Pesticide environmental indicators and the need to minimise uncertainty

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Environmental indicators are invaluable for assessing the progress made over time towards environmental objectives. They help to provide insight into specific aspects of the environment or human health and are used extensively within policy to help establish priorities, evaluate environmental policy implementation and for assessing compliance with international commitments. However, indicators are a huge simplification of reality and have faced significant criticism for not accounting for uncertainties as well as their, often, arbitrary nature. Uncertainties are often unavoidable arising from the natural data variation, data gaps and inherent assumptions made in the data generation and selection. Whilst some of these issues can be overcome by using more complex environmental models and sophisticated environmental impact methodologies, a common issue relating to the acquisition of quality data remains.

This issue can be clearly illustrated with pesticide indicators. Pesticides play a significant role in delivering quality, plentiful food and food security generally but are also associated with potential risks to human health, biodiversity and the wider environment. Therefore, a key challenge for policy makers and other stakeholders is the development of tools to adequately characterise these risks and to support the development of sound, evidence-based policies. Over the last two decades numerous pesticide indicators have been developed for this purpose and tend to be used as a proxy measure of environmental risk. Some of the simplest are based on quantity of active substance used whilst others are more complex composite indicators that attempt to combine usage information with chemical data relating to environmental fate, transport and (eco)toxicity[1,2,3].

One of the more successful composite indicators is the Danish Pesticide Load Indicator[4,5] (PLI). Within the Danish PLI, a pesticide load is calculated for three sub-indicators (human health, environmental fate, and ecotoxicity) based on scores allocated to specific fate and (eco)toxicological parameters within each sub-indicator and expressed as the load per unit of commercial product (e.g. litre, kilogram, standard dose). More recently, the Danish PLI has been amended to better suit the needs of the UK[6,7]. The UK PLI consists of 16 ecotoxicity and 4 fate metrics (which are not aggregated) and is now being used as the basis of a national target to reduce pesticide load by at least 10% between 2018 and 2030[8]. Other frequently used composite indicators include the Environmental Impact Quotient[9] (EIQ) which has been developed to provide growers with data regarding the environmental and health impacts of their pesticide options so they can make better-informed decisions regarding pesticide selection. The pesticide occupational and environmental risk[10] (POCER) indicator, based on Annex VI of the European Directive 91/414/EC, is also well established and considers the risk arising from occupational, non-dietary exposure and the risk to the environment. More recently the Total Applied Toxicity (TAT) indictor and its associated aggregated version (ATAT) have emerged[11,12]. The TAT is similar to the PLI, integrating the total amount of applied pesticides, weighted by a measure of their individual (eco)toxicities.

All these types of indicators rely on large amounts of data related to, for example, the amount applied, the physico-chemical properties of the pesticide, data that describes how the pesticide disperses in the environment and its toxicity to humans and biodiversity. The latter may well cover multiple different terrestrial and aquatic species. An indicator for a single pesticide may need 15 different

parameters or more. The problem is that not only are there hundreds of different pesticides in active use globally (each having a unique dataset) but also that the data is scattered throughout numerous online and offline resources and is inherently variable in nature (for example ecotoxicity data will vary according to species, sub-species, gender, and life stage). Indicators and risk assessment approaches are constantly developing and expanding with respect to the data needed, new data is constantly being generated and so it is imperative that data resources are regularly maintained. However, few of the available resources are actively maintained and updated. There are often significant data gaps to be managed, and data quality is not always known. Consequently, uncertainty can be very significant and if not properly understood and managed can lead to flawed decision making. As uncertainty is almost impossible to avoid completely (as all indicators are simplifications of reality), it is important to understand and minimise additional uncertainty introduced from the data used in their calculation.

Regardless of what form the composite indicator takes, data on the quantity of pesticide applied in each country will be needed. The availability of this data is inherently down to national policy and priorities. Some countries have strict reporting requirements, for example Denmark, Japan, USA and Australia, whilst others use a survey approach such as the UK, Canada and New Zealand, and apply statistical techniques to provide estimates of national usage. Yet other countries have no reporting requirements whatsoever (e.g. India, Brazil and Nigeria) and so might use pesticide sales as a surrogate for usage. Consequently, there will be inherent and potentially significant uncertainty in usage data. Whilst, it is possible to determine uncertainty in the statistical estimation of national usage, as is done in the UK PLI, there is rarely much potential to improve usage data availability especially in the short term and without policy impetus.

