Insects: biodiversity, threat status and conservation approaches

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Insects are an important component of the ecosystem and fast dwindling of its diversity is reported globally. The International Union for Conservation of Nature has assessed a total of 77,435 species of insects between 1996 and 2020, of which 18,180 (23.47%) species are reported to be threatened and the majority of threatened species was reported in Odonata followed by Orthoptera, Coleoptera, Lepidoptera and Hymenoptera. Out of 1843 species listed as critically endangered, endangered, extinct, extinct in wild and vulnerable, from the literature it was found that 596 are predators, 40 are pollinators, 164 are saprophagous, 620 are herbivores, 272 are omnivores, 137 are parasites and 14 are unknown. This study provides concise information on insect diversity, global threat status and major driving factors for population decline, which will be helpful in determining the priority insect groups that require conservation.

Keywords: Conservation approaches, ecological indicators, insect biodiversity, population decline, threatened species.

INSECTS are among the crucial components of several ecosystems, where they perform many important ecological services. They aerate the soil, pollinate flowering plants, act as predators, parasites and parasitoids to manage the insect pests, and act as plant pests[1,2]. Except for most saline and coldest locations on the earth, insects dominate compositional diversity in all other ecosystems[3]. Despite their diminutive size, they play a key role in maintaining natural balance. Insects are among the most ecologically connected species and they interact virtually with every component in the terrestrial and freshwater realms[4,5]. At the global level, a total of 1,552,319 reported species in the kingdom Animalia, phylum Arthropoda represent about 80% (1,241,855 species) of insects. They are the major group, constituting up to 66% (1,020,007 species) of all animals and 82% of arthropods on earth (Figure 1). The insects evolved around 400 million years ago during the Devonian period of the Palaeozoic era[6]. They have survived the last Cretaceous–Palaeogene extinction event (66 million years ago), including several glacial maxima and minima by adopting to temperature changes and to some extent, independent of plants[7,8]. Currently, we are in the middle of the sixth mass extinction, i.e. the Anthropocene. Several recent findings indicate that insect diversity is dwindling at a higher rate, with reports of decline in flying, ground and aquatic lineages being documented all across the world[9]. This is a major source of concern for humanity. Before planning conservation activities for any species, appraisal of the threat status over the years is important. This study thus intends to compile information on insect biodiversity and its global threat status.

Knowledge about the threat status of any species is a preliminary step in developing conservation strategies and taking preventative measures before it becomes extinct. At the global level, this activity is being carried out by the International Union for Conservation of Nature (IUCN), Gland, Switzerland, for all the four kingdoms, namely Animalia, Plantae, Fungi and Chromista, and it serves as a global standard for extinction risk assessment[10]. The IUCN Red List is the only available source to assess the threat status and extinction risk of species, which in turn helps prioritize conservation of important species[10], and plays a crucial role in generating public and policy support for species conservation[11]. The Red List process takes an intrinsic value approach, assuming all species are equal[12].

Method

Information related to the global threat status of insects was collected from IUCN as well as the published literature

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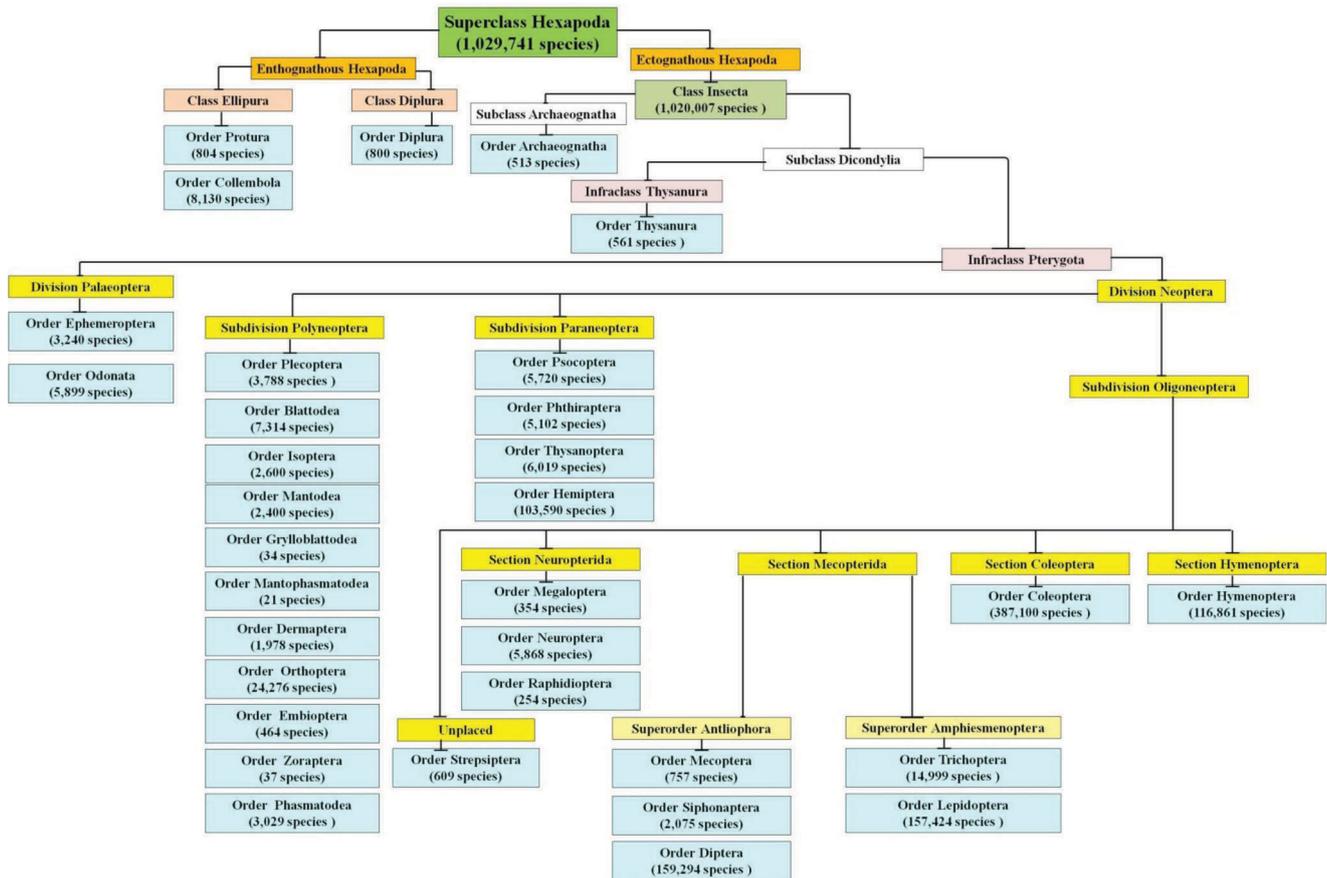
Figure 1. Representation of species richness of insects using Kristensen's classification. Values in parentheses represent the total number of species reported, including fossil species. Data obtained from Cranston and Gullan[71] and Zhang[72].

