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Early Warning, Emerging Issues and Futures

We are losing the "Little things that run the world"

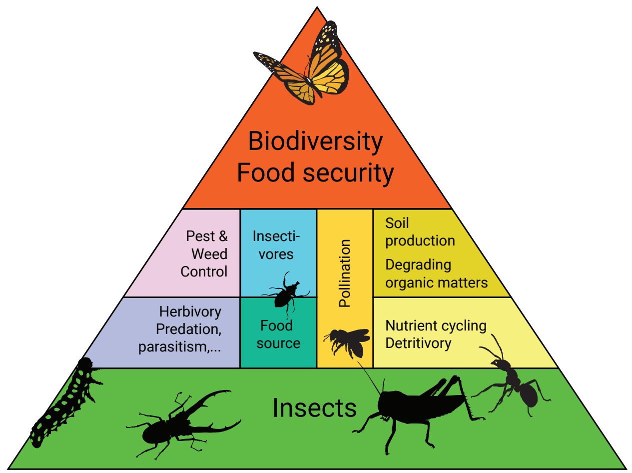
Abstract

Insects make up about half of all known living organisms. They play key roles in, pollination, nutrient cycling, food chains of birds and other insectivores, and are one of the pillars of our ecosystems. However, the wide use of insecticides, fragmentation of habitats and climate change are placing multiple threats on them and their populations are under sharp decline. This Foresight Brief explores insect services, threats and solutions to sustain insect populations.

Introduction

Insects have been embedded in terrestrial ecosystems for over 400 million years. They make up about half of all known living organisms and three quarters of the animal kingdom (Schoonhoven et al., 2005). They have been called 'the little things that run the world' (Wilson, 1987). There is no doubt that they constitute, by their abundance, diversity and adaptability, a crucial component of life on earth. They enable the maintenance and dynamic equilibrium of ecosystems through the services they provide, such as pollination (Öckinger & Smith, 2007; Ollerton et al., 2011), herbivory and detritivory (Mattson & Addy, 1975; Yang & Gratton, 2014), nutrient cycling (Yang & Gratton, 2014), pest control, and food source provision for birds, mammals and amphibians. Recognition of their importance for human beings is however largely restricted to scientists, environmentalists, and naturalists. The alarming and accelerating loss of insect species and their populations over recent decades (Dirzo et al., 2014) is barely registered by the general public and is of little concern to policy and decision makers who focus on immediate demands for food security, human health, and economic development. Given the recent and independent documentation of drastic reductions (over 75%) in insect biomass *within protected areas* (nature reserves) in Germany (Hallmann et al., 2017) and in a National Park Puerto Rico (Lister & Garcia, 2018) over the last 3-4 decades, this situation must change. Insect conservation has become an urgent issue.

Despite recent headlines in the press referring to an insect 'apocalypse' or 'Armageddon'[1], insect declines continue to attract insufficient attention, even within the conservation community. For example, in a recently published 353-page book on ecosystem services and poverty alleviation (Schrekenberg et al., 2018), insects, biocontrol of pests and pollinators are each mentioned only once, bees not at all. Yet food provision is crucially dependent on the ecosystem services provided by insects. Agriculture in its current form could not exist without insects. The tiny wasps and flies that are the invisible workers on every farm are seldom noticed, but they naturally control crop pests at no cost to us. Without them, crops would be devastated, livestock would be plagued, and dependence on agrochemicals, with all the associated environmental and financial costs, would be ruinous. To take just one example, the wasp (*Cotesia flavipes*) that was imported to East and Southern Africa to control the invasive Lepidoptera maize stem borer *Chilo partellus* in the 1990s is estimated to have saved the livelihoods of more than 130,000 rural farmers in the region. Cost benefit analysis suggests that the economic benefit over a 20-year period from this tiny wasp was 183 million dollars in Kenya (Kipkoech et al., 2006) and 39 million dollars in Zambia (Midingoyi et al., 2016), including savings on insecticides. More globally, over 75% of the world's 115 top crops benefit from pollination, accounting for 35% of food supplies (Klein et al., 2007). Gallai et al. (2009) estimate that insect pollination services to vegetables and fruits are worth 153 billion Euros a year. And without the insect life underground, nutrient recycling would stagnate, and soils would quickly become infertile.