Each indicator and each application thereof, inevitably, uses a unique dataset comprised from various, often undisclosed sources. If the indicator is applied in an identical manner, temporally, for a specific country or study then the uncertainty will remain relatively constant and so not be a huge issue, provided it is interpreted appropriately. However, there are various activities ongoing where such indicators are being proposed for monitoring, comparing and contrasting pesticide use internationally and so there is potential for different countries to collate and manage data differently.

As an example, it is currently anticipated that the ATAT will be used for the Headline Indicator 7.2 currently being developed for the monitoring framework of the Kunming-Montreal Global Biodiversity Framework for the Convention on Biological Diversity (CBD). This has an overall commitment to achieve a 50% reduction in pesticide use globally by 2030 based on the ATAT. The intention is that each country calculates the indicator and reports the national value back to the United Nations for comparison and monitoring purposes. The ATAT utilises Regulatory Threshold Level (RTL) values as a measure of ecotoxicity. A pesticide RTL is an exposure level above which adverse effects are observed in (eco)toxicological studies, and below which adverse effects are not expected to occur. In other words, the worst case ecotoxicity value for a particular species group (e.g. fish, birds, terrestrial arthropods etc.) is used. Ideally, this would be a chronic toxicity threshold such as the NOEL or NOEC but often these data are not available so acute toxicity data (e.g. LC50, LD50, ER50) is used together with a (somewhat arbitrary) safety/conversion factor. There is no single data source for RTLs with regulatory authorities and researchers creating their own datasets using various data sources and methodologies (including experimental activities and mathematical modelling) to establish these thresholds. There is little doubt that this introduces significant uncertainty for several reasons. Firstly, each dataset is likely to be very different and potentially not reproducible by third parties. Secondly, it is very difficult, if not impossible to know when the worst-case value has been identified (when do you stop the data search?). There is no clear definition of what species (or sub-species) comprise a particular biodiversity group. For example, in a study that applied the TAT to German agriculture ten

different fish species were used, but their precise identification is not given[11]. This uncertainty within the ATAT is addressed by the introduction of another factor to provide a safety margin. Within the ATAT pesticide usage data may be derived from a range of sources including farmer or producer reports to governments, pesticide sales, trade information (import/export) or national crop production data. Therefore, there is considerable scope for additional uncertainty. This presents challenges as an approach for comparing data on an international basis.

The application of the PLI (Danish and UK) along with other composite indicators such as POCER, SYNOPS[13] and the EIQ[1,14] take a different approach. Instead of using RTLs they utilise a suite of indicator species identified for regulatory purposes from experimental work. These species are selected as being particularly sensitive to environmental pollution and because they can represent their broader ecological group. For example, the indicator species for fish are rainbow trout (*Oncorhynchus mykiss*) and bluegill sunfish (*Lepomis macrochirus*). The selected ecotoxicity endpoint used would be the lowest for these species. Whilst it may be that 'risk' is, in some rare instances, underestimated, the data is much more transparent, and data tends to be more readily available. This approach allows for consistency and comparability across different studies and assessments where the same indicator methodology is applied.

The need, therefore, especially where the indicator is used for meeting international commitments, is for a single, readily available, comprehensive managed source of the data to be used regardless of the indicator chosen. One solution utilised by the most common composite indicators is the Pesticide Properties Database[15,16]. This database has been available since 1996 in various formats and available as an online free-to-use resource since 2006. More recently, a variety of new parameters, data sources and improvements in functionality have contributed to the growth and utility of the resource. The database uses a rule-based system to source and present the best-available data and it is continuously updated and expanded. It is endorsed by IUPAC and the FAO and is now the most significant and comprehensive resource of data world-wide providing a consistent source of quality, peer reviewed data.

We live in an information age that is driven by data and interpretations of that data that paint the pictures on which decisions are based. When painting these pictures, if we use different datasets and different methods, we risk having different pictures of the same thing, resulting in barriers to consensus and in a worst-case scenario making the wrong decisions. In the context of understanding and assessing the environmental impacts of pesticide use, there needs to be agreement on the most appropriate and reliable methods for the context in hand; and these methods need to be underpinned by common curated datasets. The key word here is 'curated', where the governance of the dataset is transparent and independent. If there can be global agreement on what data should be used for common metrics, then this can then be made available via multiple sources (such as the PPDB and similar resources) to those that need this data. Without this we risk a free for all, where everyone cobbles together their own datasets and the metrics that emerge cannot be compared and/or we end up with a patchy, inconsistent and ultimately an unreliable global picture.

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