and reference therein on the species population decline using Google Scholar and other search engines. From the collected data, figures were prepared to depict the proportion of threatened species in different orders of class Insecta and the proportion of threatened species in different families of five major orders, viz. Odonata, Orthoptera, Coleoptera, Lepidoptera and Hymenoptera. Since class Insecta contains both beneficial and harmful insects, it was deemed important to determine the economic importance of a threatened species. Hence, with the available IUCN data on threatened species, an exercise was carried out to identify which category a particular species belonged to, elicited from a literature survey using the Google search engine for each species listed in IUCN. Accordingly, they were grouped as predator/pollinator/saprophagous/herbivore/omnivore/parasite (harmful) and unknown. Graphs were generated using MS Excel 2010. Figures were generated in Microsoft Office PowerPoint 2010.

By following the IUCN Red List, several successful conservation activities have been performed on plants and animals. Based on a comparison between consecutive assessments of British butterflies, the current IUCN criteria are considered a more valid assessment of extinction risk than earlier versions[13,14]. Each species in the IUCN system is classified as extinct (EX), extinct in the wild (EW), critically endangered (CR), endangered (EN), vulnerable (VU), near threatened (NT), least concern (LC) or data deficient (DD) based on quantitative criteria of extinction risk (Figure 2). The IUCN has conducted a global evaluation of threat status of insects since 1996, and its efforts to assess the threat status of insects from 1996 to 2020 revealed that the number of species has risen from 730 in 1996/1998 to 9425 in 2020 (Figure 3).

Proportion of threatened species in different orders of class Insecta

A total of 9425 insect species were assessed in the IUCN Red List Version 2020.2. Majority of the assessed species (4511 species) were classified as LC, followed by DD (2505). Likewise, 322 species were assessed as CR, 641 as EN, 585 as NT, 796 as VU, 61 as EX, 1 as EW and 3 as lower risk (LR) (Figure 4). The proportion of threatened species in different orders of class Insecta (CR, EN, VU and NT), revealed that the highest number of threatened species is in Odonata (702), followed by Orthoptera (677), Coleoptera (368), Lepidoptera (271) and Hymenoptera
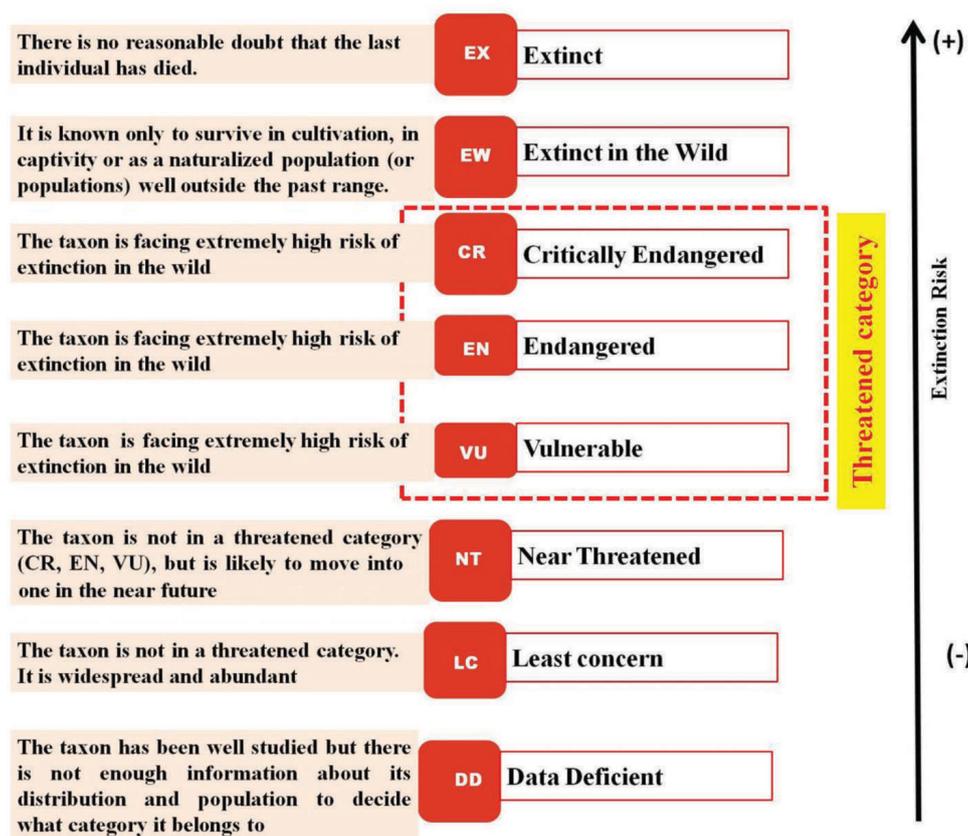
Figure 2. The International Union for Conservation of Nature (IUCN) threat categories and extinction risk.

