A Proposal for Terrestrial Environmental Monitoring of Plant Protection Products (PPP)

First published June 2023

Natural England Commissioned Report NECR337

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Catalogue code: NECR337

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Keywords

Pesticides, herbicides, insecticides, fungicides, plant protection products, monitoring scheme, monitoring platform, residues, soils, honey, predatory birds, Wildlife Incidents, Pesticide Use Surveys

Citation

Walker, L.A, Shore, R.F, Chaplow, J.S., Barnett, E.A., and Spurgeon, D. 2023. *A proposal for terrestrial environmental monitoring of Plant Protection Products*. NECR377. Natural England.

Acknowledgements

The authors would like to thank the contributions made to this review by the stakeholder groups and organisations for their written and workshop-based comments, the project steering group from the various Defra teams and agencies and particularly Genevieve Madgwick, Alastair Burn, and Suzane Qassim from Natural England for their guidance on style and approach for this study. We would also like to thank the representatives of the existing monitoring schemes for their time and contributions to developing the proposal, Patricia Draycott for proof reading of the report, and finally to the late Professor Richard Shore for his leadership in the conception of the proposed pesticide monitoring scheme, he is missed by colleagues both in UKCEH and more broadly.

Foreword

Natural England commission a range of reports from external contractors to provide evidence and advice to assist us in delivering our duties. The views in this report are those of the authors and do not necessarily represent those of Natural England.

Background

There are many reasons to look afresh at environmental monitoring for pesticides just now. The Government is developing indicators to measure progress against the various actions set out under the 25 Year Plan for the Environment (25YEP). These actions include exploration of options to consolidate monitoring for emerging chemicals issues and working with industry to assess progress of activities like the pesticides voluntary initiative. Policy initiatives under development like the National Action Plan for Pesticides and the Chemicals Strategy will provide important opportunities to examine the role of chemicals and pesticides monitoring. Alongside this, the necessary revisions following EU Exit to the way pesticides are authorised in the UK presents an opportunity to re-examine the role of environmental monitoring in informing regulatory processes and decision-making. Work under the 25 YEP to develop indicators for environmental exposure and effects of chemicals has highlighted the paucity of such chemicals' monitoring in the terrestrial environment compared with freshwater and marine habitats. Natural England has been leading work under this programme to develop and explore the potential for further terrestrial monitoring for chemicals. The work described in this Report was commissioned by Natural England to contribute to the development of a monitoring programme in support of such indicators, as well as to contribute to discussions on environmental monitoring for pesticides under the National Action Plan. The approach taken in this report was to evaluate existing (UK and wider) terrestrial chemicals and wildlife monitoring programmes and data collection platforms that might contribute to or provide examples for a UK monitoring programme, rather than to develop a proposed monitoring programme entirely afresh. Within those existing data collection platforms there is scope to look at fresh (for example more targeted or pesticides focussed) approaches and these opportunities have been drawn out in the report. The work reported here has already been used to inform further research in support of the chemicals' indicators under the 25 YEP. We hope it will contribute to debates on the future of pesticides monitoring and research priorities as the National Action Plan is progressed. Extensive stakeholder feedback was sought through workshops and discussions in developing this report. The authors have tried as far as possible to incorporate that feedback into the findings and conclusions but there are plainly differing expectations and emphasis from different stakeholders. Natural England would welcome further feedback and suggestions for further work. The views in this report are those of the authors and do not necessarily represent those of Natural England

1. Executive Summary

Background

In the UK, the authorisation of plant protection products (PPPs) involves conducting a comprehensive suite of tests on ecotoxicology, fate, and behaviour in the environment. This involves a combination of laboratory and field studies aimed at refining the risk to key species. These data are used to assess environmental risks that may be associated with the use of the active substance as a PPP. After authorisation, plant protection products may be used for specific applications. Although these prospective risk assessment approaches are established, there is a growing call for improved post authorisation monitoring to understand plant protection product fate and exposure in the environment to supplement that done in other media (i.e., food).

The residues of plant protection products (and other compounds) are monitored in surface (and ground) waters in England by the Environment Agency (EA) in order to monitor compliance with the European Union Drinking Water Directive; such monitoring is conducted by similar agencies in the other countries of the UK. Fish kills are likewise investigated in order to determine probable cause that may include exposure to toxic substances. However, there is no equivalent residue monitoring for PPPs in the terrestrial environment (i.e., areas up to and including riparian edges, but not the water bodies themselves), reflecting the lack of a legislative requirement for such measurements. There is monitoring broadly analogous to fish kill monitoring in that the Wildlife Incident Investigation Scheme (WIIS) investigates incidents (typically mortalities) in invertebrate species (most commonly pollinators, typically honey bees assessed in collaboration with Natural England, and a Bee Inspector depending on the circumstances) and particularly in wild vertebrates and companion animals to determine whether such incidents are linked to the use of PPPs or some biocides. This is the only UK scheme that attempts to assess the possible direct effect of PPPs on terrestrial wildlife.

The lack of systematic monitoring of PPPs in the terrestrial environment led Natural England, in collaboration with Defra and Health and Safety Executive's (HSE) Chemical Regulation Division, to award a contract for a study, the key objective of which was the development of proposals for post authorisation terrestrial monitoring of PPPs and their effects in wildlife.

Objectives

The subsequent project was designed to develop an approach that would include the following elements:

- A literature review of existing PPP terrestrial monitoring schemes to inform the development of any new proposals
- Use of information from the literature review and elsewhere to undertake an initial selection of monitoring activities that may be suitable components of an over-arching, post-registration monitoring scheme for PPPs
- Development of a proposed monitoring scheme that involved workshops with key technical specialists to understand how to enhance existing monitoring activities and platforms, improve potential for join up of reporting, and to identify gaps in monitoring
- Stakeholder engagement to access non-governmental organisations (NGOs) and industry expertise, and feedback on any proposed scheme
- Consideration of potential costs of a holistic monitoring scheme
- Production of this final report that describes:
    - the structure, activities and two-way reporting to stakeholders in a proposed monitoring scheme,
    - what monitoring activities already exist that can be used or, conversely, that need development,
    - the scientific rationale behind the proposed monitoring activities,
    - constraints and logistical challenges associated with the monitoring.

Overview of potential features of a terrestrial PPP monitoring scheme:

Post registration monitoring of PPPs in the terrestrial environment within the UK is currently based on the WIIS scheme for investigating suspected poisoning incidents and the Pesticide Usage Survey (PUS) for gathering of usage data. These schemes compare favourably with those employed by other countries, including many European Union (EU) countries, both in the number of active ingredients assessed and the scale of usage data collection and reporting. However, additional monitoring efforts to fill gaps in environmental compartments, expansion of existing spatially restricted monitoring, or broadening of scope of existing schemes will result in a more comprehensive environmental monitoring system.

The proposed monitoring scheme will not in most cases provide data that alone will be able to provide diagnostic answers as to whether PPPs are having an impact at the population, community or ecosystem level. Instead, the ambition would be that any program should be able to identify changes in the levels of plant protection products present in different media in the terrestrial environment including in soil and different biological samples (e.g., beehive products, samples from potentially exposed species). Any observed changes in status of components should be viewed as a trigger for further review and investigation.

A number of schemes were identified that could contribute to the proposed monitoring scheme and these are discussed below:

- Monitoring of PPP usage remains an important component of the proposed scheme in order to both identify changes in the prevalence and magnitude of use, and for supporting other components of the proposed scheme. This usage data can also be used to generate finer spatial resolution and more frequent/rapid reporting of monitoring of PPP use across usage sectors (arable, pasture and fodder crops, amenity use etc.), either through modelling approaches such as the Pesticide Application Maps, or through real time application recording. For the latter, there are practical limitations and the significant issue of data protection and data access would need to be satisfactorily addressed.

- Inclusion of monitoring of soil concentrations to identify, for example, unexpected combination of PPPs present in soil, and to identify potential unexpected persistence, including through the formation of bound residues. There are currently national-scale platforms collecting soil samples, i.e., the ASSIST farmland soils project, the Soil and Vegetation Research Platform, and National Soil Inventory, that could potentially be adapted to fulfil this current gap. This would require initial method validation to confirm that sample collection and pre-analysis storage is appropriate for monitoring PPPs, establishment of baseline year’s data, and subsequent annual analysis.

- The proposed soils monitoring component of the scheme would also readily contribute to the initiatives to develop H4 – Exposure and adverse effects on wildlife of chemicals in the environment indicator, part of the Outcome Indicator Framework (OIF) for England for assessing progress against Defra’s 25 Year Environment Plan goals. Monitoring designed for PPPs with this program would be conducted alongside assessments for other chemical classes such as trace metals, persistent organic pollutants and emerging contaminants which are also a focus of assessment for chemical management within the proposed 25 Year Environment Plan.

- Emerging methods for potential effect measurement that could potentially be used to investigate and monitor the effects of plant protection product on the soil biota would be through the assessment of soil community diversity, most notably through assessment of bacterial or fungal populations. This is an emerging area that is rapidly maturing, although still requires development before it is ready for routine use. The development of new DNA barcoding techniques makes rapid and cost-effective characterization and monitoring of microbial and eukaryotic soil communities more tractable than was previously possible. Questions that can be investigated using DNA-based omics approaches in soil include how exposure changes community structure through meta-barcoding and the impacts of exposure on function through the measurement of microbial functional genes. To address such questions, issues such as the choice of species/communities for monitoring (e.g., bacterial/fungal), the robustness of these communities to other, potentially co-occurring communities, impacts of other environmental changes and the relevance of selected indicators for different soil types and habitats need to be defined and optimized for particular situations.

- Field-derived information on earthworm communities in agricultural soils is likely to be useful in cases where, in common with other biodiversity assessment, trends of community change can be related to likely PPP exposure. The reactivation of the Rothamsted Earthworm Survey, with the collection of additional information on PPP use as a routine element would provide data valuable for interpretation of, or linkage across monitoring components. However, the methodology developed in the survey is clearly transferable, and potentially could be adopted by the ASSIST farm network through which it has been suggested that soils could be collected. Given the collection of earthworm data would need reactivation of the Rothamsted Earthworm Survey network or transfer to an alternative collector network, inclusion of earthworm monitoring is considered an activity that could be reviewed and developed once a monitoring framework was established. One aspect that will need to be addressed is the potential effects that different land management and tillage may have on earthworm populations and the extent to which this can be separated from potential pesticide impacts.

- Chick Food Index (CFI) values, already included in the Pesticide Forum annual reports, have been identified as fundamental information for the terrestrial invertebrate compartment of the proposed scheme. This would provide information on the annual CFI values and the grey partridge adult to juvenile ratio. This approach is valuable because it potentially addresses the indirect effects of plant protection products on trophic interactions, rather than focusing only on direct effects. One of the drawbacks of the CFI is that it is based on measurements at just two sites. Expansion of measurements to a wider number of sites would increase the robustness of the measure as a national indicator and merits consideration but would require additional resource.

- It is proposed that the National Honey Monitoring Scheme (NHMS) be expanded in scope to include measurement of PPP concentrations in hive products. Pesticide residues in honey are not exposure measures themselves. This is because residues in honey cannot readily be converted to daily intake of residues in pollen or nectar. However, a study by Woodcock et al. (2018) demonstrates how honey PPP residues can be used as a quantitative index to infer differences in exposure and changes over time or following mitigation interventions. The methodologies by which monitoring of plant protection products in honey would be conducted require development and would need to consider a number of factors including: sample stability and long-term preservation; sample numbers used for annual analysis; stratification of annual samples by provenance and sampling date; time period of honey collection (including repeated analyses from the same hive); analytical methods and determinants, analytical quality assurance and control; and standardised collection of ancillary data. These are, however, all tractable issues that could be addressed to develop a robust and systematic scheme. Establishing links with beekeeper communities building on existing relationships developed with the current pilot program can support efficient sample collection. Furthermore, the potential value of a scheme can be increased if studies go beyond detailing frequencies of detection and exposure concentration to relate levels to known bee toxicity for the chemical present to allow a comparative assessment of potential risk.

- In addition to the expansion of the NHMS, it is proposed that the WIIS investigations of bee mortalities should be included as it is already running and provides fundamental information for this compartment. In summary, WIIS investigations of acute mortalities in bees are ongoing. When coupled with NHMS data, they would provide information on aspects of both exposure, and also acute effects as indicated through dietary exposure studies for honey bees conducted for plant protection product authorisations. In particular, knowledge of the presence of commonly detected substances that have relatively high risk may be useful in cases of effect attribution with WIIS investigations (even if it is to exclude those pesticide commonly detected in honey as causative factors of observed mortalities of bee colonies). Therefore, the WIIS investigations into bee poisonings should be considered as fundamental information for this compartment. Additionally, there may be the potential to link observation with measurement of residues in honey to support diagnostics.

- The WIIS is the only scheme that examines whether the deaths of vertebrate wildlife may be attributable to pesticides, including plant protection products. The focus is on acute poisoning incidents, but it may be argued that such incidents are likely to be rare, outside of deliberate poisonings. The potential infrequency of such effects is because during authorisation the acute toxicity profile of most compounds rarely raises concerns, except in a relatively low number of cases for example, pellets, granules and seed treatments applications. The key area that causes most concern during the authorisation process is the long-term/reproductive risk assessment. Hence, the greatest need is for chronic effect monitoring. To develop WIIS functioning for routine monitoring potential, an enhanced WIIS could be separated into the detection of poisoning incidents on one hand, and a separate component to look at the detection of the pesticide in different environmental matrices at different trophic levels through normal permitted use, including the link between measured exposures and the potential for realized risk to exposed populations.

- If the WIIS was to incorporate an element of wildlife PPP exposure monitoring, then we recommend that the individuals selected for analysis should include those that have died from a variety of causes to avoid potential bias. The WIIS, by its nature, has no particular focal species of interest, instead being incident based. However, a wider monitoring framework would be better to be restricted to focal species commonly associated with agricultural habitats. These targets for monitoring could include the wider collection of individuals of gamebirds shot for sport and/or dead individuals of UK Farmland Bird Indicator species (e.g., grey partridge) collected and submitted by citizen scientists, as used successfully in the Predatory Bird Monitoring Scheme (which could organize collection) using its existing networks and could oversee key aspects of delivery and interpretation.

- For the potential monitoring of amenity use, other schemes linked within the Wildlife Disease and Contamination Monitoring & Surveillance Network (WILDCOMS), e.g., The Garden Wildlife Health project, already receives samples of garden birds, amphibians, reptiles and hedgehogs for disease surveillance and could be used for sample collection from peri-urban areas. Monitoring of pesticide residues in peri-urban wildlife could provide some information about the patterns of amateur use, which is a current knowledge gap relating to exposure, and any potential for impacts.

- Monitoring for the presence of plant protection products in predators does not in itself generate information on effects, although such insights can be inferred through further diagnostic assessment. Residue measurement studies alone can, however, be used to provide data on spatial trends and temporal (e.g., year on year) changes in presence and magnitude of residues of the more persistent plant protection products, such exposure estimation often being the primary aim of these schemes. Optimum focal species for such studies are those that hunt predominantly in agricultural habitats. Carcasses for analysis would be readily available from collections already made through the WIIS and especially the Predatory Bird Monitoring Scheme (PBMS) which is designed with non-targeted collection strategy that is well suited for this application. A strategic approach to analysis would best include a combination of non-targeted screening to identify exposures and targeted measurements focusing on widely detected plant protection products. This approach would also be valuable for wider monitoring as it would also support detection of a wider presence of other chemical contaminants from industry, pharmaceuticals, veterinary medicines, wastewater treatment, road run-off, biocides and non-biocides.

- The proposed plant protection product monitoring scheme described contains various component elements. These are likely to be conducted by a range of different governmental and NGOs. While some would be a continuation of existing activities, other activities will require development of new collaborative agreements, protocols, pilot-scale testing, full implementation, and data reporting activities. A management structure or group will be required to manage and oversee the functioning, budgeting accountability, and overall reporting of the proposed monitoring scheme.

• Any potential terrestrial pesticide monitoring program has the potential to include a number of measurements relating to the use, loading, occurrence, and by comparison to hazard value risks, of PPPs under different cropping and land management systems. Desk studies using submitted and publicly available data can be used to assess both usage and pesticide loading; while measurements of the presence of PPPs in different environmental and biota samples can provide a measure of exposure that can be used along with information on hazard to assess potential risk. However, while it is possible to build a combined monitoring scheme that includes these components building on existing programs, there remain some notable gaps in the potential for exposure and effect monitoring that cannot be so easily filled. These gaps exist both among the taxa sampled and also in the aims of the analysis. Examples of taxa for which there are current no schemes readily available for sample collection include non-target terrestrial plants and amphibian and reptile species. For plants, mosses are included in sampling programs for air pollution monitoring. However, this sampling is focused in woodland system and so likely to be of limited value of PPP monitoring. Both amphibians and reptiles are recognised as being poorly covered by current risk assessment approaches and this includes monitoring efforts for which in the UK and internationally there are no long-term national scale schemes currently in place. Another notable gap in monitoring is approaches to measure the effects of PPPs on microbial species. A recent review identified certain active ingredient can change the structure of soil bacterial and/or fungal communities at field application rates. This assessment was based on the use of molecular methods for DNA based monitoring, which could become with development part of an integrated monitoring scheme. A further recognised gap in monitoring is in the assessment of sub-lethal effects among both invertebrate and vertebrate species. Current agreed approaches for sub-lethal monitoring have not been robustly trialled for widespread field application. Particularly challenging currently is an understanding of the baseline values and individual variation for specific effect based (e.g. biomarker) measurements and an understanding of how non-chemical and non-PPP chemical stressors may affect measured effect parameters. This challenge of aligning cause to effect is common with the use of species biomonitoring data. Combining such potential metrics with Adverse Outcome Pathway understanding and weight of evidence approaches can provide a means to integrate such data into any future monitoring scheme.

Specific issues for implementing a terrestrial plant protection product monitoring scheme:

• Within the earlier stage of the implementation of a terrestrial plant protection product monitoring scheme, there is a need to establish baseline datasets for some components and to identify the availability of suitable hazard data that could be used to support assessment of the toxicological significance (at individual or population level) of the mixtures of pesticides likely to be measured. A review to identify the status of baselines in existing monitoring programs that are brought into any developed scheme can be conducted to assess the status of current knowledge and any gaps that need to be addressed in such baseline knowledge. Expert review, e.g., by Expert Committee on Pesticides, could be used to provide an overview of the status and trend data for individual active substances (or their metabolites), and their suitability to act as a baseline for further assessment.

- In environmental (e.g., soil) and biological (e.g., invertebrate and vertebrate tissue) samples in which a broad spectrum of pesticides are quantified during monitoring, prior agreement would be needed on how these measures of multiple chemicals in the same sample are best presented. This situation would be especially relevant if samples were used to also identify the presence of other non-plant protection product contaminants. It is our recommendation that as the components of the monitoring scheme are developed, efforts should be made to co-align these approaches with those of the Defra 25 Year Environment Plan OIF metrics that are currently being developed as part of the plan under H4: Exposure and adverse effects of chemicals on wildlife in the environment (exposure of wildlife to harmful chemicals).

- Measurement of the presence of PPPs in media such as soils, water and biological samples (e.g., tissue samples, honey) are likely to form a key component of any monitoring scheme. The development of analytical method means that it now feasible to measure low concentrations of multiple PPPs in samples at parts per billion levels or lower. With such an ability for low level detection across chemicals, the detection of PPPs in samples will not itself be sufficient to make conclusions on whether individual substances (or mixtures) are likely to be causing adverse effects. Landscape scale population assessment (i.e., farmland bird monitoring, arable plant monitoring) can provide supporting evidence on species trajectories in agroecosystems over time. Such data can support understanding of the roles that different drivers, including PPPs, may play in determining terrestrial biodiversity under different land use and land management regimes. However, the challenge with such data is interpreting cause and effect in the presence of multiple drivers. Hence, there will be a need to expert overview of these different exposure and biodiversity data-sets to understand the links between PPP presence in different samples and potential effects on different species.

- An issue discussed during the stakeholder consultations that involved representatives from industry, a user community group, conservation bodies, and an NGO group was that the power to detect change of the monitoring in the various proposed components should be established based on baseline datasets to facilitate communication of sensitivity to change. Currently available datasets provide a sound platform on which studies can be conducted to look at how within and between sample variation for different measurements and analytes may affect the potential to identify pairwise differences between sample types and temporal trends. Pilot work to undertake such analysis has recently been commissioned by Defra working with the UK Centre for Ecology and Hydrology.

- A final key area that would need coordination and managerial oversight is the reporting of the outcomes of monitoring and associated stakeholder engagement. Reporting of data should be as timely and transparent as possible, with consideration given to the curation of annual data in national data centres, and annual publication of data with digital object identifiers. Stakeholder feedback during the course of this project has also emphasized the need to provide a balanced and contextual interpretation to accompany the data reporting. There will also be a need to ensure that data and reports are made readily available to key stakeholders, such as risk assessors, and for potential inclusion in wider sets of metrics, such as the outline indicators for Defra's 25 Year Environment Plan. The potential for the results from monitoring to inform risk assessment and authorization was also recognized, although pathways for this two-way exchange of information are not yet fully elaborated. Finally, the participation and interest in the current project from a range of industry and NGO stakeholders also emphasizes the need to develop a clear stakeholder engagement platform for any plant protection product monitoring scheme.

Contents

2. Introduction and project aims

2.2 Background

In the United Kingdom (UK), the authorisation of plant protection products (PPPs) involves conducting a comprehensive suite of tests on ecotoxicology, fate, and behaviour in the environment. This involves a combination of laboratory and field studies aimed at refining the risk to key species. These data are used to assess environmental risks that may be associated with the use of the active substance as a PPP. After authorisation, PPPs may be used for specific applications. Although these prospective risk assessment approaches are established, there is a growing call for improved post authorisation monitoring to understand pesticide fate and exposure in the environment, to supplement that done in other media (i.e., food).

The development of testing methodologies, protocols and understanding of the outcomes of risk assessment has become a branch of ecotoxicological scientific research in its own right. Risk assessment processes have developed over time as the underpinning science and knowledge has evolved. The exposure determination follows a tiered approach starting with highly conservative lower tiers and then, when needed, progressing with more refined exposure elements in the risk assessment and finally the conduct of field measurements. Within the predictive models used for exposure assessment, there is inevitably some degree of uncertainty associated with their use. To account for this uncertainty, conservative assumptions and safety factors are used in model applications for PPP exposure assessments. This is especially true for the simpler lower tier modelling approaches.

The hazard data that feed into the risk assessment are based on tests on a limited number of endpoints, and test species and so, like the exposure data, also have a degree of uncertainty. The species used for testing were initially selected for practical reasons relating to ease of handling and experimentation, rather than any prior information on their potential sensitivity. However, by choosing a set of species that cover different trophic levels and phylogenies, it is hoped that vulnerable species may be included in the assessment, although this is not assured. Uncertainties on the vulnerability of tested species to each assessed active ingredient that may lead to failure to identify some potential effects when a wider set of species are exposed in the environment is potentially mitigated by the use of assessment factors placed on measured toxicity endpoints in tested species that are used for the hazard assessment. In the current risk assessment process the assessment factors are logarithmically scaled (10,100,1000), with the choice being driven by the nature of the hazard endpoint (acute/chronic, short-term/long-term, etc.). In the risk assessment process, it is currently not clear on the extent to which such factors are adequate and indeed whether they are actually over- or under-protective (Shore et al., 2005). Where structured analysis has been conducted, e.g., in the EFSA

Guidance Document on Risk Assessment for Birds and Mammals, the potential conservatism that is assumed to be inherent in the design of current schemes has been largely supported. However, uncertainties in the range of species variation in exposure and sensitivity, among other factors means that an inherent conservatism cannot be ensured. Thus, it is impossible to ensure that authorised use of PPPs will never result in adverse effects and such effects have indeed occurred. Examples range from the classic case of organochlorine insecticides affecting vertebrate populations around the world in the mid-20th century first identified in the 1960s that led to the decline of predatory bird populations and subsequent population recovery after pesticide removal from use (Newton and Wylie, 1992), through to more recent examples such as field studies that have identified negative impact of the approved use of neonicotinoid seed treatments on pollinator populations (Woodcock et al. 2017, Rundlof et al. 2015).

Pesticides in general are often cited as a cause of adverse effects in the environment, though often with limited evidence to justify the full veracity of these claims. This reflects awareness of the historic (e.g., effects on top predators), and more recent effects (e.g., identified population level effects on pollinators) that have been identified following PPP use. The challenge of identifying or refuting links between PPP use and adverse ecological effects arises because it is recognised that there is no easy way of testing for or detecting a range of other possible impacts such as:

- whether there are any landscape level or long-term effects of PPP use that may affect potentially exposed species (although see Woodcock et al. 2016)

- whether declines seen in populations of invertebrate and vertebrate farmland species may be linked to the indirect environmental effects of PPP use (e.g., on insect food availability)

- whether there is a need to consider the toxicological effect of mixtures of different products as an explanatory variable of impacts as has been observed in aquatic ecosystems (Vaj et al. 2011, Kortenkamp et al., 2019)

- sub-lethal effects on a range of endpoints and/or species not tested as part of the authorisation protocol (e.g., as with the finding of neonicotinoid effects on populations of bees as measured and reported in field studies) (Woodcock et al. 2017, Rundlof et al. 2015).

This project aimed to draw together information on the use and assessment of PPPs in order to identify a potential approach that could support monitoring of the terrestrial environment in support of policy initiatives, including under Defra’s 25 Year Environment Plan. The overall approach to identify methodologies recognised that monitoring of PPP residues in environmental matrices cannot alone provide assessment of the above factors. However, such monitoring does provide a first step in understanding the likely magnitude of exposure of organisms to PPPs and whether any such exposure may be a possible causal agent of adverse effects. The intention is not that any newly implemented and coordinated monitoring scheme would replace any part of the current PPP risk assessment framework or indeed make it more of less conservative. Rather that monitoring can provide an extra level of confidence in the outcomes derived from the different aspects of the overall PPP risk assessment process.

The residues of PPPs and other compounds (e.g., metals, industrial chemicals, pharmaceutical, consumer product chemicals, hydrocarbons) are monitored in surface water and groundwater samples in England by the EA in order to monitor compliance with the European Union Water Framework Directive[1] and also for wider chemical detection and assessment to identify patterns of exposure to chemicals of known concerns for the identification of potential substances of concern. Such monitoring is conducted by similar agencies in the other countries of the UK, although the exact suites of chemical that are measured under each jurisdiction vary. Fish kills are likewise investigated in order to determine probable cause. However, there is no equivalent residue monitoring for PPPs (or indeed more widely for other substances) in the terrestrial environment, reflecting the lack of a legislative requirement for such measurements. There is the equivalent of fish kill monitoring in that the WIIS[2] investigates incidents (typically mortalities) in pollinators, typically bees, (in collaboration with Natural England and a Bee Inspector depending on the circumstances) and particularly in wild vertebrates and companion animals to determine whether such incidents are linked to the use of PPPs or some biocides. This scheme is, however, targeted at assessing causality in potential acute cases of poisoning, rather than in identifying the potential for chronic effects, even though these are often the impacts of greatest uncertainty within the regulatory assessment conducted for authorisation. The WIIS scheme is the only UK wide activity that attempts to assess the possible direct effect of PPPs on terrestrial wildlife.

[1] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/307788/river-basin-planning-standards.pdf

[2] https://www.fera.co.uk/chemical-regulation/post-market-stewardship/wildlife-incident-unit

2.3 Current information on the impact and sustainable use of PPPs

Current information reporting on PPPs in the terrestrial environment in the UK is overseen by the Chemical Regulation Directorate (CRD) of the HSE. CRD organise and manage a number of programs relating to the terrestrial use of PPP (Pesticide Usage Survey) and the potential for effects such as WIIS (as discussed above), as well as supporting the development of endpoints for monitoring, such as Maximum Residue Levels, for human exposure. CRD act to collate and assess the available information and present results on a range of activities and indicators to stakeholders, such as the Pesticide Forum[3]. The forum publishes an annual report[4], the most recently available of which is for 2019[5]. The annual reports describe the activities that have been undertaken by the members of the Pesticide Forum and provide updated information on various indicators that have been adopted by the Forum. These indicators are used to reflect the progress made in encouraging farmers and growers to minimise the risks and impacts resulting from the use of PPPs leading to their presence in the environment.

There is a wide variety of data collected on PPP use and the potential for exposure and effects by the CRD that are developed and presented to stakeholders such as the Pesticide Forum. These existing sources of pesticide use, exposure and potential impacts range from information on training undertaken on PPP use and sales, the extent of membership of farm assurance schemes, and the extent of PPP use through to residue monitoring (surface and ground waters, unprocessed fruit and vegetables) and monitoring of adverse effects of pesticide exposure in humans. Of the indicators that are available, perhaps those that are most directly pertinent when considering PPPs in the terrestrial environment and potential environmental impacts are:

- the Pesticide Usage Survey (PUS)
- areas under organic farming, IPM plans and agri-Environment options
- Wildlife Incident Investigation Scheme (WIIS) (wildlife, bees)

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[3] https://webcommunities.hse.gov.uk/connect.ti/pesticidesforum/groupHome

[4] https://webcommunities.hse.gov.uk/connect.ti/pesticidesforum/view?objectId=38419

[5] https://webcommunities.hse.gov.uk/connect.ti/pesticidesforum/view?objectId=698373

- Chick food index (CFI)
- Farmland bird indicator populations and populations of all bird species

2.4 Aim of the current report

The limited monitoring of PPPs in the terrestrial environment led Natural England, in collaboration with Defra and HSE's Chemical Regulation Division, to award a contract for a study, **the key objective of which was the development of proposals for post authorisation *terrestrial* monitoring of PPPs and their effects in wildlife.** Effectively, two possible options were considered. These were to either: (i) develop a completely new monitoring scheme that did not necessarily take into account current activities, or (ii) build on, enhance and add to existing relevant activities, including those that were relevant to, but not specifically designed for, PPP monitoring and assessment. The latter approach was adopted as it was considered that utilisation of existing relevant PPP activities, together with leverage of resources associated with other relevant schemes, was most likely to result in a monitoring scheme that could begin relatively quickly and that would not require excessive additional resourcing, although it was accepted that any scheme extension would by definition require additional support.

Based on this overarching approach of gaining best value from the use of existing programs, but where needed identifying potential new components, this commissioned project undertook a review and assessment of currently available approaches and tools used for PPP monitoring in the UK and other countries. This information was then collated and used to identify potentially promising approaches for monitoring that were then presented to stakeholders for two-way feedback. The project included the following elements to deliver its broader objectives:

- A literature review of existing PPP terrestrial monitoring schemes, including in other countries to inform the development of any new proposals
- Use of information from the literature review and elsewhere to undertake an initial selection of monitoring activities that may be suitable components of an over-arching, post-registration monitoring scheme for PPPs
- Workshops with key technical specialists to understand how to enhance existing monitoring activities and platforms, improve potential for join up of reporting, and to identify potential gaps in the available tools for monitoring
- Stakeholder engagement to access NGO and industry expertise, and feedback on any proposed scheme
- Consideration of potential costs of a holistic monitoring scheme

- Production of this final report that describes:
    - the structure and activities in a proposed monitoring scheme,
    - what monitoring activities already exist that can be used or, conversely, that need development,
    - the scientific rationale behind the proposed monitoring activities,
    - constraints and logistical challenges associated with the monitoring, including identification of where gaps may exist and approaches that could be used to fill these and practical issues for implementation such as sample provision, sample prioritisation, and resource and cost issues.

3. Objectives of the proposed monitoring

The project was governed by a steering group, consisting of a variety of governmental and arm's-length organisations with responsibilities related to PPP use and environmental protection. At the start of the project, the steering group identified and agreed the scope of project which is presented in Textbox 1.

Textbox 1. Define and agreed scope of the project

1. The purpose of the project is to identify the potential overall design and specific components of a monitoring scheme designed to the presence of, and detect any unforeseen and/or detrimental environmental consequences resulting from, pesticide (PPP) use at different scales and in different environmental compartments.

2. Although the design of a proposed monitoring scheme should take into account the nature of the tests carried out during the PPP risk assessment process, the aim of the scheme would not be to replace or add aspects into the current agreed risk assessment process. Instead, the outcomes of monitoring could inform the future development of the risk assessment process to address any gaps that monitoring outcomes may identify and to underpin any potential decisions made on risk management and stewardship.

3. The scheme intends to produce data which may flag any unexpected exposure and associated consequences of PPP use. The data from the scheme will need to be reviewed and reported on regularly, (albeit not as part of the PPP risk assessment process) so that issues are identified and investigated further.

4. The monitoring scheme should be developed in such a way that the data generated can be used to inform wider policy requirements. For example, it is likely to improve understanding of and inform policy regarding farm practice more widely, ecological management and conservation of vulnerable habitats and species. As such any scheme would provide value in supporting key aspects of policies developed under umbrella such as the Defra 25-Year Environment Plan.

4. Literature and stakeholder led review of UK and international schemes

4.1 Introduction to literature and stakeholder review of existing schemes

In the UK, investigations through the WIIS provide the main current approach for the post-registration monitoring for unexpected mortality in terrestrial and aquatic invertebrate (e.g., bees) and vertebrate (e.g., birds, mammals) species that may the consequence of PPP use and exposure. WIIS reports have identified several examples of cases relating to potential pesticide poisoning in wildlife using an approach based on body tissue residue analysis and toxicological comparison e.g., organophosphate sprays and seed treatments and some granular insecticides (see https://www.hse.gov.uk/pesticides/reducing-environmental-impact/wildlife/wiis-quarterly-reports.htm). However, with reduced toxicity of authorised pesticides and growing recognition of the potential for species to be exposed to pesticide mixtures increasing it is recognised that some of the adverse effects of pesticides may arise through chronic exposure to single active and pesticide mixtures. Hence, there is a potential need for a more integrated approach to monitoring pesticides impacts that can build on current work to identify acute poisoning cases.

To build an understanding of the potential overall design and specific components that may be included in a more holistic terrestrial monitoring program for pesticides, a literature review was conducted. The aim of this assessment was to generate an overview of current methods and approaches used for pesticides monitoring both in the UK and also around the world. The review was not intended as an exhaustive review of all monitoring options used worldwide. Instead it was intended to gain a view on the nature of any particularly relevant monitoring methods, their strengths and weaknesses, and relevant any information to be considered should they be identified as candidates to be taken forward for further assessment and piloting. The review was particularly focused on identifying the range of approaches that may be applicable for biomonitoring. This was done, as a such methods are likely to be in the earlier stages of development than approaches for chemical measurement in environmental media, such as soils, which as establish analytical approaches for residue detection are likely to form an important part of any terrestrial biomonitoring scheme.

To undertake the assessment, a review of the available published open and “grey” literature was conducted. The assessment of the open literature was conducted using a Web of Science search. To supplement this formal published literature assessment a second approach identified authors who have collectively worked in the field of environmental monitoring and accessed any available reports and information help online or offline relating to the design and outcomes of those monitoring schemes. Finally, to ensure that any emerging approaches was identified, a consultation with UK stakeholders was conducted during the formulation of this report to allow us to identify any potentially missing schemes, including those in early development (e.g., UK Pesticide Load Indicator). The schemes identified are discussed in section 4.3.

4.2 Literature review

4.2.1 Methodology

For the literature search, the Web of Science collection (all databases) of ISI research papers was used to search for relevant references that contained report information on the design of a PPP monitoring scheme, and/or the results arising from these studies or wider review of their operation and success. The Web of Science database catalogue provides a listing of all ISI cited research papers published since 1981. Notably, "grey" literature publications are missing from Web of Science. As reports to funders may be the frequent outcome from monitoring, there was a potential that a focus on the published scientific literature alone could miss a reference to some scheme. To address this, the project team consulted with international experts working in the area of terrestrial PPP assessment to ensure that major international programs were identified.

The search terms used for the Web of Science search were agreed between the project team (see Appendix 11.1). The initial search identified 5,751 references, from 1980 to 2019, that were downloaded to a single EndNote file. This complete list of references was assessed by the lead for the literature review who refined a list of 693 references from 2001 onwards, which were selected and transferred to a separate EndNote library (see Appendix 11.3). The references removed at this initial screening stage were primarily those that involved studies on animals that mainly inhabit non-terrestrial environments, e.g., cetaceans, seals and sea birds, or studies on lake and stream environments. The refined references list remaining after this first stage screening were next evaluated for their potential to inform on monitoring approaches based on the reference title. All references were screen and scored separately by multiple members of the project team (see Appendix 11.3). References where at least two people identified it the work as likely to contain relevant information or data were taken forward for detailed review (see Appendix 11.2 for list - 64 references). Through this assessment phase, the two researchers worked closely together to ensure that there was a consistent basis for the selection, and especially the exclusion, of specific papers. This involved extracting the required information from each paper using the questions listed in Table 3.1. The literature reviewers conducted this detailed review and compiled the resultant information into Excel spreadsheets.

Following the reference review, the data was assessed by the literature review lead and the papers were compiled into one of the subject areas listed in Table 3.2. The subject areas include a number of critical areas relating to the environmental monitoring for PPPs covering assessments of honey bees, pollen, and honey (Bee biomonitoring); non-destructive sampling for assessment of exposure in wildlife (Exposure biomonitoring); monitoring of effects in wildlife (Effects); methodology studies to advance effects and exposure assessment methods (Methods); studies that assess specific species to monitor potential risks (Focal species); and scheme and data review articles (Reviews)(n.b. the scope of each of these subject area is included in the relevant Results section). Some papers could be ascribed to more than one subject area. In these cases, a decision was made to ascribe the particular paper to a category based on its dominant theme. A single Excel file with a spreadsheet for each subject area was compiled from the data provided by each reviewer, extracting where possible the information listed in Table 3.1.

Table 3.1 Data extracted from literature review.

