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How should conservationists respond to pesticides as a driver of biodiversity loss in agroecosystems?

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ABSTRACT

Conservation biologists should seek to work with those involved in sustainable agriculture and rural development in expanded integrated approaches to reduce pesticide harm to humans, biodiversity and environmental services. Despite new evidence, conservation organisations have tended not to fully recognize the impacts of pesticides on biodiversity, and current conservation strategies pay little heed to addressing this threat. A comprehensive suite of strategies are required to reduce and rationalize pesticide use and mitigate risks to species conservation. This paper proposes six steps for conservationists to address pesticide problems: (1) revisit the *land sparing* versus *land sharing* debate and include the external impacts of agriculture as vital components in systematic conservation planning; (2) redefine narratives on *intensive* agriculture and support emerging forms of sustainable intensification; (3) focus and inform on improved delivery mechanisms and monitoring legal use to achieve better pesticide targeting and a major reduction in volumes used; (4) support efforts to reduce wastage and inefficiency in the food system by promoting technical changes and informed consumer choice; (5) design and encourage resilient temperate and tropical landscapes that minimise pesticide contamination on farms and at landscape scale; and (6) develop comprehensive policy responses to promote both better alternatives to synthetic pesticides and limit the use of the most harmful pesticides.

1. Introduction: re-emergence of an under-estimated driver of biodiversity loss

The last two decades have seen growing concern that many pesticides, particularly the insecticides known as neonicotinoids, are harming pollinators such as domesticated and wild bees (Goulson et al., 2015). Evidence has emerged that ecological damage may extend far beyond bees. In 2015 the IUCN report *Worldwide Integrated Assessment of the Impacts of Systemic Pesticides on Biodiversity and Ecosystems* (van Lexmond et al., 2015), authored by 29 independent scientists, synthesised over a thousand peer reviewed studies and concluded that systemic pesticides have serious negative impacts on pollinators and other terrestrial and aquatic invertebrates, amphibians and birds, and on ecosystem functioning and services (Chagnon et al., 2015). Soon afterwards, the European Academies Environmental Science Council published another comprehensive review reaching broadly similar conclusions (EASAC, 2015).

In 2016, the Intergovernmental Science-Policy Platform on Biodiversity (IPBES) published the results of a two-year study on pollinators. IPBES estimated the annual value of crops directly affected by pollinators as US$235–577 billion, and that over 40% of invertebrate pollinators were facing extinction, with neonicotinoid pesticides among the important factors threatening pollinators worldwide (IPBES, 2016).

These findings highlight wider concerns that the adverse environmental impacts of pesticides (which include insecticides, molluscicides, herbicides and fungicides) have tended to be under-estimated, particularly in the tropics, (Costantini, 2015), as have the substantial external economic costs of pesticides worldwide to both human health and ecosystem services (Pretty and Bharucha, 2015). Evidence has been

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building of serious biodiversity declines (Mason et al., 2013) caused by a range of insecticides (Luzardo et al., 2014) and herbicides (Chiron et al., 2014) often acting in combination with other stressors (Goulson et al., 2015). Pesticides with long half lives, the occurrence of spray drift or a combination of both can also adversely impact biodiversity in protected areas (Martín-López et al., 2011).

The joint work of IUCN, EASAC and IPBES help to explain why biodiversity continues to decline in modern farmed landscapes, even in Europe where habitat loss and poaching pressure have largely been halted, and where there is considerable investment in agri-environment schemes intended to increase biodiversity (Donald et al., 2006). Negative impacts of pesticides on non-target organisms have important economic considerations, for example, by contributing to the global decline of pollinators (Goulson et al., 2015). In parts of China, farmers are now pollinating plants by hand in order to provide a surrogate for the loss of pollination ecosystem services (Partap and Ya, 2012).

Until recently there has been a tendency for many conservation practitioners to assume that the most serious pesticide problems have been addressed with the banning of most organochloride and organophosphate insecticides. For example, while pesticides were a constant feature of resolutions at IUCN's World Conservation Congress until 1990, they virtually disappeared for 20 years until the formation of the task force on systemic pesticides in 2012 (www.tfsp.info), which advises the IUCN Commissions on Ecosystem Management (CEM) and Species Survival (SSC). Annual horizon scans of conservation biology priorities have not mentioned pesticides for over ten years (e.g. Sutherland et al., 2015), nor did a survey of 100 pressing questions for conservation biologists (Sutherland et al., 2009) and work on pesticides by agricultural scientists does not generally focus on impacts on wild biodiversity (Pretty and Bharucha, 2015). Historic impacts of organochlorine and organophosphate pesticides are acknowledged, but impacted species mostly recovered following the ban on pesticide compounds such as DDT (e.g., Ambrose et al., 2016). Continued biodiversity loss has been linked more generally to resource-intensive models of development and consumption, invasive species, nitrogen pollution, and climate change (Butchart et al., 2010); where agriculture is highlighted the focus tends to be on land use change and general intensification (Maxwell et al., 2016). While recognizing the critical importance of all these factors, we argue that the role of pesticides in driving biodiversity loss also deserves renewed emphasis, quantification and amelioration.