(211), while rest of the orders had below 60 species (Figure 5). A total of 77,435 species of insects were assessed between 1996 and 2020, of which 18,180 (23.47%) species belonging to different insect orders were threatened.

Approximately, half of the Coleoptera and Lepidopteran species (both moths and butterflies) are declining at a fast rate of 2.1% and 1.8% respectively, than the annual average. In addition, to the efforts of IUCN, several regional assessments have been carried out by several scientific groups to assess the threat status of region-specific species. Long-term assessment of insect population trends suggests that many insects show a declining trend worldwide; however, there are several examples of increasing trend of insect abundance and diversity as well (Table 1). As presented in Table 1, there has been an 80% decline in opportunistic butterflies in the Netherlands from 1890 to 2017 (ref. 15), 83% decline in beetles over a 45-year period in USA[15], 50% decline in abundance of all forest-dependent orchid bees in England[16], and 60% decline in butterfly species from semi-natural grasslands. On the other hand, 86% of the butterfly species from open field margins have increased in Finland over a span of 50 years[17], but the overall butterfly population has declined by 56.20%. Likewise, 47.7% increase in dragonfly population has been documented in the Netherlands[15]. Figure 6 depicts the proportion of threatened species in different families

of five major orders, viz. Odonata, Orthoptera, Coleoptera, Lepidoptera and Hymenoptera (IUCN, 2020). Insects are one of the essential components of our planet, because of their diversity and ecological role, and impact on agriculture, human health and natural resources. Insects form the biological foundation for all terrestrial ecosystems. Despite their critical importance for the ultimate functioning and sustainability of ecosystems worldwide, for many years, insects have been systematically underrepresented in biodiversity and conservation studies[18–20]. Drivers of population decline in the above orders are discussed below.

Odonata

This is a group of relatively small insects comprising dragonflies (Anisoptera) and damselflies (Zygoptera) that majorly depend on water bodies for their naiad development. Odonatans are predaceous both during the naiad and adult stages, and play an important role in controlling mosquitoes and agricultural pests[21]. It has been documented that one in every ten species of dragonflies and damselflies is on the verge of extinction[22]. Habitat degradation has led to local extinction of the forktail damselfly, *Ischnura gemina* in Glen Canyon Park, San Francisco, California, USA[23]. Clausnitzer *et al.*[24] identified several

factors that contribute to the extinction of odonatans. These include deforestation, forest fragmentation, prolonged periods of hot and dry weather, desiccation of brooks and rivers and water pollution in and around forests. Furthermore, the Odonata is more vulnerable to climate change[25]. It has been reported that the local extinction rate of odonatans is higher in low-quality ecosystems than in high-quality habitats[22,24]. According to the IUCN Red List, 2020, different species of Odonata fall under various categories of threat status, e.g. CR – *Neurolestes nigeriensis* and *Archi-*

neura maxima; EN – *Acanthaeschna victoria* and *Caliphaea angka*; VU – *Amphicnemis ecornuta* and *Brachygonia puella*.

Orthoptera

This is a diverse group of insects that mainly comprise Caelifera (short-horned grasshoppers) and Ensifera (long-horned bushcrickets and crickets). Majority of the species do not cause any significant damage. Orthoptera has long been recognized as a strong indicator of land-use intensity[26]. Thus, they have established themselves as one of the most essential invertebrate groups for environmental monitoring and assessment[27]. Furthermore, they are a key food source for many birds and reptiles, and their extinction could have far-reaching consequences for entire ecosystems. Among the assessed families in the present study, nearly one-third of members of Acrididae and Tettigoniidae are at risk of extinction (Figure 5). Hochkirch *et al.*[28] documented that the intensification of agricultural land use encompassing overgrazing, conversion of grasslands and shrub lands to croplands, overgrowth of abandoned pastures, use of fertilizers and heavy machinery, frequent mowing and use of pesticides as well as degradation and fragmentation of grassland habitats are the main threats to the orthopteran species[29]. In addition, rising wildfires are decimating orthoptera populations. According to the IUCN Red List, 2020, different species of Orthoptera fall under various categories of threat status, viz. CR – *Gryllapterus tomentosus* and *Dericorys minutus*; EN – *Aerotegmina taitensis* and *Bradyporus macrogaster*; VU – *Bradyporus sureyai* and *Caconemobius howarthi*.