Data collected on scheme characteristics
Paper/study title
Short version of the title for the paper/study
Website-hyperlink for the paper/study
Organisation that is the lead for the paper/study
Other collaborating organisations in the paper/study? **Recorded as none** if only one organisation involved.
Lead author for the paper/study
Contact email for the lead author if available
Quality system(s) apply to the paper/study e.g., GLP, UKAS
Estimated cost of the paper/study (if available)
Funder of the paper/study

Data collected on scheme characteristics
Geographical scale of the paper/study, e.g., Limited (i.e., local, or county, or regional scale), or Unlimited (i.e., country, national scale)
Description of the geographical scale of the paper/study, e.g., 12 field sites in Devon, or the county, country or state
Was the sampling in the paper/study planned **Active** (e.g., intentionally monitoring/looking for samples or mortality/effects) or **Reactive** (e.g., reacting to / waiting for samples or mortality/effects)
Paper/study long-term (i.e., over a year), or a one off
Paper/study is past or ongoing research
Start and end date; or the date the paper/study started for ongoing monitoring paper/studies
Sampling methodology for the paper/study, e.g., skilled or unskilled carcass search, questionnaire, trapping, tagging, tracking
Species scale of the paper/study: Is this a single species or multi-species paper/study
Species are included (provide species name for single species and class or other grouping for multi-species)
Chemical scale of the paper/study: Is this a single chemical/residue, or multi-chemical residue/chemical, or other (e.g., biomarker) paper/study
Pesticide class(es) included in the paper/study e.g., Plant Protection Products, Biocides, Veterinary medicines
Pesticide type(s) are included in the paper/study e.g., insecticides, herbicides, rodenticides etc.
The number of PPPs included in the paper/study, and if possible, list them

Data collected on scheme characteristics
Key aim of the paper/study post-registration monitoring, R&D, other
The main aim or objective of the paper/study in a sentence
The types of data or datasets that are in the paper/study
Keywords for these data and those listed in the paper
Other information that the paper/study could provide e.g., about PPPs, or data for national statistics
Key strengths of this monitoring paper/study
Suggestions for further research, or actions that could be implemented to improve, or create more useful outcomes from this paper/study
Other information about the paper/study that is not covered by the questions above then please include these details here. If there is nothing more to add please confirm this too

Table 3.2 Number of articles review for each subject area.

Subject area and type of papers included	Number of references
Bee biomonitoring - section 4.2.2.1 Papers where honey bees, pollen, honey and other hive matrices were used to investigate the extent of pesticide contamination	9
Biomonitoring of exposure – section 4.2.2.2 Papers that explore different non-destructive and destructive sampling protocols for living animals as a tool for assessing the contamination of the environment, or contamination of an individual with pesticides	10

Subject area and type of papers included	Number of references
Effects – section 4.2.2.3 Papers on monitoring effects in wildlife	17
Methods – section 4.2.2.4 Papers that focus on monitoring methodologies to detect effects and exposure to PPPs	6
Focal species– section 4.2.2.5 Papers that select a few key species to target limited resources to monitor potential risks of PPP applications	4
Reviews – section 4.2.2.6 Papers that are surveys, reviews and papers on monitoring activities (e.g., for trend comparison) that mainly involve mortality monitoring	18
Total	**64**

The data was checked, assessed and some key strengths, weaknesses, or ideas that might be used for PPP monitoring activities were summarised in the Results section. The complete references included in the review are also available as PDFs.

4.2.2 Results

Below is a summary for each subject area reviewed, with key strengths, weaknesses and ideas for PPP monitoring identified. This information summarises details from individual identified schemes which are discussed further in Section 5.

4.2.2.1 Bee Biomonitoring

Bee mortality monitoring work in England is already in place via the WIIS, (Barnett et al, 2007; see also here) which is a very long-term (30+ years), established, monitoring scheme for PPPs. The bee biomonitoring conducted in WIIS is focussed on identification and cause attribution of potential poisoning incidences. However, the area of bee biomonitoring identified from the available literature extends beyond the investigation of only acute effects. Thus, this subject area also includes papers from other work where honey bees, pollen, honey and other hive matrices were used to investigate the extent of PPP contamination. These samples were used for measurement of PPP residues for use as a bioindicator of the wider contamination of the environment, or to advance knowledge on the contamination of bee colonies with specific active ingredients. Honey bees are a useful representative pollinator species, and in the UK there is a network of beekeepers (e.g., via the Animal and Plant Health Agency (APHA) and the regional bee inspector network) that can contribute to sampling. This network was used, for example, in the ASSIST UK NHMS. The scheme project lead (Richard Pywell, UKCEH) confirmed that these networks were readily engaged for sample provisions. Hence for honey (and other hive products), this kind of distributed collection network sufficed for collection. Measurement made from these samples in the UK NHMS have confirmed the presence of multiple in use and legacy PPPs in honey samples. Collection through this scheme from focus colonies over time could further develop a temporal aspect to these residue level measurements, something that is currently largely missing from the published bee (honey) biomonitoring literature. Among studies that monitor bees, honey and hive products, the large majority are of limited scale or one-off studies. Most are focussed on honey bee species, while wild bees are less commonly included. There is though the potential to conduct studies with wild species (i.e., bumblebees) using either commercially supplied colonies or wild populations. The majority of bee studies involve active sampling of randomly selected beehives, use of pollen traps, floral surveys, or collected honey bee, honey and pollen samples from hives. These studies often involve multi-chemical analyses (mainly for PPPs), but also some veterinary medicines and other contaminant testing. The studies are mainly conducted by universities with a mix of government and EU funding.

Key strengths

- Honey bees are a species that are numerous and easily kept in agricultural or urban areas that freely visit different flower resources including crops. Use of other managed bee species or wild pollinators is also feasible, although methods are not developed as for honey bees.

- Hives kept in multiple locations allowing comparison of areas, e.g., agricultural, urban and pristine habitats.

- There is a strong community of beekeepers to support sample collection, e.g., honey which is collected by beekeepers anyway and also provide other meta-data.

- A multi-residue targeted QUECHERS-LC-MS/MS and GC-MS/MS approach has been demonstrated for residue measurements in honey (e.g., in the UK NHMS).

- Single time point monitoring provides data on potential for multiple PPP exposures and temporal monitoring on trends.
- It is possible to deliver structured and systematic sample collection and provision schemes on a national scale by linking with organisations such as the British Beekeepers Association who have a strong and widely dispersed membership.

Key weaknesses

- Honey bees may not be representative of other pollinators due to different habitat preferences. Methods for other pollinators are not yet well developed.
- Pollen traps can have negative impacts on colony development, as it reduces a food resource to the hive which may change behaviour and, hence, exposure.
- Impact of products used by beekeepers which may introduce pesticides into the hive environment, e.g., for varroa control.
- Comparative bee colony health assessments to link to studies of PPP exposure may be confounded by beekeeping practices.
- Timing of sample collection is important, as it is a point in time that will be linked to pollen and nectar resources being collected at the time, and may over- or under-estimate long-term exposure or exposure at other times of year.
- Will mainly capture exposure and effects for products applied to mass flowering crops, with less potential to capture exposure and impacts (on other receptors) applied to crops that bees are less likely to visit (e.g., cereals), except through exposure to weed flowers.

Conclusion from review on potential role in PPP monitoring

- Honey bees, pollen and honey are useful bioindicators of environmental contamination.
- The use of random or stratified sampling is feasible given the number of potential sources for sample collection through beekeeper networks.
- Pollen is most frequently contaminated, often with fungicides and from colonies near intensive farming, so may be a better focus for collection than honey, although the latter is more readily collectable.

- Investigate the extent to which contamination is related to proximity and duration of exposure.

4.2.2.2 Biomonitoring of Exposure

This area includes papers that explore different, non-destructive sampling protocols from living animals (e.g., using hair, faeces and blood) and the analysis of tissues from dead individuals for use in assessing the exposure of an organism to a PPPs. Monitoring exposure usually involves collection from either trapped animal samples or from a dead animal that is found and from which a sample is collected and analysed. The latter for example is the design of the UK PBMS which relies on citizen scientists for collection and submission of samples that are then processed, and tissues analysed for the chemical concentrations. Although most exposure monitoring schemes use tissues, rather than non-destructive samples, there is also the possibility that animals may be actively collected via trapping or shooting for tissue collection, although such a destructive sampling approach can raise ethical concerns.

Non-destructive exposure assessment approach through biological sample analysis offers a promising approach. However, these methods are somewhat limited by their need to collect adequate samples sizes to ensure detection. As analytical capacity improves, detection limits are reducing. This increase in potential capacity to detect low levels means that there is capacity to conduct measurements on a small sample while still ensuring a reliable measure of PPP concentrations. Given the improvements in analytical approaches which have driven down detection limits and as a result the volume of sample that is required to allow measurement, there is potential that methods such as blood sample testing would now be feasible for the measurement of multiple analytical measurements from the same biological sample. Further, in additional to the classical analytical approaches to measurement for chemicals in collected samples, there is also potential for approaches that do not require analytical chemistry, such as monitoring yeast (Candida spp.) from the gastrointestinal tract of raptors.

The majority of exposure assessment studies relied on measurements in tissue samples collected from carcasses. Historically, studies of this type were central to efforts to identify the presence of organochlorine insecticides in top predator species. Since their removal from use, however, concentrations of these PPPs have fallen, such that now, although detected they are rarely present at concentration of concern. The review of the current literature identified anticoagulant rodenticides as the focus for many of studies, particularly regarding contamination of non-target vertebrate species, as well as the potential for poisoning. In addition to the measurement of exposure, some studies attempted to link these residue levels to the potential for reproductive, behavioural or physiological effects as a common theme (Becker et al. 2003, Lambert et al., 2005). Some studies of rodenticide levels undertake a more detailed assessment of exposure routes that can lead to the identification of unexpected exposure pathways for rodenticides into predatory species, e.g., hedgehogs consuming rodenticide contaminated invertebrates (either contaminated directly via consumption of baits or via consumption of contaminated faeces; D'Have et alo. 2006, 2007). There is also a mix of long-term and one-off studies of effects linked to rodenticide monitoring.

Identified published exposure studies cover a range of geographical scales from one field to a national scale. The majority of such studies are conducted in small scale (temporal and/or geographical) projects (e.g., Eidels et al. 2007, Lambert et al. 2005). However, some schemes have been successful in receiving long-term sustained funding from strategic research programs, government sources and/or charities that has allowed them to operate nationally over an extended time period. Examples of such larger-scale monitoring schemes in the UK (although not all exclusively terrestrial in focus), include the UKCEH led PBMS, the Otter Project, the Zoological Society of London's (ZSL) Cetacean Stranding Investigation Program, and the UKCEH National Fish Tissue Archive. The sampling approaches used in these schemes may be both active and so often require skills (e.g., blood sampling) or opportunistic based on the collection of carcasses and the analysis of specific target tissues (e.g., PBMS, Cetacean Stranding Investigation Program). Some of the studies involve a single species, e.g., fox, wood pigeon etc., while others are multi-species where raptors or native species are sampled. These are mainly multi-chemical residue studies, particularly with biocides (e.g., multiple anticoagulant rodenticides) and also studies with a single compound (e.g., brodifacoum). The studies tend to be for post-registration monitoring, to improve knowledge on toxic effects in ecosystems, or to assess the scale and severity of exposure.

One feature of these tissue-based surveys is the need for active and skilled sampling methods such as using trapping techniques for small mammals, using homing pigeons, tagging, faeces sampling, hair samples, habitat surveys, or long-term bird population studies as indicators of environmental change. Programs of this type are usually focussed on a single species or a group of species, e.g., raptors, and use multi-chemical analyses, mainly for PPPs, (particularly organochlorines), but also other contaminants and anticoagulant rodenticides.

Key strengths

- Approaches that do not require analytical chemistry may be cheaper and easier to conduct, although this is not always the case.
- Use of non-destructive sampling may allow more targeted and structured sampling, both spatially and demographically, compared to opportunistic sampling. Repeat sampling on the same individual may also be possible to assess temporal trends.

- Collection of carcasses for sample collection and analysis can be done by citizen scientists to reduce the front-end costs of monitoring programs that include these samples.

- Collected samples can provide information on bioavailability and bioaccumulation, and also other possible impacts in health and sample status, e.g., disease.

Key weaknesses

- Benefit from being set up as long-term or large-scale studies to allow long-term, trend and spatial patterns of exposure to be identified. This design and implementation requires long-term commitment of resources.

- Need to determine sample size necessary for statistical robustness prior to study design and sample collection.

- One species, or even a species group, may not be enough to determine an environmental exposure or indeed impact on a wider group of linked species or within a complex trophic network.

- It can be difficult to identify all sources of exposure especially in more mobile species. As a result, measured concentrations need to be interpreted in wider spatial context than just the local collection site.

- Laboratory studies under more controlled conditions may be needed to interpret results from the field, especially on how measured levels of exposure is monitored in tissues may be related to other effects.

- Some approaches may require skilled sampling (e.g., blood sampling) which may need ethical approval and so may limit the scale of such studies.

- Potential public concerns on the use of animals for research, especially for destructive sampling and for work with vertebrate species. This concern can be mitigated by the use of carcasses rather than collection from culled animals.

Conclusion from review on potential role in PPP monitoring

- Careful selection of the sample for analysis to be used is necessary in scheme development, as one sample type may not be suitable for all PPPs.

- Could be used for PPPs that are excreted, for example unchanged in faeces, or those that accumulate in hair/feathers, but this may mean the need for the collection of multiple samples from more than one species.

- Inter-species differences in prey-base may affect whether the levels of contamination in their tissues reflect local contamination, or that of other locations. For example, an apex predator with a large proportion of its diet consisting of migratory species may not reflect local contamination, particularly during periods around migratory events.

4.2.2.3 Monitoring of Effects

This subject area includes a set of papers that predominantly focus on persistent, bioaccumulative chemicals (such as anticoagulant rodenticides), or cholinesterase-inhibiting PPPs and their resulting effects on the exposed species. Within such studies a number of methods are used for the collection of samples. These include carcass collection, as well as active approaches such as trapping and shooting. In some cases, such as for the measurement of acetylcholinesterase or for measurement of corticosteroids (Fildes et al 2009), collection of non-destructive samples (blood, feathers) is also possible. There is evidence in the literature that the method used for sample collection has the potential to lead to bias in the outcomes of the analysis (Fourel et al. 2018). Sampling process and storage can also have an effect on sample status that can change the outcomes from a down-stream results from an analysis. This may mean that it can be difficult to compare the results of different studies conducted using diverse methods. Further, as the results obtained from particular experimental methods may be to an extent operationally defined, this may mean that it is difficult to assess the impact of the residues found, i.e., the extent to which they may contribute to adverse outcomes, either directly or possibly through chronic effects on behaviour, physiology or health status. These latter points can be particularly challenging in those studies reported in the literature when carcasses are used. This is because there is the possibility of co-correlation of residue levels with the causes of mortality for the collected sample. To mitigate the potential aspects of sampling bias from relying on carcass collection, one study fitted wood pigeons with temperature-sensing radio-tags (Prosser 2006). This meant that when a drop in body temperature upon death was recorded, and the carcasses could be found via the radio-tags; a sample that was less biased in nature was produced as individuals were drawn from a single population. However, this is a labour-intensive active sampling approach and so may not be cost effective for national scale monitoring initiatives.

Key strengths

- Can involve species that are numerous, easily available and found in a wide range of habitats, e.g., foxes, fish, more common predatory birds.

- Use of species that are very territorial would mean that it is possible to trace potential sources of contamination as the species will reflect exposures in the immediate area.

- Sampling can be non-destructive, e.g., plasma cholinesterase, hair samples, stomach oil in marine birds, or pellets in raptors. There are options, e.g., radio-tags, to address potential sampling bias of carcass availability.

- Can target vulnerable, sensitive or sentinel species that are of particular conservation concern or occupy specific points in the trophic network.

- Data can highlight research required on possible effects, or other monitoring activities that are required.

Key weaknesses

- The ability to conduct repeated measures monitoring or to assess any effects of residues found may be limited when using opportunistic destructive sampling, e.g., shot animals and road collision victims.

- There is the potential for bias in samples due to the effects of the stressor and trauma that ultimately leads to death on the results from particular effect measurement, e.g., potential for increased stress hormones as a result of starvation.

- Additional research and development may be required to validate non-destructive sampling approaches that would allow repeat measures from the same individual.

- Need to address the uncertainty on sampling numbers that are required to detect an effect, as there is greater evidence or variation in the range of measured biological responses than is the case for chemical residue measurements.

- Sampling is often limited to being opportunistic, meaning that some samples may not be available for key species or from specific geographical areas or habitats of interest.

Conclusion from review on potential role in PPP monitoring

- Residue measurements for exposure monitoring are more developed as an approach (e.g., PBMS, the Otter Project, ZSL's Cetacean Stranding Investigation Program, Fish Tissue Archive), however, measurements of effects can add to these schemes using matching measurements from the samples.

- There is a need to understand the link between exposure and effect to link biomonitoring with effects-based results to evaluate the potential impacts of different exposures.

- These schemes can use the samples from citizen science monitoring and reporting that are used from the existing schemes.
- The methods for monitoring effects are in an earlier stage of development than residue monitoring studies, hence, there is a need to establish the background response levels of some markers and their responses to other types of non-chemical environmental stress.

4.2.2.4 Method of monitoring

This subject area includes papers that focus on the development of approaches for sample collection and analysis for PPP monitoring. These studies, thus, focus on the technical aspects, rather than the outcomes which are included under the exposure and effect monitoring classifications. One area that is discussed in this type of study is the selection of the most appropriate target tissues for analytical assessment. Such studies may include a comparison of levels in different tissue and their individual drivers and may seek to develop the use of different sample types for specific applications. For example, some tissues (e.g., liver, kidney) have been identified as sites of high accumulation making them well suited as samples for identifying the range of potential exposure in species. However other novels sample types, such as beaks or talons have also been identified as being potentially suited for identifying the long-term effects of chronic exposure, both because such samples can be easy to collect, transport and store and also because the chemicals that accumulate in such tissues may be subject to limited metabolism meaning that they are present over extended timescales.

Comparative assessments of different sample collection approaches often focus on the best approaches to sample archiving. The aim of these studies is to identify the optimum approaches to secure the samples for future use, including for emerging chemicals. A further general theme of papers identified under this topic area is the development of collaborative approaches that can be used to facilitate sample collection, such as the use of wildlife rehabilitation centres that may deal with animals affected by PPPs. Some studies included work to develop particular sampling methodology, e.g., line transect sampling methods, feasibility of detecting residues in decomposed carcasses, or the use of dogs to find carcasses. Such studies are usually focussed on specific research and development aspects and so have been designed and tested so far within the scope of defined research projects operating at the local, regional or national scale; these mainly being conducted by universities, working groups and industry and funded by government, industry and grants.

Key finding to support monitoring

- Potential to use novel samples, e.g., talons, beaks, palates, avoids looking for metabolites in tissues and can make use of predated carcasses with no soft tissue. It is also easier as ambient temperature transportation can be used.
- Best methods for potential archiving of samples to permit retrospective testing when new methods or approaches are available for sample characterisation.
- Use of "big data", e.g., cross-ecosystem meta-analysis and combining data from a range of sources to provide realistic, field-based monitoring where unforeseen effects may be identified and may calculate risk-quotients (Vijer et al., 2017).
- Development of methods to support the identification of other effects apart from mortality, e.g., immune function, hibernation, reproductive effects, deformities, that can be linked to residue levels within a more holistic assessment.

Key remaining uncertainties limiting uptake

- Novel samples not yet validated may not work for less toxic PPPs and may not be considered conclusive evidence of acute poisoning effects.
- Securing resources for the long-term archiving of samples as there can be limitations for suitable archive space, an ongoing resource.
- Uncertainty on how to acquire data to identify effects other than mortality, including which endpoints should be recorded, what are the most appropriate methods, and the extent to which measurements vary and are affected by other stressors.

Conclusions from review on potential role in PPP monitoring

- Novel sample types, such as beaks and talons from birds, may be useful for studies, although further work is needed to optimise their use.
- Agreement will be needed on the systematic archiving of samples for current use and prospective future analyses.

4.2.2.5 Selection of Focal Species

This subject area includes papers that select a key species to target limited resources to monitor potential risks of PPP applications. The specific aim of such studies was not necessarily to identify broad trends of exposure across a group of classes, but rather for case-specific assessments for a particular species. These specific species focussed papers generally highlight and promote the specific value of assessment conducted with the particular focal species. How the proposed species is used in each study, however, vary according to the overall aims of the study and also the habitat, trophic links and PPP that the study is designed to assess and monitor. Studies of this type may often focus on rarer species that could be relatively more exposed to a PPP, or more sensitive to exposure. These case studies, where rare species are the focus, can be challenging to conduct for a number of reasons. Firstly, because of their inherent rareness, it may be difficult to collect the number of samples needed for robust exposure and effect trend assessment. Further, such species may also be less well studied, meaning that it can be difficult to interpret the outcomes of measurement, particularly those for effects. Studies of this type are more normally undertaken by universities, museums and industry, with funding via research centres, industry and government. They include both national and limited scale studies using selected field sites.

Key role to support monitoring

- Potential to identify the correct indicator or focal species can highlight the exposure risks for that species, and potential for species with the same habitat preference and/or diet.
- Potential to target resources to a few key species to make studies tractable and to develop best practice that can be used for studies in less common species of specific interest.
- Capacity to compare relevant exposure and mortality rates in specific species that are most appropriate for the habitat and case of interest.

Key weaknesses

- The optimum focal species selected might change depending on exposure routes, season, study site environment, and geographic location which makes it difficult to compare the results from different studies.
- Selection of indicator species using only criteria such as abundance and ease of collection may not identify species that are at greatest risk, however, currently the capacity to rank species for potential sensitivity requires trait-based models that are not yet well established.
- Selection of less common species of high potential concern may make the collection of sufficient samples for analysis challenging.
- The view of individual scheme managers or paper authors on the value of their particular study species can be coloured by their own personal experiences rather than a broad view of relative value.

Conclusion from review on potential role in PPP monitoring

- The methods that are used for monitoring (sample collection, storage and analysis) are flexible and can be used for a range of species depending on the aims of the study, thus, studies with common and abundant species may best identify trends, but focal species studies may identify the species most at risk.

- Need to identify the dominant habitat, dietary preferences and biological traits of a species to identify those potentially at greatest risk for selection.

- Studies with focal species will need to include robust control sampling and the background exposure and biology of the species may not be known making it more challenging to interpret specific data.

4.2.2.6 Review (e.g., trend comparison) articles

This area includes those papers that conduct overarching surveys and reviews of papers on monitoring approach. Most of these studies focus on the assessment of acute poisoning schemes of exposure studies. The types of oversights and wider assessment of mortality monitoring generally focussed on those reactive (i.e., incident driven) schemes that are designed to give a “snap shot” of poisoning incidents rather than issues relating to chronic exposure. The oversight across studies that is gained through these reviews often include conclusions on those chemicals giving the greatest frequency of observed effect. Most frequently organophosphate and carbamate PPPs are implicated, often when these have been used illegally. For example, in France over 80% of the red kites tested that were poisoned were affected by PPPs from these classes, along with anticoagulant rodenticides. With the removal of organophosphates and carbamate from use, recent assessments have noted a rising contribution of other insecticides in observed cases. For example, France has also reported over 100 mortality incidents of red kites resulting from the agricultural use of imidacloprid seed treatments. As well as these reviews of acute vertebrate poisonings, studies providing an overview of bee biomonitoring studies were also conducted. For example, studies identify how trapping can be used for the monitoring of PPPs in bee samples, as well as the potential for honey monitoring for multiple residue PPP assessments. Some reviews covered pharmaceuticals (Shore et al., 2014), or in America, the Animal Poison Control Centre reported that many of the cases involved human medicines, particularly over the counter medications. Other studies provided an overview of the potential response of species to particular PPPs, such as neonicotinoids (Millot et al., 2017).

The review papers identified that look at results across comprehensive programs, were a mix of national or pan-European reviews, that were undertaken by universities, government and research institutes, with funding via government and

EU programs (e.g., EURAPMON project), and industry. Papers were not always solely PPP focussed, with some including mainly multi-residue monitoring particularly for PPPs, but also biocides, pharmaceuticals and veterinary medicines.

Key strengths

- Collaborations can produce more complete datasets, especially where different agencies are involved from different countries.
- Reviews of large datasets from multiple studies over many years that are spatially referenced and have other meta-data, e.g., age, diet data, habitat data, provide an oversight of the major patterns and trends of exposure and effect in relation to agricultural practice and policy change.
- Reviews can provide an overview of the nature of mortality and exposure effects across different countries and multiple species.
- Bringing datasets together can allow the detection of temporal changes, e.g., sampling the same bee colony over time.
- Gives the potential to identify species at risk of poisoning and can monitor success of any mitigations introduced.
- Overviews identify agricultural and other management practices that make a poisoning incident more likely to occur, providing that appropriate data is also collected.

Key weaknesses

- Methods and approaches are not always directly comparable between datasets making direct comparison challenging.
- Studies that focus only on illegal poisoning do not inform risks from correct use, but identify toxic substances that may be used for illegal poisoning and so present a hazard to wildlife and other animals.
- Studies may provide indication of the trends of change, but do not necessarily provide a link to the cause to allow identification of environmental sources of a PPP.

Conclusion from review on potential role in PPP monitoring

- Bringing data together can strengthen collaborations between surveys to increase the potential to identify common patterns in larger-scale datasets, e.g., WILDCOMS

- Comparing schemes can allow the assessment of data to determine the value of use and best approaches for analysis.
- Used to identify new approaches as biomarkers to help develop and refine best practice in exposure and effects monitoring.

4.3 Approaches to PPP monitoring in the UK and internationally identified from stakeholder input

Consultation with stakeholders identified a non-exhaustive list of schemes and programs that are used for pesticide monitoring worldwide. An early survey of the approaches used to the assessment of vertebrate wildlife incidents involving pesticides for the period 1990-1994 in Europe identified only seven countries where possible poisoning cases were systematically recorded (de Snoo et al 1999). While this information is somewhat historic (although it is the most recent available information), it does capture information of the scale of assessment applied in different localities. The number of cases investigated varied widely across different countries. In France, the UK and the Netherlands there were hundreds of poisoning cases recorded and investigated compared to tens of cases in other countries (de Snoo et al 1999). Berny, (2007) also highlighted large differences in the identification and reporting of suspected poisoning cases for some animals, e.g., hares, and this was attributed to systematic reporting of dead animals via hunters (often with well-trained dogs who could more readily find carcasses) in some countries such as France compared to *ad hoc* public reporting and submission of a dead animal into a scheme (as done in the UK and the Netherlands). Berny identified nine European countries (Denmark, Finland, France, Germany, Greece, the Netherlands, Norway, Sweden, UK) with a network of wildlife pathology and toxicological evaluation, and four other countries (Austria, Belgium, Spain, Switzerland) where there were designated laboratories.

The UK's Wildlife Incident Investigation Scheme is the only scheme worldwide to assign categories of pesticide use to all the acute poisoning cases investigated (as there is also field information to support interpretation of residues found), and is also likely to be the most long-term scheme (systematic records since 1964). The data provided by WIIS has been used to enforce legislation, as well as inform pesticide approval and review decisions. The remit of WIIS has always been driven by detecting unexpected consequences of pesticide use, as it started due to concerns on the use of organochlorine pesticides. In other countries such as in France, pesticide incident schemes (such as the SAGIR scheme) were developed from disease monitoring activities, and supplemented by monitoring activities for restored species, e.g., red kite (SAGIR), or in response to concerns on particular PPPs (e.g., many studies on neonicotinoid insecticides). Below is a brief summary of activities of current monitoring schemes run in other countries that were identified through the consultation exercise.

Scottish Raptor Health Study : NERC case studentship project at University of Edinburgh lead by Gabriela Peniche. This study is assessing the health of Scottish raptors and using them as indicators of ecosystem health; bacteriology, parasitology, virology and toxicology testing are completed. The studentship is concluding, although sample collection is continuing. At the initiation of this project and presently, enquiries relating to submission of carcasses to the PBMS were referred to this project, with sub-samples of tissues being shared between these two initiatives.

The French Agency for Food, Environmental and Occupational Health and Safety have established the French Phytopharmacovigilance, which is a national scheme for monitoring the adverse effects of PPPs. This was established in 2015 and is unique in Europe as it takes all adverse effects into account, e.g., human, animal or plant health, or food or the environment. The objective is to anticipate, detect, analyse and prevent as early as possible any signals that may require measures to be taken to prevent or limit the risks associated with PPPs. There are three approaches to data collection and knowledge production: through a network of surveillance or vigilance bodies, information is collected and regularly reviewed across wildlife, crops, fauna, flora, air, water and soil; a collection of spontaneous reports; and ad-hoc studies on the adverse effects of PPPs. The ad-hoc studies may be required if clarification is warranted from the information provided by the surveillance and vigilance bodies, or to investigate spontaneous reports, or to collect new data or information. Funding for these studies is to be from a tax on sales of PPPs that is paid by the marketing authorisation holders. In 2018, a nationwide bee apiaries reference network was established to provide health status and toxic load of apiaries in different environmental and agricultural areas.

The French SAGIR monitoring scheme led by Philippe Berny, Vetagro'Sup and run by the Office National de la Chasse et de la Faune Sauvage (ONCFS) provided one of the key components that is included under the French Phytopharmacovigilance program. The objective of the SAGIR scheme is similar to that that of the UK WIIS, i.e., the surveillance of unexpected acute effects of pesticide on free-ranging wild birds and mammals, but it is part of the national network for the epidemiological surveillance of wildlife. Partnership funding between the hunters' federations, National Game and Wildlife Agency and Bird Life pay for the costs of testing. There is similar reactive sampling to WIIS, although given the funding arrangements the species tend to be those hunted, e.g., game birds and dead animals are often actively looked for, and a range of chemicals tested (some veterinary medicines and elemental analysis too). This work is supplemented with some proactive studies. Honey bees are not included in this work and the focus is on game species. A 'Toxinelle' group, which is a multi-disciplinary team that compiles expert reports from

Institut National de la Recherche Agronomique (INRA), Vetagro'Sup Lyon, ONCFS-SAGIR network and Centre for National Information on Veterinary Toxicology-CNITV (so domestic species as well as wildlife are included) directs research on toxicovigilance.

The United States American Association of Poison Control Centers has a National Poison Data System. Within this scheme, the National Pesticide Information Portal provide a site for the reporting of cases for wildlife pesticide incident reporting. The scope of the reporting scheme covers cases of adverse field effects on non-target entities, such as wildlife, birds, fish, shellfish, bees and plants. The information submitted is sent to the US Environmental Protection Agency (EPA), but it is not used for targeted enforcement. This allows anyone to submit a report (online or via a hotline telephone number) and some of these reports may have toxicological investigations completed. An overview of the information needed to submit a report is here. The National Pesticide Information Center (NPIC) is a cooperative agreement between Oregon State University and the US EPA. Data from the portal is used to inform decision making in the regulation of substances of pesticidal action including herbicides, disinfectants, fungicides, insecticides, natural and biological pesticides, repellents and rodenticides. There are also state pesticide regulatory agencies and some centres of expertise, e.g., Dr. Barnett Rattner at the USGS Patuxent Wildlife Research Centre maintains the Contaminant Exposure and Effects-Terrestrial Vertebrates database (CEE-TV)[6], contains contaminant exposure and effects information for terrestrial vertebrates (birds, mammals, amphibians and reptiles) that reside in estuarine and coastal habitats along the Atlantic, Gulf and Pacific Coasts including Alaska and Hawaii and the Great Lakes Region.

The California Pesticide Information Portal project (CalPIP) enables the general public to query from more than one data source to find information on pesticide related issues relating to authorisation and potential ecological effects. The portal is designed to allow the querying of multiple data source to retrieve information on pesticide related issues. Data sources available for query include the California Department of Pesticide Regulation records on pesticide use and label information, Ground Water Protection Area information and any limitations on pesticide use relating to endangered species risk assessment.

At the Julius Kühn-Institute located in Quedlinburg, Germany, Dr. Jens Pistorius investigates bee poisoning incidents. The approach is similar to that used by WIIS, whereby when pesticide exposure is suspected as a cause of death, this is reported

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[6] https://www.pwrc.usgs.gov/contaminants-online/pages/CEETV/CEETVintro.htm

to a local inspector who may then advise that samples are sent for further testing. The process is free of charge to the beekeepers and the process is carried out in close cooperation with the national plant protection services.

Geological Survey of Denmark and Greenland (GEUS) operates the Danish Pesticide Leaching Assessment Program (PLAP). The PLAP is designed to 1) evaluate if approved pesticides and/or their degradation products leach to the groundwater in concentrations above the permitted limit; and 2) To prepare and inform about the scientific foundation for optimising the Danish authorities' approval and regulation procedures for pesticides based on the collected monitoring data. Established in 1999, the PLAP monitors six fields, two sandy fields and four clayey till fields. Over the period 1999-2019, 130 pesticides and/or degradation products have been analysed but the suite of analytes reported each year varies according to what pesticides have been used in any given year on the six fields monitored. In the 2018/2019 hydrological year, 60 pesticides were evaluated[7].

Since 2003, the Swedish University of Agricultural Sciences (SLU) has monitored pesticides in groundwater (as well as surface waters and sediments) from four small catchments that are in relatively intensive agricultural areas[8]. These four catchments were chosen as it is thought they provide worst-case assessments of the impact from agriculture. Currently approximately 150 substances are analysed in ground water samples collected four times per year. The selection of substances to be included in the analyses is based on the usage in the model catchments, the mobility of the substance in soil, and the toxicity for aquatic organisms. Farms within the catchments are surveyed for agricultural practices including pesticide applications.

The German Environment Agency (UBA) has commissioned a proposal for an integrated in-field monitoring of PPPs (IMoP). Currently being drafted, the schemes will be designed to record and assess the presence of PPPs in the environmental and also their potential effects on biodiversity in the agricultural landscape. Included in the proposal are assessments of application rates of PPPs, residues in soil and biota, other factors (e.g., fertilization, soil cultivation, type of management, etc.), and biotope type-specific changes in the biotic community in a spatial as well as temporal context. These assessments would be carried out in target areas as well as on the spatially adjacent non-target areas. The proposal does not specify the scale of the

[7] http://pesticidvarsling.dk/wp-content/uploads/2021/01/The-Danish-Pesticide-Leaching-Assessment-Programme-2019-.pdf

[8] https://www.slu.se/en/departments/aquatic-sciences-assessment/environment/pesticide_monitoring/

monitoring but sets out the principles for samples and data collection, pesticide analysis, data management and implementation and coordination of the different components of the IMoP.

Potential lessons that can be taken from the stakeholder identified PPP monitoring schemes

- Some programs have identified the need to provide "one stop shop" for pesticide information. This could be done, for example, by bringing all PPP and contaminant related data together on a searchable online database, e.g., as done in the CalPIP[9].

- Some national schemes require authorisation holders to submit adverse data to CRD[10]. However, there could be a similar approach to the Yellow card scheme[11] for pharmaceuticals and adverse reactions for veterinary medicines[12]. Similar approaches for PPPs could also help identify possible trends or emerging issues of concern and horizon scan contaminants as is done for food monitoring work.

- Different national programs have different approaches to linking authorisation decisions to monitoring programs. In some case one agency conducts both aspects (e.g., US-EPA) while in other (notably across many European countries, authorisation and environmental monitoring is separate. Currently in the UK, we lack an overarching coordination or consistent way to access (e.g., mix of free telephone, online) all chemical incidents as HSE, local authorities, EA or WIIS could be involved. This depends on what is involved in any incident (e.g., people, environment, animals) and where the incident has occurred (i.e., workplace/home/garden) see here[13].

- In the UK, the split in authorising agencies, e.g., CRD (PPPs/Biocides etc.), Veterinary Medicines Directorate (veterinary medicines) and Medicines and

[9] https://calpip.cdpr.ca.gov/main.cfm

[10] http://www.hse.gov.uk/pesticides/topics/pesticide-approvals/pesticides-registration/applicant-guide/the-applicant-guide-adverse.htm

[11] https://yellowcard.mhra.gov.uk/the-yellow-card-scheme/

[12] https://www.vmd.defra.gov.uk/adversereactionreporting/Product.aspx?SARType=Animal

[13] http://www.hse.gov.uk/pesticides/topics/pesticide-approvals/enforcement/reporting-incidents.htm

Healthcare products Regulatory Agency (pharmaceuticals) can make it more challenging to fund tests for a wide range of contaminants. Although this review has focussed on PPPs, it is clear that there are other chemicals of concern that may impact on wildlife and the environment. Similarly, food, environment and farming are all regulated by separate agencies or departments (although Fera Science Ltd works across all these areas), which again makes a holistic approach more difficult to achieve. Also, given that going forward effects of PPPs are less likely to be from an acute mortality, there is a need for data across the ecosystem, to ensure that there are not unintended consequences of PPP use.

4.4 Conclusions

This literature review summarises some of the current approaches, research and surveillance activities centred on better assessment of PPP impacts in the terrestrial environment.

Several of the studies reviewed were monitoring activities centred around assessing honey bees and hive products, both through assessment of effects on populations and also pollen and honey, data which can be used as a potential bioindicator of environmental contamination and resulting chronic exposure, including larval stages. Monitoring of honey bees can provide data on spatial and temporal trends in the health status of bee colonies as potential information that may be relevant to PPP exposure impacts. The challenge with bee populations may be in linking hive and population status to exposure, although measurement of hive resources can help in this aspect.

Monitoring of vertebrate species, especially top predators, is also commonly used to assess both exposure and effect of PPPs resulting from direct contact and in some studies residues in dietary items. For these studies, ensuring that sampling strategies are fit for purpose and focussing resources on a few key species, with a comparison of exposure and mortality in different habitats is important. Other countries have also taken actions to ease and promote the reporting, collection and coordination of all PPP and contaminant related data by an online presence and using searchable databases. This approach could also help identify possible trends or emerging issues of concern and horizon scan contaminants as is done for food monitoring work (the WILDCOMS network partly addresses coordination of some monitoring activities already).