One common response to scientific evidence of serious ecological impacts from a pesticide is to consider a ban. However, there are considerable challenges to achieving this; the agrochemical industry is influential and well-organised to argue for the role of pesticides to protect crops against pests, diseases and weeds. The European Union's initial two year restrictions on using some systemic pesticides on plants that bees are likely to visit reached a stalemate in the European Parliament, resulting in the European Commission exercising its right, and imposing a restriction. Pesticide manufacturers challenged the decision in court and some governments remain openly critical of the Commission's decision (McGrath, 2014).Many farmers perceive themselves to be reliant to varying extents on currently available pesticides and restrictions need to be aligned with effective and practicable alternatives. Moreover, agroecological alternatives such as Integrated Pest Management are knowledge-intensive, and need effective extension and support services to mobilize new techniques, train farmers and provide ongoing support (Pretty and Bharucha, 2015).

Many compounds have been used for years after serious health and environmental problems were identified, particularly in developing countries (e.g. Sherwood and Paredes, 2014). Continued efforts to ban certain active ingredients, strengthen regulatory frameworks and improve the application of existing laws are important. But while withdrawal of compounds that pose the highest risk is one solution, efforts to address all pesticide externalities need to be situated within a wider strategic framework for biodiversity conservation, not least to avoid this scenario being re-enacted into the future with new generations of pesticides. We suggest six strategies that conservationists should consider to address biodiversity loss from pesticides. None of these steps are new. However, some have been largely ignored by the conservation community, while others have been subject to intense debate, which is influenced by a renewed focus on pesticide risks.

2. Revisit the *sharing* versus *sparing* debate

New evidence of pesticide impacts puts a fresh slant on a continuing debate. Rising human populations and changing consumption patterns mean that natural ecosystems will likely continue to be converted to agriculture (Harvey and Pilgrim, 2010). Conservation biologists disagree about the best way to respond. Some argue for *land sparing*, where agriculture is intensified and concentrated into as small an area as possible, leaving maximum space for conservation, while others argue for *land sharing*, de-intensifying agriculture, or intensifying production through more environmentally benign approaches (Bommarco et al., 2013), to increase biodiversity on farmland and reduce impacts on non-farmed areas (Fischer et al., 2008). A variety of shades of opinion exist between; most land sparing advocates stress the need to minimise detrimental off-farm impacts and there are many efforts to find an optimal mix between sharing and sparing (e.g., Kremen, 2015).

The land sparing argument assumes that land not used for agriculture is generally unaffected by agriculture and that intensification reduces the need for more land to be converted to agriculture. But the offsite impacts of agriculture, as evidenced by data on systemic pesticides, have now been recognized as greater than often assumed, and the impacts of pesticides on non-target species shown to be influenced by landscape context (Park et al., 2015). Research also suggests that intensification does not necessarily reduce the area under agriculture, or even slow the rate of agricultural expansion, particularly if there are strong market drivers (Byerlee et al., 2014). While new understanding of pesticide impacts does not provide a decisive answer to the sharing or sparing debate, future discussions need to recognize that agricultural impacts extend beyond land clearing (Matson and Vitousek, 2006); failure to do so has contributed to the current crisis. Greater efforts are needed to mitigate offsite impacts as factors in systematic conservation planning, developing new tools to help if necessary.

3. Redefine what *intensive* means in agriculture and support and fund emerging forms of sustainable agriculture

Pretty and Bharucha (2015) calculate that 50% of all pesticides are not necessary for agricultural benefit (drawing on data from 85 projects in 24 countries). The sharing or sparing debate focuses on distinguishing “intensive” from “extensive”, whereas the real issues should be about types of intensification (Tscharntke et al., 2012). A variety of agroecologically-based intensification strategies allow for ‘wildlife friendly’ farming, particularly for smallholders in developing countries who experience declines in biodiversity and food security (Pretty and Bharucha, 2014).