Coleoptera

This is another group of insects in the risk of extinction category. Several authors have reported habitat destruction
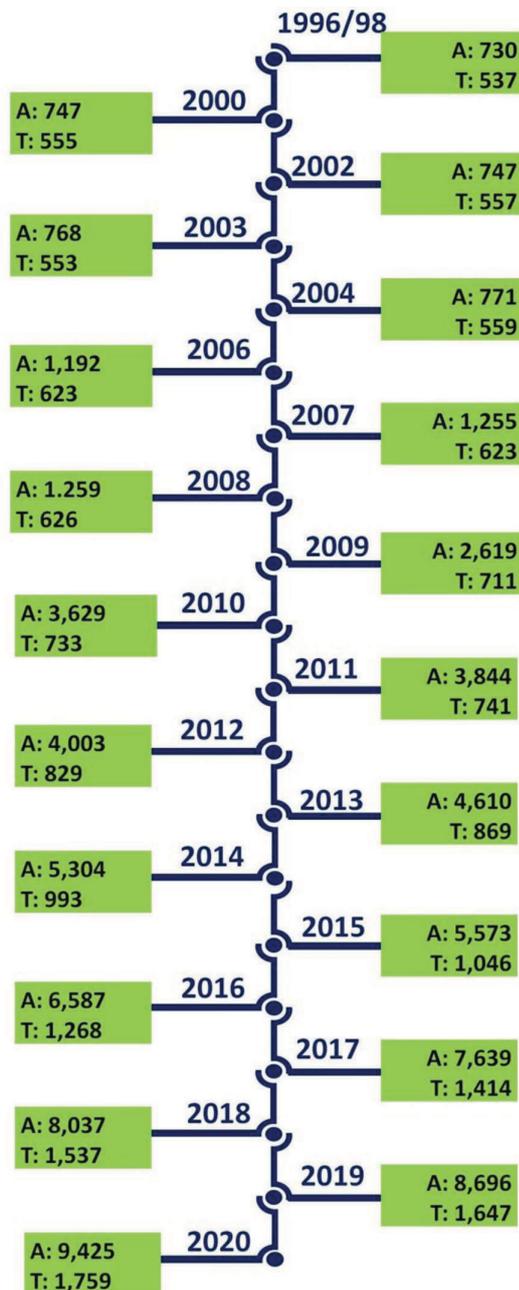
Figure 3. The efforts of IUCN towards assessment of threat status of insects from 1996 to 2020. A indicates the total number of species assessed, while T indicates threatened species such as endangered, critically endangered and vulnerable.
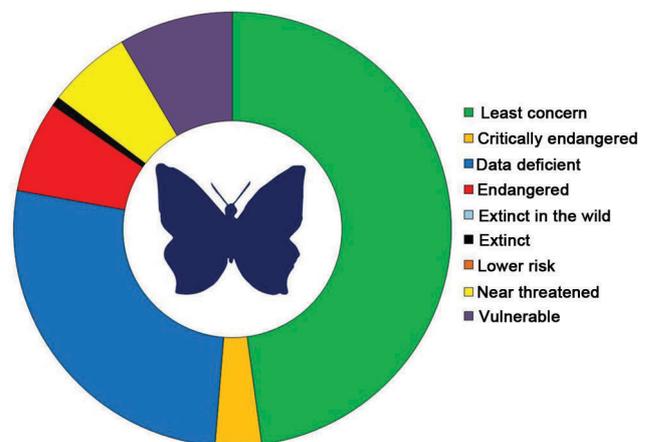
Figure 4. Status of insect species under different threat categories at the global level (Source: IUCN Red List of Threatened Species, Version 2020.1).

Table 1. Global reports on population trend in insects

| Insect species	Country	Observations	Reference
Butterflies	The Netherlands	84% decline in butterflies.	15
Butterflies	North Belgium	19 out of 64 indigenous butterfly species have become extinct and half of the remaining species are threatened.	49
Butterflies	Finland	Out of 74 butterfly species, 60% from semi-natural grasslands had declined.	17
Butterflies	UK	37% of the total insects were regionally extinct (RE) or threatened. Four species were listed as RE, 19 as threatened and 11 classified as near threatened.	13
German butterflies and burnet moths	Germany	Decline in the number of species from 117 in the year 1840 to 71 in 2013; most of these are endangered at present.	51
Butterflies	European Union	31% decline in species of European butterflies.	50
Butterflies	The Netherlands	Out of 63 species analysed, 29 (46%) had decreased in population or become extinct, 17 (27%) hardly changed their range.	52
Flying insects	Germany	There was a seasonal decline (March to October) of 76% and mid-summer decline of 82% in flying insect biomass over the 27 years of study.	9
Butterflies and dragonflies	The Netherlands	There was 56.20% decline in butterfly (51 species) population and 47.7% increase in dragonfly (57 species) population.	53
Bees	USA	Out of 187 native species analysed individually, only three declined steeply among genus *Bombus*.	54
Bees and hoverflies	Britain and the Netherlands	There was decline (pre- versus post-1980) in local bee diversity in both countries.	37
Carabid beetles	UK	Three-quarters of the species studied had declined in population, half of which was estimated to be undergoing population reduction of >30%, when averaged over a 10-year period.	55
Monarch butterflies	Mexico	The total annual area occupied by overwintering monarch butterflies from 1994 to 2011 had declined significantly, with the all-time smallest area reported during 2009–10 over wintering season.	56
Ladybird beetles	England	Three native ladybird species of England experienced a decline in population due to invasion of non-native ladybird beetle *Harmonia axyridis*.	57
Bees	USA	There was a loss of 50% of bee species population.	58
Bumble bees	USA	Relative abundances of four species had declined by up to 96%.	59
Roller dung beetles	Italy	Six species showed a significant decline, while two disappeared from majority of the northern regions of Italy.	60
Widespread and common macro-moths	UK	Two-third of the 337 widespread and common macro-moths species studied had declined over 35 years of study.	61
Common macro-moths	UK	The percentage of species displaying significant decreases (54) was more than double compared to those displaying an increase (22%).	62
Moths	Scotland	Moth abundance (based on 176 species) in Scotland decreased by 20% for 1975–2014 and by 46% for 1990–2014.	63
Ground beetles and tiger beetles	Europe	Carabid species of beetles of dry and poor grasslands and heath vegetation have decreased significantly in all the study areas.	64
Insects	Global	33% insects showed a declining trend with strong variation among orders Orthoptera > Coleoptera > Hymenoptera (Formicidae) > Lepidoptera > Odonata).	65
Butterflies	USA	Neonicotinoid application and land conversion WAS negatively associated with butterfly populations.	45
Butterflies	USA	High-elevation (altitude) butterfly communities had declined, especially those sensitive to dry years with warmer minimum temperatures.	66
Moths	European countries	Substantial decline in abundance and distribution of macro-moths was reported.	67
Butterflies	UK	70% (40 species) of the butterfly species declined in occurrence and 57% (32 species) declined in population.	68
Butterflies	Scotland and England	72% of butterfly species declined in abundance.	13
Butterflies	Great Britain	Out of 673 macro-moth species studied, 260 had declined significantly, whereas 160 had increased significantly.	69
Moths	Great Britain	The total abundance of larger moths declined by 28%, while 37% of the 337 species decreased by at least 50%.	18