One of the major challenges for any environmental PPP assessment study is to move beyond measurement and correlation to investigate the potential links resulting from exposure to any effects on individuals or populations at field and larger spatial scales. Making use of other datasets that are not directly related to PPPs on the presence and distribution of focus taxa and species may also be important to help identify other more subtle effects, such as reproductive success, that ultimately may impact populations. Many of the papers reviewed long-term datasets and these are clearly valuable in elucidating possible trends and potential impacts that could arise for these monitored populations as a result of PPP use. Funding for such research was variable and rarely long-term. Given the vagaries of national and international funding, the long-term sustainability of these schemes can often be in doubt. Analytical chemistry is an expensive resource, so data that does not require such laboratory approaches may be valuable (e.g., usage survey information, species surveys and demographic trend analysis). Further there is a trade off in analysis between broad screening approaches that may be used to identify the presence of 10s or even 100s of chemical, albeit semi-quantitatively and fully quantitative high resolution targeted measurements for specific substances. The former can deliver extensive information, however, to detect quantitative trends full quantification may be needed. Monitoring programs also need to be realistic in terms of the difficulty in finding samples for analysis particularly for passive schemes. Citizen science is a common solution to these challenges and has worked well in a number of cases, including notably the PBMS in the UK. Widespread, intensive monitoring studies may detect unforeseen effects or indirect effects and allow estimation of the level of mortality due to PPPs within a population.

No ideal monitoring methodology was found that could be used as a single, overall approach for terrestrial PPP exposure and effect monitoring. Other countries also rely on multiple approaches organised through different centres of expertise, or key professionals, and there may be tensions between the stakeholders involved in the monitoring activities, e.g., shooting and hunting agencies and conservation organisations. Typically, the research activities and surveillance programs may only demonstrate a causal link to PPPs where an acute mortality occurs, while other effects that may impact populations such as sub-lethal effects on immune function, or reproductive output are more challenging to monitor. These are likely to require intensive and expensive research studies in order to tease out the impacts from PPPs alone. The development of greater understanding of the “Adverse Outcome Pathways” of PPP effects on species that will arise through ongoing scientific research may help in the future to identify the potential suites of biological measurements that could be used as an indicator of species effect. At present the number of such agreed and verified effects based indicators is limited. However, even in the absence of such measures, coordinated monitoring programs to assess PPP residues across multiple environmental compartments will still offer the potential to assess temporal or spatial trends in occurrence of PPPs and to identify any associations with biodiversity changes that may be taken forward for further diagnostic investigations.

5. Initial selection of existing monitoring programs

This section provides information on the range of potential approaches and monitoring schemes that were considered for potential inclusion a potential scheme for the terrestrial monitoring of authorised PPPs and their effects. The assessment concentrates on approaches that are currently ongoing or are under development that focus on UK specific pesticide use, exposure or impact assessment. Additionally, schemes were also assessed that are not currently assessing pesticide exposure or impacts, but which are involved in activities that could provide resources that could be used for pesticide assessment, e.g., field sampling to collect environmental samples such as soils or biological information or samples.

5.1 Scope of schemes considered

For the purposes of this report, the monitoring schemes that were considered included those that directly quantify PPPs in terrestrial samples, generate similar samples that could be analysed, or monitor wildlife populations in direct relation to PPP use. Monitoring schemes that monitor populations without reference to PPP use were considered outside of the scope of this report. However, the authors acknowledge that such data, which could for example provide information on population trends or spatial distributions of invertebrate and vertebrate species could be complementary to, and could be used in conjunction with, the results of PPP monitoring. The potential for the integration of this wider resource of biodiversity and below-ground environmental "health" information is discussed latter in this report (see Section 9).

Following identification of candidate schemes for inclusion in the proposed monitoring program through the literature and existing scheme review, background knowledge of authors and experience through the WILDCOMS network, one-to-one discussions were held with scheme representatives to gather generic information on the schemes (see Appendix 5.1 for types of information gathered). Candidate schemes were then selected for inclusion in a second phase of development by the report authors and agreed by the project steering group. Individuals able to act as representatives of the schemes that were identified for inclusion within this second phase of assessment were invited to participate in two technical workshops to discuss the potential value and wider integration of their schemes within a potential overarching monitoring program. The first technical workshop presented the aims, scope and status of the project to the scheme representatives and gave the opportunity for each scheme to give a summary of its aims, how it works and data outputs. The schemes considered in the first phase of the review are described below.

United Kingdom Eutrophying and Acidifying Network (UKEAP)

The UK Eutrophying and Acidifying Pollutants (UKEAP)[14] network project combines two Defra atmospheric pollutant monitoring projects, which have measured air pollutants at rural sites across the UK over the past two decades. This network provides information on deposition of acidifying compounds in the UK. Its main emphasis has always been the assessment of potential impacts on UK ecosystems. Other measurements including sulphur dioxide, nitrogen dioxide and particulate sulphate have also been made within the program in order to provide a more complete understanding of precipitation chemistry in the UK. The network provides access to a set of sampling sites that could potentially be used to collect samples for pesticide analysis. The network manages in total 41 sites, collecting samples of media such as rainwater that could in theory be used to assess the movement and transport of pesticides via air to reach terrestrial ecosystems via rain. The focus on rainwater monitoring is, however, less relevant than other sampling programs that would provide access to soil samples.

Pesticide Usage Survey (PUS)

Data on the usage of pesticides in the UK has been collated from across Great Britain for the last 50 years and continues to be collated today[15] and published as the Pesticide Usage Survey (PUS). The Land Use Sustainability team at Fera Science Ltd. plays a leading role in this, applying their skills, knowledge and experience to gather the data, produce guidelines and create powerful, accessible databases for industry. Fera is commissioned to conduct agricultural, horticultural and amenity pesticide usage surveys by the CRD of the HSE. The surveys are funded from the pesticides charge on turnover, and the costs are paid to Fera by the CRD. The survey provides information on the predicted application amounts of PPPs for a range of UK crop categories (e.g., major UK arable crop types, soft fruit production, orchard crops). Data for these different crops are generated for a sub-sample of grower submissions, with this data scaled up to national scale based on the proportion of grower samples and acreage covered under the submissions compared to the total national crop. PUS assessments are undertaken from crops either biennially, or every four years. The repeat temporal nature of the collection of PUS data means that it is possible to track trends in pesticide use across crop types and at a regional (e.g., county level) scale.

[14] https://uk-air.defra.gov.uk/networks/network-info?view=ukeap

[15] https://secure.fera.defra.gov.uk/pusstats/surveys/

Pesticide Application Maps (PAM)

By combining information on cropping patterns from CEH Land Cover® plus: Crops with national survey data on pesticide and fertiliser use, UKCEH has created two new data products: CEH Land Cover® plus Fertilisers and CEH Land Cover® plus Pesticides[16], known as Pesticide Application Maps (PAM).

These maps estimate average fertiliser and pesticide applications between 2012 and 2016 for the whole of England, and Great Britain respectively. The data that is used for the assessment of pesticide inputs to crops is drawn from the PUS, which has resolution only at country scale, meaning that assessment of use are not site specific, but averaged across the particular country area used. The assessment of the locations of application, i.e., cropping information, is, however, available at smaller scale, meaning that the potential for aggregated addition to individual crops can be mapped for each 1km^2, although finer-scale estimates (potentially at the field-scale) would be feasible should this be desired. The PAM offer a unique fine resolution national dataset of application rates. The maps have been developed to aid research into the environmental impacts of agriculture and to help develop sustainable farming solutions.

UK Pesticide Load indicator (UKPLI)

Defra and contractors at the HSE and University of Hertfordshire have been undertaking a project that aims to build on a Danish method for pesticide load assessment to develop a UK specific approach – the UK Pesticide Load Indicator (UKPLI). A three phase approach has been followed in the modification of the Danish approach to the UK circumstance. The overarching approach is based on an initial scoping of the Danish method; its co- development following a stakeholder consultation exercise; and a final stage that demonstrated its application in two well-chosen case studies based on recent decisions in UK pesticide management policy. The UKPLI approach is based on using input data drawn from two existing databases, the UK Pesticide Usage Survey and Pesticide Properties Database. Information from these two sources are used to derive a series of volume usage related and “hazard” metrics for each active ingredient and some primary metabolites for those pesticides that have approved uses recorded appropriately over the last decade. These collated use and hazard data are analysed in order to calculate a load indicator value for each of the different active ingredients. The values are then aggregated into values for all substances for generating the overall UKPLI that is

[16] https://www.ceh.ac.uk/services/ceh-land-cover-plus-products-fertilisers-pesticides

used to look at different aspects and trends in UK pesticide use and changes in responses to different UK pesticide management policies. To date, the UKPLI approach is in development, with plans for inclusion as one of the potential indicators currently being developed as part of the Defra 25 Year Environment Plan, specifically the *H4: Exposure and adverse effects of chemicals on wildlife in the environment (exposure of people and wildlife to harmful chemicals)* that is being developed collaboratively by representatives from Defra, the Environment Agency, the Health and Safety Executive, Natural England, and UK Centre for Ecology and Hydrology, with contributions from organisations such as Cefas and Fera.

ASSIST Farmland Soils Archive (ASSIST)

Samples of farmland soils are collected and archived as part of the Achieving Sustainable Agricultural Systems (ASSIST) program, a long-term collaborative National Capability program lead by UKCEH with contributions from Rothamsted Research and the British Geological Society. Samples, stratified over soil types, are taken from 400 sites per year, with multiple samples from individual farms allowing within-farm variation to be quantified. Sampling from specific fields is on a five year cycle, and the main data generated by this project are soil health and physicochemical properties, soil mesofauna, and microbial biodiversity (both by e-DNA analysis). Soil samples are archived alongside their associated meta-data relating to collection location, site characteristic and collection times. These samples would be available for PPP analysis and collection could be extended with the provision of additional resources to manage the organisation of collection within the network.

Soil and Vegetation Research Platform (SVRP)

UKCEH's Soil and Vegetation Research Platform (SVRP) samples soils from a range of agricultural and natural semi-natural habitats, generating soil chemistry data (soil pH, carbon, nitrogen and phosphorous). Soils are archived (at -20°C), and would be available for analysis of PPPs. Sampling followed countryside survey methodology and is structured across habitat types.

Long Term Monitoring Network (LTMN)

Natural England contributes to the Environmental Change Biodiversity Network through its Long-Term Monitoring Network (LTMN)[17]. The LTMN monitors weather,

[17] http://publications.naturalengland.org.uk/publication/4654364897050624

air quality, land management, vegetation, soil chemistry and communities, bird and butterfly populations in 37 sites across England on a multi-annual rolling program. As part of these activities, soil samples are collected and stored.

National Honey Monitoring Scheme (NHMS)

The National Honey Monitoring Scheme (NHMS)[18] has been operated by UKCEH since 2018. The aim of the scheme is to collect honey samples from known locations across the UK (around 600 sites). Beekeepers send in between one and three samples directly from the honeycomb, representing early-, mid- and late-season depending on location. DNA barcoding is used to determine the plant species the honey bees are feeding on. Research has been undertaken to explore the potential of barcoding to identify the presence of fungal and bacterial diseases on bees. Archived samples have previously been used to determine concentrations of pesticide residues. As part of the submission process supplementary information is collected such as: (i) how much honey the hive or apiary is producing, and (ii) whether there have been any hive deaths, occurrence of disease, or disease treatments applied.

Rothamsted Insect Survey (RIS)

The Rothamsted Insect Survey (RIS)[19] is operated by Rothamsted Research and consists of a nationwide network of suction and light traps that aim to specifically collect aphids and larger moths, but that also will collect many other insect species. The two trap networks have been in operation since 1964, with 16 suction trap sites that capture daily samples of aphids in spring through autumn, and weekly samples in winter, while the light-trap network consists of 80 traps across the UK and Ireland with most traps run by volunteers who contribute data to the network. The identification of the aphids and moths collected is carried out by Science and Advice for Scottish Agriculture (SASA) and Rothamsted Research. The information from the aphid survey is used to act as triggers for the authorised use of some PPPs for pest management. The overall platform currently has a focus mainly on assessing the two priority groups. However, the sampling methods (especially the suction traps) will collect a wider group of insects and indeed other invertebrate species that could be used to support understanding the status of invertebrate communities (including as part of CFI calculation, see below).

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[18] https://honey-monitoring.ac.uk/

[19] https://www.rothamsted.ac.uk/insect-survey

Rothamsted Earthworm Survey (RES)

The Rothamsted Earthworm Survey (RES)[20], which was a coordinated one-off survey that concluded in 2019, was conducted by Rothamsted Research and generated data on the abundance and types of earthworm present in pasture, arable and horticultural fields. This was a citizen science project where farmers surveyed earthworm populations in their fields and provided field management data such as PPP application and tillage regimes. The scheme organisers designed an earthworm sampling process that could be conducted consistently by a distributed set of volunteers within 60 minutes. The scheme was explained in a guidance document that described how to do the survey. The scheme was successful in securing sampling of 126 sites for earthworms. This information was then collated, assessed and analysed in relation to field management practices by Rothamsted Research and has been reported and published (Stroud 2019).

Wildlife Incident Investigation Scheme (WIIS)

The Wildlife Incident Investigation Scheme (WIIS)[21] is a long-running surveillance program that investigates the death or illness of wildlife, companion animals and beneficial invertebrates (honey bees, bumblebees and earthworms) that may have resulted from pesticide poisoning. Where poisoning is suspected, a combination of field work, veterinary examination and chemical analysis is used to try to determine the underlying cause of death.

The scheme is operated independently in all four countries of the UK with joint quarterly reports published. In England, the CRD of the HSE has overall responsibility for the policy of the scheme which is run on HSE's behalf by Natural England. If a suspected case satisfies the criteria for further investigation a Wildlife Management Advisor from Natural England carries out a field investigation taking samples for analysis. A veterinary examination is usually carried by one of the APHA laboratories and residue analysis is conducted by Fera Science Ltd.

If the incident involves the death of honey bees and samples have been sent to the National Bee Unit (NBU) for an assessment for disease, the NBU will contact Natural England to alert them of a potential incident. A Wildlife Management Adviser will

[20] No website is available for this scheme.

[21] https://www.hse.gov.uk/pesticides/reducing-environmental-impact/wildlife/

liaise with the Bee Inspector and depending on the circumstances may arrange a visit with the bee inspector if this has not already been done.

Mortalities resulting from exposure to pesticides may be categorised as resulting from one of three types of use:

- Approved use – a pesticide is used in accordance with its conditions of authorisation;
- Misuse – the product has not been used according to the conditions of its authorisation, but often just carelessly or accidently, without the intention of harming animals;
- Abuse – a pesticide has been deliberately used in an unknown, including potentially illegal, manner to poison, or to try to poison animals.

The results of WIIS provide information to the regulator on hazards to wildlife and companion animals and beneficial invertebrates from pesticides.

Chick Food Index (CFI)

The Chick Food Index (CFI)[22], operated by the Game and Wildlife Conservation Trust, monitors insect and weed taxa diversity in arable crops in relation to field management, in particular PPP applications. This data is used to predict consequences for game and wild bird populations. Monitoring is carried out at two sites, one in Sussex and a second at Loddington, Leicestershire; these sites have been monitored for 50 and 25 years, respectively. The monitoring involves annual sampling of invertebrates, identification, data processing, analysis and reporting. The information from the results of the CFI studies are included in information provided on the Game and Wildlife Conservation Trust website[23] and in research papers (e.g., Holland et al. 2012).

Predatory Bird Monitoring Scheme (PBMS)

The Predatory Bird Monitoring Scheme (PBMS)[24], operated by UKCEH, is a long-term, national monitoring scheme that quantifies the concentrations of contaminants

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22 https://www.gwct.org.uk/research/species/birds/grey-partridge/chick-food-index/

23 https://www.gwct.org.uk/research/species/birds/grey-partridge/chick-food-index/

24 https://pbms.ceh.ac.uk/

in the livers and eggs of selected species of predatory birds in Britain. The aim of the PBMS is to detect and quantify current and emerging chemical threats to the environment. It achieves this by monitoring the concentrations of contaminants of concern in bird carcasses and eggs. This provides information on the extent of risk to vertebrate wildlife (and potentially humans), and how this varies temporally and spatially. The PBMS is a citizen science project that relies upon submission of dead birds by the general public. All birds received are examined and tissue samples archived, the archive holds samples from the late 1960s to the present. A stratified sub-set of archived samples are analysed for contaminants on an annual basis. The current suite of contaminants monitored does not include PPPs, but UKCEH has the capability to do so, and has done so in the past. Data from the PBMS are published in annual reports that are available through the UKCEH website[25], as well as being extensively published by the scheme researchers and scientists from the funding agencies.

Garden Wildlife Health (GWH)

Garden Wildlife Health (GWH)[26] is a collaborative project between the Zoological Society of London (ZSL), the British Trust for Ornithology (BTO), Froglife, and the Royal Society for the Protection of Birds (RSPB) which aims to monitor the health of and identify disease (contagious and non-contagious) threats to British wildlife. As part of the project, an archive of samples is generated and maintained with associated post-mortem observations. In recent years, a sub-sample of tissues has been submitted to the PBMS for inclusion in their contaminant monitoring. Residue analysis of PPPs is not routinely carried out, rather conducted as retrospective studies in collaboration with analytical laboratories (such as the PBMS).

Disease Risk Analysis and Health Surveillance (DRAHS)

The Disease Risk Analysis and Health Surveillance (DRAHS)[27] project is a collaborative initiative between the ZSL and Natural England established to investigate the health and disease implications of interventions carried out for conservation purposes. As part of the project, DRAHS receives wildlife carcass submissions, including re-introduced species such as red kites and threatened native species. Specimens are examined and tissue samples are archived. In recent years,

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[25] https://pbms.ceh.ac.uk/content/pbms-reports

[26] https://www.gardenwildlifehealth.org/about/

[27] https://www.zsl.org/science/wildlife-health/disease-risk-analysis-and-health-surveillance

a sub-sample of raptor tissues has been submitted to the PBMS for inclusion in their contaminant monitoring.

Wildlife Disease and Contaminant Monitoring and Surveillance Network (WILDCOMS)

While not a monitoring scheme in its own right, the Wildlife Disease and Contaminant Monitoring and Surveillance Network (WILDCOMS), has been established from Knowledge Exchange funding from the Natural Environment Research Council (NERC) as a collaborative network between various UK surveillance schemes that monitor disease and contaminants in vertebrate wildlife. The aim of WILDCOMS was to provide a central point for disease and contaminant monitoring in wild vertebrates to provide a platform for a more integrated overview of the health status of UK wild vertebrates. The network facilitates collaboration between the different WILDCOMS partners. These partners include: UKCEH's PBMS, WIIS and WISS Scotland, APHA's Diseases of Wildlife Scheme (DoWS), Cardiff University's Otter Project, Marine Scotland's Clean Seas Environment Monitoring Programme (CSEMP), ZSL's Disease Risk Analysis and Health Surveillance Program, UK Cetacean Strandings Investigation Program (CSIP), Scottish Environment Protection Agency's (SEPA) Lipophilic monitoring network, and the National Fish Tissue Archive. As many of the individual schemes in the WILDCOMS network rely on the public to send in dead birds and mammals that they find, the scheme has the potential to support the effective sourcing of samples from a range of different existing networks.

5.2 Schemes carried forward to second phase of review

Table 5.1 briefly summarises the pros and cons for each candidate scheme and the reasons for excluding some schemes from the second phase of the review. Four candidate schemes were excluded from the second phase of review, and so were not invited to attend the two technical workshops; namely UKEAP, LTMN, RIS and DRAHS.

Table 5.1 Summary of main pros and cons for each candidate scheme and the reason for exclusion from the second phase of review.

Scheme	Take to Phase 2?	Pros	Cons	Notes
1.UKEAP	No, exclude from second phase review because air concentrations are rarely used in environmental risk assessment and is not thought to be a significant exposure pathway for wildlife			
2. PUS	Yes	• Directly relates to PPPs • Key data for linking use and effect. • Only information we have on use. • Short to Medium term security in funding. • With electronic recording of use becoming more prevalent then potential for improved precision and frequency of survey.	• Currently generates interpolated data from surveys that receive information from growers for specific crops every two of four years. • Only statistically robust down to a regional scale	
3. PAM	Yes	• Gives prediction of risk from multiple PPP applications. • Allows second tier risk assessment (at local scale)	• Modelled based on PUS (i.e., interpolated data).	• Refinement of PUS through use of crop maps

Scheme	Take to Phase 2?	Pros	Cons	Notes
4. UKPLI	No	• Calculate a load of PPP applied in relation to a number of fate and hazard related effect metrics. • Can be calculated from existing data collected in PUS and from regulatory data in the pesticide property database,	• The UKPLI approach is not yet finalised for applications • The approach is designed for higher level reporting, its use for case specific assessment will be best supported by assessment of how change in usage affects individual metric rather than the overall indicator. • The Pesticide Property database provide a set of data on studies conducted to support the regulatory assessment of PPP, but this dataset may miss key studies conducted in the scientific literature that could contribute to the assessment.	• A report on the current status of development of the UKPLI is being prepared for publication. After this is released, the status of this potential indicator should be assessed to determine if it should be included within the developing overall scheme.

Scheme	Take to Phase 2?	Pros	Cons	Notes
4. ASSIST farmland soils	Yes	• Source of agricultural soils for analysis. Includes measures of soil function that would provide supplementary information to any PPP analysis carried out. • Easy to increase scale of monitoring.	• Reliant on NERC NC funding.	• Further funding would be required to add PPP analysis
5. SVRP	Yes	• Source of agricultural and non-agricultural soils for potential PPP residue measurement.	• Rolling program so number of samples available from different habitat types can vary within years • Program operates on a 5 year time window for site resampling meaning that high resolution temporal assessment at the same sites are not possible.	
6. NE LTMN	No, exclude from second phase review because this scheme is only conducted in protected areas and so not representative of wider environment			

Scheme	Take to Phase 2?	Pros	Cons	Notes
7. NHMS	Yes	• Provides measure of aspects of the exposure of pollinator species, including larval stages, to pesticides. • Samples are already archived. • Complementary source of information to inform National Pollinator Strategy. • Could inform wider-use chemical management.	• Currently not measuring PPPs routinely (but studies have been carried out for neonicotinoids). • Dependent upon NERC NC funding. • Kinetics of accumulation in unclear and may vary among active substances.	• Coupling sampling strategy with PUS or PAM could provide platform to assess exposure, while use of existing hazard information may allow the modelling of potential hazard based on exposure levels (e.g., for larvae).

Scheme	Take to Phase 2?	Pros	Cons	Notes
8. RES	Yes	• Strong links to environmental risk assessment (ERA) procedures as earthworms are a focus taxa for terrestrial assessment. • Potential valuable information, although the extent to which the results are impacted by other driver (e.g., tillage) will need to be considered.	• Sampling of earthworms would require significant change to protocol and would require continuous buy-in and support from by farmers for sample collection, although reports from the scheme identified enthusiasm for earthworm monitoring among land managers (stroud 2019). • Earthworm populations are known to be affected by land and soil management practice (Spurgeon et al 2013) and these effects could override any potential primary or secondary effects results from PPP applications and exposure.	• Inclusion or co-alignment with ASSIST program would increase value of RES.

Scheme	Take to Phase 2?	Pros	Cons	Notes
9. RIS	No – this scheme provides vital information for monitoring moths and aphids, however, there is a wide interest in the effects of PPPs on terrestrial insect species including beneficial natural enemies and pollinators. For pollinators, there are already alternative monitoring approach available (e.g., through the UK Pollinator Monitoring Scheme[28]). Further the scheme as it stands does not include assessment of all of the groups needed for calculation of other metrics.			

[28] https://www.ceh.ac.uk/our-science/projects/pollinator-monitoring

Scheme	Take to Phase 2?	Pros	Cons	Notes
10. CFI	Yes (effects measure but not specific to PPPs)	• Opportunity to roll out to farmers to complete as part of agri-environment scheme. • Generates data on the effect of PPP use in the field on species from taxa, e.g., beneficial natural enemies, already considered (e.g., though lab based testing and higher tier field studies) as focus groups within regulatory risk assessments. • Provides information on potential PPP effects on food resources to allow the assessment of potential secondary effects on species of conservation concern (e.g., farmland birds).	• Currently of limited spatial scope (two areas) but ones that are fairly representative of farming practice cross UK. • Rolling out to agri-environment scheme would require training of farmers.	• Similar to RES

Scheme	Take to Phase 2?	Pros	Cons	Notes
11. WIIS	Yes	• National, long-term, multiple species. • Identifies mortalities by type of use (approved/misuse etc.). • Identifies incidents where approved use results in mortalities.	• Measures effect at individual rather than population level. • Mortality focussed (doesn't address sub-lethal effects). • Biased sample in terms of cryptic or uncharismatic species are under reported. • Incident are treated as individual events and there is not clear mechanisms to feed information into PPP use and management. • Incidents may be missed where mortality is latent. • Misses opportunities to archive samples due to strict WIIS investigation criteria.	• More can be done to utilise the platform to proactively archive and analyse carcasses. For example, application could be extended to investigations of amenity use and for repeat case assessments.

Scheme	Take to Phase 2?	Pros	Cons	Notes
12. PBMS	Yes – but likely ancillary in that could support sample collection	• Has established network and methods for collection by members of the public. • Existing archive of samples. • Provides information on secondary exposure.	• Detection of secondary exposure may be limited because many PPPs are rapidly metabolised and not accumulated. • Not currently focussed on analysing wide range of PPPs, with the current focus including industrial pollutants (PCBs, PBDEs, fluorinated chemicals), mercury and biocides used as rodenticides.	• Quantification of primary exposure likely to require different species to those currently studied.
13. GWH	Yes – but likely ancillary in that could support sample collection	• Existing archive of samples. • Could be a measure of amateur and urban use that is not currently monitored. •	• Mostly restricted to peri-urban samples.	
14. DRAHS	No - Covered by other schemes as it refers samples to both WIIS and/or PBMS			

5. 3 Final shortlist of schemes to fit into the monitoring program

The questions that could be addressed and the monitoring metrics recorded were discussed as part of the second technical workshop and through further review by the project team. For the schemes that are recommended for inclusion in the monitoring program, these are described throughout Section 6 and summarized in Section 6.8. The type of information captured, and questions discussed is illustrated in an exemplar for the Rothamsted Earthworm Survey (Table 5.2). The information to support the completion of these tables for each assessment scheme was collected by asking the set of questions details in Table 5.3 to the representatives of each of the assessed schemes.

Table 5.2. Exemplar of summary data produced during technical workshops

Question	Observation
Component:	Effects
Compartment:	Terrestrial Invertebrate
Questions that monitoring would address:	Is earthworm density (three ecological groups rather than species), or adult to juvenile ratio changing over time in agricultural soils?
How data gathered:	Farmer survey of soils Survey carried out in one week (23rd-31st March) of the year – negates intra-year variation.
Draft reporting metrics:	❑ Average abundance of worms per unit sampling effort ❑ Average adult to juvenile ratio
Directly related to PPPs:	No, although field management including pesticide applications are recorded
Scheme:	Rothamsted Earthworm Survey
Deliverable under future anticipated activity:	Yes

What would additionally need to be done to report these metrics?	None
What aspect of the RA would this inform?	Knowledge of extent of specific PPP use is simplest measure of possible risk [no use = no risk]
How do existing activities need to be enhanced to strengthen information?	Annual values [but note concern over farmer resistance to more frequent surveys] This data is recorded on an annual basis but not a legal requirement to report.
Information on power of monitoring or additional analyses/comments?	No information but should be able to assess given standardised sampling technique.

Table 5.3. Questions asked during one-to-one interviews and questionnaire completion in Phase One of candidate scheme selection.

Questions:	
1	Please provide the full name of the scheme.
2	Please provide the usual, or preferred abbreviation of the scheme.
3	What legislation is enforced by the scheme, or not?
4	If available, please provide the website-hyperlink for the Scheme.
5	What organisation runs the scheme?
6	What are the other collaborating organisations in the Scheme? Put **none** if only one organisation involved.
7	Who is the key named contact for the scheme?
8	Please provide the email and telephone for the key named contact.

Questions:	
9	What quality system(s) does your organisation adhere to e.g., **ISO 9001**? Please include those of other collaborators if available or known.
10	What quality system(s) apply to the scheme e.g., **GLP, UKAS?**
11	Estimated cost of the scheme (annual cost if long term or ongoing)
12	Please indicate who funds the scheme.
13	Please describe the security or commitment of funding e.g., it may be an annual budget, MoA etc.
14	What are the key outputs, or how are results of the scheme reported e.g., **peer reviewed publication, published report, internal report** etc.
15	What is the frequency of these outputs, results or reports e.g., **monthly, quarterly, annual**?
16	What is the geographical scale of the scheme e.g., **Limited** (i.e., local, or county, or regional scale) or **Unlimited** (i.e., country, national scale)?
17	Please describe the geographical scale of the scheme e.g., 12 field sites in Devon, or the county, country or state?
18	Is the sampling in the scheme planned **Active** (e.g., intentionally monitoring/looking for samples or mortality/effects) or **Reactive** (e.g., reacting to / waiting for samples or mortality/effects)?
19	Please indicate if the scheme is **long-term** (i.e., over a year)**,** or a **one-off**.
20	Please indicate if the scheme is **past or ongoing**.
21	If available, please provide the start and end date; or the date the scheme started for ongoing monitoring schemes.
22	What is the sampling methodology for the scheme, e.g., skilled or unskilled carcass search, questionnaire, trapping, tagging, or tracking.

Questions:	
23	What is the timescale for sample storage e.g., **short-term** i.e., dispose sample when testing complete, **long-term** i.e., kept for specified time, **archived** i.e., samples are archived for future use.
24	Species scale of the scheme: Is this a **single species** or **multi-species** scheme?
25	What species are included (provide species name for single species and class, or other grouping for multi-species)?
26	Chemical scale of the scheme: Is this a single chemical/residue, or multi-chemical residue/chemical, or other (e.g., biomarker) scheme?
27	What pesticide class(es) are included in the scheme (historic and current) e.g., **Plant Protection Products, Biocides, Veterinary medicines**
28	What pesticide type(s) are included in the scheme e.g., **insecticides, herbicides, rodenticides,** etc.
29	Please provide the number of pesticides included in the scheme and if possible, provide a separate list of them.
30	Is the key aim of the scheme **post-registration monitoring, research and development, other?**
31	Please describe the main aim or objective of the scheme in a sentence.
32	Please describe the types of data or datasets that you produce.
33	Please can you provide keywords for these data?
34	Is there any other information that the scheme could provide e.g., about pesticides, or data for national statistics?
35	What are the key strengths of this monitoring scheme?

Questions:	
36	Are there any actions that could be implemented to improve, or create more useful outcomes from this scheme?
37	Are there any barriers to these improvements, or better outcomes, for this scheme?
38	Is there any other information about your scheme that is not covered by the questions above then please include these details here. If there is nothing more to add, please confirm this too.

6. Description of component monitoring activities

6.1 Composition and structuring of the monitoring scheme

In this section, how monitoring activities shortlisted in Section 5 can be incorporated as component parts of an overall holistic monitoring program are described. The aim is that the activities link across different purposes (usage, presence and magnitude of residue levels as indicators of use and persistence, measurements of effects) and environmental or trophic compartments. Usage (Section 6.2) would be a distinct activity while residue and/or effects monitoring would span the following four environmental compartments:

- Soil (Section 6.3)
- Terrestrial invertebrates (Section 6.4)
- Pollinators (Section 6.5)
- Vertebrate wildlife (Section 6.6)

In addition, one further activity, "Coordination and reporting" is also considered (Section 6.7)

The proposed general monitoring activities are described in each section below and how the activities could record metrics that would address key exemplar questions are outlined.

It is stressed that the descriptions of the activities are broad-brush. The aim here is to provide an understanding of the types of information that could be obtained from the monitoring activity and how each would be a component part of a holistic monitoring program. The specific details of how each activity would operate and contribute to the overall monitoring program requires further detailed development that is beyond the scope of the current project. Similarly, the questions posed in this section are exemplars rather than definitive and the detailed aims and objectives of each component of a monitoring program would need to be worked through.

Each activity in the proposed monitoring program is classified into one of three levels based on: (i) whether the activities currently exist or would have to be developed from new, and: (ii) the extent to which such activities are likely to be a fundamental requirement of an integrated monitoring program. The three levels are shown in Table 6.1 below.

Table 6.1. Description of the different levels assigned to monitoring activities

Level	Descriptor
Level 1	Already running/could be adapted from current schemes.
	Fundamental information for compartment
Level 2	Would provide additional data valuable for interpretation of, or linkage across, environmental/compartments.
	Potential development could be reviewed once Level 1 monitoring is established
Level 3	Needs further research to assess value and practicality

6.2 Usage

Usage data itself does not specifically provide information on exposure to or the effects of PPPs on the environment. However, such data are a fundamental building block of any overall post-registration monitoring scheme for PPPs. Knowledge of usage is a key element when examining changes in environmental residues or exposure and effects in biota. In particular, the occurrence of any such changes in the absence of altered usage may well be a first indicator of a change in the environmental fate, behaviour and subsequent risk for an active substance.

There are currently two possible data sources by which usage data could be incorporated into an overall holistic pesticide monitoring scheme.

6.2.1 Pesticide Usage Survey (PUS)

Level 1	Already running/could be adapted from current schemes. *Fundamental information for compartment*

The Pesticide Usage Survey (PUS), as briefly described in Section 5, conducts surveys of PPP use on crops across the UK. The type of data provided in each report by the PUS includes:

- Area of crops grown, and areas treated with different PPPs broken down by region
- Timing of application
- Average numbers of applications
- Weight of individual PPPs applied (data also summarised by pesticide type such as insecticides, fungicide, etc.)
- Change over time in the above metrics

It is not the purpose of the current report to review the methodologies of the PUS. However, it is clear that the PUS provides fundamental information on the extent of PPP usage and spatial and temporal trends therein. These data may be reported in their own right to address questions, as in the bullets below. Such data provide an indication of the rise and decline in usage of both individual PPPs and in classes (based on chemistry or function) of active substances.

Examples of questions which can be addressed by PUS are:

- Which are the top 20 of each of insecticides, fungicides, herbicides, nematicides, in terms of total area applied and total weight applied?
- How has spray area and application weight of each active substance changed over the last 10 years?

Furthermore, PUS data are needed to understand the extent of, and changes in use of, specific PPPs that may be flagged elsewhere in the monitoring program. However, because the PUS describes pesticide use on different crops in alternate (or in some cases every four) years, consideration over methodology would be needed if usage data was required on an annual basis.

The PUS can provide information in both temporal and spatial changes in use. However, spatial information is typically reported at a regional level, and reflects that the data that are collected are not spatially structured at a landscape level. More detailed consideration of spatial variation in pesticide use requires other techniques (see Section 6.2.2).

Finally, the PUS is a long-established viable program that could continue reporting under existing resourcing arrangements. This, together with the fundamental nature of the data provides, means that the PUS has been classified as a Level 1 level activity in the proposed overall monitoring scheme.

6.2.2 Pesticide Application Map (PAM)

Level 2	Would provide additional data valuable for interpretation of, or linkage across, environmental/compartments. *Potential development could be reviewed once Level 1 monitoring is established.*

The Pesticide Application Map (PAM), as described in Section 5, utilises information from the PUS and from the UKCEH Land Cover® plus: Crops[29] to produce a spatially-explicit mapped national surface for PPP applications for each $1km^2$.

The map *per se* can provide a visualisation tool for estimated PPP applications across Great Britain. More importantly, the spatially explicit nature of the data represents a key advance in capability. Using the data that underpins the maps, it is possible to gather estimates of PPP applications at a spatial resolution that can be directly related to samples in which pesticide residues are measured; these could include biota, soil and, as recently demonstrated, honey (Woodcock et al., 2018). In this way, it would be possible to integrate data from two or more streams of the proposed monitoring program and thereby explore, for example, associations between PPP applications (from the PAM data) and exposure in bees (as measured using honey residues as a proxy indicator of exposure - Section 6.5.1). Similarly, it would be possible to relate both sets of measures to population trend data for key receptors, such as pollinators[30], and to changes in geographic distributions (for example, Woodcock *et al.*, 2016). As with all monitoring data, any associations would be correlative in nature, but the potential for such preliminary investigations would add significant strength to the value of the monitoring program. They would also

[29] https://www.ceh.ac.uk/crops2015

[30] https://www.ceh.ac.uk/our-science/projects/pollinator-monitoring

signpost where more detailed experiments designed for specific field assessment of real world effects of a given compound on a specific taxa should be focused (Woodcock et al, 2017).

The PAM data itself would also be capable of producing novel metrics that cannot be derived from just PUS data. For example, the data could be used to explore potential hotspots of application and whether these are changing over time. For example, an annual metric could include:

- How many “x” km^2 squares have total insecticide/fungicide/total PPP applications of greater than “x” kg each year, and is this metric changing over time?

Such a question is crude in that it implies an underlying assumption that there is a direct relationship between weight of active substance and potential toxicity to non-target organisms. However, it would be possible to link PAM application estimates to hazard data for each active substance, and thereby generate a toxic loading approach. This overall approach is taken within the UK Pesticide Load Indicator approach that is currently being developed by Defra in collaboration with the HSE and University of Hertfordshire.

A further metric that monitoring using PAM data could provide is the weight of active substances (or toxic loadings) estimated to be applied to specific water catchments. This information can be generated using spatially explicit approaches such as the UK PAM. Annual recalculation based on the latest usage and cropping information could be used to track how loadings into different catchments change over time. Such measurements could be linked to water quality data, and thus couple together terrestrial and freshwater monitoring effort.