The concept of “sustainable intensification” is gaining traction (Pretty and Bharucha, 2014), including application of Integrated Pest Management (IPM) approaches on many millions of farms. In 2009 the European Parliament introduced a directive (2009/128/EC) for achieving sustainable pesticide use, which provides a comprehensive framework for reducing pesticide use and obliges Member States to encourage farmers to adopt IPM or organic methods, including through provision of capacity building material (http://eur-lex.europa.eu/legal-content/en/ALL/?uri=CELEX:32009L0128). Evidence on IPM shows that higher yields can be achieved with reductions in pesticide use (Pretty and Bharucha, 2015), intra-specific crop diversity can be used to manage pests (e.g., Bommarco et al., 2013; Ssekandi et al., 2016), and efficient agriculture does not require the adoption of large-scale monocultures (Mulumba et al., 2012). Resource-conserving agriculture can be highly efficient, as can small-scale, labour-intensive, lower external-input farming systems, frequently leading to higher yields than conventional systems (Pretty, 2008). Yet, there is comparatively little investment in research into lower external-input systems, and they remain undervalued. This is due in part to opposition from vested interests and poor understanding of comparative externalities and the productivity of small farms, leading to lack of support in trade and agricultural policies (De Schutter and Vanloqueran, 2011). Calculations of agricultural efficiency that include net nutritional benefits, offsite impacts and water/energy use, alongside productivity per area, will give a clearer picture of costs and benefits. Extension approaches such as Farmer Field Schools, promoting education, co-learning and experiential learning can help to reduce wasteful and unnecessary use of pesticides (Waddington et al., 2014).

Organic agriculture is a concrete example of sustainable intensification. There are already over 43 million hectares of organic agriculture production worldwide, with a further 35 million hectares of natural or semi-natural areas used for collection of "wild" organically certified products such as honey and some herbs (Willer and Lernoud, 2015). Global sales of organic produce were already worth USD 72 billion in 2013 and are predicted to double that by 2018 (Reaganold and Wachter, 2016). Organic farming focuses on sustainability; reducing soil loss and boosting soil organic matter, increasing on-farm biodiversity and using less energy (Gomiero et al., 2011). A recent meta-analysis shows that in some conditions organic agriculture comes close to matching conventional agriculture in terms of yields, while in other cases at present it does not (Seufert et al., 2012). Until recently, organic agriculture has tended to work with single crop varieties, managing the agronomic system around them, rather than using diverse crop varieties within an organic system; as greater crop varietal diversity is slowly introduced this is also to some extent substituting for pesticides, further increasing the efficiency of the system (Jarvis et al., 2016).

Conservationists need to understand and support lower external input, high diversity farming, integrating such approaches into landscape-scale conservation and promoting them to policy-makers.

4. Focus on improved delivery mechanisms, rationalisation and efficient, legal use of pesticides

The impacts of pesticides are magnified because many farmers use them inefficiently (Skevas and Lansink, 2014); without understanding side effects (Banerjee et al., 2014); becoming "locked in" to an increasing cycle of use (Wilson and Tisdell, 2001); and continuing to use banned products (Ruiz-Suárez et al., 2015). Further, much spray technology remains relatively crude, resulting in both drift and wastage through release of large droplets. Sprayer technology, spraying processes (height and angle) and droplet characteristics all influence the chances of spray drift occurring (Al Heidary et al., 2014). Improved technologies and methods can dramatically reduce pesticide volumes (e.g., Zhao et al., 2014) and drift to natural habitats, and thus off-site impacts and total toxic load. Improved spraying efficiencies also benefit farmer's incomes. Yet despite technical improvements going back decades, uptake remains low (Matthews, 2014).

Public funding for research has been reduced, on the basis that pesticide companies should pay. Sales of pesticides continue to rise (Pretty and Bharucha, 2015), demonstrating a successful market, and companies have little incentive to invest in systems that would reduce their sales. There is nonetheless an urgent need for an international initiative to increase pesticide efficiency and rationalize use: assembling existing knowledge, providing effective capacity building, commissioning new research and addressing legal loopholes that foster deliberate misuse (Centner, 2014). A key element in this is improvement in the equipment for applying chemicals and adequate training in their use. Such efforts needs to be coordinated with, but remain independent from, businesses involved in manufacturing and distributing pesticides.