Insects play fundamental roles in the ecosystems, so maintaining insect populations is essential.

The conservation of arthropod species cannot follow the same rules as vertebrate species. On the positive side, their higher levels of abundance and their capacity in terms of reproduction make them more resilient. It is clear from the studies of Hallmann et al. (2017) and Lister & Garcia (2018) that the current system of protected areas is failing to maintain viable populations of insect species. Equally, a focus on threatened species and the sites where they are found will not work as so few insects

[1] https://www.theguardian.com/environment/2018/jun/17/where-have-insects-gone-climate-change-population-decline; https://www.nytimes.com/2018/11/27/magazine/insect-apocalypse.html

have been assessed for their Red List status, and many of those that have been red-listed are living in non-protected semi-natural habitats (e.g. *Carabus* beetles, swallowtail butterflies, and the Spanish moon moth, *Graellsia isabellae* in Europe). Some species rely directly on the management of the ecosystems by human activity. For example, the survival of the Hermit beetle, a well-known European flagship species, is mainly based on the special treatment of their hosts, which are hollow trees (Audisio et al., 2007; Hilszczanski et al., 2014). Similarly, the traditional approach to animal conservation involving restrictions on hunting and wildlife trade is rarely effective. Neither the prohibition of collection nor the protection of large areas of natural ecosystems are sufficient measures for the conservation of species that are crucial in the functioning of the ecosystems on a global scale.

There is an urgent need for the development of innovative solutions to preserve insects and the ecosystems where they live. These solutions must be more broadly targeted at conserving insect diversity in general rather than at particular species that are recognized as being endangered, and they must be based on an understanding of the forces that are currently driving general declines in insect abundance and on the attendant consequences. This Foresight Brief aims to contribute to a wider recognition of the challenges involved.

Causes of insect decline

The causes of this insect decline have been attributed to human actions and to associated climate and global ecological changes (Dirzo et al., 2014; Hallmann et al., 2017; Lister & Garcia, 2018). Hallmann et al. (2017) placed responsibility for the decline on agricultural intensification (insecticides, microbial pesticides, herbicides, year-round tillage, increased use of fertilizers and agronomic measures). The introduction of neonicotinoids (neonics) in the United States and Europe in the mid-1990s has been particularly damaging, especially as they have been applied on a prophylactic basis (regardless of actual need) on seeds. Only 20% of the insecticide present in the coating of the seeds is taken up by the crop, so the remainder of this persistent neurotoxin accumulates in soils and water bodies (Simon-Delso et al., 2015). Neonics, together with fipronil are increasingly being recognized as the DDT of the early 21st century, with knock-on effects throughout the food chains, and they have been strongly implicated as adversely affecting bees and other pollinators. An International Task Force on Systemic Pesticides (TFSP) has been set up to conduct a world-wide integrated assessment of their effects. The conclusions of the TFSP are very clear: neonicotinoids are threatening not only biodiversity but also ecosystem services and public health (Pisa et al., 2017).

Insect declines have resulted not only from the intensification of agriculture but also from its expansion. The extension of areas devoted to agriculture (especially in monocultures) eliminates biodiversity, destroys natural habitats, and fragments landscapes, together with transport systems, industrial plants, urban expansion and rural settlements. Continent-wide light pollution is impacting on moths and other nocturnal insects. Fragmentation increases the risk of extinction in populations of limited dispersers due to the combined effects of reduced population size and increased isolation. Reduced levels of gene flow among small remnant insect populations decrease genetic variability, increasing inbreeding and genetic drift, and consequently reducing survival and reproductive success (Willis et al., 2007). Fragmentation also increases extinction risks as insects become trapped in habitats that are adversely affected by climate change. The current situation is therefore quite unlike that faced by beetles in the Pleistocene when continuity of habitat allowed insects to simply move in response to advancing and retreating ice sheets (Coope, 1994). Lister and Garcia (2018) attributed the reductions in insect biomass that they observed in Puerto Rico to climate warming (2.0°C increase over the past 30 years). Because the location in which they worked is an isolated fragment of what used to be continuous rain forest, recruitment of insects from adjacent areas is prevented and indigenous insects that suffer from climate change are lost within their deteriorating habitat.