This brief discussion of the potential of the PAM approach highlights the value of scalable, spatially explicit application data and some of the purposes to which it can be put as part of a wider holistic monitoring program. Stakeholder feedback during the course of this project suggested that such data could be further improved by utilising real-time, geo-spatially resolved data that are uploaded direct from the pesticide sprayer at the time of application. Collation of such data would provide timely and empirical data on application that would be more accurate than the questionnaire-derived PUS data and the derived modelled PAM data. While it is theoretically possible to gather data in this way, UKCEH’s experience to date when examining precision yield data collected by combine harvesters from over 7,000 fields (an analogous situation to pesticide application data) suggests there are currently some operational difficulties in accessing such data for monitoring purposes. These principally are data access[31], accuracy[32] and ownership[33] (R.F. Pywell-*pers. comm*). While none of these issues are insurmountable, they represent significant obstacles that are likely to take time to resolve. However, while development is still needed, the PAM approach may ultimately prove to be an effective means of obtaining spatially resolved application data in the short to medium term.

Incorporation of the PAM into the overall monitoring scheme would also depend upon the availability of new application data. Current PAM estimates are based on PUS data collected between 2014 and 2016. Future pesticide application maps would need to incorporate newly collected data from the PUS or other sources such as the farming industry, as future estimated annual changes in the PAM data would otherwise be based solely on changes in cropping patterns.

It is clear that inclusion of spatially resolved data, such as pesticide application maps, in the monitoring scheme would provide new monitoring metrics and, more importantly, enhance potential to examine trends and drivers in other metrics in the monitoring scheme. However, the data are not essential for initiation and operation of the monitoring scheme and uncertainties remain about future updating of the PAM and how quickly the PAM approach may be superseded by direct data upload and analytics. It is for these reasons that the PAM has been classed as a Level 2 activity in in the proposed overall monitoring scheme.

[31] Agricultural machinery manufacturers do not currently employ data standards or protocols to readily allow access and inter-operability. Data is often stored in bespoke formats and requires the manufacturers specialist software to read it. Similarly, many manufacturers do not currently have APIs (application programming interface) associated with their software to allow easy third party access to data.

[32] Data accuracy relies on the machinery operator correctly inputting information on the product label, and ensuring the equipment is correctly calibrated (e.g., GPS and date stamp are correct).

[33] Pesticide application data is the property of the farmer and permission is required from each individual farmer to access this information. This is further complicated when pesticide application is carried out by a third party (contractor).

6.3 Soils

6.3.1 Measurement of PPP residues in soils

Level 2	Would provide additional data valuable for interpretation of, or linkage across, environmental/compartments. *Potential development could be reviewed once Level 1 monitoring is established.*

There is currently no formalised monitoring of PPP or other pesticides concentrations in soil. The design and value of any such monitoring critically depends upon its aim. Application of insecticides, herbicides, fungicides, or growth regulators to arable crops occurs in most months of the year, except in winter (particularly January and February)[34]. It would be expected, therefore, that measurement of residues in soils collected in-field in most months would reveal the presence of PPPs applied immediately prior to sample collection or indeed at some time previously that have not yet been passed through mineralisation, as determined by PPP half-life (DT50) of run-off. The timing of sampling is therefore critical to understanding and comparing pesticide use, as samples collected at different times may show different patterns driven more by the temporal patterns of use rather than any differences in comparative use between sites. Timing of sampling will, thus, be dependent on the specific aims of the monitoring.

It is beyond the scope of the current report to outline a detailed PPP monitoring program for soils, but two possible exemplar objectives and activities that could be addressed are outlined in Box 6.1. The first would provide field-based measurements that could be related to residue persistence and accumulation, while the second would provide data that could support future assessments of risk associated with exposure to multiple PPPs that could go beyond the current approach of assessing only multiple active ingredients present in a single formulation to also consider cases of sequential and overlapping exposure due to soil residence times.

[34] https://secure.fera.defra.gov.uk/pusstats/surveys/documents/arable2018.pdf

Knowledge gap	Aim	Timing of sampling	Key data
Active ingredient used and field evidence that PPP dissipation from soil under full field conditions is broadly consistent with DT50 values determined in regulatory laboratory and field studies	Confirm PPP concentrations are within the envelope expected from the laboratory and field DT50 values used in the risk assessment. Re-sampling of fields annually to identify if unexpectedly there is long-term residue accumulation. Repeat sampling to understand year on year change including any carry over.	February-March, although repeat sampling within the year would increase knowledge of use and fate.	Presence and concentrations of PPPs that carry-over to the next growing season. Comparison to regulatory calculated PECs, although these maybe conservative.
Potential exposure of soil organisms to mixture of PPP residues. Risk not addressed in risk assessment	Provision of residues for soil organism to underpin new evaluations of the impact of PPP mixtures on soil fauna and flora. Repeat sampling to understand year on year change including any carry over.	Monthly sampling: (April-May or Oct-Nov), when organisms most active	Identification of predominant PPP residue mixtures in agricultural soils

Box 6.1. Exemplar objectives for monitoring of PPP residues in soil

Although there is no current PPP residue monitoring program for soil, there are two established platforms by which soil samples could possibly be obtained without incurring large collection costs. These two programs, part of the UKCEH's long-term National Capability work[35]; are the ASSIST farmland soils archive, and the Soil and Vegetation Research Platform (SVRP) (Section 5). The farms in the ASSIST network currently take an annual soil sample and re-sample the same fields every five years and used in conjunction with any available PPP usage information to understand fate and exposure. These samples could be sub-sampled and stored preferably fresh and

[35] https://www.ceh.ac.uk/national-capability

used for measurement of PPP residues and/or the network of collaborative farms could be requested to take additional samples at the times required to meet the objectives of residues monitoring. The SRVP also surveys and collects soils from around 100 sites annually. A proportion of these samples will be from arable fields. However, the soil sampling is part of a wider monitoring program largely undertaken from spring to early autumn and sites are visited just once per year; flexibility to vary collection times and to take multiple samples through the year is likely to be problematic. Nevertheless, limited sampling from non-agricultural soils (e.g., nature conservation sites not subject to either agricultural or amenity pesticide use) from the SRVP may be worthwhile to assess the presence of background PPP inputs to soil, if relevant, or more likely to confirm absence and, hence, the agricultural association of the PPPs measured in farmland soils. In addition, there may be a need to determine the presence/levels/persistence of soil residues PPPs used in forestry and for chemical control of invasive plants and insects in a variety of habitats.

Overall, soil monitoring of pesticide PPP residues could provide fundamental data that would provide information on the degree of conservatism (or not) of the current regulatory exposure assessment approach for determining predicted environmental concentrations in the current risk assessment process for authorisation. Soil PPP monitoring can also underpin future assessments on the risks associated with simultaneous exposure to multiple PPP soils residues. However, the aims, design, sampling protocols, piloting and resourcing of such a monitoring program requires development. For example, research and development will be needed to solve issues relating to transport of soil samples for residue analysis, and to determine the most appropriate extraction methods and their alignment with regulatory approaches.

6.3.2 Microbial abundance/diversity in agricultural soils

Level 3	Needs further research to assess value and practicality

Soil health is highly dependent upon microbial abundance, diversity and the function process that these taxa undertake. These characteristics of the soil microbial community are determined by a range of soil properties including the chemical status of soils. It is not clear what effects PPP (particularly fungicidal) applications may have on these measures and if there are such effects, whether they are functionally important. In regulatory assessment, measurement is made of active ingredient impacts on the nitrification process. However, this functional property is known to have high functional redundancy for delivery and so is generally insensitive to chemical impacts. Other functions related to specific substrate removal and chemical transformations undertaken by fewer taxa are potentially more sensitive to exposure. These processes are, however, currently not widely assessed outside of academic studies. The development of new DNA barcoding techniques makes rapid and cost-effective characterisation and monitoring of microbial soil communities more tractable than was previously possible. The application of these methods for potential pesticide and wider chemical monitoring have recently been assessed in a rapid evidence review on 'Omics approaches' for the biomonitoring of effects of pesticides on soil species, communities and functions: Rapid evidence review on current use and future needs. (Swart et al. 2021). This assessment established that when identified, such methods can be optimised for chemical exposure and effect assessment. However, further fundamental research is needed to evaluate what kind of questions such monitoring could address and how any such data could be used. Monitoring of microbial communities is considered to be a Level 3 activity for the proposed overall PPP monitoring scheme.

6.4 Terrestrial invertebrates

Potential monitoring activities have focussed on two possible activities, the Rothamsted Earthworm Survey (Section 6.4.1) and the Chick Food Index (Section 6.4.2).

6.4.1 Rothamsted Earthworm Survey

Level 2	Would provide additional data valuable for interpretation of, or linkage across, environmental/compartments. *Potential development could be reviewed once Level 1 monitoring is established.*

This pilot survey was developed as a citizen science project that gathered data on the abundance of three different ecological groups of worms (epigeic, anecic and endogeic species) and their adult to juvenile ratios in agricultural soils in March and April. Volunteer farmers dug soil pits as the most easily tractable and repeatable approach for extracting and counting adult and juvenile worms. The volunteers assessed more than 1,300 hectares of farmland soils (Stroud, 2019). There are a range of drivers that may impact on numbers and adult to juvenile ratios. The early results from the project indicated that tillage was a key factor that negatively affected earthworm populations. Pesticide residues in soil and worms were not measured as part of the project.

The relevance of the Rothamsted Earthworm Survey (RES) to the currently proposed PPP monitoring scheme is that it demonstrates the viability of using a volunteer network to collect salient information on earthworm abundance and juvenile recruitment. The chronic effects of chemicals generally on endpoints such as reproductive output and juvenile recruitment can be assessed through laboratory studies. Indeed, this is a routine aspect of PPP research for inclusion in risk assessments conducted for authorisation. Therefore, field-derived information on worms in agricultural soils is likely to be highly useful if it can be related to information on likely exposure to PPPs that could, for example, be generated by soil monitoring for PPP residues. This assessment of exposure is important as earthworm populations can respond to a number of stressors in agricultural ecosystems, such as tillage regimes, and it is possible that such impacts may dominate. Hence, measurement of PPP residue would be essential to both identifying, and potentially refuting, a link to PPP impacts. The RES would have enhanced value if data were available on PPP applications made in the 16 or so months prior to the worms being counted. This information was not requested because PPP use was not a focus of the project. It is unknown how many volunteer farmers would be willing to respond to a request for such information.

It is possible that the RES could be reactivated and additional information on PPP use collected as a routine element. However, the methodology developed in the survey is clearly transferable, and potentially could be adopted by the ASSIST farm network through which it has been suggested that soils could be collected (Section 6.3). Worm counting could be conducted at the same time as soil collection, depending upon the sampling strategy for soil. Whatever collection network was used, the typical annual metrics reported could include:

- Average abundance of worms per unit sampling effort
- Average adult to juvenile ratio

These metrics would provide a general measure of variability in, and changes over time in earthworm abundance and productivity. They would be one measure of soil health and not directly relatable to PPP use. However, collection of concurrent data on PPP use and other salient variables (e.g., weather statistics and management practices, such as tillage etc.) would allow exploration of the factors that affect worm populations and the relative importance, if any, of PPP use. Interrogation of data amalgamated over a number of years could identify the key factors driving variability in earthworm numbers and juvenile recruitment. If use of specific PPPs was identified as a significant explanatory variable, this would flag that further investigation might be needed to determine if any such association was correlative or causal. Such analyses could only be periodic but would seek to draw on the annual monitoring data that is collected and, in particular, usage data which is needed for the interpretation of the survey results.

Given the collection of earthworm data would need reactivation of the RES network or transfer to an alternative collector network, inclusion of earthworm monitoring is considered an activity that could be reviewed and developed once a monitoring framework was established. It has therefore been classed as a Level 2 activity.

6.4.2 Chick Food Index

Level 1	Already running/could be adapted from current schemes. *Fundamental information for compartment*

The Chick Food Index (CFI), developed and run by the Game and Wildlife Conservation Trust (GWCT)[36], has been described briefly in Section 5 . It has been produced as part of a series of seminal studies that have demonstrated the indirect effects (reduction in available invertebrate prey items) that herbicides and insecticides can have on grey partridge chick survival and overall population numbers in arable areas (for example see Aebischer, 1991, Aebischer & Sotherton, 1995, Ewald & Aebischer, 2000, Ewald *et al*., 1999, 2002). The CFI is directly calculated from data on the number of invertebrates collected from cereal fields and studies have indicated that a CFI value of at least 0.8 is needed to maintain grey partridge populations.

CFI values for the grey partridge, corn bunting and yellowhammer, together with a value for a “generic farmland bird” are reported as part of ongoing work by the GWCT[37]. They are included as one of the indicators in the Pesticide Forum annual reports[38].

The CFI is an effects measure and, as with most other effects indicators, can vary as a result of a range of pressures, not just PPP use. Monitoring of the CFI is unlikely to identify impacts that are clearly attributable to a specific single PPP, and attribution of effects even to a class of PPPs will need careful mining of the regulatory dossiers and scientific literature to gather sufficient toxicological information for specific taxa through which to investigate causality of any potential effects. However, the CFI is a powerful effects indicator in that it monitors the extent to which managed arable ecosystems can provide sufficient invertebrate prey to maintain sentinel avian populations. The well-established relationship between PPP use and the CFI, and between the CFI and population numbers, means the CFI is a key effects measure for the current proposed monitoring scheme. It is also the only indicator that encompasses three areas of major uncertainty in the risk assessment process: (i) “indirect effects”; (ii) “carry-over effects” due to a lack of within-year recovery; (iii)

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[36] https://www.gwct.org.uk/home/

[37] https://www.gwct.org.uk/research/species/birds/grey-partridge/chick-food-index/

[38] https://webcommunities.hse.gov.uk/connect.ti/pesticidesforum/view?objectId=56979&exp=e1

landscape-scale effects on invertebrate prey abundance. Overall, the CFI provides "weight of evidence" as to whether PPP use may be impacting ecosystem functioning and require further investigation.

One of the drawbacks of the CFI is that it is based on measurements at just two sites. Expansion of measurements to a wider number of sites would increase the robustness of the measure as a national indicator and merits consideration, but would require additional resource. Natural England has commissioned a study from the GWCT to determine the feasibility for expanding the CFI scheme for application in monitoring schemes. The report and results from this work can be used to guide the application and development of the CFI within any terrestrial PPP monitoring program.

An additional allied metric that is collected by the GWCT is the number of adult and young grey partridges present on farms as recorded in spring and autumn volunteer counts from across more than 400 farms[39]. Although an independent measure, trends in the ratio of young to adult birds would be expected to be positively correlated with trends in the CFI to some degree if the CFI measures derived from two sites are representative of arable farms generally. The reporting of this ratio in conjunction with the CFI would likely add robustness in providing an overall effects measure.

These two metrics could be used to address the following question:

- What is the annual CFI and grey partridge adult to juvenile ratio, and how have these changed over time?

Given the CFI and partridge counts are ongoing, relevant, and provide unique and fundamental insights into the potential effect that PPPs may have on arable ecosystem functioning, the CFI and grey partridge counts are classed as Level 1 activities for the proposed monitoring scheme. The schemes are well suited to application on arable crops, given the association of the assessed and receptor species with such habitats and the focus of the index on arable weed species. Further, a value of the CFI is that it measures not only the potential effects of PPP use directly, but also indirect effects results from changes in provisioning for the high receptor species.

[39] https://www.gwct.org.uk/research/long-term-monitoring/partridge-count-scheme/

6.5 Pollinators

There has been a large amount of attention focussed on the declines of insects in the UK and concern that this has been driven at least in part by exposure to PPPs and other PPPs. Pollinators have been a particular concern, not least because of the role they play in the provision of ecosystem services, and because of the high-profile concerns through the last decade over the impact of neonicotinoid insecticide seed treatments and its impacts on bees. The risk to bees from PPPs is specifically examined as part of the authorisation process for PPPs. The EU risk assessment guidelines established in 2013[40] are currently undergoing review[41].

Wild pollinator populations in the UK are subject to monitoring, such as through the UK Pollinator Monitoring Scheme[42]. Similarly, managed honeybee populations are monitored (e.g., overwinter hive survival) by the NBU surveys[43]. However, investigation of exposure or effects of PPPs is currently limited to investigations of bee mortality incidents by the WIIS (see Section 6.5.2). As described below, three different monitoring activities could be linked together to enhance the information available on the exposure to, and effects of, PPPs on bees.

6.5.1 National Honey Monitoring Scheme (NHMS)

Level 1	Already running/could be adapted from current schemes. *Fundamental information for compartment*

A brief description of the general activities of National Honey Monitoring Scheme[44] has been given in Section 5. The scheme receives and archives honey samples from some 400-600 beekeepers across the length and breadth of the UK (Figure 6.1). Of the ancillary information that is collected, data on hive location, surrounding crop and land cover, and deaths of hives are all relevant when considering how the scheme can be used for monitoring exposure and effects.

[40] http://www.efsa.europa.eu/en/efsajournal/pub/3295

[41] http://www.efsa.europa.eu/en/news/bees-and-pesticides-third-consultation-guidance-review

[42] https://www.ceh.ac.uk/our-science/projects/pollinator-monitoring

[43] http://www.nationalbeeunit.com/index.cfm?pageId=203

[44] https://honey-monitoring.ac.uk/

Currently, the honey samples are collected throughout the year (one to three samples per hive), archived and analysed using DNA barcoding to identify plant DNA present from pollen and nectar. This provides information on what the bees are feeding on in different parts of the country and at different times of year. All honey samples are archived for further research.

The honey samples are not routinely screened (non-target scanning) or analysed (targeted analysis) for PPPs because of the costs of conducting such measurements. However, the value of such measurements was illustrated in a study that investigated whether there was any change in the occurrence and magnitude of imidacloprid, clothianidin and thiamethoxam residues in honey collected following the moratorium on the use of these neonicotinoids as seed treatments in mass flowering crops (Woodcock et al., 2018). The frequency with which neonicotinoids were detected in honey samples fell from approximately 50% before the moratorium to approximately 20% following its implementation, suggesting that the moratorium reduced, but did not eliminate, neonicotinoid exposure in bees. A recent combined analysis of honey samples for the occurrence of neonicotinoid residues and plant DNA (Woodcock et al. 2021) suggest a strong correlation between PPP residues and the presence of DNA from mass-flowering crops, such as oilseed rape. This indicates a possible route of exposure was untreated mass-flowering crops grown in soils containing residues of the PPP. Although the crops themselves were not treated, they may have been grown in soil that contained neonicotinoid residues that persisted from a previous crop rotation.

Pesticide residues in honey are not exposure measures themselves. This is because residues in honey cannot readily be converted to daily intake of residues in pollen or nectar for adults, although they may be easier to transform for exposure estimates for larvae. The study by Woodcock et al. (2018) demonstrates how honey PPP residues can be used as a quantitative index to infer differences in exposure and changes over time or following mitigation interventions. Coupling this residue analysis to plant DNA analysis further provides the opportunity to relate changes or differences in exposure to predominant food sources, and so gain greater understanding of likely exposure pathways. This would provide a focus for more detailed mechanistic studies of exposure routes and the effects of specific compounds. Furthermore, the Honey Monitoring Scheme has demonstrated this large network of hobby and professional beekeepers have a strong interest in the effects of PPPs on bees. These citizen scientists are likely to be willing to provide further relevant information linked to the effects of PPPs (e.g., overwinter survival, a key metric in the PPP risk assessment), and participate in targeted monitoring for PPPs in different hive products (e.g., pollen, nectar). Finally, the strong regional structure and organisation of the British Beekeepers Association and the Bee Farmers Association mean there is potential to have geographically targeted campaigns of sampling for particular PPPs residues should the need arise.

Exemplar annual metrics that could be recorded using a honey monitoring scheme would depend upon the types of residue analysis conducted. For instance, samples could be analysed using semi-quantitative scanning methods in an attempt to identify all of the compounds present in the honey and/or involve a targeted fully quantitative analysis for a selected suite of active substances. The maintenance of an archive of all honey samples collected by the scheme, together with the curation of a number of historic honey collections going back decades, mean there is potential for baseline residue detection of a given compound, and then track changes in frequency and geographic distribution through time. The methodologies by which monitoring of PPPs in honey would be conducted require development but would need to consider a number of factors including: sample stability and long-term preservation, sample numbers used for annual analysis, stratification of annual samples by provenance and sampling date, time-period of honey collection (including repeated analyses from the same hive), analytical methods and determinants, analytical quality assurance and control, and standardised collection of ancillary data including information on in hive treatments used for the control of pathogens, such as the Verroa mite and any local amenity uses.

The metrics that any monitoring program could report annually would be likely to include:

- Number of samples containing PPP residues and the concentrations of those residues

Accumulation of such data would enable the following questions to be addressed:

- What PPP residues are detected in honey?
- What are the frequency of occurrence and concentrations of different PPPs and how do they change over time?
- Do changes over time reflect changes in usage?
- How does detection of PPPs relate to plant DNA found in the same sample as a possible route of exposure?

As outlined above, accumulation of data over several years would allow investigation of associations between use, food source, severity of exposure and incidence of acute mortalities (see Section 6.5.2).

Although PPP monitoring is not routinely undertaken by the NHMS and monitoring protocols would have to be established, the framework of sample provision and archiving is established. That framework is currently resourced as a component of UK Research and Innovation (UKRI) National Capability activities and therefore PPP monitoring in honey would benefit from the resourcing supporting the NHMS. Given that the NHMS is already established and exposure monitoring of pollinators is likely to be an essential component of any PPP monitoring scheme in wildlife, the NHMS has been classed as a Level 1 activity in the proposed overall monitoring scheme. NHMS could also be a platform to collect bees in the future to relate exposure to specific effects.

6.5.2 Wildlife Incident Investigation Scheme (WIIS) investigation of honey bee mortalities

Level 1	Already running/could be adapted from current schemes. *Fundamental information for compartment*

The WIIS has been described briefly in Section 5 . It investigates mortality incidents to determine whether they may have been caused by exposure to PPPs and certain biocides. Most of the investigations involve analysis of vertebrate wildlife and baits associated with poisoning incidents but a proportion involve investigations into poisonings of bees in work that is conducted in collaboration with Natural England and also local (honey) bee inspectors. The focus of this aspect of WIIS is on managed honey bees, rather than other managed bees or indeed wild pollinators. The annual number of WIIS incidents between 2016 and 2019 involving honey bees ranged between 14 and 25 and represented between 4% and 9% of the total investigations undertaken each year by the WIIS[45]. The number of investigations is therefore relatively small.

Although limited, the data on bees gathered through the WIIS provides the only ongoing national-scale program that measures PPP residues in bees and investigates whether acute mortalities may be linked to that exposure. As such, this information is useful in its own right. Even where PPPs are not considered to be the causative agents of mortality, the measurements of residues in the bees, conducted as part of the investigation, would provide useful exposure data. The extent to which a broad suite of PPPs are quantified would depend upon whether the analysis focussed on semi-quantitative non-target scanning, or quantitative analysis for a targeted suite of PPPs. More comprehensive analyses would enable a number of specific questions to be addressed which could include:

- What PPP residues are detected associated with bee samples and at what concentrations?

[45] https://www.hse.gov.uk/pesticides/reducing-environmental-impact/wildlife/wiis-quarterly-reports.htm

- How do PPP residues detected in bees compare with toxicity endpoints for this species that are included in regulatory dossiers and in the wider scientific literature, including recent work conducted to link residue levels to effect for Defra by Fera Scientific[46]?
- What is the number of poisoning incidents per year by PPPs in bees resulting from approved use?
- How is exposure and the number of mortality incidents changing over time?

It would also be possible to link the WIIS data with that from NHMS (Section 6.5.1) in that the extent of exposure (proportion of honey samples with detected residues) could be calculated for PPPs that were also found to have caused mortality incidents. The two pieces of information together would help contextualise interpretation of the data and aid decision making over whether there were grounds for further investigations into specific active substances.

In summary, WIIS investigations of acute mortalities in bees are ongoing. When coupled with NHMS data, they would provide fundamental information on exposure and effects. Therefore, the WIIS investigations into bee poisonings have been classed as a Level 1 activity in the proposed overall monitoring scheme.

6.6 Monitoring of residues and effects in terrestrial vertebrate wildlife

As discussed in Section 5 and Section 6.5.2, the WIIS is the only scheme that examines whether the deaths of vertebrate wildlife may be attributable to PPPs, including PPPs. The focus is on acute poisoning incidents in particular, but it may be argued that such incidents are likely to be rare because acute toxicity is one of the more extensively covered data packages required in the approvals procedure. Here, we suggest that the WIIS functioning could be separated into detection of poisoning and detection of primary and secondary exposure.

6.6.1 Detection of mortality incidents - poisoning

Level 1	Already running/could be adapted from current schemes. *Fundamental information for compartment*

[46] http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&ProjectID=18321

Detection and attribution of poisoning incidents is the current purpose of the WIIS. In the years 2016-19 inclusive, between 265 and 328 incidents per year were investigated[47], most of which were related to suspected deliberate or accidental poisoning of vertebrate wildlife and companion animals. The data available for 2019 (not all data for that year had been published when this report was prepared) indicated that 265 incidents were investigated for PPPs and some biocides. Of these, 19 (7%) were abuse[48], 10 (4%) were misuse[49], and 10 (4%) were unspecified use[50] but no PPPs were found in 126 (48%) incidents[51]. These data reflect the large amount of effort required to detect relatively small numbers of abuse and misuse incidents. It is important to note only reported incidents that fit the investigation criteria are currently investigated or analysed. This means that with the exception of predatory birds, the majority of reported incidents are not accepted. Carcasses are also not archived. There could be an opportunity to do more particularly with red foxes. Cases can be rejected for many reasons:

- Case falls outside WIIS remit (i.e., within the remit of local councils and not Natural England or HSE),

[47] https://www.hse.gov.uk/pesticides/reducing-environmental-impact/wildlife/wiis-quarterly-reports.htm

[48] **Abuse:** An investigation into the circumstances of the case concluded that the pesticide(s) involved had been used in breach of their authorisation conditions and that this has been done with the deliberate intent of harming or attempting to harm wildlife or other animals. Where an animal is involved the cause of death has been established as pesticide poisoning.

[49] **Misuse:** An investigation into the circumstances of the case concluded that the pesticide(s) involved were not used in accordance with their conditions of authorisation. The pesticides involved may have been used carelessly or accidently but there was no indication of any intention to deliberately harm wildlife or other animals. Where an animal is involved the cause of death has been established as pesticide poisoning.

[50] **Unspecified:** An investigation into the circumstances of the case could not establish where the pesticide may have come from and therefore if the pesticide(s) involved were used in accordance with their conditions of authorisation; if the pesticide had been misused or whether or not there was a deliberate intention to harm wildlife or other animals. Where an animal is involved the cause of death has been established as pesticide poisoning.

[51] Classed as **Unknown:** The cause of death has not been established as pesticide poisoning; an investigation into the circumstances of the case could not establish a cause of harm or death and found no evidence of the involvement of pesticides.

- The suspected poison is not a PPP / biocide – e.g., antifreeze and paracetamol,
- A case might be reported a number of times – a dead fox being reported separately by two people,
- A body may be too decayed for analysis,
- There is a clear other cause of death – disease or trauma,
- There is no evidence to suggest a link to professional PPP / biocide use.

If there were to be additional elements to the WIIS (Section 6.6.2) but no greater resourcing, some of the effort currently devoted to investigation of potential poisoning incidents would need to be re-directed. This might require review of, and a renewed focus on some but likely not all, the main purposes for conducting poisoning investigations (Box 6.2).

- Detect (and potentially prosecute or other enforcement action) deliberate cases of pesticide abuse that may involve wildlife and/or companion animals
- Detect, and understand the causes of, misuse of PPP that lead to wildlife/companion animal deaths
- Detect which PPPs cause wildlife/companion animal mortalities following the approved use of pesticides and how often this detected
- Rapidly determine whether mass mortality events may be due to PPP use

Box 6.2. Current purposes for investigating poisonings in vertebrate wildlife and companion animals

Monitoring of wildlife poisonings is likely to remain an important component of any overarching PPP monitoring scheme. This is because it provides fundamental information on whether approved use of authorised PPPs results in any unintentional poisonings and provides some indication of the frequency with which this occurs. Furthermore, a general low-level or absence of mortality incidents related to approved use of PPPs provides reassurance that the risk assessment process is functioning as expected in terms of preventing acute mortalities. However, if cases of poisoning through authorised use do occur, then these findings can be considered as relevant information to support the development of stewardship and mitigation measures. Some of the key questions that such monitoring can address are:

- Which PPPs are associated with poisonings of vertebrate wildlife?
- What is the frequency of vertebrate poisonings recorded each year, and is this changing?

Given the fundamental information on effects provided by the WIIS investigations of mortality incidents, and given that such monitoring is already in place, the WIIS mortality incident monitoring has been classed as a Level 1 activity in the proposed overall monitoring scheme.

6.6.2 Detection of exposure

Level 2	Would provide additional data valuable for interpretation of, or linkage across, environmental/compartments. *Potential development could be reviewed once Level 1 monitoring is established.*

When considering residue monitoring of PPPs in vertebrate wildlife, it is evident that metabolism and elimination of some active substances (and metabolites) and recovery of any biomarker responses will be rapid. This time-course of response is an active area of research in ecotoxicology, as is the role that pesticide metabolites may play in any potential pesticide impacts. The absence of detected residues in organisms therefore is not necessarily indicative of a total absence of exposure and monitoring data must be considered in this light. Although “false negatives” (absence of detectable residues despite relatively recent exposure) would be expected, this does not negate the value of undertaking residue monitoring, particularly if the focus was on active substances with longer biological persistence (longer tissue half-lives). Non-target screening would be of value as it could identify the unexpected presence of active substances and metabolites.

Currently WIIS investigations do not automatically conduct assessment of tissues for PPP exposure. Animals are typically only analysed for PPPs if there is a suspicion that they have died as a consequence of exposure to PPPs. If the WIIS was to incorporate a routine element of wildlife PPP exposure monitoring, individuals selected for analysis should include those that have died from a variety of causes to assess the wider basis of species exposure to PPPs. Furthermore, the WIIS, by its nature, has no particular focal species of interest. In contrast, if the main aim was to assess primary exposure, analyses would be better restricted to focal species from agricultural habitats as these may be at most risk of exposure (Bonneris et al., 2019). These could include gamebirds shot for sport (Bro et al., 2015,2016; Lennon et al., 2020) and so easily sourced for analysis.

It would also be appropriate to analyse dead individuals of species that typically inhabit agricultural landscapes, such as UK Farmland Bird Indicator[52] species. Chance discovery of bird carcasses for analysis is likely to be more difficult than the sourcing of shot individuals but bespoke schemes, such as the PBMS[53], already have a citizen science collector network who discover and send in carcasses. It is possible that such schemes could widen their collection scope to incorporate farmland indicator species. A number of disease and contaminant national surveillance schemes in the UK are linked and collaborate through the WILDCOMS network[54], and their collective effort would be likely to enhance the availability of suitable carcasses for PPP monitoring.

One member of the WILDCOMS network is the Garden Wildlife Health project[55] that principally aims to monitor the health of, and identify disease threats to, British wildlife. It has a particular focus on garden birds, amphibians, reptiles and hedgehogs, and its activities involve the collection (and necropsy) of wild vertebrates found dead in peri-urban areas. As some of these species are recognised as a potential gap in current approaches used for risk assessment (e.g., amphibians), monitoring of these species may be particularly beneficial for detecting effects on these less well studied groups. If such samples were available for residue analysis, this would provide information on potential exposure of wildlife that is most likely associated with amateur and/or amenity use of PPPs and other pesticides. Exposure of wildlife to pesticides in peri-urban areas is currently not directly assessed as the risk assessment scheme is focused on agricultural/horticultural uses (for example, residues on food items for the bird and mammal risk assessment are derived from agricultural uses). In addition, there are uncertainties related to appropriate focal species, the likely residues on items of food due to the method of application compared to agricultural and horticultural applications. Monitoring of pesticide residues in peri-urban wildlife would provide a means of identifying unexpected exposures while an absence of detected residues, at least for the more persistent PPPs, would provide some reassurance about the safety of amateur use. Monitoring primary exposure would enable the overall monitoring program to address exemplar questions such as:

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[52] https://www.rspb.org.uk/our-work/conservation/conservation-and-sustainability/farming/near-you/farmland-bird-indicator/

[53] https://pbms.ceh.ac.uk/

[54] https://www.wildcoms.org.uk/

[55] https://www.zsl.org/science/research/gwh

- Which PPPs are detected in focal vertebrate species from agricultural habitats, and how do frequency of detection and concentrations vary over time?

- Which PPPs are detected in focal vertebrate species from peri-urban habitats, and how do frequency of detection and concentrations vary over time?

The detection of residues in gamebirds, farmland and peri-urban birds would be expected to be predominantly a result of exposure to PPPs. Secondary exposure of predators through consumption of contaminated prey and predators can occur (for example, Byholm et al., 2018; Taliansky-Chamudis, et al., 2017). The risk assessment process has a specific element within it that examines the bioaccumulation potential of PPPs. The science underpinning the estimates of such accumulation is mature and it can be argued that secondary exposure leading to adverse acute effects is unlikely for currently authorised PPPs[56]. The general lack of reported secondary poisoning amongst predatory species resulting from approved current use of PPPs supports this view, at least in terms of acute mortalities. However, prediction of the risk from long-term exposure is more difficult, not least because exposure regimes in chronic exposure laboratory studies cannot accurately mimic real-world exposure scenarios. Thus, whilst the exposure in the studies does not equate to the exposure in the field, there is a need to ensure that long-term effects from short-term exposure are addressed and that the sensitive stage of the reproductive cycle is also addressed. Although monitoring of PPPs in predators will not generate information on effects, it can provide data that can be used to determine and track changes in presence and magnitude of residues of the more persistent PPPs. Such monitoring may most usefully be focussed on species and individuals that hunt predominantly in agricultural habitats. Carcasses for analysis would be readily available from collections already made through the WIIS and could be supplemented by samples provided by other collection platforms, such as the PBMS. The most useful analyses might involve non-target screening to identify unexpected exposures, and/or targeted measurements focussing on those PPPs that are widely detected, or present in the highest concentrations, in agricultural focal species (see above). The type of questions such monitoring could address might include:

- What PPPs are detected in focal predatory species from agricultural habitats, with what frequency, and at what concentrations, and how do measured

[56] the same is not true for certain authorised biocides, such as second-generation anticoagulant rodenticides, for which there is a large body of evidence demonstrating bioaccumulation in the liver

residue levels relate to those known to be linked to adverse physiological impacts?

The resultant data for predators could provide a basis to inform decisions as to whether further investigation of exposure of higher tropic level vertebrates to specific PPPs at a wider spatial and temporal scale is warranted.

Overall, monitoring of PPPs in focal vertebrate wildlife species would provide basic information on the occurrence, potential scale, and relative magnitude of PPP residues in wildlife species in agricultural landscapes. Because residues can be metabolised rapidly by vertebrates, such monitoring is likely to underestimate the extent of exposure. However, in the absence of any current annually collected data, residue monitoring (providing a proxy for exposure) merits consideration, especially in those cases where this can be linked to the potential for adverse effects through toxicological knowledge and understanding of the links between tissue concentrations and internal physiological effects. However, a program of such monitoring and the broadening of scope and collaboration of multiple collection platforms would require time and effort to implement. Therefore, exposure monitoring in vertebrates is classed as a Level 2 activity. It would provide valuable data but could be developed and implemented once Level 1 monitoring was established.

6.7 Coordination and reporting

The proposed PPP monitoring scheme described in Sections 6.1-6.6 contains various component elements. These are likely to be conducted by a range of different governmental and non-governmental organisations. While some would be a continuation of existing activities, some Level 1 and all Level 2 activities will require development of new collaborative agreements, protocols, activities and data reporting. Given the considerable number of Level 2 activities that have been outlined, this group would also need to oversee the development of Level 2 activities and ensure they were clearly focussed and fit for purpose. To support delivery, a management structure or group will be required to manage and oversee the functioning, budgeting accountability and overall reporting of the proposed monitoring scheme.

Perhaps most importantly, there will be a need for the management group to undertake, or commission, critical evaluation of the different strands of monitoring data. This group would be actively involved in the refinement of monitoring scheme design and in directing the questions of pesticide exposure and potential impacts to be addressed. A strength of multi-faceted monitoring is that diverse data strands can be integrated to enhance the robustness of, and provide greater insights into, the environmental signals that are detected. In terms of robustness, a lack of unexpected residues, or of effects, when recorded across multiple environmental compartments, provides some reassurance that current risk assessment and mitigation procedures are functioning as expected. Conversely, unexpected detection of a PPP in any one single environmental compartment may raise minor concerns, but the occurrence of such detections across all environmental compartments would instead provide a clearer indication that follow-on investigations are warranted. In terms of providing greater insights, one basic example is that when investigating why measured residues vary temporally or spatially, it is imperative to examine if that variation reflects differences in scale and type of use, or is more likely due to other, perhaps unknown, factors. Another example is that while mortality investigations indicate if approved use of PPPs results in poisonings, concurrent measurement of exposure (residues in honey or biota for example) provides additional context by indicating the prevalence of exposure to that PPP and if it is changing. Such insights may be gained from examination of annual data but other investigations of associations between different metrics and with other environmental drivers are likely to require data collected over multiple years. A key role of any management group will be to consider when and how to undertake these more periodic investigations.

A range of relevant population monitoring schemes were not included in the current proposal. Examples include the Breeding Bird Survey[57], Farmland Bird Indicator[58], the UK Pollinator Monitoring Scheme[59], the Rothamsted Insect Survey[60], and the spatially explicit data on the presence or absence (occupancy) of one km^2 areas using information from species and taxa recording schemes that is assembled and held by the Biological Records Centre[61]. This was because they do not have measures that can be directly related to PPP exposure; the exception was the CFI because of its focus on a sentinel species, and the established link between the CFI and PPP use (Section 6.4.2). However, population monitoring data schemes are a rich source of data that can provide insights into potential associations between population-level metrics and PPP use or exposure. Such analyses allow questions to be asked of the possible population-level significance of PPP use or exposure.