(Contd)

Table 1. (*Contd*)

Insect species	Country	Observations	Reference
Bees	Costa Rica	Population of bees (large anthophorid bees and honey bees) visiting flowers of *Andira inermis* showed greatly reduced average abundance level of population per tree and reduced overall species diversity over time.	70
Butterflies and burnet moths	Germany	There was a substantial decline in the number of species from 117 in the year 1840 to 71 in 2013.	51
Butterflies	Belgium	19 out of 64 indigenous species had became extinct and half of the remaining species are threatened.	49
Bees	Brazil	There was 50% decline in abundance of all forest-dependent orchid bees (24 species).	16
Insects	Global	Over 40% of insect species are threatened with extinction. Lepidoptera, Hymenoptera and Coleoptera (dung beetles) are the taxa most affected.	25
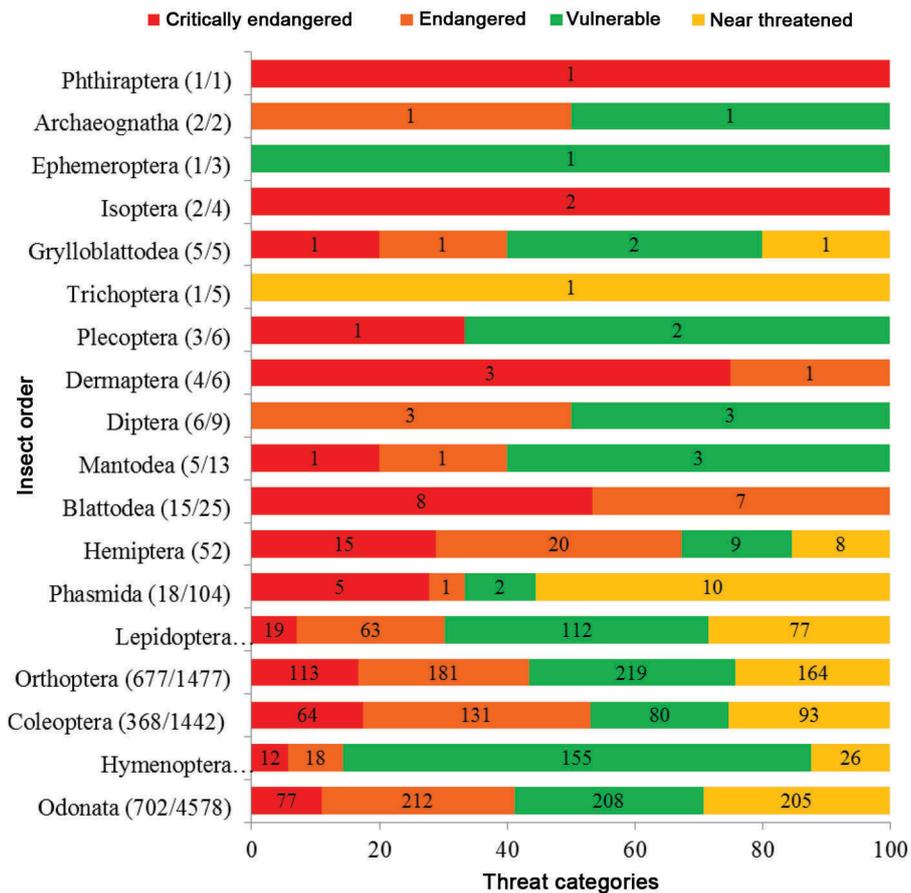
Figure 5. Proportion of threatened species in different orders of class Insecta (source: IUCN Red List of Threatened Species, Version 2020.1). Values in parentheses indicate the number of threatened species/the number of assessed species.