Consequences: Why is this issue important?

Reducing the insect diversity of ecological systems makes them less prone to cope with invasive species (Zavaleta & Hulvey, 2004), weakens regulation of pest populations by natural enemies (Perfecto et al., 2004; Tscharntke et al., 2005; Tylianakis et al., 2007), disturbs pollination (Klein et al., 2007) and reduces biomass transformation and decomposition rates. All these processes make ecosystems less resilient.

This much is clear to biologists. In order to mobilize action, a case must be clearly stated for the ecological and economic importance of insects. Ecological concerns center on the multifarious roles that insects play in maintaining ecosystem functions and the consequences if these roles are undermined by insect losses and extinctions. Ecology and economics are inextricably linked, but for decision makers, the latter take precedence, so there has been considerable effort to determine what insects are worth in monetary terms for the welfare of humankind. This is not an easy question to answer, since many of the services that insects deliver are diffuse and not directly related to consumable deliveries. The answers that have been suggested vary widely, but, taken together, they point to a total global economic value for all insect services that amounts to thousands of billion dollars a year. One estimate for just four services from wild insects (domesticated species such as honeybees and silkworms excluded) and for the US alone places the annual figure at 57bn USD (Losey & Vaughan, 2006).

Ecological Concerns: *Trophic cascades*

Lister and Garcia (2018) report declines in the abundance and diversity of frogs and birds in Luquillo rainforest (a national park in Puerto Rico), that were correlated with insect losses, and they attribute the former to the latter. While direct evidence for this causal link was lacking, such impacts on other taxa are a logical and inevitable consequence of insect extinctions. Insectivorous taxa, particularly birds, are the most obvious victims (Hallmann et al., 2014; Rioux Paquette et al., 2014). The British Trust for Ornithology has documented drastic falls for swifts in Britain since 1994. Similar declines in swallows and starlings have also been noted. Narango et al. (2018) found that most insectivorous birds are now absent or declining in urban areas, a result that they attribute to invasive plants and reduced food supplies.

The risk of trophic extinction cascades, both bottom-up and top-down, is real (Dirzo et al., 2014). Sanders et al. (2018) demonstrated secondary extinctions of other species in a field experiment following the harvesting of a parasitoid wasp, and showed that the probability of such extinctions was lower in complex communities because of trophic redundancy. The authors concluded that biodiversity losses "leading to a reduction in redundant interactions, can increase the vulnerability of ecosystems to secondary extinctions, which, when they occur, can then lead to further simplification and run-away extinction cascades". As Ehrlich and Walker (1998) concluded: 'A policy of trying to increase or at least to maintain redundancy in ecosystems will maximize the maintenance of ecosystem resilience'. Given the scale and extent of insect losses already recorded, the protection from trophic redundancy is being eroded. The danger of run-away trophic extinction cascades needs to be further investigated and closely monitored.

Ecological concerns: *Loss of endemic species in critically endangered ecosystems*

Although the most immediate pragmatic consequences of insect losses relate to their economic values, the extinction of endemic species remains a concern. For example, the highlands of Cameroon on the Cameroon Volcanic Line host many endemic species (Bergl et al., 2007). These highlands comprise submontane and montane forests, and patches of savannah. Several endemic insects specialized to the savannah ecosystems have been described, such as the grasshopper *Eyprepocnemis montana* (Mestre & Chiffaud, 2009), only known from the original specimens, or the extremely rare *Ophryodera pseudorusticana* on the Bamboutos Mountain (Werner, 2000). Due to severe deforestation for the production of potatoes, it has been difficult to discover places where they still occur. Three years of active research revealed a remnant of the original savannah with a maximum area of 10,000 m^2 at an altitude of around 1000 m. asl. A second patch was found near the Kovifem forest at 2000 m. asl. These patches are found on top of a rocky area with a maximum area of 25,000 m^2. They host several endemic grasshoppers, and one flower beetle (Cetoniidae) (Muafor et al., 2010), which is probably new to science. These remnants show the importance of small patches of preserved ecosystems. If the two savannahs described here disappear, endemic insects of high- altitude savannah ecosystems will be lost.