57 https://www.bto.org/our-science/projects/bbs

58 https://www.rspb.org.uk/our-work/conservation/conservation-and-sustainability/farming/near-you/farmland-bird-indicator/#:~:text=Farmland%20Bird%20Indicator-,The%20Farmland%20Bird%20Indicator,Trust%20for%20Ornithology%20since%201967.

59 https://www.ceh.ac.uk/our-science/projects/pollinator-monitoring

60 https://www.rothamsted.ac.uk/insect-survey

61 https://www.brc.ac.uk/

Although correlative in nature, these studies can provide weight of evidence in terms of suggesting that population effect may (for examples, see Woodcock et al., 2016), or may not (for example, see Lennon et al., 2019) occur. Such investigations typically require data collected over multiple years and it would again be a requirement of the management body to determine if and when such studies would be undertaken.

Another key area that would need coordination and managerial oversight is the reporting of the outcomes of monitoring and associated stakeholder engagement. Reporting of data should be as timely and transparent as possible, with consideration given to the curation of annual data in national data centres and annual publication of data with digital object identifiers. Stakeholder feedback during the course of this project (Section 7) has also emphasised the need to provide a balanced and contextual interpretation to accompany the data reporting. There will also be a need to ensure that data and reports are made readily available to key stakeholders, such as risk assessors, and for potential inclusion in wider sets of metrics, such as the outline indicators for Defra's 25 Year Environment Plan[62]. Finally, the participation and interest in the current project from a range of industry and NGO stakeholders (Section 7) also emphasises the need to develop a clear stakeholder engagement platform for any PPP monitoring scheme.

6.8 Summary of the proposed overall monitoring scheme

The different components of the proposed monitoring scheme are described across Sections 6.1-6.7. The key questions, activities and metrics are summarised together in Table 6.2 below.

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[62] https://www.gov.uk/government/publications/25-year-environment-plan-progress-reports

Table 6.2. Overview of the proposed scheme for monitoring exposure and potential for impacts for authorised PPPs.

Data category	Source of information	Exemplar Key Questions addressed	Activity undertaken	Exemplar annual metric	Sample archive	Level[63]	State of readiness
Use	Pesticide Usage Survey	Which are the top 20 of each of insecticides, fungicides, herbicides and nematicides, in terms of total area applied and total weight applied? How has spray area and application weight of each active substance	Stratified sampling of use metrics and scaling up to provide national level estimates on usage	Area of crops (i) grown, (ii) treated with different PPPs Timing of application Average numbers of applications Weight of individual PPPs applied	N/A	1	Data currently produced

[63] Level 1. Already running/could be adapted from current schemes. Fundamental information for compartment; Level 2. Would provide additional data valuable for interpretation of, or linkage across, environmental/compartments. Potential development could be reviewed once Level 1 monitoring established; Level 3 Needs further research to assess value and practicality

Data category	Source of information	Exemplar Key Questions addressed	Activity undertaken	Exemplar annual metric	Sample archive	Level[63]	State of readiness
		changed over the last 10 years?		(data also summarised by pesticide type such as insecticides, fungicide etc.) Change over time in the above metrics			
Use	Pesticide Application Maps	How many active substances have applications of > "x" kg each year and what is the potential load for different receptors that is associated with this input and how is this metric changing over time?	Linkage of usage data with UKCEH Land Cover® plus: Crops	Annually updated fine-scale resolution pesticide application maps	N/A	2	Data currently produced

Data category	Source of information	Exemplar Key Questions addressed	Activity undertaken	Exemplar annual metric	Sample archive	Level[63]	State of readiness
Soil	New activity that can build of existing soil sample collection platforms	Is there unexpected PPP accumulation in soil over time? Are there any unexpected (based on knowledge of typical application rates and soil half-life values) PPP residues in soil at different times of the growing season? What are the predominant PPP residue mixtures in agricultural soils and the ratios of principle components, including toxicologically	Residue analysis on soil samples	Non-target and target scan data on PPP residues and concentrations in soils collected from across Britain	Available/ historic and ongoing	2	Monitoring needs to be developed but soil samples potentially available through existing UK National Capability programs

Data category	Source of information	Exemplar Key Questions addressed	Activity undertaken	Exemplar annual metric	Sample archive	Level[63]	State of readiness
		significant metabolites?					
Soil	New activity	Is microbial abundance/diversity changing in agricultural soils? Can variation in microbial community structure be related to PPP use or to inputs in soil both at the taxa level as indicated by metabarcoding or functional characteristic as indicated by meta-genomic assessments.	DNA analyses to characterise microbial communities in agricultural soils	To be determined	?	3	

Data category	Source of information	Exemplar Key Questions addressed	Activity undertaken	Exemplar annual metric	Sample archive	Level[63]	State of readiness
Terrestrial Invertebrates	Resumption or adaptation of Rothamsted Earthworm Survey	Is the density and adult/juvenile density of earthworms in agricultural soils changing over time? Is abundance or age structure associated with use of specific PPPs?	Recording [following specific protocol] of number and age class of earthworms in agricultural fields	Average abundance of worms per unit sampling effort Average adult: juvenile ratio Information on prior PPP use	N/A	2	No ongoing survey but methodology demonstrated
Terrestrial Invertebrates		What is the annual CFI and grey partridge adult to juvenile ratio and how have these changed over time? Are changes in CFI and chick survival	Counts of abundance for selected invertebrates and grey partridges	Annual calculated Chick Food Indices Average juvenile: adult	Not currently available	1	Data currently produced – number of sites upon which CFI based could be expanded

Data category	Source of information	Exemplar Key Questions addressed	Activity undertaken	Exemplar annual metric	Sample archive	Level[63]	State of readiness
		associated with changes in the use of specific pesticides?		ratio for grey partridge			
Pollinators		What PPP residues are detected in honey? What are the frequency of occurrence and concentrations of different PPPs and how do they change over time? Do changes over time reflect changes in usage? How does detection of PPPs relate to plant DNA found in	Measurement of PPP residues and plant DNA in honey samples	Number of honey samples containing PPP residues Average PPP concentrations in honey	Available/ historic and ongoing	1	Honey archiving and plant DNA analysis ongoing. Ongoing measurement of PPP residues needs commissioning

Data category	Source of information	Exemplar Key Questions addressed	Activity undertaken	Exemplar annual metric	Sample archive	Level[63]	State of readiness
		the same sample as a possible route of exposure?					
Pollinators		What PPP residues are detected on bees and in what concentrations? How do PPP residues in bees compare with toxicity endpoints? What is the number of poisoning incidents per year in bees resulting from approved use? How is exposure and mortality incidents changing in time?	Investigation of bee mortality incidents Mass spectrometry scans and quantification of PPPs in bees	Number of bee poisonings per year by PPP Frequency of detections and concentrations of PPPs detected in bees	Not currently available	1	Poisoning incidents currently investigated Non-target screening/ widespread targeted measurements need commissioning

Data category	Source of information	Exemplar Key Questions addressed	Activity undertaken	Exemplar annual metric	Sample archive	Level[63]	State of readiness
Terrestrial vertebrates – poisoning investigations		Which PPPs are associated with poisonings of vertebrate wildlife? What is the frequency of vertebrate poisonings recorded each year and is this changing?	Investigation of vertebrate mortality incidents	Number of vertebrate poisonings by compound	Not currently available	1	Data currently produced
Terrestrial vertebrates – monitoring exposure		Which PPPs are detected in vertebrate from agricultural areas and do detection frequency and levels vary over time?	Mass spectrometry scans and quantification of PPPs in focal agricultural, peri-urban and	Frequency of detection and concentrations of PPPs	Available/ historic and ongoing through WILDCOMS	2	Collection platforms in place for peri-urban and predatory species but need to be expanded to focal species used for

Data category	Source of information	Exemplar Key Questions addressed	Activity undertaken	Exemplar annual metric	Sample archive	Level[63]	State of readiness
		Which PPPs are detected in vertebrates from peri-urban habitats and do detection frequency and levels vary over time?	predatory species				monitoring primary exposure. Non-target screening/ widespread targeted measurements need commissioning
Co-ordination and Management		What does current monitoring tell us about the sustainable use of PPPs in the UK?	Scheme development and management data analysis and reporting, stakeholder engagement	Annual reports		1	Needs to be established

7 Stakeholder consultations

7.1 Introduction

There were two phases of stakeholder consultation in the development of the current project. The first was a request for written submissions in response to circulation of a description of the project (Section 7.2). The second consisted of two workshops, one involving representatives from PPP producers and users and the other involved representatives of NGOs engaged in conservation (Section 7.3).

Stakeholders that attended the workshop were also invited to provide written comments on a draft version of the current report Appendix 11.7.

In addition, the draft scheme proposals presented at the workshops were also presented to two technical fora: The Natural England Scientific Advisory Committee (which consists of independent scientists from across disciplines related to Natural England's remit), and the more specific Expert Committee on Pesticides (consisting of independent scientists who provide impartial advice to the government on the science relating to pesticides). A summary of their comments were provided in minutes of the meetings which are presented in Appendix 11.8 and Appendix 11.9, respectively.

7.2 Written stakeholder feedback about the overall aims of developing a post-registration PPP monitoring scheme

On 19 May 2019, a briefing note and request for written responses (Appendix 11.4) was sent directly to 46 representatives from the PPP industry and user community, conservation bodies and non-governmental organisations. Nine written responses were received by the 05 July 2019 deadline. The full responses can be found in Appendix 11.4.

The stakeholders were asked for responses to four specific questions.

1. What information do stakeholders have on available methods and approaches for monitoring PPP exposure and effects in the terrestrial environment?

There was considered to be some overlap between this review and the NERC funded research project "*ChemPop: What are the impacts of chemicals on wildlife populations?"*[64] which focusses on the population or community-level impacts of chemical exposure. The National Farmers Union (NFU) is currently developing approaches for gathering information on what is happening over time in terms of the level of risk from and impacts associated with pesticide use rather than rely solely on usage statistics that relate to area to which PPPs are applied, weight of active substance used, number of applications or number of different actives used.

A desire for revision of pesticide usage statistics was supported by several stakeholders. There was also a common desire for monitoring to assess and report the impact of pesticide use rather than residue levels alone, and the effects of resulting pesticide mixtures in the environment.

Stakeholders also considered that any future monitoring scheme should be designed so that the data generated is statistically robust, and that data collection and analysis is performed to recognised standards, where available. Care needs to be taken to ensure any scheme devised is based on sound science; clearly identifies 'cause and effect'; provides outcomes which benefit the environment; is not just an academic exercise; and should be affordable and workable for those concerned.

In terms of methodologies used in other countries, in January 2019 EU Member States adopted a new system for monitoring pesticide use based on a set of 'Harmonised Risk Indicators'. These take into account both sales and usage levels of

[64] https://www.ceh.ac.uk/our-science/projects/chempop-does-discharge-chemicals-environment-harm-wildlife-populations

active substances that are categorised as low risk, those that are approved and considered to present "normal" risk, and those that are considered candidates for substitution.

Stakeholder responses also highlighted several monitoring programs from France, Sweden and Denmark. In Sweden, there is a monitoring program for PPPs in surface waters, air and precipitation[65]. In France, an indicator ("NOmbre of Doses Units" (NODU)[66]) has been developed with stakeholders for monitoring the use of phyto-pharmaceutical products. This is calculated using sales data provided by the distributors of PPPs. The NODU corresponds to a number of "average" treatments applied annually to all crops nationwide. It overcomes the substitution of active substances by newer substances that have similar effects but at lower application rates by calculating the unit dose (DU) for each specific substance that is applied. Thus, in relation to the useful agricultural area (UAA), the NODU makes it possible to determine the average number of treatments per hectare.

In Denmark, the use of a Treatment Frequency Index (TFI) to measure the intensity of pesticide usage has been superseded by the Pesticide Load[67] metric which amalgamates three sub-indicators for human health, ecotoxicology and environmental fate. In addition to being used to monitor trends in pesticide use and load, it is also used for setting quantitative reduction targets. The Danish approach for load assessment has been used as a basis for the development of a potential future UK Pesticide Load Index. In contrast to the Danish index, the UK metric has a solely environment focus. It is derived from input data drawn from two existing databases, the UK Pesticide Usage Survey and Pesticide Properties Database. Information from these two sources are combined to generate a series of volume usage related and "hazard" metric for each active ingredient and some primary metabolites that can be combined and used for comparative assessments.

Some stakeholders recommended a number of matrices in which PPPs should be monitored to test for exposure of various key taxonomic groups and trophic levels to a range of PPPs and their breakdown products. These matrices included soil (stratified by regional land use and soil type), plants (stratified by life history and regional land use), invertebrates (primary and secondary consumer species,

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[65] https://www.slu.se/en/pesticide_monitoring

[66] https://agriculture.gouv.fr/quest-ce-que-le-nodu

[67] https://doi.org/10.1016/j.landusepol.2017.11.010

carabids, and crop pollinators), and vertebrates. A notable gap identified by more than one stakeholder was the lack of monitoring of PPP concentrations in soil.

Several responses also highlighted that there should be consideration of the impact of non-PPP use factors, such as soils cultivation, on the metrics monitored. Additionally, the extent of data collected at each site would need consideration; for example, would soil samples be taken at a set depth or multiple depths to form a PPP profile through the soil depth?

2. What is the appetite for more comprehensive post authorisation environmental monitoring?

A commonly held view among the conservation NGOs was that whatever the outcome of the monitoring review (and whatever the post-EU exit approvals process for pesticides looks like), the precautionary principle should remain central, and indeed be strengthened. A monitoring scheme, however robust, does not negate the importance of a hazard-based approach. A monitoring system both pre- and post-approval that looks at 'downstream' and non-lethal effects (in addition to what is currently assessed pre-approval) will be key to this.

Several contributors to the written responses expressed a need for monitoring schemes to identify the cause and effect of PPP use on the environment, with some commenting that such monitoring would be expensive and complex to conduct. More generally, several responses called for clarity on the objectives of monitoring and how any post-registration monitoring data would be used in policy-making.

Stakeholders also encouraged a proportionate approach to monitoring PPP in the environment, taking account of other contaminants released from other sources. Any monitoring initiative should be strongly risk and science based, taking into account different UK landscapes. There was also a call for careful communication of results from any monitoring scheme and that 'communication of any findings must put the magnitude of the findings in context, together with an explanation as to why PPPs are used and possible sources, which may include use of PPPs in home and garden situations or use of flea control products on companion animals.'

Stakeholders also felt that any monitoring scheme need to be fair and equitable to all sides and the language used in reporting should be neutral. Monitoring that was integrated with the current regulatory process and statistically robust would be worthy of further consideration.

3. Did stakeholders have views on potential frameworks for an "idealised" scheme?

The stakeholder responses argued that the following points should be taken into account in the design of any potential frameworks:

- Relevant stakeholders should be consulted on the design and have oversight of the project;

- Governance of the project to ensure that data collection, analysis and reporting are to agreed protocols and conclusions drawn are scientifically robust;

- Any monitoring scheme should have a clear, stated focus (e.g., active substance with identified concern or data gap), targets (e.g., species, environmental compartment) and success criteria;

- It needs to be clear whether the aim of monitoring is to set an acceptable level for a PPP residue in the environment (if so, how can this be achieved?) or a reduction in PPPs detected (but it is not clear what would be the scientific basis for this);

- Monitoring could aim to provide measurements of the effectiveness of mitigation measures within the environment, such as habitat provision, and thereby provide opportunities to inform better integration, mitigation, or optimisation of chemical use;

- Decisions on what active substances should be monitored should be based on information on, for example, intensity of use or the chemistry of the active substance. It was suggested that monitoring could focus on products and active substances where, for example, risk mitigation measures have been recommended to satisfy the risk assessment;

- Monitoring could include or focus on active substances following their withdrawal from use, and on new active substances. Monitoring should be compatible with and complementary to existing, long-term national monitoring schemes;

- There should be a clear basis for selecting sites and include consideration of previous PPP use, soil type, soil structure, soil chemistry and previous cropping;

- Initially monitoring at one or two sites for one or two active substances may help determine how to progress developing a larger monitoring scheme;

- Data on PPP use are held by users of professional PPPs who are required to retain records on their PPP use for five years. Data on non-professional use (home, garden and allotment) could be very difficult to collate;

- Two key areas where monitoring could target environmental residues and their impacts on wildlife but where no monitoring currently exist are:

(i) the monitoring of pesticide residue levels in agricultural soils and soil biota to detect changes over time. Considering the number of different types of pesticides used on the typical farm field over the course of a year, such monitoring would inform a greater research focus on the effect of these pesticides on soil life and soil health, as well as persistence and fate information for key pesticides and mixtures.

(ii) the monitoring of residues in wildflower pollen around agricultural fields. If residues levels could be analysed in conjunction with information on insect population changes in the same areas, this could be used to inform more real-world level exposure experiments. Monitoring could focus on pesticides of key concern but would also need to look at estimating the total pesticide toxic exposure to wildlife.

- Collection and publication of data is the key to the success of any monitoring system. Key areas for data collection should be:
    - Pesticide sales data should be collected and published so that it will be possible to determine changes in what products are being used by farmers and growers. The data collected would give a clear indication of whether the uptake of less toxic active substances by farmers and growers is increasing or decreasing. It would also assist the UK in developing a system similar to that laid down in Commission Directive (EU) 2019/782 for developing Harmonised Risk Indicators for pesticide use.
    - Farmers spray records, including area and frequency of treatment
    - Presence of pesticides in the environment, soil, water and flora
    - Exposure of wildlife to pesticide residues
    - Presence of pesticides in aquatic and terrestrial fauna
- Results are reported in a balanced way to prevent unnecessary public alarm;
- There would need to be an agreed protocol of what should be done, specific deadlines for the provision of data and a process for evaluating those data;
- The monitoring data should be evaluated and, if the outcome is satisfactory, it could end the requirement for further monitoring. Any continuous monitoring without an end date would need to be government-run.

- Recognition that the outcomes of monitoring could inform policy responses in contrasting ways. For example, they could show that the regulatory process is not robust enough, or they could show that the regulatory process is actually too precautionary and conservative;

- Assessment of how the levels of detected PPPs relate to any impacts on end points in wildlife and the terrestrial environment would be needed, and take into account the impact of other factors on the same end point. It is important that PPPs are treated in a comparable way to other chemicals in the environment. This means that the specific use, release fate and hazard of chemicals should be part of the background considerations. Outcomes from monitoring should not be compromised by other factors that cannot be unpicked;

- Any scheme would need to be clear about the limitation and assumptions of the approach finally adopted, making the most of opportunities to inform better integration, mitigation, or optimisation of chemical use;

- A new monitoring system should ideally be managed by one coordinating department, even if the actual testing is undertaken by other relevant agencies;

- There needs to be absolute transparency of the monitoring results which must be made available to all interested parties, including members of the public;

- Monitoring results must be provided in a timely manner. At present, monitoring results (most notably the pesticide usage statistics) lag far behind their collection, making it impossible for concerned stakeholders to analyse or respond to findings in real time.

4. Options for funding.

Suggestions included:

- a pesticide tax based on the environmental and/or human health toxicity, such as that used in Denmark[68].

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[68] https://foodresearch.org.uk/publications/brexit-pesticides-crossroads/

- measures developed by government and stakeholders to assess landscape-scale environmental impacts of pesticide use with charge on this basis.

- all beneficiaries should contribute to the costs of any scheme, and this is likely to result in an increase in food prices. Willingness to contribute would depend on the extent of the monitoring and the timeframe over which it is to take place, as this will determine cost. A long-term scheme over years is probably less likely to be funded by stakeholders so will require government funding. Costs could be minimised by using infrastructure and data from current monitoring schemes if they met the agreed protocols of this scheme. In addition, some monitoring could be undertaken by volunteer recorders (as with BTO work with volunteers).

- government funding for general monitoring schemes, a government run scheme funded by an industry levy on authorisation holders.

- redistribution of funds received as part of the Pesticide Levy (more than £3.1million in 2018/19) could be a viable option as a proportion of this fee is already used to support environmental monitoring and surveillance through the WIIS.

7.3 General format of stakeholder workshops

Two stakeholder workshops were held at Imperial Hotel London, Russell Square on 21 and 29 January 2020. The first, for representatives from the PPP industry and user community bodies, involved 10 representatives from eight PPP companies and user community organisations. The second was comprised of 9 representatives from eight conservation bodies and NGOs.

The same generic format was used in both workshops, and the standardised agenda is shown in Table 7.1. The first session involved the presentation of the post-registration monitoring draft scheme, including the Level 1, 2 and 3 options (see Section 5). Comments and questions arising from this initial presentation were recorded.

Table 7.1 General agenda used for the stakeholder workshops

Time	Item	Lead
1030-1100	Coffee and arrival	
1100-1110	Welcome and aims for the day	Gen Madgwick/ Richard Shore
1110-1200	Presentation of proposed PPP post-registration monitoring scheme (including questions)	Richard Shore
1200-1240	Breakout 1. Pairs/quads to consider questions 1-3	All
1230-1310	Feedback from breakout 1 and scoring of responses	Richard Shore/ Lee Walker
1310-1350	Lunch	
1350-1430	Breakout 2. Pairs/quads to consider questions 4-6	
1430-1500	Feedback from Breakout 2 and scoring of responses	Richard Shore/ Lee Walker

Stakeholders were then asked to discuss their responses to specific questions (Box 7.1) in breakout groups.

Breakout 1

A. Will post-registration monitoring (as or similar to the scheme outlined) help identify unexpected consequences of PPP use at different scales? Give your reasons.
B. Are there missing elements that should be included in the proposed scheme and how would they be of value?
C. Are there elements of the draft monitoring scheme considered not of value?-state which and why.

Breakout 2

D. What do you perceive to be the barriers to any implementation of such a scheme?
E. How should any post-registration monitoring scheme be resourced?
F. How/where do you think the results from monitoring should be disseminated?
G. List any other key issues not addressed elsewhere.

Box 7.1. Questions posed of breakout groups in the stakeholder workshops

The responses from the breakout sub-groups were reported back during the workshop. They were subsequently summarised and, after the workshop, attendees were asked to score their top three comments in response to each question. The first, second, or third most important response to each question from each delegate were assigned a score of 3, 2, or 1, respectively.

The complete list of comments made throughout the various agenda items from both workshops are presented in Appendix 11.5 and Appendix 11.6, respectively but an overview of those identified by the participants as the most important are presented in the two subsequent sections of this report.

7.4 First stakeholder workshop – industry and user community

Attendees of the industry and user community workshop are listed in Table 7.3 Appendix 11.5 and prioritised responses to breakout session questions are discussed below. The tables outlining the scores given to responses are also in Appendix 11.6 and a narrative summary is given below. Prioritization scores were received from nine delegates and so the maximum sum score possible for a response to an individual question was 27.

Question A - Will post-registration monitoring (as or similar to the scheme outlined) help identify unexpected consequences of PPP use at different scales?

The highest scoring responses were related to definition and identification of "unexpected consequence" and communication of monitoring results.

The workshop highlighted that there was a need to establish a baseline for any monitoring metrics, otherwise it is not possible to determine whether or not a 'consequence' is 'unexpected' (sum score 13). Any monitoring scheme needs to be clear on the definition of unexpected 'consequences' (sum score 17), with a clearer explanation of whether it relates to environmental exposure or something else and defining what consequent actions may be. It was felt that post-monitoring registration may be able to identify a consequence or change but will not necessarily be able to assign the consequence to a particular driver. Some reservation was expressed that 'consequence' is not the right term as it automatically implies or presupposes that the outcome is the result of an action (i.e., PPP use) and the language used should actually be about unexpected 'occurrence' or levels. Furthermore, public understanding of whether the presence of any residue might be expected or a cause for concern will be a challenge for communications (sum score 6). It was felt that careful terminology needed will be needed when presenting the results of monitoring (sum score 3)

The workshop attendees also thought that the proposed scheme could provide more realistic information on scale of use and exposure than currently available (sum score 3), potentially flag issues where there are potential concerns, and where investigations were needed (sum score 7), and identify the presence of what types of mixtures may be present in the environment (sum score 1).

Question B - Are there missing elements that should be included in the proposed scheme and how would they be of value?

Workshop participants agreed that it is important to manage expectations for the scheme in terms of defining purpose and scope. The scheme needs to be clear from the outset that it is not able to identify that PPP X is causing impact Y. It can only flag that occurrence of PPP X is outside what would be expected and that this would then trigger separate investigative work to determine why and the relevance of this, if any (sum score 15). More granularity of PUS data would enhance the usefulness of the scheme and the use of the Environmental Land Management Scheme[69] (ELMS) (sum score 14). The workshop also thought that the baseline (including historical exposures) from which unexpected results will be compared needs to be clearly defined (sum score 6).

Other responses to the question on identifying gaps in current monitoring and the proposed scheme, that received relatively low prioritisation scores (3-4), included the need for information on amenity, allotment, home and garden use of pesticides, and a need for data on other potential "contaminants" that may affect wildlife, such as fertilisers and micro-nutrients.

Other stakeholder responses of similar scores related to the reporting and interpretation of monitoring data and included:

(i) the report needs to be transparent about the reasons why prospective elements have been excluded from the scheme,

(ii) communications around the publication of the report and initiation of any subsequent scheme need to be clear;

(iii) concerns that the detection of pesticide residues is used as justification to reduce or restrict use, without taking the step of finding out whether presence is actually causing an unacceptable problem;

(iv) a need for monitoring to be timely, consistency and establish a baseline "norm".

Question C - Are there elements of the draft monitoring scheme considered not of value? - state which and why.

None of the proposed elements were considered not to be of value.

The responses to this question focussed on how to contextualise the data generated through the proposed monitoring scheme. The workshop highlighted that detection of the presence of PPPs alone is not helpful, particularly with sensitive analytical techniques capable of detecting active substances or their metabolites at

[69] https://consult.defra.gov.uk/elm/elmpolicyconsultation/

concentrations at part per billion (e.g., ng/g) or lower (sum score 26). Residues need to be assessed in the context of the potential for effects or risk, based on available ecotoxicological data. It was thought that the number of active substance applications, as generated by the PUS, would not be a useful metric for a pesticide monitoring scheme (sum score 13). The workshop also raised the question as to how current elements of post-registration monitoring are fed into regulatory assessment (sum score 7), e.g., WIIS – how successfully have issues identified as resulting from approved use fed back into the regulatory assessment process?

Other stakeholder responses of similar scores (4) included:

(i) fitting analysis to exposure assessment; and

(ii) use of state-of-the-art usage data requires clear data management, particularly regarding ownership and access to any data from farm management data software (see also question D below).

Question D. What do you perceive to be the barriers to any implementation of such a scheme?

The stakeholders identified limitations on the utility of the PUS generated data namely:

(i) if these statistics are to be used as a basis for other metrics (e.g., pesticide application maps), the PUS data need to be sufficiently robust. This was queried on the basis that the number of farms sampled is low and that amenity use is infrequently reported (sum score 12),

(ii) the granularity of the PUS data may limit the ability to analyse and follow up of unexpected findings (sum score 11).

(iii) a question as to whether sufficient resources, both in terms of funds, personnel and organisational capacity, would be available to enable follow–up investigation and study where unexpected findings have been flagged (sum score 9).

Additionally, stakeholders stated that the scope of the project should be agreed among stakeholders (sum score 6), and that an ability to utilise any detailed data generated through on-farm upload (such as use of digital labels), will be reliant upon definition of data ownership and use (sum score 6).

Other stakeholder responses of (sum scores of 4 to 1) included:

(i) It is possible to record targeted and precision applications of PPPs, rather than whole field applications;

(ii) Resourcing is likely to be a barrier;

(iii) Agreement on dissemination of findings and level of detail of finding – who, what they see and when;

(iv) Detected PPP residues in vertebrate carcasses may not be representative of exposure in populations.

Question E - How should any post-registration monitoring scheme be resourced?

The two main sources of funding identified by the stakeholders were public funding through government departments and agencies (sum score 19), and the existing pesticide finance levy (sum score 17).

In relation to the levy, the delegates thought there might be a distrust in the outcomes of monitoring if industry was seen as a funder of the project. Therefore, it was suggested that an approach similar to the Environment Agency's monitoring might be suitable with monitoring driven through Defra or a related regulatory body to ensure "independent" and transparent verification of data (sum score 5). The stakeholders also noted that additional funding may be needed – in particular to address 'flags' of unexpected observations, if identified (sum score 6).

Other stakeholder responses that received sum score of 2 or 1 included:

(i) a potential issue may occur if the authorisation holder may be needed to provide funding – but that would require the issue being tied to a specific active substance. Consequently, if it was tied to a specific active substance and the authorisation holder wanted to resource further work, there may be a public perception issue with this;

(ii) there is a potential route to reward for data provision from farmers through ELMS;

(iii) long-term funding would be needed for the monitoring program;

(iv) existing data sources may be available for use that do not require additional funding;

(v) multi-stakeholder funding, including industry and environmental groups may be desirable.

Question F - How/where do you think the results from monitoring should be disseminated?

The stakeholders felt that dissemination would need to be carefully handled with public communication through a mechanism that understands the consequences of reporting issues (sum score 14). Furthermore, it would be useful to have stakeholders involved in initial review of reporting (sum score 14). Transparency was considered a key issue. Free availability of results would be desirable but there would also be a need for accompanying science and evidence based expert interpretation (sum score 13). Reporting was identified several times as an issue requiring consideration and that analysis and interpretation of data is the key thing to communicate, not just the data itself (combined sum score 8).

Other stakeholder responses, that received sum score of 3 or below, included the point that the frequency and scale of reporting has yet to be defined, (monthly, annual, farm, regional, country, UK-wide).

Question G – List any other key issues not addressed elsewhere.

The key issue not covered in previous questions was that any monitoring and reporting thereof should be cognisant of other stressors on signal change (sum score 15). The current report should explain why some existing monitoring, including the farm bird index, the butterfly survey and Rothamsted Insect Survey, were excluded from the proposed monitoring scheme (sum score 13).

Sources of other uses (veterinary, biocidal, pharmaceutical) of active substances used as PPPs should be considered (sum score 9) as this could compromise the ability to link detected presence of active substances to PPP use. The consistency and traceability of reporting metrics was also considered an important issue (sum score 8).

Other stakeholder responses, that received sum score of 4 or below, included:

(i) a need to explain the extent to which different datasets may effectively be compared;

(ii) a concern over the gap in information on amateur and amenity use;

(iii) incorporation of new data and the sources from which those data are obtained needs to be presented in a clear way.

7.5 Second stakeholder workshop – conservation bodies and NGOs

Attendees of the conservation bodies and non-governmental organisations workshop are listed in Table 7.4 in Appendix 11.6. Prioritised responses to breakout session questions are discussed below. The tables outlining the scores given to responses are also in Appendix 11.6, and a narrative summary is given below. Prioritization scores were received from six of the 9 delegates and so the maximum sum score possible for a response to an individual question was 18.

Question A - Will post-registration monitoring (as or similar to the scheme outlined) help identify unexpected consequences of PPP use? Give your reasons.

The responses considered to be the most important by the stakeholders were that there needs to be a mechanism to trigger policy change or registration status (sum score 11), and there needs to be a clear definition of who is responsible for taking further action, e.g., commissioning in-depth studies (sum score 8). Related to the latter response, there is a need to decide who is going to use the data generated and what they would do with it (sum score 6).

Other stakeholder responses, that received a sum score of 1 to 5, included:

(i) better data where there are particular gaps would be useful;

(ii) need to change the title of the scheme to clarify its purpose;

(iii) a lot of data would need to be collected in order to be useful to identify “fine-brush” consequences;

(iv) a need to clarify in the current report the value of the monitoring scheme to renewal process.

Question B -Are there missing elements that should be included in the proposed scheme and how would they be of value?

The workshop identified the Pollinator Monitoring Scheme (POMS) as an element that could be included (sum score 11), both as a source of data and samples for analysis. There may be a need to increase sample numbers/sites in the scheme. Two types of PPP use not currently reported in PUS were identified, namely forestry and amenity use (sum scores of 4 and 9, respectively).

Other stakeholder responses, that received sum score of 1 to 3, included:

(i) potential use of sales data for monitoring;

(ii) potential for coordination with aquatic monitoring – picking up terrestrial signals that influence aquatic contamination with PPPs;

(iii) proposed monitoring scheme could be extended to veterinary medicines;

(iv) spatial data on species distributions from the National Biodiversity Network (NBN) and Biological Records Centre (BRC) could be included but probably at Level 3 monitoring;

(v) farmer collected field-level data on use could also be a source of data;

(vi) pesticide load indicator project outputs[70] may be worth considering;

(vii) work from the University of Reading on individual based models on exposure and impacts.

Question C -Are there elements of the draft monitoring scheme considered not of value? State which and why.

Only two responses were received to this question, namely; (i) PUS in its current form is of limited value and; (ii) there is a caveat to the value of the WIIS scheme as it is a reactive scheme (both assigned a sum score of 15).

Question D -What do you perceive to be the barriers to any implementation of such a scheme?

The workshop delegates thought that the primary barrier to implementation was political will (sum score 12). Securing long-term funding for monitoring, and short burst funding for intensive investigations scored equally (sum score 10). There is also a need to put in place mechanisms to act upon signals from monitoring schemes and commission intensive studies (sum score 4).

Other stakeholder responses, that received sum scores of 1 to 3, included:

(i) challenge would be to get buy-in from multiple providers of data, capacity to meet needs, and scope of information being gathered;

(ii) clarity on where this monitoring sits in the policy landscape;

[70] http://www.europarl.europa.eu/RegData/etudes/STUD/2018/627113/EPRS_STU(2018)627113_EN.pdf

(iii) need clear governance and ownership of the monitoring scheme to ensure it is fit for purpose;

(iv) accountability for the monitoring scheme;

(v) no overarching regulatory requirement for this monitoring currently.

Question E - How should any post-registration monitoring scheme be resourced?

The stakeholder's responses identified a hypothecated pesticide industry tax on products (sum score 12) as the preferred funding source. A further three funding sources (all sum score 7) were well supported by workshop attendees, namely through: (i) a pesticide industry levy charge to user or distributors or a licencing approach; (ii) the public purse, potentially through a share of the agri-environment budget; (iii) funding through research councils such as UKRI. Two more responses were that costs be covered through registration or a pay per spray charge to the user; both received sum scores of one.

Question F - How/where do you think the results from monitoring should be disseminated?

The principle of open data and transparency should be central to the approach and communication of any scheme (sum score 15) through annual and/or continuous ongoing reporting (sum score 6). The impartiality of reporting was considered important (sum score 4) and results should be disseminated to agricultural training and agronomy advice services, industry and to government departments (sum score 4).

Other stakeholder responses that received sum scores of 2, included:

(i) highlighting the need for transparency of what the data is being used for;

(ii) dissemination of reporting to the UK Expert Committee on Pesticides (ECP), and bodies involved in authorisations and renewals of PPPs, such as the CRD;

(iii) results should inform roll-out or further roll-out of integrated pest management.

Question G - List any other key issues not addressed elsewhere.

The workshop attendees thought that there is currently no overarching regulatory requirement for this monitoring (sum score 14), and that any reporting of the project should highlight that the proposed monitoring scheme will not even in part replace risk assessment requirements (sum score 8). There also needs to be clarity on how a monitoring scheme would inform the risk assessment process (sum score 5).

Other stakeholder responses, that received sum scores of 2 to 4, included:

(i) the scheme should encompass flexibility to address specific questions;

(ii) the proposed scheme does not include monitoring of efficacy of PPP use and to do so would require yield data;

(iii) combination use of analytical target and non-target scanning are options for monitoring that could be explored.

7.6 Summary

The top priority responses identified by stakeholders that attended either of the workshops are presented in Table 7.2.

The focus of the responses by the two stakeholder groups attending the workshop differed. With regard to the utility of the proposed scheme, industry and user community groups considered the priority to be definition of what was meant by unexpected consequences and what the baseline should be for comparison against current status. Conservation bodies and NGOs emphasised the need for clarity on who is going to use the data generated, i.e., who is responsible for taking further action, and how the data that is collected from monitoring will be fed back in the regulatory process to support the identification and assessment of any authorisation changes?

Both sets of stakeholders agreed that the proposed monitoring scheme would in all probability only be able to act as a flag for unusual findings or detection of trends that would warrant further investigation. This was likely to remain the case given the challenges of developing robust and reliable effects based measurements to support the measurement of pesticides in environmental and organism samples. As such there would likely remain questions around linking exposures to impacts, especially given the difficultly in assigning cause and effects in the presence of potentially confounding factors affecting organism, physiology, life-history and population dynamics. However even in the face of this challenge, terrestrial pesticide monitoring could play and important role in determining whether PPP exposure could plausibly play a role in wildlife impacts or whether residue levels occur at well below those known to cause and adverse effects.

Another similarity in opinion between the stakeholder groups was the desire for PUS statistics to utilize modern and upcoming PPP usage approaches to generate more precision or granularity of usage data. More broadly there was a view that the Pesticide Usage Statistic in their current form may no longer be fit for purpose and that a review of their use and availability should be initiated, although such a review was beyond the scope of the current review. However, they also recognised that issues around data ownership would need to be resolved in order to utilise these data sources. Areas of use that are not currently covered by PUS reporting were also identified including amenity and forestry use.

The stakeholders considered that all the proposed monitoring activity would be useful and suggested some potential additional activities.

Stakeholders agreed that reporting of the monitoring scheme would require explanation and interpretation of the relevance of the results and not just simple presentation of the monitoring data alone.

In terms of barriers to implementation of the proposed scheme, both sets of stakeholders thought that the key barrier was provision of sufficient funds to both maintain annual monitoring and to support follow-up studies to investigate the cause of unexpected observations. This requires both the political will to support these activities and clear mechanisms in place to act upon the findings of the monitoring and subsequent follow-up studies. Maintenance of the impartiality of reporting was an important principle to both stakeholder groups with both public and industry funding, or a combination of both, suggested as possible sources of funding.