as the major factor contributing to the extinction of the coleopteran group[30,31]. A Review of the IUCN reports on threat category indicates that among the coleopterans, the highest number of scarabids (dung beetle) and cerambycids (longhorn beetles) are under threat (Figure 6). Dung beetles have a wide range of environmental benefits, including nutrient cycling, parasite control, carbon dioxide and methane reduction, soil aeration and secondary seed

dispersal[32]. They are also important in food webs because they serve as prey for birds, bats and other insectivorous animals as well as decomposers. However, conversion of grasslands into croplands, unsustainable farming, intense grazing and use of unauthorized veterinary medicine has led to loss of dung beetle diversity. Studies on these specialized beetles have been conducted only in the Mediterranean region, which has the most diverse dung beetle
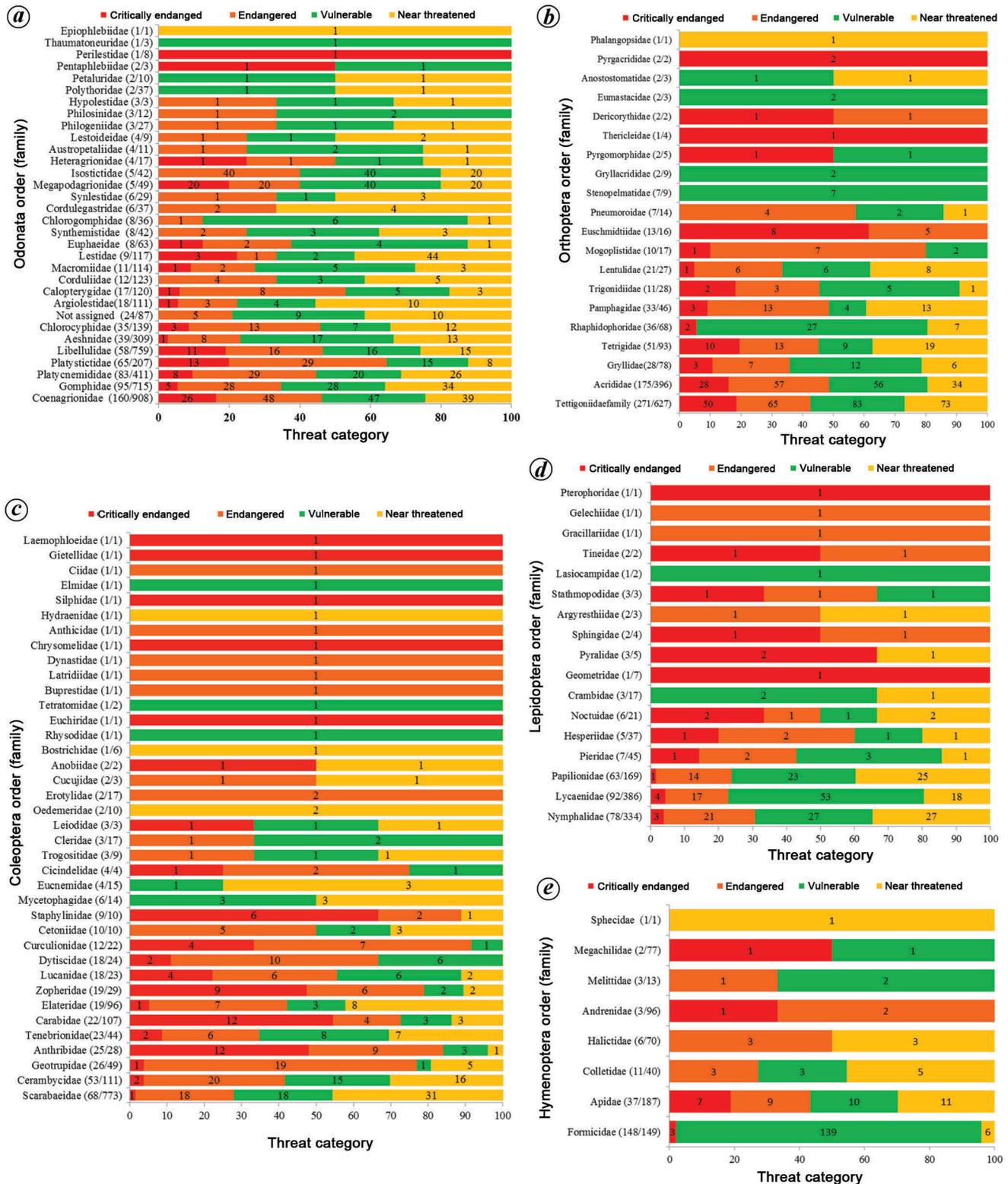
Figure 6. Proportion of threatened species in different families of five major orders: *a*, Odonata; *b*, Orthoptera; *c*, Coleoptera; *d*, Lepidoptera; *e*, Hymenoptera (source: IUCN Red List of Threatened Species, Version 2020.1). Values in parentheses indicate the number of threatened species/ the number of assessed species.

population in Europe[25]. It has been reported that dung beetles in the Mediterranean countries have suffered the greatest biodiversity loss among terrestrial taxa, with more than 60% of the species declining and a large proportion under threat. Numa *et al*.[33] reported that about 20% of the 200 dung beetle taxa had been threatened with

extinction, including 21 endemic species. They also identified overgrazing and livestock abandonment among the major threats for Mediterranean dung beetles[33]. According to IUCN Red List, 2020, different species of coleoptera fall under various categories of threat status, e.g. CR – *Cicindela albissima* and *Donus multifidus*; EN – *Thorectes chersinus* and *Triplax castanea*; VU, *Ateuchetus semipunctatus* and *Clypeodrepanus striatus*.