It is also unclear whether all pesticide applications are necessary; farmers often rely heavily on advice from agrochemical companies or their agents, frequently because independent advice is not available to them (Brooks et al., 2015). As an example, the US Environmental Protection Agency concluded in 2014 that applications of neonicotinoid seed dressings to soya bean provide "limited to no benefit", yet they were being widely used at a cost to farmers of $176 million per annum (calculated from EPA, 2014). Other long-term studies published recently suggest that past and current applications of insecticides to maize in Italy and elsewhere in Europe are often unnecessary and unprofitable (Furlan et al., 2016a, 2016b). There is nonetheless little publicly available research demonstrating the cost-effectiveness of most pesticide applications. If unnecessary applications could be identified and excluded, this would provide an immediate benefit to farmers, consumers and the environment (Brooks et al., 2015).

Outside of the agrochemical industry, conservation organisations could help by exposing illegal use, and lobbying for more effective legal controls, more effective equipment that reduces negative effects, investment into independent research looking at both more efficient and rationalized pesticide use, and sustainable alternatives.

5. Support efforts to reduce wastage and inefficiency in the food system

Another way of reducing pesticide use is to reduce the volume of food produced. Consumption of food, fuel, fibre and feed continues to rise globally. High consumption is exacerbated by food waste, with estimates varying from a third to half of all food wasted globally (Bajželj et al., 2014). This over-consumption has knock-on effects on requirements for land, water, energy and pesticide compounds. Consumption of intensively-raised meat is critically important because of the inefficiencies involved, and the large areas of intensively grown crops such as soya needed to provide feed (Foresight, 2011), which increases net pesticide usage. Even a slight reduction in average meat consumption would have a wide range of beneficial impacts in terms of environment and food security (McMichael et al., 2007), including a reduction in pesticide use. There are a variety of alternative livestock systems that are low-impact, particularly grass-fed management intensive rotational grazing systems (Pretty and Bharucha, 2014).

Analysts point to the resource-impossibility of the global population consuming at industrialized country levels of diet and food waste, and the importance of reducing both waste and intensively-reared meat consumption (Dogliotti et al., 2014). Many larger conservation organisations have so far remained timid about tackling consumption, and the role pesticides, antibiotics and hormones play in intensive meat-systems (Sumpter and Johnson, 2005). But alliances among conservation, health, social welfare and development bodies, aimed at increased efficiency of food use and improved diets, would simultaneously provide major gains for both food security and biodiversity conservation.

6. Support the design of resilient temperate and tropical landscapes

Conservation organisations have a role to play in supporting planning processes that take better account of contamination pathways, sensitive habitats, species-rich areas and human communities could help to contain and limit contamination from pesticides. This includes maintaining a diversity of farmed and natural areas; addressing agricultural impacts (of agrochemicals, water use and land erosion) within broad-scale conservation planning; increasing crop varietal diversity and avoiding large-scale planting of single crop cultivars; and promoting on-farm efforts to reduce impacts on biodiversity including by maintaining diversity of farmed components (Jarvis et al., 2011). Effective buffering of sprayed areas can, for instance, reduce impacts on the environment and biodiversity (Aguiar et al., 2015).

While the significance of the agricultural matrix is well understood in temperate regions, in many subtropical and tropical countries the introduction of large-scale agriculture is a relatively recent phenomenon (Attwood et al., 2009). Here, conservation strategies have so far focused largely on prevention of land clearing. In recent years there has been an increasing recognition of the influence of the agricultural matrix in frontier agricultural regions in driving ecological processes such as landscape permeability (Kennedy et al., 2011), the utilisation of agricultural habitats in subtropical and tropical countries by a range of threatened species (Wright et al., 2012); and the impacts of agricultural intensification on remaining natural habitats. Landscape approaches are therefore needed in both tropical and temperate environments.

The relative importance of landscape or site-scale approaches differs among groups, with for example sessile plants more responsive to site scale actions while mobile vertebrates require greater landscape complexity (Gonthier et al., 2014). Nonetheless, the basic techniques are already understood; the task now is to introduce them into farming as a matter of course, rather than as exceptional, voluntary practice.

7. Develop comprehensive policy responses

The assumption that pesticides are no longer a primary conservation problem can no longer be justified. A global policy for pesticide reduction and more efficient and safer use is an urgent conservation priority; and should be coordinated by an agency with international reach, such as IUCN, CBD or UNEP, with involvement of a wide range of stakeholders. It is now an imperative for independent conservation and development organisations, donor agencies and international institutions to drive the innovations for development of sustainable production systems that will help deliver the Sustainable Development Goals (e.g. goal 12.4). This should include the withdrawal of the most harmful pesticides and a radical, evidence-based reduction in application volumes of the remainder. Bringing such thinking into mainstream conservation policy is now an urgent priority: it will benefit biodiversity as well as farmers and consumers.

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