The challenge of ensuring timely and useful dissemination of results was another shared view. Such reporting needs to be transparent, available to all stakeholders, and specifically directed toward those who can act upon the information provided.

Table 7.2. The top three responses to breakout questions posed during the stakeholder workshops.

Question	Industry and user community group	Conservation bodies/ and non-governmental organisation group
A - Will post-registration monitoring (as or similar to the scheme outlined) help identify unexpected consequences of PPP use? Give your reasons.	• Need to be clear on definition of unexpected 'consequences' – be more specific whether it relates to environmental exposure. i.e., what consequences and what would be unexpected. • Need to establish baseline – otherwise you cannot determine whether or not a 'consequence' is 'unexpected' • Potentially flag issues where potential concerns and where further investigations were needed.	• Needs a mechanism to trigger policy change or registration status. • Who has responsibility for taking further action, e.g., commissioning in-depth studies? • Need to decide who is going to use the data and what would they do with it
B - Are there missing elements that should be included in the proposed scheme and how would they be of value?	• It is important to manage expectations for the scheme defining purpose and scope of scheme. • More granularity of PUS data would enhance the usefulness of the scheme and use of Environmental Land Management Scheme (ELM Scheme)	• Could UK Pollinator Monitoring Scheme (POMS) be included? • Amenity use not picked up by PUS reporting. • Forestry use not picked up by PUS reporting.

Question	Industry and user community group	Conservation bodies/ and non-governmental organisation group
	• The baseline (including historical exposures) from which unexpected results will be compared needs to be clear.	
C - Are there elements of the draft monitoring scheme considered not of value? -state which and why.	• Presence of PPPs alone is not helpful, particularly with sensitive techniques detecting at ppb/ppt level – residues need to be assessed in context of potential for effects/risk based on available ecotox data. • Number of applications is not a useful indicator in PUS. • How have current elements fed into regulatory assessment, e.g., WIIS – how successfully have issues identified as resulting from approved use fed back into the regulatory assessment process	• Caveat of value of WIIS as it is a reactive scheme. • PUS in current form of limited value compared to alternatives data sources.
D. - What do you perceive to be the barriers to any	• PUS limitations – if used as basis need to be comfortable with data produced by PUS. Is it enough, given low number of farms sampled?	• Political will.

Question	Industry and user community group	Conservation bodies/ and non-governmental organisation group
implementation of such a scheme?	Amenity sector not covered frequently, and amateur use missed? • Granularity of data (e.g., PUS only statistically robust to regional scale – so how do your follow-up unexpected findings?). • Will there be sufficient resources to look at further detail following flag?	• Securing long-term funding for monitoring and short burst funding for intensive investigations. • Having mechanisms in place to act upon signals from monitoring scheme and commission intensive studies.
E - How should any post-registration monitoring scheme be resourced?	• Public funding –government sources. • Existing pesticide levy could be a start. There could perhaps be a mistrust in the outcomes if industry was seen to fund the project. • Some additional funding may be needed – in particular to address ‘flags’, if identified.	• Hypothecated pesticide industry through pesticide tax on product. • Public purse – share of agri- environment money • Pesticide industry levy – charge to users or distributors – licencing approaches.
F - How/where do you think the results from monitoring should be disseminated?	• Need for careful dissemination – need for carefully handled public communication through a mechanism that understands the consequences of reporting issues.	• Open data and transparency. • Annual reporting or ongoing dissemination of data, or both.

Question	Industry and user community group	Conservation bodies/ and non-governmental organisation group
	• Useful to have stakeholders involved in initial review. • Availability of initial results – freely available – transparency being key here, but need science and evidence based expert interpretation with that.	• Dissemination into agricultural training and agronomy advice, industry and departmental lit.
G – List any other key issues not addressed elsewhere.	• Cognisance of other stressors on signal change. • Why for example were farm bird index, Rothamsted Insect Survey and butterfly survey and other perceived 'relevant' data not included? Report needs to explain why these were excluded from scheme. • Sources of other uses of actives e.g., veterinary meds, biocides, pharmaceuticals, are not accounted for	• Currently no overarching regulatory requirement for this monitoring. • Include in report that will not even in part replace RA requirements. • Relating to informing Risk Assessment process – what would need to be in place in order for feedback to happen?

8. Potential costs and funding routes for Level 1 schemes

8.1 Introduction

This section of the report estimates the costs to run the level 1 components of the proposed pesticide monitoring scheme and the current funding routes. Some of the component schemes proposed in section 6 rely upon volunteer/citizen science activities and so these direct collection costs in kind are not considered. Furthermore, the costs discussed in this section are indicative figures rather than detailed costings. The potential costings are assessed based on the experience of the project team on managing monitoring activities and through consultations with other scheme managers and stakeholders. There would need to be a discussion of what exactly was wanted from expanding either in scale or scope, e.g., addition of PPP residue analysis, in order to develop a more accurate and detailed budget for these activities.

8.2 Pesticide Usage Survey

The Pesticide Usage Survey (PUS) is funded through the pesticides levy that is charged each year on HSE approved PPPs. The levy collection exercise commences each year in September with a request to approval holders to declare their sales turnover for a given 12-month period. Invoices are subsequently sent out the following January. The levy is expressed as a percentage of the declared sales turnover, and each year approval holders are invoiced for the appropriate amount. The current proposed monitoring program would not necessarily require substantial change to the nature of the data collected in the PUS program. This means that costs and requirement for PUS operation to support any enhance terrestrial monitoring program would not create a major additional cost. However, the stakeholder consultation did note a need to improve the nature of reporting of the collected data. For example, it was identified by multiple stakeholders that it would be beneficial to the understanding of pesticide loads, for example, if it was possible to go beyond the regional information available within the current PUS reporting to allow more detailed local-scale assessment of scrutiny of pesticide use. Further, while PUS does provide information on the use of individual active substances, it doesn't have any mechanism for assessing the combinations of active substances that are actually being used within the same agricultural cropping systems. This shortcoming hinders any attempt at trying to document or assess the nature of real world exposures to pesticide and the potential (if any) for impacts of pesticide in use. Such information would be potentially useful to enhance the usefulness of the scheme for applications including within the Environmental Land Management Scheme (ELMS)

8.3 UK Pesticide Load indicator

Defra and contractors at the HSE and University of Hertfordshire have been undertaking a project that aims to develop a UK Pesticide Load Indicator (UKPLI). A three phase approach has been followed in the modification of the Danish approach to the UK circumstance. The UKPLI approach is based on using input data drawn from two existing databases, the UK Pesticide Usage Survey and Pesticide Properties Database. Information from these two sources are used to derive a series of volume usage related and "hazard" metric for each active ingredient and some primary metabolites for those pesticides that have approved uses recorded appropriately over the last decade. These collated use and hazard data are analysed in order to calculate a load indicator value for each of the different active ingredients.

8.4 ASSIST - Farmland Soils

Currently the farmland soil survey conducted by UKCEH is funded through the UK Research and Innovation's Achieving Sustainable Agricultural Systems (ASSIST) program. ASSIST is a five-year program that runs until 2021. There are proposals to extend some aspects of the ASSIST project as a new 5 year £11M program under NERC funded National Capability – called "Green Ag" lead by UK CEH. The project benefits from existing soil sampling programs undertaken by commercial soil survey companies. There would be significant costs and time required in setting up similar soil sampling from scratch. Permissions for access to sampling sites would also need to be sought. The costs associated with conducting analysis for PPP residues in soil samples would be dependent upon the type and number of analytes to be quantified. The cost of performing PPP residue analysis that utilized both gas chromatography (GC) and liquid chromatography (LC) procedures to quantify a broad suite of active compounds would be £300 to £400 per sample. This would provide measurements of multiple pesticide residues within a single sample. The precise nature of the focus analytes would need to be agreed before the start of any proposed monitoring. This could be achieved through the review of current usage patterns and consultation with stakeholder and experts. Analytical method establishment and quality assurance development would require some additional upfront spend. Assuming that the core platform secures NERC funding, and all sites currently sampled annually under ASSIST were analysed, then annual additional analytical costs would be up to £160,000, in addition there would be sample handling and reporting costs of approximately £25,000. Stratification of the data to support a more targeted measurement program that could still generate data that could address the majority of the questions addressed in a full survey. The identification of this stratified design could be conducted based on the statistical analysis of a pilot measurement dataset.

8.5 Rolling Soil and Vegetation (RSV) platform

The Rolling Soil and Vegetation (RSV) platform is run by UK Centre for Ecology and Hydrology and is funded through the UK Research and Innovation's 'UK Status, Change and Projections of the environment' (UK-SCAPE) program.

PPP residue analyses are not currently carried out as part of the RSV platform therefore additional funds would be require to conduct these analyses. The costs associated with conducting analysis for PPP residues in soil samples would be dependent upon the type and number of analytes to be quantified. The cost of performing PPP residue analysis that utilized both gas chromatography (GC) and liquid chromatography (LC) procedures to quantify a broad suite of active compounds would be £300 to £400 per sample. As for the proposed analysis of ASSIST program samples, the exact suite of analytes would need to be agreed through consultation. The analytical methods would also need to be optimised and tested. The same choices of analytes would mean that any method would be applicable to both samples sets and to soils more generally.

8.6 Chick Food Index

The work in developing and testing the Chick Food Index (CFI) has been funded through a combination of self-funding by the Game and Wildlife Conservation Trust, targeted charitable donations, and competitively won income. Cost associated with annual monitoring at Loddington and the Sussex study, including sampling, identification, data processing, analysis and reporting, would be £150-160,000 per year. However, for Loddington little analysis has been done since 2004. In order to deal with a backlog of data there would need to be some additional funding in the analysis section if this was required.

If this scheme was expanded to other sites – for instance to other farmer clusters in other DEFRA regions, there would be a need for some capital costs to replace the DVac suction collection system with a Stihl system. At least two of the Stihl machines (one and a backup) would be needed for each additional area. The issue for a lot of this sampling is that it must be done at the same time of year, across large areas and requires sunny, dry weather for sampling. It is best to have multiple teams and equipment across the country. The costs of the Stihl system would be £3,600 per team. This would entail the need to hire field ecologists and – if more than one additional study area were required – at least one additional expert technician for invertebrate identification. There would be a need for purchase of at least one microscope and perhaps other capital expenditure to expand the system. The options for extending the CFI work have been considered further in a separate study and the outputs from that study will be considered in developing the CFI further.

8.7 ASSIST - National Honey Monitoring Scheme

Currently the National Honey Monitoring Scheme conducted by UKCEH is funded through the UK Research and Innovation’s Achieving Sustainable Agricultural Systems (ASSIST) program. ASSIST is a five-year program that runs until 2021. Running costs of the NHMS based on 600 samples and including consumables sample pack dispatch and receipt, dissemination and contributor communication activities would be £300,000-£350,000 per year. These costs are based on those that have been used to cost and deliver the measurements of pesticide concentrations made to date in honey samples submitted to the scheme based on analysis costs of £300 to £400 per sample. The costs associated with conducting analysis for PPP residues in soil samples would be dependent upon the type and number of analytes to be quantified. The cost of performing PPP residue analysis that utilized both gas chromatography (GC) and liquid chromatography (LC) procedures to quantify a broad suite of active compounds would be £300 to £400 per sample.

8.8 Wildlife Incident Investigation Scheme – honey bee surveillance (Bee unit)

The Wildlife Incident Investigation Scheme (WIIS) is funded through the pesticides levy that is charged each year on HSE approved PPPs. The levy collection exercise commences each year in September with a request to approval holders to declare their sales turnover for a given 12-month period. Invoices are subsequently sent out the following January. The levy is expressed as a percentage of the declared sales turnover, and each year approval holders are invoiced for the appropriate amount. The current proposed monitoring program would continue the operation of the WIIS as it stands and so costs are likely to be similar to what they are currently.

8.9 Wildlife Incident Investigation Scheme – other wildlife

The current proposed monitoring program would continue the operation of the WIIS for acute poisoning assessment and so costs are likely to be similar to what they are currently for the delivery of the current aspects, although extension to new measurements would require additional resources. The potential extension of WIIS for the analysis of wider exposure from supplied carcasses would involve additional costs. The size of these would depend on the number and range of substances and species to be analysed. Sample collection could build on existing Citizen Science based schemes, such as the Predatory Bird Monitoring Scheme or other scheme under the WILDCOMMS umbrella. This may require the extension of these programs to new species. With Citizen Science providing the basis for sample collection, the major cost of any WIIS extension would be for the handling and analysis of samples. The selection, development and per sample costs of sample analysis would mirror those above for soil sample. The split of additional analysis between any extension to WIIS and existing or additional work done of the Predatory Bird Monitoring Scheme would need careful management.

8.10 Predatory Bird Monitoring Scheme

The Predatory Bird Monitoring Scheme (PBMS) is funded through a combination of competitively won income and the UK Research and Innovation's 'UK Status, Change and Projections of the environment' (UK-SCAPE) program. The PBMS is a citizen science project that relies upon volunteers submitted predatory bird carcasses for necropsy and analysis. The annual costs of dissemination and contributor communication, sample receipt, necropsy, and maintenance of the tissue archive costs approximately £100,000 per year.

The residue analysis carried out each year is agreed on an annual basis among funding partners, and in recent years there has been a focus on non-PPP contaminants. The costs associated with conducting analysis for PPP residues in predatory bird tissue samples would be dependent upon the type and number of analytes to be quantified, but would be similar to those outlined for the other proposed components where PPP analysis is not currently carried out, based on expected analytical costs of The cost of performing PPP residue analysis that utilized both gas chromatography (GC) and liquid chromatography (LC) procedures to quantify a broad suite of active compounds would be approximately £400 per sample.

8.11 Coordination and reporting of the pesticide monitoring scheme

The coordination and collated reporting of the composite elements of the scheme is likely require similar effort to those employed for the H4 indicator: exposure and adverse effects of chemicals on wildlife as part of the UK Government's 25-year Environment Plan. The development H4 indicators covers a broader range of contaminants and habitats (terrestrial, freshwater and marine) but fewer components for each habitat. Therefore, the funding required for coordination and reporting of terrestrial PPP monitoring is likely to be less than that needed for H4 monitoring. These costs could be in line with those that are applicable to the organization and management of the H4 - Exposure and adverse effects on wildlife of chemicals in the environment indicator, part of the Outcome Indicator Framework (OIF) for England for assessing progress against 25 Year Environment Plan goals. This program requires similar aspects of multiple stakeholder engagement and inputs to support the identification of data for specific assessment, although this broader pesticide monitoring scheme would require a greater involvement of the organizing team to deliver specific operational aspects.

Table 8.1. Table of information of the current and potential future operating costs for programs that may be included in a terrestrial PPP monitoring scheme

Scheme Component	Current Cost per year	Estimated Cost per year if included in future monitoring scheme	Notes
Pesticide Usage Survey (current methods and reporting)	Unknown	Similar to current cost	Current costs would be expected to be sufficient for data collection, although increased granularity of data reporting may result in additional costs.
Pesticide Load indicator	Method under development	Low as would largely use existing data	Overall cost would depend on the final agreed design of the indicator. Access of PUS data needed and to Pesticide Property database. Main cost for interpretation of outcomes of analyses.
ASSIST - Farmland Soils – pesticide analysis	N/A	£185,000	Based on analysis of samples from current annual monitoring based on analysis cost of £400 per sample, with an additional £25,000 for sample handling, data analysis and reporting costs.

Scheme Component	Current Cost per year	Estimated Cost per year if included in future monitoring scheme	Notes
Rolling Soil and Vegetation (RSV) platform	N/A	£400 per sample	Soil samples not currently analysed for residues. Costs analysis would depend on the number of samples to be analysed, plus scalable costs for data analysis and reporting.
Chick Food Index	£160,000	*Pro rata* to current costs plus capital costs	Current costs based 2 farm clusters, additional clusters would need capital investment (£3,600 per cluster and £15,000 for microscopy equipment) and additional staff to allow concurrent sampling at multiple locations.
ASSIST - National Honey Monitoring Scheme	Citizen science (beekeeper) network for data collection. Current samples used for plant pollen source analysis not for pesticide residues	Analysis of 600 samples £300,000-£350,000 for sample collection costs and costs at £300 to £400 per sample for pesticide analysis	Running costs for 600 samples and including consumables sample pack dispatch and receipt, dissemination and contributor communication activities and chemical analysis costs of £300 to £400 per sample. PPP residue analysis costed for gas chromatography (GC) and liquid chromatography (LC) procedures to quantify a broad suite of active compounds.

Scheme Component	Current Cost per year	Estimated Cost per year if included in future monitoring scheme	Notes
WIIS - honey bee surveillance	Unknown	Similar to current cost for current acute incident scope, increased cost for chronic monitoring	Current costs would cover continued use to assess incident of acute poisoning. Use for wider chronic effect and temporal exposure and effect monitoring would result in increased cost.
WIIS - other wildlife	Unknown	Similar to current cost for current acute incident scope, increased cost for exposure monitoring	Current costs would cover continued use to assess incident of acute poisoning. Use for wider chronic effect and temporal exposure and effect monitoring would result in increased cost.
Predatory Bird Monitoring Scheme	Approximately £100,000 for sample collection and archiving.	Sample analysis cost depends on the analytical suite, but for PPP could be typically £400 per sample,	Current use of PBMS includes analysis for POPs, Hg and rodenticides. Samples are available for PPP measurements from a number of farmland associated bird species.

9. Conclusions/Final discussion

Post registration monitoring of pesticides in the terrestrial environment in the United Kingdom, as it stands, is based on the Pesticide Usage Survey for gathering usage data and the WIIS scheme for investigating suspected poisoning incidents. This means that with the current scheme there is a significant gap in the areas of pesticide fate and occurrence in different environmental media and for sub-lethal and chronic impacts resulting from exposures to terrestrial, freshwater and marine receptors. Current UK schemes are broadly comparable with the approaches adopted in other countries. However, additional monitoring efforts to fill gaps in environmental compartments, expansion of existing spatially restricted monitoring, or broadening of scope of existing schemes will result in a more comprehensive environmental monitoring system. This would increase public confidence in pesticide use and would provide post-approval monitoring data to support policy objectives relating to pesticide and wider chemical management.

The stakeholder consultation conducted as part of this project was designed to communicate the purpose of a potential scheme to stakeholders and to gather feedback on aspects of the design and use of the data generated. There was generally a view that the current status of pesticide monitoring did not fully support the delivery of current and future policy objectives. The focus on use by amount applied alone did not support a comparative assessment of potential risk. This has been addressed in some countries (e.g., Denmark, France) by a movement toward the development of pesticide load indicators. This approach has been investigated in research funded by Defra (Rainford et al. 2022). While there were differing views among stakeholders, there was a broad support for a review of the current approach to pesticide monitoring in the UK. Common preferences identified were enhanced understanding of usage and application patterns; improved environmental surveillance through linked soil, water and biota measurement; and a desire for the interpretation of pesticide use and exposure data within an ecosystem focused risk-based approach.

Any developed enhanced pesticide monitoring scheme would not in most cases be able to generate data and information that would alone be able to provide answers as to whether pesticides are having an impact at the population, community or ecosystem level. This is because of the spatial and temporal complexity of agroecosystems. Instead, the ambition of a program would be to provide improved knowledge of spatial and (over time) temporal trends of pesticides in the terrestrial environment. Within the remit of the study we sought to identify where additional monitoring schemes could be used as a basis for future monitoring. Currently schemes exist that collect soils that could be measured for pesticide and conduct pesticide measurement in pollinators and hive product and in vertebrate species. Hence these taxa are a natural focus for inclusion in any potential monitoring program. Measurement would allow a better real world understanding of pesticides behaviour and exposure in soil, providing additional information above that considered at the authorisation stage. Such information indicating, for example, wider than anticipated presence in monitored wildlife or greater persistence than predicted in soils could act as a trigger for further review and investigation. The timescale at which trends could be observed would depend on the nature of the underlying data, including detection frequencies of PPPs and spatial and temporal variation. The H4 indicators program has developed a specific statistical tool, the H4 Power of Metrics tool that can be used to assess the number of samples needed to identify changes that were considered of biological or environmental relevance in pesticide residue levels in measured sample sets.

A number of schemes that could contribute to the proposed monitoring scheme are discussed below:

• Monitoring of pesticide usage remains an important component of the proposed scheme to both identify changes in the prevalence and magnitude of use, and for supporting other components of the proposed scheme. However, stakeholders expressed views on a number of ways that current pesticide usage monitoring could be improved. This included finer spatial resolution and more frequent/rapid reporting of monitoring of pesticide use across usage sectors (arable, pasture and fodder crops, amenity use etc.), either through modelling approaches such as the Pesticide Application Maps, or through real time application recording (n.b. for latter there are practical limitations, and a significant issue of data protection and data access would need to be satisfactorily addressed). Additionally, there were some views that assessment of pesticide use should move from a weight based to a load based approach. Such a pesticide load indicator would take pesticide "potency", as well as usage amount, into account. This would mean for example, that application of a smaller amount of a high potency substance may be seen as providing a greater pesticide "load" than a large amount of a less potent active ingredient. Such an approach for Pesticide Load Indication has been developed in Denmark and is being assessed for application in the UK in Defra funded research being conducted by the Fera and University of Hertfordshire in work published in 2022. (Rainford et. al.)

• Inclusion of monitoring of soil concentrations to identify the spatial occurrence and potential unexpected persistence of PPP could play an important role in understanding the real-world environmental behavior of pesticides. Such soil monitoring is an important missing step between current collected data on usage and on presence in water bodies conducted through selected environmental agency monitoring programs for groundwater and surface water. The proposed soils monitoring component of the scheme would also readily contribute towards the initiatives to develop H4 – Exposure and adverse effects on wildlife of chemicals in the environment indicator, part of the Outcome Indicator Framework (OIF) for England for assessing progress against 25 Year Environment Plan goals.

• To deliver a soils monitoring component there are currently national-scale platforms collecting soil samples, i.e., the ASSIST farmland soils project and the Soil and Vegetation Research Platform and National Soil Inventory, that could potentially be adapted to full-fil this current gap. Measurements of organic pollutant, including pesticide, concentrations in the soils are currently not being conducted. Support would be needed to develop an approach to pesticide measurement and appropriate sample handling and analysis workflow. An approach to sample collection transport and pre-analysis storage is needed that is both operable at scale and appropriate for monitoring PPPs. Further, research would be needed to optimize methods for sample extraction and analytical methods, and to understand their effectiveness in recovering pesticide present in soils including strongly bound residues. Current methods used in regulatory fate assessment for pesticide would be a logical starting point for method development. On establishment of a method, it would then be possible to conduct an initial survey and analysis to establish a baseline of data to underpin trend analysis for subsequent measurements.

- Soil monitoring for pesticide will deliver understanding of below ground terrestrial fate, occurrence and potential exposure of soil organisms. However, it will not alone deliver an understanding of impacts. The inclusion of a measure of pesticide exposure and effects on soil biota would be a useful addition to any scheme as it could enhance interpretation beyond exposure and hazard assessment. Currently no one measure is immediately deployable for this purpose. A recent rapid evidence review has been conducted by the UK Centre for Ecology and Hydrology that has identified the potential value of genomics tools for the assessment of soil community diversity and functional change. This work will be reported in 2021. The development of new DNA barcoding techniques could make the rapid and cost-effective characterization and monitoring of microbial and eukaryotic soil communities more tractable than was previously possible. However, fundamental research is needed to evaluate what kind of questions such monitoring could address and how any such data could be used. In particular, there are question that need to be addressed on the choice of species (or communities) for monitoring; the robustness of these communities to other co-occurring stressors; the impacts of other environmental changes on response; the comparative sensitivity of indicators and the relevance of selected indicators for different soil types and habitats. Further comparative studies of different ‘omic approaches to pesticide impact monitoring are needed to address some of these topics. This work could be linked with future work on soils quality conducted under other programs.

- Field-derived information on earthworm communities in agricultural soils could be useful in understanding exposure to PPPs. The Rothamsted Earthworm Survey, with the collection of additional information on PPP use could provide data and samples valuable for interpretation of pesticide impact, exposure and potential for food chain transfer in soils. The methodology developed in the survey could be adopted by the ASSIST farm network (or its successor), which is better suited to the collection of pesticide usage data and soil sampling for analysis. Inclusion of earthworm monitoring is considered an activity that could be reviewed and developed once a monitoring framework was established. One aspect that will need to be addressed is the potential effects that different land management and tillage may have on earthworm population and the extent to which this can be separated from potential pesticide impacts.

- Chick Food Index (CFI), already included in the Pesticide Forum annual reports, has been identified as fundamental information for the soil invertebrate compartment of the proposed scheme. This would provide information on the annual CFI values and the grey partridge adult: juvenile ratio. The CFI is valuable because it potentially addresses the indirect effects of pesticides on trophic interactions, rather than focusing only on usage, loading concentration or direct effects on lower tropic levels. One of the drawbacks of the CFI is that it is based on measurements that are currently conducted only at two sites. Expansion of measurements to a wider number of sites would increase the robustness of the measure as a national indicator and merits consideration, but such expansion would of course require additional resource.

- The National Honey Monitoring Scheme (NHMS) has been piloted as an approach that can be run at scale to sample PPP concentrations in hive product and for the analysis of multiple active ingredients in parallel. Establishing links with beekeeper communities has been demonstrated as an efficient approach to national scale sample collection. Pesticide residues in honey are not exposure measures themselves to adult bees, although they are a good proxy for larvae. For adult bees residues in honey cannot, however, be readily converted to daily intake of residues in pollen or nectar as chemical may be metabolised before transfer into honey. Woodcock et al. (2018) were, however, able to demonstrate how honey PPP residues could be used as a quantitative index to infer differences in exposure and changes over time or following mitigation interventions. The methodologies by which monitoring of pesticides in honey would be conducted require development and would need to consider a number of factors for the delivery of a robust sample collection and monitoring program. Key components to be optimized include optimizing sample stability and long-term preservation; sampling design to ensure suitable within key spatial and temporal coverage, stratification of annual samples by provenance and sampling date, time-period of honey collection (including repeated analyses from the same hive), analytical methods and determinants, analytical quality assurance and control, and standardised collection of ancillary data. These are, however, all tractable issues that could be addressed to develop a robust and systematic scheme.

- The National Honey Monitoring Scheme provides a vehicle to understanding patterns and trends in landscape level exposure of adult bees and larval exposure. However, the scheme does not in itself represent an understanding of effects on bees. The Wildlife Incident Investigation Scheme (WIIS) investigations of bee mortalities provide a mechanism for identifying acute poisoning events. The scheme is already running and has been demonstrated as effective in identifying and understanding acute incidents. WIIS investigations into bee poisonings should be considered as an important aspect to continue, as part of a program to oversee how pesticide use may be impacting on managed pollinator populations. Inclusion of honey monitoring would provide additional support that could help in the identification of trends in exposure that may help to support diagnostic assessments conducted under WIIS.

- The Wildlife Incident Investigation Scheme is the only scheme that examines whether the deaths of vertebrate wildlife may be attributable to pesticides, including PPPs. The focus is on acute poisoning incidents, but it may be argued that such incidents are likely to be rare, outside of deliberate poisonings, because acute toxicity is one of the more extensively covered data packages required in the approvals procedure. We suggest that the WIIS functioning could be separated into the detection of poisoning incidents on one hand and a separate component to look at the detection of primary and secondary exposures through normal permitted use. Any such expansion of WIIS would require a formal review and may require additional resources, the extent of which would be determined by the specific outcomes of that review. If rolled out on a national scale, such additional cost would be likely to be significant depending on the scope and implementation approach of any proposed changes.

- If the WIIS was to incorporate an element of wildlife exposure monitoring, then the focus would need to move from only collecting samples associated with suspected pesticide exposures, to a wider and more unbiased sample collection approach. This would allow the individuals used for analysis to be selected in an unbiased manner to support spatial and temporal trends analysis. WIIS, by its nature, has no particular focal species of interest, instead being incident based. If developed with an aim of assessing exposure, then the sample collection and analyses would be better restricted to focal species from agricultural habitats as these may be at most risk of exposure. These could include gamebirds shot for sport and so easily sourced for analysis and/or dead individuals of species that typically inhabit agricultural landscapes, such as UK Farmland Bird Indicator species. Chance discovery of bird carcasses from indicator species is likely to be more difficult than the sourcing of shot individuals but bespoke schemes, such as the Predatory Bird Monitoring Scheme, have an established history of using a citizen-science collector network to discover and send in carcasses for processing and analysis. It is possible that the Predatory Bird Monitoring Scheme could widen their collection scope to incorporate farmland indicator species.

- As well as the option of bespoke selection through an expanded WIIS or expanding the scope of carcass collection to additional species through the Predatory Bird Monitoring Scheme, there could be potential to piggyback sampling on other programs. A number of disease and contaminant surveillance schemes in the UK are linked and collaborate through the WILDCOMS network and could provide a platform for such collection at limited additional cost. The Garden Wildlife Health project principally aims to monitor the health of and identify disease threats to British wildlife. It has a particular focus on garden birds, amphibians, reptiles and hedgehogs, and its activities involve the collection (and necropsy) of wild vertebrates found dead in peri-urban areas. If such samples were available for residue analysis, this would provide information on potential exposure of wildlife that is most likely associated with amateur and/or amenity use of PPPs and other pesticides. Exposure of wildlife to pesticides in peri-urban areas is currently a major knowledge gap and monitoring of pesticide residues in wildlife active in such environments could provide some additional information on the nature of exposure in such settings. Identifying unexpected exposures in such locations could provide an indication of additional exposure beyond that an animal may receive when occupying only agricultural habitats.

- Although monitoring of PPPs in predators will not generate information on effects, it can provide data that can be used to determine spatial trends and track temporal (e.g., year on year) changes in recent exposure to shorter lived substances, residue levels of the more persistent PPPs and any indication of unexpected occurrences of PPPs not anticipated to be present in wildlife. Carcasses for analysis would be readily available from collections already made through the WIIS and could be supplemented by samples provided by other collection platforms, such as the PBMS for bird species or one of the other surveillance programs linked to WILDCOMS. The most useful analyses may involve a combination of non-target screening to identify the nature of unexpected exposures including to known and potential metabolites and targeted measurements focusing on those PPPs that are widely detected, or present in the highest concentrations, in order to develop fully quantified datasets for temporal and spatial trend analysis. The resultant data for predators could provide a basis to inform decisions as to whether further investigation of secondary exposure to specific PPPs is warranted.

- The scope of sample analysis in any scheme will be operationally defined by the question relevant at the time of design. As new risks emerge, the scheme would benefit from the opportunity to go back and resample from stored historic samples. To allow this effective archiving and sample management is key. Sample storage needs a number of different elements to be effective. This includes not just robust infrastructure (e.g., fully back-up freezer capacity), but also meticulous record keeping of sample provenance and meta-data) and open data reporting. Schemes that have operated over years to maintain long-term samples (e.g., selected schemes under WILDCOMMS) provide a blue-print for how to achieve this. Such schemes require continued investment in their sample management and data infrastructures.

- Any analysis of terrestrial soil, invertebrate or vertebrate tissues samples would be conducted on a multi-residue basis. This would mean that in any given sample it may be possible to detect 10s of different active ingredient and/or metabolites. If a broad spectrum of pesticides are quantified, there would need to be agreement on how the exposure and potential risks of the mixtures are best presented. Mixture toxicity principles are available to integrate this data. Their use and application for species monitoring has been recently reviewed by EFSA (EFSA 2019). The conclusion of this work was that mixture assessment of potential exposure and effects is achievable based on current knowledge and that its integration into existing programs for chemical management would support landscape level risk assessment.

- Any assessment will need to link information of detected chemical concentrations to their potential effects, where needed taking into account the fact that exposure may be to multiple chemicals. To provide a risk based analysis, information on thresholds will need to be available that link concentrations predicted or measured in the samples (e.g., modelled from PUS data or measured in soil or tissues) to effects on exposed species. The status and trend data for individual active substances (or their metabolites) and of resultant risks would benefit from expert review, e.g., by Expert Committee on Pesticides. This would provide external oversight that the scheme operates effectively; is able to effectively link exposure to potential risk and that in doing so it produces results that are valuable for pesticide risk assessment and stewardship.

- An issue discussed during stakeholder consultation was the power of the monitoring to detect change in the various proposed components. Establishing robust baselines for measurements will provide a basis from which to identify change in individual metrics. Currently available datasets provide a sound platform on which studies can be conducted to look at how within and between sample variation for different measurements and analytes may affect the potential to identify pairwise difference between sample types and temporal trends. Pilot work to undertake such analysis has recently been commissioned by Defra working with the UK Centre for Ecology and Hydrology to identify the sampling intensity needed to detect change in residue levels with a set of analysed samples. It is an obvious point that increasing sample intensity and extending the time-scale of monitoring increases the potential to detect change.

- The proposed PPP monitoring scheme described contains various component elements. These are likely to be conducted by a range of different governmental and non-governmental organisations. While some would be continuation of existing activities, other activities will require development of new collaborative agreements, protocols, pilot scale testing, full implementation and data reporting activities. A management structure or group will be required to manage and oversee the functioning, budgeting accountability and overall reporting of the proposed monitoring scheme.

- Another key area that would need oversight is the reporting of the outcomes of the results and the subsequent data archiving. Reporting of data should be as timely and transparent as possible, with consideration given to the curation of annual data in national data centres and annual publication of data with digital object identifiers. Stakeholder feedback during this project has also emphasised the need to provide a balanced and contextual interpretation to accompany the data reporting. Early sign of unexpected exposure or impact could be reported in near real time, following the approach currently used for WIIS. For longer term trend reporting, there will also be a need to ensure that data and reports are made readily available to key stakeholders, giving the potential inclusion of the outcomes into a wider set of metrics, such as the outline indicators for the UK 25 year Environment Plan. Finally, the participation and interest in the current project from a range of industry and NGO stakeholders also emphasised the need to develop a clear stakeholder engagement platform for any pesticide monitoring scheme.

Any potential terrestrial pesticide monitoring program has the potential to include a number of measurements relating to the use, loading, occurrence, and by comparison to hazard value risks, of PPPs under different cropping and land management systems. Desk studies using submitted and publicly available data can be used to assess both usage and pesticide loading; while measurements of the presence of PPPs in different environmental and biota samples can provide a measure of exposure that can be used along with information on hazard to assess potential risk. However, while it is possible to build a combined monitoring scheme that includes these components building on existing programs, there remain some notable gaps in the potential for exposure and effect monitoring that cannot be so easily filled. These gaps exist both among the taxa sampled and also in the aims of the analysis. Examples of taxa for which there are currently no schemes readily available for sample collection include non-target terrestrial plants and amphibian and reptile species. For plants, mosses are included in sampling programs for air pollution monitoring. However, this sampling is focused in woodland systems and so likely to be of limited value for PPP monitoring. Both amphibians and reptiles are recognised as being poorly covered by current risk assessment approaches and this includes monitoring efforts for which in the UK and internationally there are no long-term national scale schemes currently in place. Another notable gap in monitoring is approaches to measure the effects of PPPs on microbial species. A recent review conducted by Swart et al. (2021) identified certain active ingredients can change the structure of soil bacterial and/or fungal communities at field application rates. This assessment was based on the use of molecular methods for DNA based monitoring, which could become with development part of an integrated monitoring scheme. A further recognised gap in monitoring is in the assessment of sub-lethal effects among both invertebrate and vertebrate species. Current agreed approaches for sub-lethal monitoring have not been robustly trialled for widespread field application. Particularly challenging currently is an understanding of the baseline values and individual variation for specific effect based (e.g., biomarker) measurements and an understanding of how non-chemical and non-PPP chemical stressors may affect measured effect parameters. This challenge of aligning cause to effect is common with the use of species biomonitoring data. Combining such potential metrics with Adverse Outcome Pathway understanding and weight of evidence approaches can provide a means to integrate such data into any future monitoring scheme.

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11. Appendices

11.1 Web of science terms used for literature review

pesticide* or insecticide* or herbicide* or fungicide* or acaricide* or nematicide* or molluscicide* or rodenticide* or agrochem* or "plant protection product" or "plant protection compound" or "plant protection chemical"

AND

vertebrate or wildlife or bird* or avian or mammal* or reptile* or amphibian* or bee or bees or honey bee

AND

poisoning or poisoned or exposure* or fatal or mortality or intoxicate* or carcass* or contaminant or contaminated or hazard*

AND

terrestrial or farmland or agriculture* or field or environment* or habitat* or arable or pasture* or grassland* or meadow or plantation* or orchard* or vine or fruit or garden* or "small holding" or mainfield or crop or crops or headland* hedgerow* or ditch*

AND

monitoring or surveillance or survey or detection or incident or "post-registration" or "post registration" or scheme

NOT

human OR infant* OR child* OR Worker* OR occupational or “occupational health” OR patient*

11.2 Articles reviewed for literature assessment

Subject area	Reference No.	Author-title (No. 0 is where additional references identified in course of study)
Bee biomonitoring	27	Niell, S., et al., Beehives biomonitor pesticides in agroecosystems: Simple chemical and biological indicators evaluation using Support Vector Machines (SVM). Ecological Indicators, 2018. 91: p. 149-154.
Bee biomonitoring	78	Colwell, M.J., et al., Honey bee-collected pollen in agro-ecosystems reveals diet diversity, diet quality, and

Subject area	Reference No.	Author-title (No. 0 is where additional references identified in course of study)
		pesticide exposure. Ecology and Evolution, 2017. 7(18): p. 7243-7253.
Bee biomonitoring	120	de Oliveira, R.C., et al., Bee pollen as a bioindicator of environmental pesticide contamination. Chemosphere, 2016. 163: p. 525-534.
Bee biomonitoring	148	David, A., et al., Widespread contamination of wildflower and bee-collected pollen with complex mixtures of neonicotinoids and fungicides commonly applied to crops. Environment International, 2016. 88: p. 169-178.
Bee biomonitoring	157	Oliveira, R.C.d., et al., Bee pollen as a bioindicator of environmental pesticide contamination. Chemosphere, 2016. 163: p. 525-534.
Bee biomonitoring	260	Lambert, O., et al., Widespread Occurrence of Chemical Residues in Beehive Matrices from Apiaries Located in Different Landscapes of Western France. PLOS One, 2013. 8(6).
Bee biomonitoring	375	Kozmus, P., et al., Monitoring the influence of different agricultural production areas on the level of pesticide residues in the pollen and its influence on development of Carniolan honeybee (Apis mellifera carnica). Zbornik Predavanj in Referatov, 10. Slovenskega Posvetovanja o Varstvu Rastlin, Podcetrtek, Slovenia, 1.-2. Marec 2011, ed. J. Macek and S. Trdan. 2011. 165-169.
Bee biomonitoring	96	Silvina, N., et al., Neonicotinoids transference from the field to the hive by honey bees: Towards a pesticide residues biomonitor. Science of the Total Environment, 2017. 581: p. 25-31.
Bee biomonitoring	0	Tosi S., Costa C., Vesco U., Quaglia G., Guido G., A 3-year survey of Italian honey bee-collected pollen reveals widespread contamination by agricultural pesticides. Science of the Total Environment, 2018. 208-218.