Hymenoptera

This is the third biggest insect order and perhaps the most beneficial to humankind among all insect orders[34]. Bees are important pollinators of flowering plants, accounting for one-third of all pollinators[35]. They have been exploited for millennia as a source of honey and beeswax. Nearly 90% of all wild flowering plant species rely, at least partially, on animal pollination services[35]. Also, 87 out of 115 staple food crops grown worldwide depend on biotic pollination, majorly on entomophily[36]. The analysis of threatened status revealed that a similar pattern of extinction can be observed in bees, where one in every six species has become regionally extinct[37]. Due to anthropogenic impacts, the current species extinction rate of pollinators is 100–1000 times higher than normal. Insects are projected to account for most future biodiversity loss, with 40% of invertebrate pollinator species, particularly bees and butterflies, facing extinction.

Among the hymenopterans, members of the Formicidae (ants) and Apidae (honey bees) are at a higher risk of extinction (Figure 6). Nemesio[16] reported a 50% decline in abundance of all forest-dependent orchid bees in England. Kwon *et al.*[38] reported habitat disturbance as one of the main causes for the decline in diversity of natural communities of ants. Graham *et al.*[39] reported that highly disturbed areas had fewer trees, diminished ground cover, warmer soils in summer and more compacted soils with a shallow A-horizon, which together contributed to lower species diversity of ants. Honey bees are the most altruistic insects, pollinating crops and contributing to crop production. However, since the advent of synthetic pesticides for pest control, honey-bee diversity and abundance have decreased[25]. Furthermore, more virulent parasites and pathogen infections in recent years[40], lack of genetic variability[41], agro-landscapes dominated by monocultures with low nutritional value[42] and harsh climatic conditions in recent decades are adversely influencing honey-bee diversity. Vertebrate pollinators (16.5%) are also threatened with extinction on a global scale, albeit to a lesser extent[43]. Several anthropogenic factors linked to loss of pollinator diversity include fragmentation and degradation of their habitats, especially changes in land-use patterns, use of pesticides, monocultures and intensive agricultural practices. In addition, climate change also has an adverse effect on hymenopterans. However, the fate of other pollinators, such as hoverflies, is largely unknown[44]. According to

IUCN Red List, 2020, different species of hymenoptera fall under various categories of threat status, e.g. CR – *Andrena labiatula* and *Bombus affinis*; EN – *Colletes merceti* and *Halictus microcardia*; VU – *Bombus mexicanus* and *Anergates atratulus*.

Lepidoptera

This comprises moths and butterflies and is the second largest group in class Insecta. Evaluation of the status of lepidopteran species shows that the butterfly subgroups, including Papilionidae, Lycaenidae and Nymphalidae, are at greater risk of extinction (Figure 6). According to van Strien *et al.*[15], opportunistic butterflies have declined by 80% in the Netherlands from 1890 to 2017. Also, 60% of the butterfly species from semi-natural grasslands have declined in England. On the other hand, Kuussaari *et al.*[17] reported an 86% increase in butterfly species from open field margin in Finland over 50 years. However, there has been a 56.20% decline in the overall butterfly population in their study region[17]. Warren *et al.*[14] observed that butterflies were declining faster in the United Kingdom, with 74% of 46 non-migratory butterflies limiting their distribution between 1970 and 1999. Several factors have been associated with the decrease in lepidopteran diversity, including habitat fragmentation and/or destruction, agricultural intensification and greater use of chemical fertilizers and pesticides[25]. Forister *et al.*[45] reported a negative association between butterfly populations and increasing neonicotinoid application in northern California, USA. According to the IUCN Red List, 2020, different species of lepidoptera fall under various categories of threat status, e.g. CR – *Lepidochrysops lotana* and *Phlogophora kruegeri*; EN – *Eurytides iphitas* and *Hipparchia christenseni*; VU – *Aegialia crescent* and *Amauris nossima*.