Ecological and economic concerns: *Loss of ecosystem services*

Insects do not just provide food for other organisms; they provide additional critical links in maintaining ecosystem functions and services. Most attention to date has focused on pollination. A recent review of pollination services (IPBES, 2016), based on almost 3,000 scientific publications, concluded "that 75% of our food crops and nearly 90% of wild flowering plants depend at least to some extent on animal pollination and that a high diversity of wild pollinators is critical to pollination even when managed bees are present in high numbers". The IPBES assessment provides a detailed review of global estimates for the total economic value of pollination services to agriculture. These range from 160bn to 689bn USD per year, using 5 different methods, and standardized as 2015 USD values. As IPBES notes, they are calculated for the most overtly consumable benefits of pollination; they exclude those that flow from the pollination of 87.5% of wild flowering plants. The great majority of all pollinators are insects, and most insect pollinators are bees (over 20,000 species worldwide). The decline of "wild" bees and other pollinators may be an even more alarming threat to natural ecosystems and crop yields than the loss of honeybees (Garibaldi et al.,

An overview of the Bamboutos mountains showing the extension of agriculture (Photo P. Le Gall).

The last remnant of natural savannahs at Kovifem (North West Cameroon)(Photo P. Le Gall).

The impact of anthropization at Kovifem: the anarchic development of ferns (Photo P. Le Gall).

2013). Other pollinators include flies (especially hover flies), with butterflies, moths, beetles, wasps, thrips, and ants playing lesser roles. If insect pollination services are substantially damaged, there will be severe impacts on agricultural economies and food security. Aizen et al. (2009) project that world global crop production would fall by 3–8% in the absence of pollinators, intensifying demand for agricultural land. A decline in pollinator abundance will also be detrimental to wild plant species (Kluser et al., 2010). There could be another wave of run-away extinction cascades resulting from reduced seed set in wild flowering plants.

Unlike pollination, other ecosystem services (control of pests and invasives, decomposition and nutrient cycling, maintenance of soil structure and fertility) provided by insects are often difficult to link directly to consumables, and are therefore harder to evaluate in global monetary terms. Their effects are diffuse and can only be gauged in exceptional cases where the absence of the service in question has been sufficiently serious to warrant a concerted response. Examples include the control of alien invasive species such as *Chilo partellus* (referred to above) and the cassava mealybug (*Phenacoccus manihoti*). This cassava pest threatened the livelihoods of 200 million rural farmers in Africa in the 1980s, though it was virtually unknown in its native South America where it was controlled by (among others) an encyrtid wasp (*Epidinocarsis lopezi*). The African introduction of this wasp led to benefits estimated over 40 years at 8-37 billion dollars (Alene et al., 2005).

Overall, invasive species are estimated to cost the global economy 1.4 trillion USD a year (Pimentel et al., 2001). Classical biological control, involving the mass rearing and release into the new areas of natural enemies (most often insects) from their host countries is frequently the best and often the only solution. It has been applied to invasive weeds as well as to crop pests. The invasive water hyacinth, *Eichhornia crassipes* (Pontederiaceae) in Africa has been controlled since 1991 through regular releases of South American insects, the weevils *Neochetina eichhorniae* and *N. bruchi* (Col: Curculionidae), and the moth *Sameodes albiguttalis* (Lepidoptera: Pyralidae) (Neuenschwander et al., 1996; Wilson et al., 2007). These particular examples shed selective light on what is only a small portion of the overall value of natural biocontrols, estimated by DeBach (1974) to be effective against 99% of potential pests. As insect diversity and abundance are reduced on a global scale it will be become increasingly difficult to identify, locate and breed biocontrol species for emerging pests.