Subject area	Reference No.	Author-title (No. 0 is where additional references identified in course of study)
Biomonitoring of exposure	108	Prat-Mairet, Y., et al., Non-invasive monitoring of red fox exposure to rodenticides from scats. Ecological Indicators, 2017. 72: p. 777-783.
Biomonitoring of exposure	122	Abbasi, N.A., et al., Use of feathers to assess polychlorinated biphenyl and organochlorine pesticide exposure in top predatory bird species of Pakistan. Science of the Total Environment, 2016. 569: p. 1408-1417.
Biomonitoring of exposure	308	Brilhante, R.S.N., et al., Yeast microbiota of raptors: a possible tool for environmental monitoring. Environmental Microbiology Reports, 2012. 4(2): p. 189-193.
Biomonitoring of exposure	395	Liu, W.X., et al., Preliminary evaluation on the use of homing pigeons as a biomonitor in urban areas. Ecotoxicology, 2010. 19(2): p. 295-305.
Biomonitoring of exposure	498	Bennett, B.S. and M.L. Thies, Organochlorine pesticide residues in guano of Brazilian free-tailed bats, Tadarida brasiliensis Saint-Hilaire, from east Texas. Bulletin of Environmental Contamination and Toxicology, 2007. 78(3-4): p. 191-194.
Biomonitoring of exposure	509	D'Have, H., et al., Non-destructive pollution exposure assessment in the European hedgehog (Erinaceus europaeus): IV. Hair versus soil analysis in exposure and risk assessment of organochlorine compounds. Environmental Pollution, 2007. 145(3): p. 861-868.
Biomonitoring of exposure	511	Eidels, R.R., J.O. Whitaker, Jr., and D.W. Sparks, Insecticide residues in bats and guano from Indiana. Proceedings of the Indiana Academy of Science, 2007. 116(1): p. 50-57.
Biomonitoring of exposure	536	D'Have, H., et al., Nondestructive pollution exposure assessment in the European hedgehog (Erinaceus europaeus): III. Hair as an indicator of endogenous

Subject area	Reference No.	Author-title (No. 0 is where additional references identified in course of study)
		organochlorine compound concentrations. Environmental Toxicology and Chemistry, 2006. 25(1): p. 158-167.
Biomonitoring of exposure	562	Lambert, M.R.K., Lizards used as bioindicators to monitor pesticide contamination in sub-Saharan Africa: a review. Applied Herpetology, 2005. 2(2): p. 99-107.
Biomonitoring of exposure	630	Becker, P.H., Biomonitoring with birds. Bioindicators and biomonitors: principles, concepts and applications, ed. B.A. Markert, A.M. Breure, and H.G. Zechmeister. 2003. 677-736.
Effects	36	Sainsbury, K.A., et al., Long-term increase in secondary exposure to anticoagulant rodenticides in European polecats (Mustela putorius) in Great Britain. Environmental Pollution, 2018. 236: p. 689-698.
Effects	37	Fourel, I., et al., Liver and fecal samples suggest differential exposure of red fox (Vulpes vulpes) to trans- and cis-bromadiolone in areas from France treated with plant protection products. Science of the Total Environment, 2018. 622: p. 924-929.
Effects	77	Rodriguez-Jorquera, I.A., et al., Contamination of the Upper Class: Occurrence and Effects of Chemical Pollutants in Terrestrial Top Predators. Current Pollution Reports, 2017. 3(3): p. 206-219.
Effects	143	Espin, S., et al., Tracking pan-continental trends in environmental contamination using sentinel raptors-what types of samples should we use? Ecotoxicology, 2016. 25(4): p. 777-801.
Effects	168	Secord, A.L., et al., Contaminants of Emerging Concern in Bats from the Northeastern United States. Archives of Environmental Contamination and Toxicology, 2015. 69(4): p. 411-421.

Subject area	Reference No.	Author-title (No. 0 is where additional references identified in course of study)
Effects	180	Berny, P., KN Monitoring unintentional effects of plant protection products and other environmental contaminants on non-target species: how can we manage? Journal of Veterinary Pharmacology and Therapeutics, 2015. 38: p. 72-72.
Effects	254	Hughes, J., et al., Monitoring agricultural rodenticide use and secondary exposure of raptors in Scotland. Ecotoxicology, 2013. 22(6): p. 974-984.
Effects	300	Tosh, D.G., et al., Rodenticide exposure in wood mouse and house mouse populations on farms and potential secondary risk to predators. Ecotoxicology, 2012. 21(5): p. 1325-1332.
Effects	354	Elmeros, M., T.K. Christensen, and P. Lassen, Concentrations of anticoagulant rodenticides in stoats Mustela erminea and weasels Mustela nivalis from Denmark. Science of the Total Environment, 2011. 409(12): p. 2373-2378.
Effects	371	Foster, K.L. and S.W. Wang, THE CANARY IS ALIVE AND SINGING: BIRDS CONTINUE TO PROVIDE INVALUABLE INFORMATION ABOUT OUR CHANGING ENVIRONMENT. Integrated Environmental Assessment and Management, 2011. 7(1): p. 148-149.
Effects	403	Dowding, C.V., et al., Accumulation of anticoagulant rodenticides in a non-target insectivore, the European hedgehog (Erinaceus europaeus). Environmental Pollution, 2010. 158(1): p. 161-166.
Effects	427	Fildes, K., et al., Plasma cholinesterase characteristics in native Australian birds: significance for monitoring avian species for pesticide exposure. Emu, 2009. 109(1): p. 41-47.

Subject area	Reference No.	Author-title (No. 0 is where additional references identified in course of study)
Effects	451	Helander, B., A. Bignert, and L. Asplund, Using raptors as environmental sentinels: Monitoring the white-tailed sea eagle Haliaeetus albicilla in Sweden. Ambio, 2008. 37(6): p. 425-431.
Effects	515	Prosser, P.J., et al., Estimating the rate of poisoning by insecticide-treated seeds in a bird population. Ecotoxicology, 2006. 15(8): p. 657-664.
Effects	543	Hoare, J.M. and K.M. Hare, The impact of brodifacoum on non-target wildlife: gaps in knowledge. New Zealand Journal of Ecology, 2006. 30(2): p. 157-167.
Effects	626	Mora, M.A., et al., Environmental contaminants in surrogate birds and insects inhabiting Southwestern Willow Flycatcher habitat in Arizona. Ecology and Conservation of the Willow Flycatcher, ed. M.K. Sogge, et al. 2003. 168-176.
Effects	649	Eason, C.T., et al., Assessment of risks of brodifacoum to non-target birds and mammals in New Zealand. Ecotoxicology, 2002. 11(1): p. 35-48.
Methods	84	Richards, N., et al., Talons and beaks are viable but underutilized samples for detecting organophosphorus and carbamate pesticide poisoning in raptors. Vulture News, 2017. 72: p. 3-13.
Methods	93	Vijver, M.G., et al., Postregistration Monitoring of Pesticides is Urgently Required to Protect Ecosystems. Environmental Toxicology and Chemistry, 2017. 36(4): p. 860-865.
Methods	199	Alix, A. and C. Garrido, Monitoring effects of pesticides on pollinators - a review of methods and outcomes by the ICPPR working group, in Hazards of Pesticides to Bees: 12th International Symposium of the Icp-Pr Bee Protection Group, P.A. Oomen and J. Pistorius, Editors. 2015. p. 284-295.

Subject area	Reference No.	Author-title (No. 0 is where additional references identified in course of study)
Methods	454	Walker, L.A., et al., The Predatory Bird Monitoring Scheme: Identifying chemical risks to top predators in Britain. Ambio, 2008. 37(6): p. 466-471.
Methods	574	Rivera-Milan, F.F., M.E. Zaccagnini, and S.B. Canavelli, Field trials of line-transect surveys of bird carcasses in agro-ecosystems of Argentina's Pampas region. Wildlife Society Bulletin, 2004. 32(4): p. 1219-1228.
Methods	642	Mineau, P. and K.R. Tucker, Improving detection of pesticide poisoning in birds. Journal of Wildlife Rehabilitation, 2002. 25(2): p. 4-13.
Focal species	0	Bonneris, E. Selecting appropriate focal species for assessing the risk to birds from newly drilled pesticide-treated winter cereal fields in France: Focal bird species in drilled winter cereal... Integrated Environment Assessment and Management. 2019. 1-15
Focal species	235	Borges, S.L., N.B. Vyas, and M.C. Christman, The Influence of Study Species Selection on Estimates of Pesticide Exposure in Free-Ranging Birds. Environmental Management, 2014. 53(2): p. 416-428.
Focal species	291	Andrade, C., F. Chiron, and R. Julliard, Improving the selection of focal species exposed to pesticides to support ecological risk assessments. Ecotoxicology, 2012. 21(8): p. 2430-2440.
Focal species	634	Vavrova, M., et al., Game animals and small terrestrial mammals - Suitable bioindicators for the pollution assessment in agrarian ecosystems. Fresenius Environmental Bulletin, 2003. 12(2): p. 165-172.
Reviews	212	Shore, R.F., et al., Detection and drivers of exposure and effects of pharmaceuticals in higher vertebrates.

Subject area	Reference No.	Author-title (No. 0 is where additional references identified in course of study)
		Royal Society Philosophical Transactions Biological Sciences, 2014. 369(1656): p. 20130570-20130570.
Reviews	502	Berny, P., Pesticides and the intoxication of wild animals. Journal of Veterinary Pharmacology and Therapeutics, 2007. 30(2): p. 93-100.
Reviews	0	Gomez-Ramirez, P., et al., An overview of existing raptor contaminant monitoring activities in Europe. Environment International. 2014. 67: 12-21
Reviews	0	Laakso, S. Suomalainen, K. and Koivisto, S. Literature Review on Residues of Anticoagulant Rodenticides in Non-Target Animals. 2010. Print on demand
Reviews	0	Hladik,M.L., Vandever M. and Smalling K.L., Exposure of native bees foraging in an agricultural landscape to current-use pesticides. Science of the Total Environment., 2016, 542:469-477
Reviews	0	de Snoo, G.R., Scheidegger, N.M.I. and de Jong F.M.W., Vertebrate wildlife incidents with pesticides: a European survey. Pesticide Science 1999. 55:47-54
Reviews	6	Ostiguy, N., et al., Honey Bee Exposure to Pesticides: A Four-Year Nationwide Study. Insects, 2019. 10(1).
Reviews	14	Means, C. and T. Wismer, An Overview of Trends in Animal Poisoning Cases in the United States: 2011 to 2017. Veterinary Clinics of North America-Small Animal Practice, 2018. 48(6): p. 899-+.
Reviews	98	Millot, F., et al., Field evidence of bird poisonings by imidacloprid-treated seeds: a review of incidents reported by the French SAGIR network from 1995 to 2014. Environmental Science and Pollution Research, 2017. 24(6): p. 5469-5485.
Reviews	159	Kim, S., et al., Analysis of Insecticides in Dead Wild Birds in Korea from 2010 to 2013. Bulletin of

Subject area	Reference No.	Author-title (No. 0 is where additional references identified in course of study)
		Environmental Contamination and Toxicology, 2016. 96(1): p. 25-30.
Reviews	164	Botha, C.J., et al., Confirmed organophosphorus and carbamate pesticide poisonings in South African wildlife (2009-2014). Journal of the South African Veterinary Association, 2015. 86(1).
Reviews	228	Cutler, G.C., C.D. Scott-Dupree, and D.M. Drexler, Honey bees, neonicotinoids and bee incident reports: the Canadian situation. Pest Management Science, 2014. 70(5): p. 779-783.
Reviews	450	Gjershaug, J.O., et al., Monitoring of raptors and their contamination levels in Norway. Ambio, 2008. 37(6): p. 420-424.
Reviews	452	Garcia-Fernandez, A.J., et al., Raptor ecotoxicology in Spain: A review on persistent environmental contaminants. Ambio, 2008. 37(6): p. 432-439.
Reviews	460	Berny, P. and J.-R. Gaillet, Acute poisoning of Red Kites (Milvus milvus) in France: Data from the SAGIR network. Journal of Wildlife Diseases, 2008. 44(2): p. 417-426.
Reviews	470	Konstantinou, I., et al., Monitoring of pesticides in the environment. Analysis of Pesticides in Food and Environmental Samples, ed. J.L. Tadeo. 2008. 319-357.
Reviews	488	Shore, R.F., et al., Review of the Predatory Bird Monitoring Scheme (PBMS) 2006. JNCC Report, 2007. 400: p. 1-51.
Reviews	591	Fleischli, M.A., et al., Avian mortality events in the United States caused by anticholinesterase pesticides: A retrospective summary of National Wildlife Health Center records from 1980 to 2000. Archives of

Subject area	Reference No.	Author-title (No. 0 is where additional references identified in course of study)
		Environmental Contamination and Toxicology, 2004. 46(4): p. 542-550.

11.3 Complete list of references initially assessed for literature review

No.	EAB	RFS	LW	Reference (Number was generated by EndNote file)
1	0	0	0	Van Meter, R.J., et al., Agrochemical mixtures and amphibians: The combined effects of pesticides and fertilizer on stress, acetylcholinesterase activity and bioaccumulation in a terrestrial environment. Environmental Toxicology and Chemistry, 2019.
2	0	0	0	Fulton, C.A., et al., An assessment of pesticide exposures and land use of honey bees in Virginia. Chemosphere, 2019. 222: p. 489-493.
3	0	0	0	Abu Zeid, E.H., et al., Dose-related impacts of imidacloprid oral intoxication on brain and liver of rock pigeon (*Columba livia domestica),* residues analysis in different organs. Ecotoxicology and Environmental Safety, 2019. 167: p. 60-68.
4	0	0	0	Tapkir, S.D., et al., Impact, recovery and carryover effect of Roundup on predator recognition in common spiny loach, *Lepidocephalichthys thermalis*. Ecotoxicology (London, England), 2019.
5	0	1	0	Gomez-Ramos, M.M., et al., Exploration of environmental contaminants in honeybees using GC-TOF-MS and GC-Orbitrap-MS. Science of the Total Environment, 2019. 647: p. 232-244.
6	1	1	1	Ostiguy, N., et al., Honey Bee Exposure to Pesticides: A Four-Year Nationwide Study. Insects, 2019. 10(1).
7	0	1	0	Sadowska, M., et al., Comparison of the contents of selected elements and pesticides in honey bees with regard to their habitat. Environmental Science and Pollution Research, 2019. 26(1): p. 371-380.
8	0	0	0	Zeid, E.H.A., et al., Dose-related impacts of imidacloprid oral intoxication on brain and liver of rock pigeon (*Columba livia domestica*), residues analysis in different organs. Ecotoxicology and Environmental Safety, 2019. 167: p. 60-68.

No.	EAB	RFS	LW	Reference (Number was generated by EndNote file)
9	0	0	1	Gooley, Z.C., A.C. Gooley, and R.D. Fell, Relationship of Landscape Type on Neonicotinoid Insecticide Exposure Risks to Honey Bee Colonies: A Statewide Survey. Journal of Economic Entomology, 2018. 111(6): p. 2505-2512.
10	0	0	0	Hao, C., et al., Part-per-trillion LC-MS/MS determination of neonicotinoids in small volumes of songbird plasma. Science of the Total Environment, 2018. 644: p. 1080-1087.
11	0	0	1	Sgolastra, F., et al., Pesticide Exposure Assessment Paradigm for Solitary Bees. Environmental entomology, 2018.
12	0	0	0	McGee, S., et al., Field evaluation of the potential for avian exposure to clothianidin following the planting of clothianidin-treated corn seed. Peerj, 2018. 6.
13	0	0	0	Wolmarans, N.J., et al., Linking organochlorine exposure to biomarker response patterns in Anurans: a case study of Muller's clawed frog (*Xenopus muelleri*) from a tropical malaria vector control region. Ecotoxicology, 2018. 27(9): p. 1203-1216.
14	1	1	1	Means, C. and T. Wismer, An Overview of Trends in Animal Poisoning Cases in the United States: 2011 to 2017. Veterinary Clinics of North America-Small Animal Practice, 2018. 48(6): p. 899-+.
15	0	0	0	Siviter, H., et al., Quantifying the impact of pesticides on learning and memory in bees. Journal of Applied Ecology, 2018. 55(6): p. 2812-2821.
16	0	1	0	Beyer, M., et al., Pesticide residue profiles in bee bread and pollen samples and the survival of honeybee coloniesa case study from Luxembourg. Environmental Science and Pollution Research, 2018. 25(32): p. 32163-32177.
17	0	0	0	Manning, R., Chemical residues in beebread, honey, pollen and wax samples collected from bee hives placed on

No.	EAB	RFS	LW	Reference (Number was generated by EndNote file)
				canola crops in Western Australia. Journal of Apicultural Research, 2018. 57(5): p. 696-708.
18	0	0	0	Rattner, B.A., et al., Examination of contaminant exposure and reproduction of ospreys (*Pandion haliaetus*) nesting in Delaware Bay and River in 2015. Science of the Total Environment, 2018. 639: p. 596-607.
19	1	0	0	Byholm, P., et al., First evidence of neonicotinoid residues in a long-distance migratory raptor, the European honey buzzard (*Pernis apivorus*). Science of the Total Environment, 2018. 639: p. 929-933.
20	0	0	0	Muli, E., et al., Detection of Pesticide Residues in Selected Bee Products of Honeybees (*Apis melllifera* L.) Colonies in a Preliminary Study from Seychelles Archipelago. Bulletin of Environmental Contamination and Toxicology, 2018. 101(4): p. 451-457.
21	0	0	0	Malik, A., N. Dharaiya, and S. Espin, Is current information on organochlorine exposure sufficient to conserve birds in India? Ecotoxicology, 2018. 27(8): p. 1137-1149.
22	0	0	0	Siede, R., et al., A long-term field study on the effects of dietary exposure of clothianidin to varroosis-weakened honey bee colonies. Ecotoxicology, 2018. 27(7): p. 772-783.
23	0	0	0	Arikan, K., et al., The association between reproductive success with persistent organochlorine pollutants residue in feathers of spur-winged lapwing (*Vanellus spinosus* L.). Environmental Science and Pollution Research, 2018. 25(26): p. 26423-26432.
24	0	1	0	Vallon, M., et al., Focal Species Candidates for Pesticide Risk Assessment in European Rice Fields: A Review. Integrated Environmental Assessment and Management, 2018. 14(5): p. 537-551.
25	0	0	0	Hong, S.-Y., et al., Recent avian poisonings suggest a secondary poisoning crisis of black kites during the 1980s

No.	EAB	RFS	LW	Reference (Number was generated by EndNote file)
				in Taiwan. Journal of Raptor Research, 2018. 52(3): p. 326-337.
26	0	0	1	Nicholls, E., et al., Monitoring Neonicotinoid Exposure for Bees in Rural and Peri-urban Areas of the UK during the Transition from Pre- to Post-moratorium. Environmental Science & Technology, 2018. 52(16): p. 9391-9402.
27	1	1	1	Niell, S., et al., Beehives biomonitor pesticides in agroecosystems: Simple chemical and biological indicators evaluation using Support Vector Machines (SVM). Ecological Indicators, 2018. 91: p. 149-154.
28	0	0	0	Diao, Q., et al., Enhancement of chronic bee paralysis virus levels in honeybees acute exposed to imidacloprid: A Chinese case study. Science of the Total Environment, 2018. 630: p. 487-494.
29	1	0	0	Boehme, F., et al., Pesticide residue survey of pollen loads collected by honeybees (*Apis mellifera*) in daily intervals at three agricultural sites in South Germany. PLOS One, 2018. 13(7).
30	0	0	0	Dolores Hernando, M., et al., Viability of honeybee colonies exposed to sunflowers grown from seeds treated with the neonicotinoids thiamethoxam and clothianidin. Chemosphere, 2018. 202: p. 609-617.
31	0	0	0	Odemer, R., et al., Sublethal effects of clothianidin and *Nosema* spp. on the longevity and foraging activity of free flying honey bees. Ecotoxicology, 2018. 27(5): p. 527-538.
32	0	0	0	Buchweitz, J.P., et al., DDT poisoning of big brown bats, *Eptesicus fuscus*, in Hamilton, Montana. Chemosphere, 2018. 201: p. 1-5.
33	0	0	0	Nambirajan, K., et al., Incidences of mortality of Indian peafowl *Pavo cristatus* due to pesticide poisoning in India and accumulation pattern of chlorinated pesticides in tissues of the same species collected from Ahmedabad

No.	EAB	RFS	LW	Reference (Number was generated by EndNote file)
				and Coimbatore. Environmental Science and Pollution Research, 2018. 25(16): p. 15568-15576.
34	0	1	0	MacDonald, A.M., et al., Neonicotinoid detection in wild turkeys (*Meleagris gallopavo silvestris*) in Ontario, Canada. Environmental Science and Pollution Research, 2018. 25(16): p. 16254-16260.
35	0	0	0	Rutkoski, C.F., et al., Lethal and Sublethal Effects of the Herbicide Atrazine in the Early Stages of Development of *Physalaemus gracilis* (Anura: Leptodactylidae). Archives of Environmental Contamination and Toxicology, 2018. 74(4): p. 587-593.
36	1	1	1	Sainsbury, K.A., et al., Long-term increase in secondary exposure to anticoagulant rodenticides in European polecats (*Mustela putorius*) in Great Britain. Environmental Pollution, 2018. 236: p. 689-698.
37	1	0	1	Fourel, I., et al., Liver and fecal samples suggest differential exposure of red fox (*Vulpes vulpes*) to trans- and cis-bromadiolone in areas from France treated with plant protection products. Science of the Total Environment, 2018. 622: p. 924-929.
38	0	0	0	O'Neal, S.T., T.D. Anderson, and J.Y. Wu-Smart, Interactions between pesticides and pathogen susceptibility in honey bees. Current Opinion in Insect Science, 2018. 26: p. 57-62.
39	0	0	0	Drummond, F.A., et al., Exposure of Honey Bee (*Apis mellifera* L.) Colonies to Pesticides in Pollen, A Statewide Assessment in Maine. Environmental Entomology, 2018. 47(2): p. 378-387.
40	0	0	0	Fisher, A., II, et al., The Effects of the Insect Growth Regulators Methoxyfenozide and Pyriproxyfen and the Acaricide Bifenazate on Honey Bee (Hymenoptera: Apidae) Forager Survival. Journal of Economic Entomology, 2018. 111(2): p. 510-516.

No.	EAB	RFS	LW	Reference (Number was generated by EndNote file)
41	0	0	0	Basley, K. and D. Goulson, Neonicotinoids thiamethoxam and clothianidin adversely affect the colonisation of invertebrate populations in aquatic microcosms. Environmental Science and Pollution Research, 2018. 25(10): p. 9593-9599.
42	0	0	0	Hladik, M.L., A.R. Main, and D. Goulson, Environmental Risks and Challenges Associated with Neonicotinoid Insecticides. Environmental Science & Technology, 2018. 52(6): p. 3329-3335.
43	0	0	0	Moore, D.R.J., et al., A Probabilistic risk assessment for the Kirtland's warbler potentially exposed to chlorpyrifos and malathion during the breeding season and migration. Integrated Environmental Assessment and Management, 2018. 14(2): p. 252-269.
44	0	0	0	Wirtz, I.P., et al., Investigations on neonicotinoids in guttation fluid of seed treated sugar beet: Frequency, residue levels and discussion of the potential risk to honey bees. Crop Protection, 2018. 105: p. 28-34.
45	0	0	0	Renaud, M., et al., Effects of the neonicotinoids acetamiprid and thiacloprid in their commercial formulations on soil fauna. Chemosphere, 2018. 194: p. 85-93.
46	0	0	0	Arikan, K., Z.Y. Arikan, and S.L. Turan, Persistent Organochlorine Contaminant Residues in Tissues of Hedgehogs from Turkey. Bulletin of Environmental Contamination and Toxicology, 2018. 100(3): p. 361-368.
47	0	1	0	Daniele, G., et al., Exposure assessment of honeybees through study of hive matrices: analysis of selected pesticide residues in honeybees, beebread, and beeswax from French beehives by LC-MS/MS. Environmental Science and Pollution Research, 2018. 25(7): p. 6145-6153.

No.	EAB	RFS	LW	Reference (Number was generated by EndNote file)
48	0	0	0	Hoskins, T.D. and M.D. Boone, Atrazine Feminizes Sex Ratio in Blanchard's Cricket Frogs (*Acris blanchardi*) at Concentrations as Low as 0.1 mu g/L. Environmental Toxicology and Chemistry, 2018. 37(2): p. 427-435.
49	0	0	0	Kittle, R.P., et al., Effects of glyphosate herbicide on the gastrointestinal microflora of Hawaiian green turtles (*Chelonia mydas*) Linnaeus. Marine Pollution Bulletin, 2018. 127: p. 170-174.
50	0	1	0	Mahugija, J.A.M., P.E. Chibura, and E.H. Lugwisha, Residues of pesticides and metabolites in chicken kidney, liver and muscle samples from poultry farms in Dar es Salaam and Pwani, Tanzania. Chemosphere, 2018. 193: p. 869-874.
51	0	0	0	Seljetun, K.O., et al., Quantitative method for analysis of six anticoagulant rodenticides in faeces, applied in a case with repeated samples from a dog. Acta Veterinaria Scandinavica, 2018. 60.
52	0	0	0	Ertl, H.M.H., et al., Potential impact of neonicotinoid use on Northern bobwhite (*Colinus virginianus*) in Texas: A historical analysis. PLOS One, 2018. 13(1).
53	0	0	0	Zhang, M., et al., Potential Pesticide Use Risks to Honeybees during Almond Pollination in California, in Managing and Analyzing Pesticide Use Data for Pest Management, Environmental Monitoring, Public Health, and Public Policy, M. Zhang, et al., Editors. 2018. p. 379-404.
54	0	0	0	Meyer, E.W. and C. DeMars, A Simplified Approach to Using Pesticide Use Reporting To Prioritize Pesticide Risk in California's National Parks, in Managing and Analyzing Pesticide Use Data for Pest Management, Environmental Monitoring, Public Health, and Public Policy, M. Zhang, et al., Editors. 2018. p. 405-430.

No.	EAB	RFS	LW	Reference (Number was generated by EndNote file)
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73	0	0	0	Murray, M., Anticoagulant rodenticide exposure and toxicosis in four species of birds of prey in Massachusetts, USA, 2012-2016, in relation to use of rodenticides by pest management professionals. Ecotoxicology, 2017. 26(8): p. 1041-1050.
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156	0	0	0	Maus, C.H., et al., Assessing the use of crop protection products for potential risks to honey bees. Bulletin of Animal Health and Production in Africa, 2016. 64(1): p. 57-72.
157	1	1	1	Oliveira, R.C.d., et al., Bee pollen as a bioindicator of environmental pesticide contamination. Chemosphere, 2016. 163: p. 525-534. (repeat at 120)
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164	1	1	0	Botha, C.J., et al., Confirmed organophosphorus and carbamate pesticide poisonings in South African wildlife (2009-2014). Journal of the South African Veterinary Association, 2015. 86(1).
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No.	EAB	RFS	LW	Reference (Number was generated by EndNote file)
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649	1	0	1	Eason, C.T., et al., Assessment of risks of brodifacoum to non-target birds and mammals in New Zealand. Ecotoxicology, 2002. 11(1): p. 35-48.
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No.	EAB	RFS	LW	Reference (Number was generated by EndNote file)
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651	0	0	0	Lloyd, B.D. and S.M. McQueen, Measuring mortality in short-tailed bats (*Mystacina tuberculata*) as they return from foraging after an aerial 1080 possum control operation. New Zealand Journal of Ecology, 2002. 26(1): p. 53-59.
652	1	1	1	Crocker, D.R., et al., Estimating avian exposure to pesticides on arable crops. Aspects of Applied Biology, 2002(67): p. 237-244.
653	0	0	0	Madden, W., et al., Racumin rodenticide - potential environmental impact on birds. Ecology and Conservation of Owls. 2002. 296-301.
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655	0	0	1	Bartuszevige, A.M., et al., Organochlorine pesticide contamination in grassland-nesting passerines that breed in North America. Environmental Pollution, 2002. 117(2): p. 225-232.
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No.	EAB	RFS	LW	Reference (Number was generated by EndNote file)
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No.	EAB	RFS	LW	Reference (Number was generated by EndNote file)
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No.	EAB	RFS	LW	Reference (Number was generated by EndNote file)
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No.	EAB	RFS	LW	Reference (Number was generated by EndNote file)
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No.	EAB	RFS	LW	Reference (Number was generated by EndNote file)
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692	0	0	0	Sanchez-Hernandez, J.C., Wildlife exposure to organophosphorus insecticides, in Reviews of Environmental Contamination and Toxicology, G.W. Ware, Editor. 2001. p. 21-63.
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TOTAL	**100**	**89**	**101**	

11.4 Defra briefing note and stakeholder responses

The response in this Appendix capture the responses to a request issue by the Department of the Environment, Food and Rural Affairs for feedback on an earlier version of this report. The note issue by Defra is provided first, followed by version of the responses received.

Initial Communication from the Department for Environment, Food and Rural Affairs

Pesticides environmental monitoring review

Background

We have recently commissioned a piece of work through the Centre for Ecology and Hydrology (CEH) to explore options for the way in which we monitor pesticides in the terrestrial environment. We consider that a comprehensive environmental monitoring system is essential to support many of the measures for sustainable use and to support post-authorisation evaluation of impacts. It will also provide support for our commitments on pesticides in the 25 Year Environment Plan (Annex 1), particularly development of the regulation of PPPs on the basis of robust scientific knowledge, plus supporting sustainable crop protection with the minimum use of pesticides.

The aim of the review is to develop a proposal for an environmental monitoring program that will monitor the effects of PPPs on wildlife and the terrestrial environment. The review will evaluate mechanisms for monitoring, the role of such mechanisms in better understanding environmental effects and informing policy responses, and models for funding the program. The first stage of the work will involve assessment of existing monitoring schemes, and the second phase will consider technical options.

We will be engaging with you on this over the coming months, and would welcome your thoughts and ideas, plus any supporting evidence or other sources of information you are able to contribute.

What we are looking for

We would welcome your views and ideas on:

- available methods and approaches for monitoring pesticide exposure and effects in the terrestrial environment;
- appetite for more comprehensive post authorisation environmental monitoring
- potential frameworks for an “idealised” scheme; and,
- options for funding.

We would also welcome any evidence or other information you have in support of the above, and any suggestions on how you wish to be engaged in this piece of work between now and March 2020 (we have capacity to run a dedicated stakeholder workshop or similar as well as carrying out individual conversations where relevant).

When we need your involvement

We will be aiming to access stakeholder expertise in order to be able to understand and compile views and insights during the coming months and until the end of 2019. This will help shape the review and options appraisal, for which we would appreciate your involvement. The final report will be completed in March 2020.

Responses

Please submit any responses to Genevieve Madgwick, to whom you should also direct any queries (Genevieve.Madgwick@naturalengland.org.uk).

Responses should be received by 5 July 2019.

Thank you for your help in this matter.

May 2019

Initial Communication from the Department for Environment, Food and Rural Affairs

Response from the Amenity Forum:

Thank you for the opportunity to respond to this consultation. We very much wish to have involvement with this work and will help all we can.

The amenity sector is an important and essential one and what is undertaken in terms of weed, pest and disease management impacts upon every UK citizen every day. Professional operators seek to produce safe, healthy public spaces fit for purpose. The Amenity Forum is the voluntary initiative for the sector seeking to promote best practice throughout the sector and to be the link with government and key stakeholders in seeking to deliver the targets in the National Action Plan.

I fear, as a voluntary body, we have no resources to directly fund activity relate to this work proposed but I know that our members can provide time, experience and expertise as required. As well as being Independent Chair of our Forum, I also currently am chair of the Pesticides Forum. Ruth Mann, a key member of our Forum, is also a member of the EPC.

At this stage we don't really have any significant comments on the content of the document – feeling perhaps that it is a bit too preliminary for such comment. However, we do feel that an area missing is monitoring of illegally used pesticides and investigating potential illegal use. It seems to only be dealing with post authorisation monitoring, which we are reading as only monitoring what is permitted to be used and not looking for obsolete or illegal use.

We look forward to further involvement as appropriate

Thank you

John

John Moverley

Amenity Forum

Response from Agricultural Industries Confederation:

Pesticides Environmental Monitoring Review: AIC views June 2019

Available Methods and Approaches for monitoring PPP exposure and effects in the terrestrial environment:

A number of schemes currently exist for monitoring PPP exposure in wildlife. This includes analysis for PPP residues in vertebrate and invertebrate tissues. It would be sensible for any new scheme to review past and current environmental monitoring work being undertaken to assess if this can contribute to or corroborate data collected for example the National Pollinator Monitoring Scheme. It is essential that any sampling design is statistically robust and that data collection and analysis is performed to recognised standards if results are to be considered reliable.

In addition an insight into Good Agricultural Practice and hence a reflection of the sustainable use of pesticides is given by the monitoring of Maximum Residue Levels (MRLs) of PPPs in sampled produce.

Some of the schemes and work that AIC is aware of are noted below, with comments on potential issues which should be borne in mind in developing any scheme for monitoring effects of PPPs in the terrestrial environment.

Wildlife Incident Investigation Scheme (WIIS)

The Wildlife Incident Investigation Scheme makes enquiries into the death or illness of wildlife, pets and beneficial invertebrates that may have resulted from pesticide poisoning. The scheme aims to provide information to the regulator on hazards to wildlife and companion animals and beneficial invertebrates from pesticides and to enforce the correct use of pesticides, identifying and penalising those who deliberately or recklessly misuse and abuse pesticides.

AIC comment: reporting is likely to be correlated to public awareness of the scheme and the profile of PPPs in the media – increasing as both increases.

Campaign for Responsible Rodenticide Use (CRRU)

The Monitoring Work Group, part of the UK Rodenticide Stewardship Regime, provides oversight of and reports on studies from independent contracted agencies on;

1. The distribution and concentrations of anticoagulant residues in livers in a sample of barn owls. Data is available for 2017 and the 2016 base year. There is some indication within the data set that some of the residue parameters are showing a decline but their magnitude falls short of that needed to reach conventionally-applied scientific

requirements for statistical significance. AIC comment: a decline in distribution and level of anticoagulant rodenticide was sought, as a metric for uptake of stewardship measures. Even with a decline, no correlation could be made to any positive or negative impact on barn owls.

2. The Barn Owl Monitoring Survey (BOMS) measures key breeding performance metrics in a sample of UK barn owl nests. It is generally considered that the annual fluctuations in breeding performance over the last three years are caused by factors including climatic conditions, the availability of prey, the availability of nest sites and the numbers of birds in breeding condition. AIC comment: the metric selected is influenced by many factors which can vary from year to year. The magnitude and variability of external impacts on any metric selected must be understood and quantified.

3. DNA sequencing of UK rats and mice tissue samples is undertaken to detect common anticoagulant resistance mutations. Currently the geographical spread of samples is limited.

Monitoring for development of resistance in invertebrate pests to insecticides
Research is undertaken by research institutes, including Rothamsted to understand the nature and development of resistance to PPPs in target pests. For example, pyrethroid resistance in Cabbage Stem Flea Beetle. IRAG-UK aims to provide information on resistance avoidance and management strategies for use by UK farmers and growers, advisors and regulatory authorities.

National Honey Monitoring Scheme Honey collected from hives across the UK is submitted by beekeepers on a voluntary basis is analysed for the presence of neonicotinoid residues. This provides an understanding of the exposures of honey bees to this group of pesticides. This work may be extended to look for a wider range of pesticides in honey samples from different regions of the UK.

British Trust for Ornithology (BTO) The BTO has collated data on the distribution of breeding and wintering bird species in UK and Ireland using a network of bird enthusiast volunteers. This data is collated into a ‘Bird Atlas’

EU Regulation 283/2013 sets out the data requirements for active substances, in accordance with Regulation (EC) No 1107/2009. Information supplied by approval holders must be sufficient to evaluate immediate and delayed foreseeable risks which the active substance may entail for humans, including vulnerable groups, animals and the environment. Any information on potentially harmful effects of the active substance, its metabolites and impurities on human and animal health, groundwater, the environment, plants and plant products must be included. The information provided must include all relevant data from the scientific peer reviewed open literature on the active substance, metabolites and breakdown or reaction products and PPPs containing the active substance and dealing with side-effects on health, the environment and non-target species. This data will provide some information on movement, degradation of PPPs and any impacts PPPs may have in the terrestrial environment.

Appetite for more comprehensive post authorisation environmental monitoring

The appetite for more comprehensive monitoring depends on how the results are communicated and the actions taken by policy makers on the back of the findings.

