biol. Conserv.* **2018**, *226*, 9–15. [CrossRef]
143. Cote, I.M.; Darling, E.S.; Brown, C.J. Interactions among ecosystem stressors and their importance in conservation. *Proc. R. Soc. B Biol. Sci.* **2016**, *283*, 20–25. [CrossRef]
144. Mulieri, P.R.; Migale, S.; Patitucci, L.D.; González, C.R.; Montemayor, S.I. Improving geographic distribution data for a putatively extinct species, a test case with a disappeared fly Improving geographic distribution data for a putatively extinct species, a test case with a disappeared fly. *An. Acad. Bras. Cienc.* **2022**, *94*, 7–13. [CrossRef]
145. Cardoso, P.; Barton, P.S.; Birkhofer, K.; Chichorro, F.; Deacon, C.; Fartmann, T.; Fukushima, C.S.; Gaigher, R.; Habel, J.C.; Hallmann, C.A.; et al. Scientists' warning to humanity on insect extinctions. *Biol. Conserv.* **2020**, *242*, 10–18. [CrossRef]
146. Myers, N.; Mittermeier, R.A.; Mittermeier, C.G.; Da Fonseca, G.A.; Kent, J. Biodiversity hotspots for conservation priorities. *Nature* **2000**, *403*, 853–858. [CrossRef]
147. Zwick, P. Phylogenetic system and zoogeography of the Plecoptera. *Ann. Rev. Entomol.* **2000**, *45*, 709–746. [CrossRef]
148. Kumela, T.; Simiyu, J.; Sisay, B.; Likhayo, P.; Mendesil, E.; Gohole, L.; Tefera, T. Farmers' knowledge, perceptions, and management practices of the new invasive pest, fall armyworm (*Spodoptera frugiperda*) in Ethiopia and Kenya. *Int. J. Pest Manag.* **2019**, *65*, 1–9. [CrossRef]
149. Smith, O.M.; Cohen, A.L.; Reganold, J.P.; Jones, M.S.; Orpet, R.J.; Taylor, J.M.; Thurman, J.H.; Cornell, K.A.; Olsson, R.L.; Ge, Y.; et al. Landscape context affects the sustainability of organic farming systems. *Proc Natl. Acad. Sci. USA* **2020**, *117*, 2870–2878. [CrossRef] [PubMed]
150. Winqvist, C.; Bengtsson, J.; Aavik, T.; Berendse, F.; Clement, L.W.; Eggers, S.; Fischer, C.; Flohre, A.; Geiger, F.; Liira, J.; et al. Mixed effects of organic farming and landscape complexity on farmland biodiversity and biological control potential across Europe. *J. Appl. Ecol.* **2011**, *48*, 570–579. [CrossRef]
151. Poolprasert, P.; Jongjitvimol, T. Arthropod communities inhabiting organic rice agroecosystem. In Proceedings of the International Conference on Agricultural, Ecological and Medical Sciences, London, UK, 3–4 July 2014; Volume 29, pp. 1–5.
152. Yuan, X.; Zhou, W.W.; Jiang, Y.D.; Yu, H.; Wu, S.Y.; Gao, Y.L.; Cheng, J.; Zhu, Z.R. Organic Regime Promotes Evenness of Natural Enemies and Planthopper Control in Paddy Fields. *Environ. Entomol.* **2019**, *48*, 318–325. [CrossRef] [PubMed]
153. Katayama, N.; Osada, Y.; Mashiko, M.; Baba, Y.G.; Tanaka, K.; Kusumoto, Y.; Okubo, S.; Ikeda, H.; Natuhara, Y. Organic farming and associated management practices benefit multiple wildlife taxa: A large-scale field study in rice paddy landscapes. *J. Appl. Ecol.* **2019**, *56*, 1970–1981. [CrossRef]

154. Nakanishi, K.; Uéda, T.; Yokomizo, H.; Hayashi, T.I. Effects of systemic insecticides on the population dynamics of the dragonfly *Sympetrum frequens* in Japan: Statistical analyses using field census data from 2009 to 2016. *Sci. Total Environ.* **2020**, *703*, 13–16. [CrossRef] [PubMed]
155. Meyling, N.V.; Navntoft, S.; Philipsen, H.; Thorup-Kristensen, K.; Eilenberg, J. Natural regulation of Delia radicum in organic cabbage production. *Agric. Ecosyst. Environ.* **2013**, *164*, 183–189. [CrossRef]
156. Reddy, B.T.; Giraddi, R.S. Diversity of Pest, Beneficial Arthropods and Other Non-Target Biota as Influenced by Degree of Pesticide Usage such as Indiscriminate, High, Moderate and Low Use Situations. *Int. J. Curr. Microbiol. Appl. Sci.* **2019**, *8*, 374–378. [CrossRef]
157. Senguttuvan, K. Biodiversity of arthropod fauna in Tamilnadu cabbage ecosystems. *J. Res. ANGRAU* **2018**, *46*, 1–14.
158. Tasser, E.; Rüdisser, J.; Plaikner, M.; Wezel, A.; Stöckli, S.; Vincent, A.; Nitsch, H.; Dubbert, M.; Moos, V.; Walde, J. A simple biodiversity assessment scheme supporting nature-friendly farm management. *Ecol. Ind.* **2019**, *107*, 10–15. [CrossRef]
159. Herzon, I.; Birge, T.; Allen, B.; Povellato, A.; Vanni, F.; Hart, K.; Radley, G.; Tucker, G.; Keenleyside, C.; Oppermann, R. Time to look for evidence: Results-based approach to biodiversity conservation on farmland in Europe. *Land Policy* **2018**, *71*, 347–354. [CrossRef]
160. Jabbar, A.; Wu, Q.; Peng, J.; Zhang, J.; Imran, A.; Yao, L. Synergies and determinants of sustainable intensification practices in Pakistan agriculture. *Land* **2020**, *9*, 110. [CrossRef]
161. Elhakeem, A.; van der Werf, W.; Ajal, J.; Luc'a, D.; Claus, S.; Vico, R.A.; Bastiaans, L. Cover crop mixtures result in a positive net biodiversity effect irrespective of seeding configuration. *Agric. Ecosyst. Environ.* **2019**, *285*, 10–27. [CrossRef]
162. Chateil, C.; Goldringer, I.; Tarallo, L.; Kerbiriou, C.; Le Viol, I.; Ponge, J.F.; Salmon, S.; Gachet, S.; Porcher, E. Crop genetic diversity benefits farmland biodiversity in cultivated fields, Agriculture. *Ecosyst. Environ.* **2013**, *171*, 25–32. [CrossRef]