The single most pervasive service provided by insects, and possibly the most undervalued, is their role in developing and maintaining soil structure and fertility. They decompose plant and animal detritus, transforming biomass and releasing nutrients that sustain plant growth, preventing dung accumulation and attendant livestock pest problems, improving soil structure, reducing nitrogen losses from erosion and volatility, and increasing soil carbon and water storage (Mattson & Addy, 1975; Yang & Gratton, 2014). Losey & Vaughan (2006) estimate that the services provided in the US by dung beetles amount to 380 million USD per year.

In Australia, where the native beetles were unable to cope with the dung produced by introduced livestock, the introduction of just one species of deep-burying dung beetle is estimated to have improved pasture production by 30% (Doube, 2008). Dung beetles are but a small component of all the insect taxa that enable the rapid and effective recycling of nutrients, and animal dung is a minor component of all the organic inputs into this ecosystem process. Other relevant insect taxa include beetles, termites, ants, flies, cockroaches and springtails, and other organic inputs include vast amounts of dead plant and animal tissues.

The total economic value of insect contributions to this most vital of all ecological functions is beyond calculation. It is unlikely that it is under current threat, given the amount of redundancy involved in the dynamics of decomposition, but it is also evident that the use should be avoided of any persistent insecticide that accumulates in soils.

A surprising conclusion in Losey & Vaughan's valuation of insect benefits in the US was that the insect-dependent value of recreation (fishing, hunting and bird watching) exceeded all the other three services (dung removal, pollination and pest control) considered: it contributed 49.93bn of the total estimate of 57.75bn USD. The US is probably a special case in this respect. More globally, a live butterfly exhibit industry has been established in the last 40 years, valued in the early nineties at 100 million USD a year (Parsons, 1992), and a large deadstock trade exists for a wide range of insects, particularly for butterflies and beetles.

Despite global and largely undocumented declines in butterflies, there is no evidence that the butterfly exhibit industry is suffering from a shortage of livestock supplies, but the deadstock trade creates perverse pressures on rare species that are in demand by collectors and it is capable of driving selected species to extinction. In some cases (notably birdwing butterflies) this danger is offset by captive breeding and ranching.

What has/is being done? Four examples

Research on ecological intensification

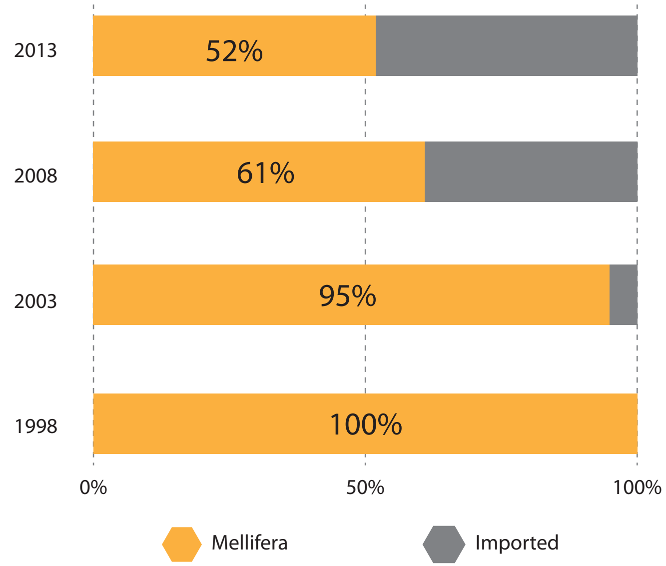
Garibaldi et al. (2016) have demonstrated that crop yields could be increased by planting flower strips and hedgerows, providing nesting resources, more targeted use of pesticides, and/or restoration of adjacent semi-natural and natural areas. This ecological intensification exploits synergies between agriculture and biodiversity. In particular, it increases pollinator diversity. The authors used standardized protocols to document effects on crop yields of enriching flower visitation rates across 344 fields from 33 pollinator-dependent crop systems in small and large farms from Africa, Asia, and Latin America. For fields less than 2 hectares, yield gaps were closed by a median of 24% through higher flower-visitor density. For larger fields, such benefits only occurred at high flower-visitor richness. These findings show that the retention and establishment of natural habitats, at small but widespread scales, will not only benefit ecosystem services but also improve food provision and the livelihoods of poor farmers across the South.