Grouping of threatened species into different categories based on feeding habit

Since class Hexapoda contains both beneficial and destructive insects, it is critical to determine whether a threatened species is beneficial or detrimental. Hence, with the available IUCN data on threatened species, an exercise was carried out to determine whether the IUCN listed insect species in the categories CE, ER, VR and EX are beneficial insects (saprophagous insects, pollinators, predators) or harmful insect species (parasites (NB), Omnivore, Herbivore). Based on the literature survey on each of these threat categories, insects were grouped into predator, pollinator, saprophagous, herbivore, omnivore, parasite (nonbeneficial) and unknown. Out of 1843 species listed as CR, EN, EX, EW and VU, 596 species were grouped as predators, 40 as pollinators, 164 as saprophagous, 620 as herbivores, 272 as omnivores, 137 as parasites (non-beneficial) and 14 as unknown (Figure 7). Predators and herbivores
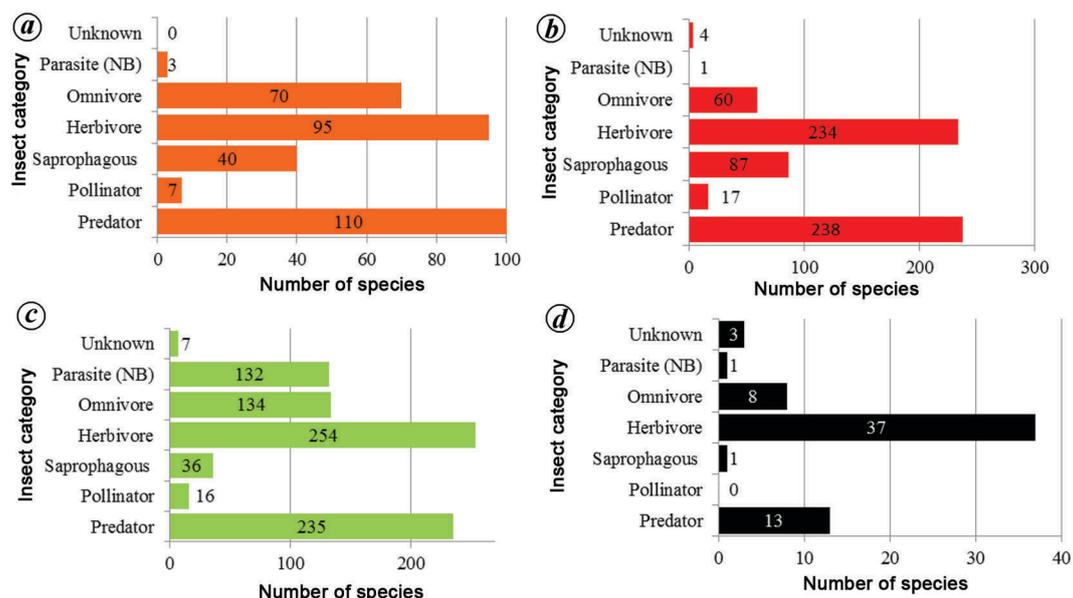
Figure 7. Number of species under different threat categories: (*a*) critically endangered, (*b*) endangered (*c*) vulnerable and (*d*) extinct based on different habits such as pollinator, predator, saprophagous, parasite (non-beneficial), omnivore, herbivore and unknown.

were more vulnerable to extinction among the various groups of insects studied (Figure 7). Harmon *et al.*[46] examined 62 historical aphidophagous coccinellids datasets from the US and Canada, spanning 1914 to 2004. According to surveys, the ladybird species richness and population sizes did not change much until 1986, when a dramatic reduction in the native species became apparent, affecting 68% of them over the ensuing 20 years[46]. The most likely reasons for the decline in predator diversity include habitat destruction, afforestation and introduction of foreign predatory beetles for managing insect pests infesting different crop ecosystems[47]. Honek *et al.*[48] reported that large-scale change in the cropping pattern and use of broad-spectrum insecticides reduced aphid number, which in turn reduced the population of the associated predators. Herbivores were more common in the threat category owing to their larger numbers. Urbanization and agricultural intensification have been mainly linked to the extinction of herbivores[49]. In addition, climate change has affected a few endemic species which are adapted to narrow ecological niche[50].

Conservation measures

The following conservation measures may be adopted to prevent the extinction of insects:

(1) Habitat restoration, combined with reduced agrochemical usage and agricultural 'redesign', is likely to be the most successful option, to prevent further decline, particularly in areas where intensive agriculture is practised.

(2) More efforts must be taken to estimate insect threat levels to formulate biodiversity policies in order to improve the status of threatened species.

(3) It is necessary to develop and implement conservation strategies for the insect species that are most at risk of extinction.

(4) Rethinking the present agricultural practices and creating awareness about the advantages of ecologically based practices and judicious use of pesticides.

(5) Need to reduce the contamination of water bodies by run-off and leaching of toxic chemicals, particularly pesticides.

(6) Conservation efforts focused on threatened insect species listed in the IUCN Red List must receive more financial support.

(7) The IUCN Red List of insects should be updated every 10 years or whenever new information becomes available.

(8) Forests should be treated as a valuable natural resource that requires immediate attention, so there will be no more deforestation.

(9) National and regional Governments must develop policies for preserving and recovering natural habitats, as well as implementing aggressive steps to cut greenhouse gas emissions and curb the deleterious effects of overexploitation of many taxa.

(10) The agriculture ecosystem, being most dynamic and unstable, remains a great threat to the loss of many agriculturally important insects, especially in annual crops. So, to minimize this and conserve such insects, entomophage parks must be developed by the public–private stakeholders.

(11) International organizations and authorities like the Convention on Biodiversity (CBD), International Plant Protection Convention (IPPC), and Sanitary and Phytosanitary (SPS) of the World Trade Organization should be linked to each other and with IUCN for better coordination and future course of action for the well-being of the environment and society.

Conclusion

Insect conservation has received considerably less attention than the conservation of plants and other animals. As ectotherms, insects are predicted to react differently to climate change than warm-blooded animals such as birds or mammals. This study highlights the poor state of insect biodiversity in the world. Over 30% of the insect species are on a decline, and one-third is endangered. The main causes of such a decrease are habitat change and pollution. The problem stems from the expansion of agriculture over the last six decades, while the widespread and unrelenting use of synthetic pesticides has been a key driver of decline in insect population in recent years. The conclusion is clear that unless we change our ways of producing food, pest management strategy and attitude toward ecological restoration, insect diversity will become extinct in a few decades. Hence, there is a need for raising awareness about the seriousness of the problem and the factors that contribute to the insect population decline, so that appropriate conservation measures can be prioritized and implemented.

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