Development of insect conservatories

The black bee (*Apis mellifera mellifera*) is a subspecies of the European honey bee *Apis mellifera*. Its natural distribution ranges cover a large part of the West Mediterranean from the Pyrenees to Scandinavia. It has colonized this area for nearly a million years and survived two glaciations (Ruttner, 1988; Garnery et al., 1992; Arias & Sheppard, 1996). This native bee has a distinctive genome (Garnery et al., 1998 a,b; Munoz et al., 2015, Pinto et al., 2014) that is adapted to the western European climate. Beekeeping developed in a traditional way until the last four decades and the diversity of natural populations had not been affected. During the last 20 years, however, efforts were made to rationalize beekeeping. Renowned, wrongly, as more aggressive and less productive than other subspecies of bees, the black honey bee was gradually abandoned by professional and amateur beekeepers who favoured the use of hybrids or other supposed highly productive honey bee subspecies.

The recent worldwide honey bee decline (causes reviewed in Van Engelsdorp & Meixner, 2010) has caused much concern. Colony losses have increased from 5-10% in the 90s to 25-30%. These losses have accelerated the honey bee trade in order to restore honeybee livestock, allowing the massive importation of exotic bees throughout the range of the black bee. Global queen and colony trade has also spread pathogen strains and bee parasites (Munoz et al., 2014; Wilfert et al., 2016). Because honey bee reproduction remains mainly natural, the forced interbreeding between these imported “exotic” bees and the black bee leads to erosion of its genetic heritage, to the detriment of the hardiness, climatic and geographical adaptations necessary for the natural maintenance of its natural diversity. The survival and maintenance of *Apis mellifera mellifera* in the wild is extremely compromised. There has been an unprecedented decline leading to its disappearance from some European countries. In response a number of black bee conservatories have been established in France.

The black bee (Apis mellifera mellifera) (Photo L. Garnery).



Increase of imported bees over 15 years in France relative to the population of the local black bee (L. Garnery).

French black bees conservatories (source: http://www.abeille-noire.org/liste-des-conservatoires.html).

Photos of different French black bee conservatories at Rochefort-en-Yvelines (France) (high) and la Claye (Yvelines, France)(down) (Photos L. Garnery).

Butterfly exhibits

Displays of wild butterflies flying freely in a contained environment have become established throughout the world, providing significant opportunities for ecotourism and for promoting insect conservation. They also contribute directly to conservation through the financial incentives they provide to rural farmers to maintain insect habitats in the tropics. These farmers rear butterflies and export the pupae to the butterfly exhibit industry which need a constant supply of livestock to maintain their attractiveness to visitors.

The linkage to conservation is explicit in cases where butterfly farms are deliberately established to build local support for threatened habitats with high biodiversity values. An example is Kipepeo project (Gordon & Ayiemba, 2003), where community-based butterfly farming was set up by Nature Kenya and the National Museums of Kenya to reduce local hostility to Arabuko-Sokoke, a forest which has been ranked as the second most important for bird conservation in mainland Africa. The reasons for hostility will be familiar to any conservationist working with the legacy of state-controlled forests in the developing world: poverty, resource-denial, wildlife crop-raiding, and hunger for land. Kipepeo was started in 1993 on a Global Environment Facility Small Grant of 50,000 USD. It has proved sustainable and has earned almost 2 million dollars to date. More importantly from a conservation perspective, together with other initiatives, it has changed local attitudes: a recent attempt to explore for oil in the forest was blocked by community protests[2].

The Task Force on Systematic Pesticides

In the 1960s, Rachel Carson in her Silent Spring raised awareness of the devastating impact of DDT on insect populations (Carson, 1962) which led to the setting up of an International Task Force on Systematic Pesticides. This led to the ban of DDT in USA in 1972, which subsequently initiated the Stockholm convention on Persistent Organic Pollutants (POPs). In 2009, a group of entomologists and ornithologists met in Notre Dame de Londres (a small village in France) to discuss shared concerns on the effects of a new generation of insecticides (neonicotinoids and fipronil) that had been introduced in the early 1990s. They concluded that this introduction was the probable cause of a sharp acceleration in what had hitherto been a gradual decline in the abundance of insects and insectivorous birds. They released a declaration entitled ‘No Silent Spring Again’ which led to the setting up of an International Task Force on Systematic Insecticides (TFSP). In the last 9 years the TFSP has examined over 1,100 scientific peer-reviewed papers and has published two sets of Worldwide Integrated Assessments (WIA) on its findings (WIA1: Bijleveld et al., 2015; Van der Sluijs et al., 2015; WIA 2: Giorio et al., 2017; Pisa et al., 2017; Furlan et al., 2018).

A third assessment is underway looking at impacts on human and mammalian health. The conclusions of the TFSP are unequivocal and have led to restrictions on the use of neonicotinoids in Europe and their outright ban in France and on the island on Marinduque in the Philippines. The ban on Marinduque was mandated because of the importance of this island’s exports to the butterfly exhibit industry.

Ecological Networks

Ecological Networks (ENs) are “interconnected conservation corridors of high-quality habitat used to mitigate the adverse effects of landscape fragmentation and to connect with protected areas” (Samways, 2007; Samways & Pryke, 2016). The EN concept has been successfully applied in forestry plantation landscapes in South Africa and is increasingly recognized as a conservation tool for increasing the resilience of natural ecosystems, particularly in the context of climate change. It has proved to be particularly well suited to the conservation of small organisms such as insects, where corridors of as little as 200 m in width can make a significant difference to connectivity and ecosystem resilience.

[2] https://africageographic.com/blog/forest-saved-as- community-says-no-to-oil/

What needs to be done?

Strengthen the capacity for insect taxonomy. There is constantly dwindling capacity to identify insect species and biological organisms in general, termed as "taxonomic impediment" (Coleman, 2015). For many taxa there are no or too few specialists, especially for megadiverse ecosystems (Paknia et al., 2015). Even a group such as African grasshoppers, which was well covered between 1960 and 1980, is now poorly studied, with a shortage of expert taxonomists in the field. The problem is worse for other taxa of lesser economic importance. Without proper insect identification we cannot determine insect diversity in a given area and we are unable to quantify if it is increasing or decreasing.

Revive, support and initiate insect monitoring programs. The recent publications of Lister and Garcia (2018) on declines in insect biomass within protected areas are like the ears of the hippo: they signal unseen dangers. Only a few countries (those with a rich tradition of natural history) have long term monitoring data on insect numbers and diversity. Entomologists in Africa (and elsewhere in the world) are painfully aware that insects are disappearing but they have little data to demonstrate the losses. Regional insect research organizations such as the International Centre of Insect Physiology and Ecology (icipe) in Nairobi should be supported to review historical data and to initiate strategically appropriate and systematic long-term monitoring programs. This action is needed not only to assess recent trends and the current situation, but also to track and evaluate impacts of future efforts to address the problem of insect decline.

Traditional hive in Oku in the Kilum Ijim forest (Photo P. Le Gall).

Intensify research on the drivers of insect decline and on the use and environmental impacts of pesticides and herbicides. Currently we can only list possible causes; we are unable to rigorously assess their relative importance on any scale, whether global, national, regional or local. We cannot initiate counter measures to conserve insects if we don't know what is responsible for their decline. Insecticides are clearly a major concern. The efforts of the TFSP and other initiatives on the issue of pesticides need support to ensure that policy on agrochemicals is informed by the best possible scientific evidence.

Support innovative methods of pest control that do not rely on agrochemicals. History has demonstrated that economic returns on successful biocontrol efforts can be massive. We are also on the cusp of new genetic technologies that could selectively control pest species and make pesticides redundant. Any perceived dangers of such methods must be assessed against the benefits that would accrue from reduced insecticide use. We are also on the cusp of new genetic technologies that could selectively control pest species and make pesticides redundant. Any perceived dangers of such methods must be assessed against the benefits that would accrue from reduced insecticide use.

Dorcasomus evani, another forest endemic species of West altitudinal zone of Cameroon described in 2017 (Photo. P. Le Gall).

Support research on climate change impacts on insects and connectivity. We need a better understanding of the impacts of climate change on insect physiology and phenology. We also need a better understanding on the challenges and opportunities in using ecological networks to maintain and improve connectivity and resilience. Without connectivity, insects that are trapped in habitats with deteriorating climatic conditions are doomed to local extinction.

Improve public understanding of insect values. Insects generally get bad press and many people, especially in urban areas, regard them with distaste. There are exceptions: butterflies and dragonflies are loved because of their aesthetic appeal, and bees are increasingly viewed as useful because of the value of bee products, their association with flowers and summer, and an increasing knowledge of their importance for pollination. We need to build on these positive perceptions and use them to instill awareness of our dependence on insects for life on earth and our own welfare. This message needs to be built into school curricula throughout the world.

Corynotrichius bicolor, endemic species of altitudinal zones of Cameroon (Photo P. Le Gall).

What are the implications for policies?

Insect species should receive greater consideration on national or regional Red List of endangered species (Goergen et al., 2011). Very few African species of arthropods are considered in the CITES appendices listing the endangered or threaten species, apart from three species of the scorpions from the genus *Pandinus* and the South African stag-beetles genus *Colophon* listed in the appendix II. However, listing insects under CITES has had mixed impacts. In Papua New Guinea, while it may protect some birdwing butterfly species, it also hinders potential trade in some species that could be appropriately farmed.

Policies for insect conservation need to be different from those applied to plant and vertebrate species. The ability of insects to spread and to occupy niches in largely man-made ecosystems implies that policies for the conservation of insect species cannot depend only on highly preserved natural ecosystems. Further, trade can be a useful tool in conserving insect habitats (Gordon & Ayiemba, 2003; Hutton & Leader-Williams, 2003).

Oku Mountain: one of the last afromountain forest in Cameroon and a "village" where 100,000 people are living.

Protea madiensis, a savannah shrub from mountain ecosystems of West Cameroon (Photo P. Le Gall).

In some cases, there is a strong link between insect trade (for foreign collectors, for local or foreign insect consumers) and the livelihoods of poor rural communities. Living on forest insects, especially by collecting and breeding them for export, can incentivize local conservation efforts.

The International Task Force on Systemic Pesticides has concluded that the consequences of losing the invertebrate fauna due to continuous exposure to ubiquitous residues of neonicotinoids [and fipronil] are … far reaching and cannot be ignored any longer". New regulations to restrict their use should be put in place urgently, as France has done totally, and EU partially. Policies should be put in place that encourage environmentally friendly alternatives to pesticides.

Environmental and agricultural policies need to recognize the positive economic values of natural habitats, ecological intensification, ecological networks, and insect conservatories, and to introduce incentives for their application in landscape management.

What can be done by individuals!

People are frequently considering insects bad such as the mosquitoes, the wasps and pests which destroy their crops. Many of them are good for human welfare: e.g. the bees, bumble bees, butterflies for pollination and lady birds, parasitoids etc. as natural enemies for controlling crop pests. There are different reasons why we need to conserve them. Among them, the most important reason is that our own survival and our economy depend on many of the insect's species that live around us.

Although different organizations are now involved in insect's conservation and different nature reserves and other areas are protecting wildlife, this is still not enough to conserve all the insect's species which currently exist, and individuals can contribute on that. Here is a list of different advices for the general public on how they can support insect's population:

- Retain unimproved grassland and prioritize native plants as much as possible;
- Maintain as much as possible hedgerows with different flowering species; Maintain flowers in the gardens;
- Maintain dead woods which constitute an important habitat for many insect's species (alternatively use insect hotel sells in the commerce);
- Avoid the use of synthetic insecticides (there are a lot of other less armful alternatives to control pest insects e.g. botanical pesticides) but also avoid an intensive use of microbial insecticides that can reproduce and last forever, versus chemical pesticides that decay in the environment.

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