Some members of the public have concerns about PPP use and PPP residues. This is in part fuelled by misinformation or biased information in the media, which does not consider the positives of PPP use. AIC members are concerned that if residues of any PPP are detected in whatever environmental compartment is tested, even at the limit of quantification, this will be used to increase public concern about PPP use generally. This in turn could lead for calls for PPPs to be withdrawn with no scientific basis behind this request or understanding of the consequences.

Therefore communication of any findings must put the magnitude of the findings in context, together with an explanation as to why PPPs are used and possible sources, which may include use of PPPs in home and garden situations or use of flea control products on companion animals. (Environment Agency monitoring found high levels of insecticide in a river which was attributed to dogs, recently treated with topical flea treatments, swimming in the river)

Before policy makers act on the findings they should be aware of the consequences of any action. For example, limiting the use of or withdrawing a PPP could lead to a reduction in agricultural productivity as alternative chemical or non-chemical technique might be less reliable, more costly or may simply not be available.

On the other hand if the results indicated a scientifically robust positive correlation between PPPs monitored and a negative impact on a particular species for example, AIC members would be keen to work with policy makers to understand what mitigation measures could be used to prevent this impact.

If monitoring led to a situation where the use of a PPP could continue, albeit with geographical or rate restrictions for example, rather than withdrawal of the PPP then members could appreciate that the monitoring could deliver positive outcomes.

Potential Frameworks for an idealised scheme

Consideration would have to be given to;

- Ensuring all relevant stakeholders are consulted on the design and have oversight of the project
- Governance of the project to ensure that data collection, analysis and reporting are to agreed protocols and conclusions drawn are scientifically robust
- Reporting results in a balanced way to prevent unnecessary public alarm

- The basis for selecting sites to be monitored. This may include consideration of previous PPP use, soil type including soil structure, soil chemistry and previous cropping

- Monitoring should be compatible with and complementary to existing, long-term national monitoring schemes. Some are referred to above.

- The extent of monitoring. Initially monitoring at one or two sites for one or two active substances may help determine how to progress with further work

- PPP use data including the dose of PPP applied, when and where. Users of professional PPPs are required to hold records on PPPs used for five years. Data on non-professional use (home and garden and allotment) could be very difficult to collate.

- What actives substances to monitor. This may be related to for example the intensity of use or the chemistry of the active substance

- Impact of soil cultivations

- The extent of data collected at each site. For example would soil samples be taken at a set depth or multiple depths to form a PPP profile through the soil depth

- How the levels of PPP detected relate to any impacts on end points in wildlife and the terrestrial environment, taking into account the impact of other factors on the same end point.

- Monitoring for active substances post withdrawal of use and new active substances

- The aim of monitoring. Is it to set an acceptable level for a PPP residue in the environment (if so how can this be achieved?) or a reduction in PPPs detected (what would be the scientific basis for this?)

- Measurement of mitigation measures within the environment, for example habitat provision

Options for funding

PPPs benefit UK plc, the PPP manufacturer, distributor, adviser, user, the consumer and the Government by improving agricultural productivity, contributing to GDP, providing jobs, and providing safe affordable food.

It could be argued that all beneficiaries should contribute to the costs of any scheme, for consumers this is likely to be an increase in food prices.

Willingness to contribute would depend on the extent of the monitoring and the timeframe over which it is to take place, which will determine the costs.

A long-term scheme over many years is probably less likely to be funded by stakeholders so will require Government funding.

Costs could be minimised by using infrastructure and data from current monitoring schemes if they met the agreed protocols of this scheme. In addition some monitoring could be undertaken by volunteer recorders (as with BTO work with volunteers.

Further engagement AIC would like to continue to be involved with this work until its completion and supports a stakeholder workshop as well as one to one conversations.

Response from BASF:

PO Box 4, Earl Road – Cheadle Hume, Cheadle – Cheshire SK8 6QG

5th July 2019

Rob Gladwin

Tel: 004 161 485 6222

Rob.gladwin@basf.com

FAO Genevieve Madgwick, Natural England

Dear Genevieve

RE: Developing a proposal for an environmental monitoring program for pesticides on wildlife and terrestrial environment.

I write to you in response to our request for contributions to your review as outlined above.

BASF plc – Agricultural Solutions are an innovation driven business focused on bring integrated solutions based around crop protection chemistry (synthetic and biological), digital and seed, delivered as key components of sustainable agriculture. We work with our customer, growers and other stakeholders here in the UK an around the globe to ensure these solutions meet their needs and those of the consumer and society as a whole.

We would like to ensure that the outcome of any review does not erode the comprehensive and rigorous regulatory process that already exists for crop protection in the UK. The process of evaluation and authorisation is the most comprehensive in the world, with a significant aspect of any evaluation taking into account the environment, including wildlife and the terrestrial environment. To develop new active substance costs in the region of 250 million Euro and takes over 10 years, a significant and growing proportion of this investment is made in the eco-tox area, a slide from Phillips McDougall illustrates the point, although dated the trend remains the same (see Appendix 1). Existing active substances in the EU are currently going through a re-renewal which updates regulatory packages for these active substances which again includes the natural environment.

BASF would request that any review acknowledges the sound regulatory regime that is in place today and that this regulatory regime within the EU is comprehensive ad precautionary in nature and does/is evolving to respond to specific issues and concerns. The review should look to build on this regulatory regime and not erode it.

We look to address your specific questions with our views and idea as requested:

1. **Available methods and approaches for monitoring pesticide exposure and effects in the terrestrial environment:**

Methods for monitoring pesticides in the environment are available and indeed are a requirement of the Regulatory process.

The European Regulatory procedure is extremely robust. Many tests are conducted on a range representative species, in the Ecotox area the representative species tested are known to be particularly sensitive and are protective of other species. These test results are used in risk assessments which use large margins of safety and are therefore very conservative. Products that do not pass the risk assessments are not authorised. Guidance documents representing the latest scientific approaches are regularly updated and incorporated into the risk assessments to ensure any advancements in science are taken into account and provide continue safe use.

The Wildlife Investigation Scheme (WIIS) relies on the reporting of mortality incidents.

It is interesting to note from a total of 305 incidents reported in 2018 that only 1 was a result of “Approved Use”. Of the other 304 incidents, 8 were “Misuse”, 20 “Abuse” 13 “Unspecified”, 139 “Unknown”, 97 “Other Cause”, 11 “Not applicable” and 16 “Category not yet assigned”. This information leads to the conclusion that the approved use of PPPs is not having adverse effects on the species monitored here.

BASF is not aware of any other environmental monitoring programs around the globe so any scheme in the UK would be unique. This in itself should not be a block, but care needs to be taken to ensure any scheme devised is based on sound science, clearly identifies “cause and effect”, provides outcomes which benefit the environment, is not just an academic exercise and should also be affordable and workable for those concerned.

The monitoring of pesticides in water is based on a “politically” derived arbitrary figure and is not based on science or environmental impact/ risk, therefore the resulting outcome does not benefit the environment per se.

2. **Appetite for more comprehensive post authorisation environmental monitoring**

Working from our starting position that all currently applied PPPs in UK have been through the regulatory process outlined above, which provides an agreed and accepted margin of safety and are approved for use according to the labels, we would view a monitoring platform that provided data to support and refine the regulatory procedure as a useful step forward. It would be counter-productive to consider the monitoring protocol as a vehicle to retrospectively review existing approved products as these have clearly passed extremely conservative risk assessments.

The initially agreed assumptions need to be fair and equitable to all sides and the language neutral. There is an assumption (which we would disagree with) in the consultation document that there are already impacts to ecology arising from farmer practice and effects of mixtures, all culminating in a landscape scale effect.

Monitoring that was integrated with the current regulatory process (not a stand-alone), was statistically robust and that supported the approved products unequivocally would be worthy of further consideration.

3. **Potential frameworks for an "idealised" scheme**

We are sure a technical protocol and monitoring approach could be designed by academics, but it is unclear at the moment on the science that would be used and the level of "assumptions" that would be made. The farmed environment is not a constant, but forever changing and adapting to a wide range of external influences, many of which are not related at all to agriculture, but are directly in the control of other industries and the general public We cannot see a clear way at this stage of unpicking the effects from farming practices and use of plant protect products, from those not associated with farming. To do so would seem to be vastly expensive and potentially statistically invalid. We would want to be sure that the project had a clear stated vision of what success looks like, where the clear data sets exist and where data is not compromised by other factors and cannot be unpicked.

4. **Options for funding**

Until we know the scope, scale and context of the monitoring task, there is little point in speculating on funding streams at this point. That said, it is worth stating that I am sure most will assume funding would/ should come from manufacturing of the products concerned, this would be an increased cost and an assumption could also be made, that this would be passed onto the grower in terms of increased cost of the products concerned. This has the potential to distort the market and have un-intended consequences.

BASF are working with two arable growers in the UK where we are monitoring a number of indicators from a production and environmental perspective. We would be willing to make these two farms in the UK available either to discuss the data sets we have compiled over the last 15 years and/or for a backdrop for practical discussions either with BASF as a business or to convene a wider group of stakeholders.

BASF would also be willing to participate in further individual discussions and make our diverse range of experts available to you and/or participate in wider stakeholder workshops/roundtables.

We look forward to hearing from you in the near future.

Yours sincerely

Rob Gladwin

Head of Technical Management, Northern Europe

BASF plc

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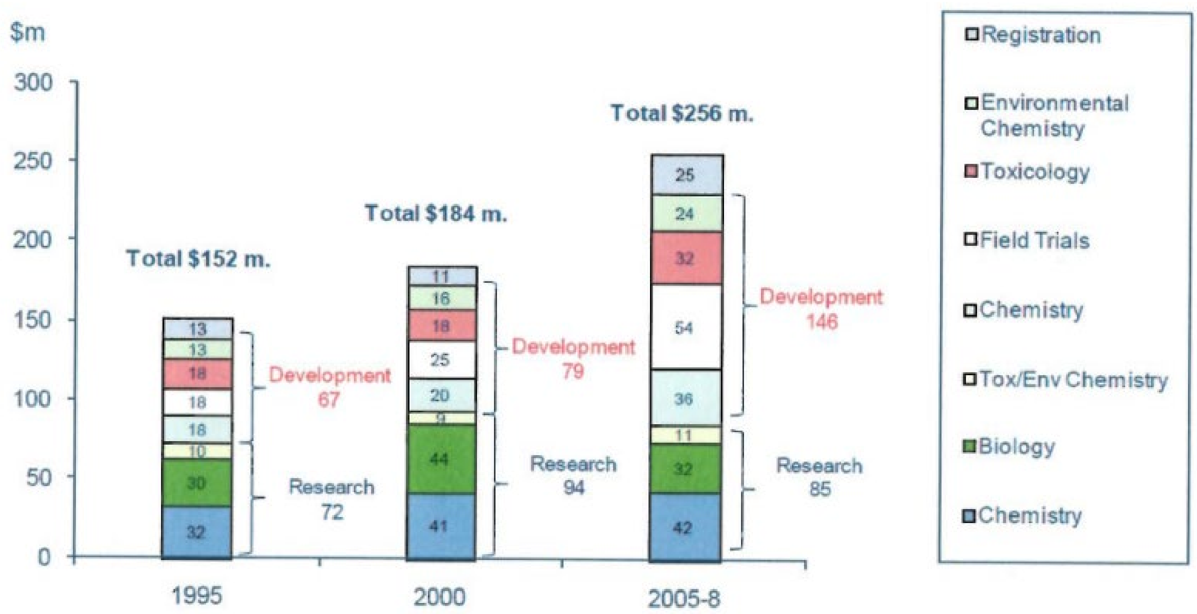
Appendix 1

Figure 1: *The increasing cost of bringing a new Active Ingredient to the market**



Source: PhillipsMcDougall

* Results of a study undertaken for ECPA and CropLife America

Response from Corteva:

Dow AgroSciences UK*

CPC2 Capital Park

Fulbourn

Cambridgeshire, CB21 5XE

* member of the Corteva agriscience group of companies

Re: Request for views and ideas on pesticide environmental monitoring by 5 July 2019, DEFRA

The Department for Environment, Food and Rural Affairs are seeking feedback on options for monitoring pesticides in the terrestrial environment. Corteva agriscience have received a copy of this request via the UK Crop Protection Association and would like to provide comments on the areas raised for discussion. As an organisation, the historical member companies of Corteva, Dow AgroSciences and DuPont, have many years of experience of pesticide environmental monitoring in a range of terrestrial systems.

DEFRA are specifically seeking inputs on the following:

1. Available methods and approaches for monitoring pesticide exposure and effects in the terrestrial environment;
2. Appetite for more comprehensive post authorisation environmental monitoring
3. Potential frameworks for an “idealised” scheme; and,
4. Options for funding.
5. Evidence to support function of items 1 to 4

Available methods and approaches for monitoring pesticide exposure and effects in the terrestrial environment

SETAC created an interest group a number of years ago, with the objective to stimulate scientific discussions (from all affiliations i.e., government, academia, industry and CROs) on how to generate meaningful monitoring data for pesticides. Below is the link to this group:

https://www.setac.org/group/SEIGPest

Four subgroups were created, with the objective to gather their expertise to review existing approaches for monitoring, in particular post-registration monitoring, of pesticides and/or pesticide effects in the following areas:

- Monitoring in groundwater, with the published recommendations below: https://link.springer.com/article/10.1007/s00003-019-01211-x)

- Monitoring in surface water (fate and effects)

- Monitoring in vertebrates (exposure and effects)

- Terrestrial invertebrates.

The subgroup dedicated to pollinators works alongside another working group of the International Committee on Plant-Pollinators Relationships (ICP-PR) who is active and proposed some recommendations for a publication. A presentation illustrating some work generated is embedded.

ICPPR Gent 2014
Monitoring 04 09 201

It is understood that Finland and Austria already have protocols available for certain aspects of pollinator monitoring.

Sheffield University are currently working on an ecosystem services project where they are assessing the appropriate parameters reflecting those services, which could be measured in monitoring studies, to increase the relevance of protection goals served by environmental risk assessments). It may therefore be valuable to capture the outputs from this research in this review.

Corteva agriscience also hold a database of extensive environmental monitoring, the outputs of which may be helpful in developing any future monitoring schemes. Two examples of such data are provided below:

- There are multi-year studies of monitoring data on birds available for chlorpyrifos, some of which was conducted in the UK. Elements of this research have been published and all studies were submitted in support of the renewal of the active substance under the AIR3 process. These studies illustrate the complexity, and multiple factors involved, in controlled monitoring of the effects of a single pesticide on bird and mammal populations. The cost and resource associated with conducting such work is significant and illustrative of such approaches.

- Corteva has also recently lead work on monitoring for the presence of pesticides in blood of wild mammals (using techniques that do not harm the individuals sampled). This requires specialist operators who are permitted to catch and sample, as well as multiresidue techniques.

Appetite for more comprehensive post authorisation environmental monitoring

Linking pesticide use to effect requires complex monitoring setups, and is often difficult to observe unless it is an immediate effect (death), immediately after application. The reason for this is the number of other factors that influence species distribution, presence, abundance, behaviour and diversity, in space and over time. Residues in the environment and in wildlife can be measured, however providing a clear link between chemical presence and effects must also take into consideration other chemical and/or non-chemical causes of any measured effects, which therefore should be measured as well. When such multi-factorial studies can be implemented, they require preliminary definition of what needs measurement, how these measurements can be interpreted and what resulting measures can be taken to mitigate risks from all the influential factors. Guidelines are still missing and are needed to optimize the value of such studies.

Potential frameworks for an "idealised" scheme

It is our view that monitoring should focus on products and active substances where e.g., risk mitigation measures have been recommended to satisfy the margin of safety recommended in the risk assessment. The objective, method of monitoring, number of sites and timescales relevant for the media and/or group of organisms under study (the what, where, when and how) should be based on existing validated monitoring methods or should be agreed with the competent authority prior to initiating any monitoring program. It is important that the monitoring proposed is realistic, achievable, technically and scientifically valid and accepted by the relevant stakeholders in EU Member States and ideally globally (so that any monitoring conducted in the UK could be recognised and accepted by other competent authorities globally).

Where possible, monitoring should be conducted using widely agreed protocols and guidance documents, which are relevant to the target and the associated environment. It is key also to establish a baseline agronomic history of the monitoring area prior to any monitoring commencing.

Options for funding

Government funded for general monitoring schemes

Government run via industry levy of authorisation holders.

Corteva Agriscience would welcome the opportunity to attend any workshops that will be run to further consider a strategy for pesticide environmental monitoring and would be happy to share company experiences on pesticide environmental monitoring in an individual capacity.

Response from Crop Protection Association:

DEFRA's Pesticides Environmental Monitoring Review – CPA's views July 2019

The Crop Protection Association (CPA) welcomes the opportunity to provide our views on the Pesticides Environmental Monitoring Review and are keen to participate further in the process leading up to the final report.

The background information states that '*the aim of the review is to develop a proposal for an environmental monitoring program that will monitor the* ***effects*** *of pesticides on wildlife and the terrestrial environment'.* The key objective here being the monitoring of actual 'effects' rather than just quantifying pesticide residues in the environment. Although we see some benefits in generating real life environmental exposure effects data, especially when compared to the European Union's (EU) proposed agri-environmental indicator pesticide risk approach (Harmonised Risk Indicators - HRIs), directly attributing any effects to single parameters within environment is incredibly challenging due to the complex nature of the environment and the number of different inputs and actions that take place on farms. This would require the generation of good quality benchmark data, consideration of all parameters (e.g., soil carbon capture and quality through use of glyphosate in no-till situations) and benefits to all species, reference to the already generated toxicology data evaluated under the pesticide regulatory regime, and would require complex analysis beyond simplistic correlations.

To achieve any benefits from environmental effects monitoring, both from an environmental and also a pesticide policy perspective, this review must establish some clearly defined objectives as merely detecting residues of pesticides within different environmental compartments is not an indicator of harm. The review must compliment, rather than undermine, the existing regulatory regime as the risks associated with pesticide use are already covered by the existing pesticide authorisation process. Additionally, it should not undermine Integrated Pest Management (IPM) approaches currently being developed and must also consider the wider environmental benefits such as the land sparing potential presented by efficient productive agriculture.

To assist the review process further we have provided feedback on each of your four questions below:

1. Available methods and approaches for monitoring pesticide exposure and effects in the terrestrial environment.

Methods of analysis for soils, water and air for the parent pesticide and its major metabolites are all a requirement of the pesticide regulatory regime and are therefore available. In addition, there are ongoing and ever increasing monitoring programs for ground and surface waters for pesticides by the Environment Agency and Water Authorities, as annually reported by the Pesticide Forum (see 'Pesticides in the UK: The 2017 report on the impacts and sustainable use of pesticides'). However, any direct effect of residual pesticides is not monitored as the potential risks are evaluated as part of the pesticide authorisation process. Linking cause to effect has always been the major issue with any monitoring data unless it is an immediate effect immediately after application. We can analyse for residues in the environment and in wildlife, but linking chemical presence to effects is not straight forward and many factors need to be monitored in addition to pesticides to allow other chemical and/or non-chemical causes of any measured effects to be ruled out. Therefore it must be established as a key focus of this review what ‘effects’ will be measured (e.g., acute mortality, or longer term population or biodiversity trends)? The pesticide levy already funds the Wildlife Incident Investigation Scheme for the monitoring and surveillance of more acute effects. However, more long-term trends would require significantly more investment over many years to understand the link between any one factor and changes in environmental quality, populations and biodiversity.

For ground water a political cut off, rather than a scientific risk-based value, is set at 0.1ug/L for pesticides and their relevant metabolites. For all non-relevant metabolites a health based value is set which should be communicated and implemented. From an ecotoxicological perspective it is almost always the case that any findings in groundwater are below the environmental quality standard (EQS). For surface water there can be times when the EQS is exceeded, but this very much depends on the methodology and standards used.

We are not aware of any routine soil monitoring, but the regulatory risk assessments are very conservative and are based on Predicted Environmental Concentrations (PECs), so it would be expected that any monitoring results would be below levels that cause effects when compared to the no-effect end points for specific organism.

For air it is even more complex as location and timing are crucial. We are not aware of any evidence of any impacts for humans or the environment.

There is a European Crop Protection Association (ECPA) sponsored Report (attached to this reply) that provides an overview and analysis of many existing monitoring schemes, including those in the UK. The report was compiled to establish what already exists so that ECPA could consider further industry lead monitoring schemes on a voluntary basis.

Our members have also identified the work of the Society of Environmental Toxicology and Chemistry (SETAC) as another great source of information on environmental monitoring. SETAC created an interest group a few years ago, with the objective of stimulating scientific discussions on how to generate meaningful monitoring data for pesticides. For further information visit: https://www.setac.org/group/SEIGPest.

Four subgroups were created by SETAC:

- Monitoring in groundwater
- Monitoring in surface water (fate and effects)
- Monitoring in vertebrates (exposure and effects), based on active and also studies in support of product authorisations.

- Terrestrial invertebrates, mostly active for pollinators and equivalent to the working group of the International Committee on Plant-Pollinators Relationships (ICP-PR).

2. Appetite for more comprehensive post authorisation environmental monitoring.

This would depend on the clarity of the objectives and how any post-registration monitoring data would be used in policy making. For example, if post authorisation environmental monitoring had been in place at the time we may have seen a different decision to the non-authorisation of outdoor use of metaldehyde. As an industry we would be cautious of developing a secondary regulatory process whereby decisions are made based on the worst-case scenario whether that’s arrived though the current risk assessment process or through monitoring.

However, it could be an opportunity to develop and base policy on real effects data rather than based on theoretical risk assessments and harmonized risk indicators.

3. Potential frameworks for an “idealised” scheme.

There is no indication of how the monitoring data will be used in terms of linking to biodiversity and how it will be applied in the context of existing pesticide risk assessment and other environmental schemes. This should be clearly defined as a first step to set the goal of the project.

Any scheme should have a clear focus (e.g., active substance with identified concern or data gap) and target (e.g., species, environmental compartment), and should not be a routine requirement for all authorisations. There would need to an agreed protocol of what should be done, specific deadlines for the provision of data and a process for evaluating those data should be set. The assessment of the monitoring data should be evaluated and the outcome should satisfy and therefore end the requirement for the monitoring work. Any continuous monitoring without an end date would need to be a government run scheme.

However, given the challenges outlined above any environmental effects monitoring should not consider pesticides exclusively. There are many other factors that contribute to environmental quality and biodiversity so it is important that these are considered within any monitoring program.

4. Options for funding.

Redistribution of funds received as part of the Pesticide Levy (>£3.1million in 2018/19) could be a viable option as a proportion of this fee is already used to support environmental monitoring and surveillance through the Wildlife Incident Investigation Scheme.

Response from National Farmers Union:

To:	Genevieve Madgwick (Genevieve.Madgwick@natural england.org.uk)	**Date:**	4 July 2019
Circulation:		**Contact:**	Chris Hartfield
		Tel:	02476 858851
		Email:	chris.hartfield@nfu.org.uk

The NFU represents 55,000 members in England and Wales, involved in 46,000 farming and growing businesses. In addition, we have 55,000 Countryside members with an interest in farming and the countryside.

NFU response to Defra's invite for ideas and evidence on the Pesticides environmental monitoring review

Pesticides are an essential, yet often misunderstood part of current farming practice and food production. Farmers recognise their use may involve risks and proactively take steps to ensure their careful and appropriate use. Regardless of whether the future scenario is one where we are closely aligned to the EU regulation or more divergent, future UK pesticides regulation needs to be fit for purpose – protecting the environment and the public, while effectively supporting productive and competitive agriculture and horticulture.

The NFU supports the development of regulation of pesticides on the basis of robust scientific knowledge. The EU is viewed as following an increasingly politicised approach on pesticides that has less to do with evidence. We believe the time is right to adopt better regulation with the robust and consistent application of scientific evidence at its heart.

By developing a better, more efficient, risk and science-based pesticides regulation, we believe there is the opportunity for the UK to achieve a triple win of maintaining the highest standards of consumer and environmental protection, continuing to enable trade, and creating better and more effective outcomes for UK farm businesses and the entire £112bn food and drink sector.

The NFU agrees with the government view expressed in the 25 year environment plan that IPM needs to be central to crop protection. Most farmers use IPM as a standard aspect of their approach to farming, combining traditional farming practices (like crop rotation, and timing planting to avoid pests) and modern farming techniques (like using resistant seed varieties, pest forecasting and biological controls) with measures that protect the environment. Employing an IPM strategy where all these techniques are used as appropriate, and where pesticides are used as the tool of last resort and only when necessary, will help realise sustainable crop protection delivered with the minimum use of pesticides.

With reference to the 25 year environment plan, we believe it is essential that this pesticides environmental monitoring review takes a proportionate approach. When the 25 year environment plan talks about impacts of different pressures on natural capital assets, it talks about chemicals in the round – highlighting chemical contaminants from industry, pharmaceuticals, waste water treatment, road run-off, biocides and non-biocides, as well as chemicals from agriculture. Can you re-assure us that by taking a proportionate approach, similar environmental monitoring reviews are being launched by Defra for all the other groups of chemicals highlighted in the 25 year environment plan? The NFU is ready to work on the challenge of further reducing the risks around pesticide use and better understanding the impacts of that use, but there has to be a balanced approach to all chemicals entering the environment if the approach is to be genuine about creating real environmental improvements.

In summer 2017 Defra chief scientist Ian Boyd co-authored a paper discussing the idea of ‘pesticidovigilance’. In short, the paper acknowledged the UK has one of the most developed regulatory and monitoring systems for pesticides in the world, but the authors felt the current system is lacking because it does little post-use monitoring and does not look for landscape scale environmental impacts. While there is no evidence of such landscape scale environmental impacts actually happening, there are some significant uncertainties around pesticide impacts (e.g., neonicotinoids) and the paper argues this is a reason why better monitoring of post-use impacts is required.

As per our response to Defra’s call for ideas about a future National Action Plan on the sustainable use of pesticides, the NFU would support measures being developed by government and stakeholders to assess landscape-scale environmental impacts of pesticide use. We think that such an initiative would need to

- be strongly risk and science based
- be based on the principle of assessing whether there are significant unsustainable biological impacts, as opposed to simply looking for presence of pesticides in the wider environment
- take into account different UK landscapes
- be clear about the limitations and assumptions of the approach finally adopted
- treat pesticides in a proportionate way compared to other chemicals in the wider environment, such as pharmaceuticals

- recognise that in informing policy responses, the findings could go two ways – they could show that the regulatory process is not robust enough, or they could show that the regulatory process is actually too precautionary and conservative

- recognise the opportunities to inform better integration, mitigation or optimisation of chemical use.

The NFU is involved as an observer with the NERC-funded ChemPop project (https://www.ceh.ac.uk/our-science/projects/chempop-does-discharge-chemicals-environment-harm-wildlife-populations) being led by researchers at CEH. We think there will be significant overlap between this work and the pesticides environmental monitoring review work that Defra has commissioned CEH to undertake. We understand that it is an early aim of this work to identify the ways to generate long term measures of pesticide exposure. It is also notable that this study, while recognising that a chemical may harm wildlife, is focussing on asking the 'so what?' question. What does this mean in terms of actual impacts in the real world? So the focus is not on the inherent toxicity or hazard of a substance, but instead on the real world risk and impact. The NFU would support the Pesticides environmental monitoring review to also take this approach.

We would also like to make you aware of some parallel work the NFU is undertaking. We are currently developing our thinking around future sustainable plant health solutions and as part of this work we recognise that current measures on pesticide use in the UK – by weight of active applied, number of applications and area applied to – are not actually giving us the information we want to know, which is what is happening over time to the level of risk and impacts associated with pesticide use.

Our expectation would be that over time, the replacement of older chemistry with safer lower risk chemistry, the increase in precision application, lower rates of use, and uptake of alternatives and IPM, would mean 'environmental loading' with pesticides has reduced. But the data is not currently there to show this. The NFU believes that going forward we should be looking at the impact of pesticide use rather than area, weight, number of applications or number of different actives.

The NFU welcomes the opportunity to be involved in this pesticides environmental monitoring review and we would be keen to be involved in any future workshops or further discussions. We would like to be consulted on proposed options as this work develops.

Response of the Voluntary Initiative

Stuart House

St Johns Street

Peterborough

PE1 5DD

neal@voluntaryinitiative.org.uk

Genevieve Madgwick

Natural England

27th June 2019

Dear Genevieve,

The Voluntary Initiative (VI) and our Sponsors are keen to be involved in the Defra Pesticides environmental monitoring review. As a non-regulatory body, the VI is not in a position to provide input to the monitoring review process *per se*, but we see the VI as a key part of the solution with a key role driving a shift within industry to an IPM-based, holistic approach to sustainable crop production.

We have recently been in contact with Dr Andrew House and colleagues at Defra and are in the process of organising meetings to discuss policy development thus far and how the VI, as the vanguard organisation for best practice and uptake of enhanced IPM can help direct future development of ELMs. As the VI is the key delivery mechanism for the National Action Plan (NAP) for the Sustainable Use of Pesticides, we see ourselves as central to helping achieve the aims of the 25 year Environment Plan, by helping growers deliver "public goods" and to help achieve the goals for improving the environment within a generation and leaving it in a better state than we found it.

We are interested to be consulted at any stage of the review process until it's conclusion in March 2020, particularly with regard to any dedicated stakeholder meetings/workshops that may be organised. The VI is happy to work with the wider Stakeholder group to help shape the outcomes of the review and wider policy on pesticide use.

Yours sincerely,

Dr Neal Evans, VI Operations Director

Response from Pesticide Action Network UK:

Pesticides Environmental Monitoring Review - PAN UK response - July 2019

PAN UK welcomes this discussion about the development of a new environmental monitoring system for pesticides. It is both overdue and, as stated, vital if the UK is to deliver on its promises made in the 25 Year Environment Plan and other key policies that will be implemented post-Brexit.

PAN UK is keen to be involved in developing this piece of work between now and March 2020. We would be happy to participate in stakeholder workshops and individual conversations as well as submitting evidence and information as necessary.

From conversations with a wide range of stakeholders, including farmers and scientists, PAN UK is confident that there is both an appetite and a real need for the development of a comprehensive monitoring system for pesticides in the UK. In fact Defra Chief Scientist, Ian Boyd, has called for the development of a system for monitoring the impacts of pesticides at a landscape scale as a requirement for halting and ultimately reversing pesticide related harms to UK biodiversity.

What would PAN UK like to see from an environmental monitoring system in the UK?

The current FERA run annual Pesticide Usage Surveys, whilst informative to a degree, have a number of serious shortcomings. They report on three metrics which all apply to use – times treated, treated area on the weight of active substances – but fail to monitor or report on the impact of that use.

Reporting weight of actives applied is particularly problematic. Weight is a meaningless metric when looking at combined pesticide use trends. It fails to take into account changing toxicities of new actives and therefore provides a misleading picture of the overall trend of pesticide use. Any new system must take into account changing toxicity and be able to assess how toxicity, and combined toxic load, is impacting on the environment including wildlife.

Another major failing of the PUSSTATS reporting is the lack of information about precisely where pesticides are use -, it provides regional information but the does not allow more localised scrutiny of pesticide use. Finally, while it does provide information on the use of individual active substances, it doesn't have any mechanism for assessing the combinations of active substances that are actually being used in real world applications. This is a serious shortcoming and hinders any attempt at trying to document or monitor the actual impacts of pesticide use on the environment.

In terms of other monitoring that is currently in place the main focus is on water bodies and to some extent catchment monitoring. There is also some reporting of wildlife poisoning incidents via WIIS. However, both of these focus on the presence of individual pesticides and are merely used as a reporting system rather than as a mechanism for identifying areas of concern or to drive reductions in, or changes to, the way in which pesticides are being used.

There is currently no system that looks at other significant aspects of pesticide pollution, the most notable gap being soil contamination. Similarly there is no system for assessing the impact of combinations of pesticides in the environment or what effect these may be having on flora, aquatic or terrestrial biodiversity. Any new system adopted by the UK must, therefore, cover a range of issues and be able not only to report on them but to provide a pathway for then tackling the problems that are identified.

As PAN UK has pointed out in its briefing (*Brexit and pesticides: UK food and agriculture at a crossroads*[71]*)* current monitoring systems are handled by a range of different actors, from the HSE to the Environment Agency, with no coherent overarching driving force dictating the strategy or approach. A new monitoring system should ideally be managed by one coordinating department, even if the actual testing is undertaken by other relevant agencies.

As part of improving the UK's monitoring system further research is required on an ongoing basis. The government urgently needs to conduct, research on the combinatory effects of pesticides of the same and different classes i.e., herbicide / fungicide interactions. Research is also urgently needed as to the impact of pesticide use on a 'landscape-scale'. This could, in part, be extrapolated from the current limited focus on catchment monitoring to assess whole landscapes.

What could a UK monitoring system be used for?

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[71] https://foodresearch.org.uk/publications/brexit-pesticides-crossroads/

Biodiversity impacts monitoring including;

- Changes in pesticide use of those actives identified as being the most harmful to biodiversity.
- Impacts on biodiversity, terrestrial and aquatic.
- Unexpected post-approval impacts on bee and pollinator species.

Changes in levels and types of use including;

- Changes in treatment frequency by farmers.
- Changes in the types of pesticides being used to identify whether increases or decreases in the types and combinations of pesticides are taking place.
- Individual farm pesticide use as a mechanism for replacement of CAP payments to the proposed ‘public money for public goods’ system.
- Monitoring and reporting of sales data to identify changes in use of actives or products of concern.
- Changes in use of pesticides persistent in the aquatic and terrestrial environment.

Presence in the environment including;

- Combined toxic load of multiple pesticides in the environment.
- Compliance with water quality legislation.
- Presence and persistence of pesticides in soil.

Post-approval including;

- Resistance issues
- Post-approval efficacy of active substances

The list above clearly shows that there are numerous things that could and should be monitored for. There needs to be a combination of monitoring for impacts and use. The two complement each other and, in fact, monitoring impacts without access to clear and detailed information pertaining to usage will hinder attempts to remedy identified problems.

In addition, there needs to be absolute transparency of the monitoring results which must be made available to all interested parties, including members of the public. Monitoring results must be provided in a timely manner. At present, monitoring results (most notably the pesticide usage statistics) lag far behind, making it impossible for concerned stakeholders to analyse or respond to findings in real time.

How could a monitoring system be developed and run?

There are a number of options and examples of environmental monitoring schemes already in existence in European countries. As part of this review, the Government should take the time to look deeper into these schemes in order to assess their relative strengths and weaknesses and explore how they might work in the UK context. These schemes each take a difference approach and the UK may well decide that in order to create a comprehensive picture of the impacts of pesticide use on the environment the best way forward is to combine existing approaches. Collection and publication of data is the key to the success of any monitoring system.

Key areas for data collection will be;

- Pesticide sales data should be collected and published so that it will be possible to determine changes in what products are being used by farmers and growers. The data collected would give a clear indication of whether the uptake of less toxic active substances by farmers and growers is increasing or decreasing. It would also assist the UK in developing a system similar to that laid down in Commission Directive (EU) 2019/782 for developing Harmonised Risk Indicators for pesticide use[72].

- Farmers spray records, including area and frequency of treatment

- Presence of pesticides in the environment, soil, water and flora

- Exposure of wildlife to pesticide residues

- Presence of pesticides in aquatic and terrestrial fauna

Toxicity indicators for pesticides used based on whether they are considered to be candidates for substitution, approved, low-risk or non-approved but applied following an emergency use derogation. Again this would allow the development of a system similar to the Harmonised Risk Indicators mentioned above. PAN UK is keen to discuss in greater detail options for specific monitoring systems as the consultation progresses. We are part of a global network and can also connect those leading on this project with our colleagues around the world to discuss the relative merits and deficiencies of other existing systems.

In the meantime, however, below are outlines of four systems that could be considered for initial discussion by stakeholders, all of which go beyond the monitoring system we currently have in the UK.

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[72] https://ec.europa.eu/food/plant/pesticides/sustainable_use_pesticides/harmonised-risk-indicators_en

1. Denmark used Treatment Frequency Index (TFI) for many years which, when combined with actual use data, made it possible to calculate the difference between the applied dose of a pesticide and its recommended dose, allowing a clearer picture of the intensity of pesticide treatment for a given crop area to be measured. Recently however, Denmark has adopted a new metric – the Pesticide Load (PL) – which has replaced TFI as its official 'pesticide risk indicator'. The PL consists of three sub-indicators for human health, ecotoxicology and environmental fate. In addition to being used to monitor trends in pesticide use and load, it is also used for setting quantitative reduction targets.

2. In January 2019, EU Member States adopted a new system for monitoring pesticide use based on a set of 'Harmonised Risk Indicators' that take into account both sales and usage levels of active substances[73]. The new system applies a 'hazard quotient' to individual active substances. The hazard quotient divides approved active substances into three categories; those that are deemed low risk, those that are approved and 'normal' risk, and those that are considered Candidates for Substitution (meaning that they are of particular concern due to their negative impacts on heath or environment and therefore a less toxic alternative should be found). There is also a category for those that are not approved but which might, under certain exceptional circumstances, be used. Once implemented, this system will, at least in theory, enable Member States to identify changes in usage levels of different classifications of pesticides and design policies and programs to support farmers to reduce usage accordingly.

3. Another example of environmental monitoring comes from the Swedish Environmental Protection Agency's national environmental monitoring program[74]. The aim of the program is to track long term trends in water quality with reference to pesticide use as well as determining the presence of pesticides in sediment / soil, air and precipitation. Whilst limited to monitoring water within a small number of catchments, there are useful approaches that could help to inform the creation of a UK monitoring system. In particular, monitoring for all actives in water on a weekly basis allows for accurate time sensitive reporting on changes in the presence of pesticides in the environment. This approach allows for potential problems to be identified almost as they occur and thus be dealt with before a serious issue emerges.

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[73] EU Directive on the Sustainable Use of Pesticides, Article 15 Indicators, https://eur-lex.europa.eu/legal-content/ EN/ALL/?uri=CELEX%3A32009L0128

[74] https://www.slu.se/en/departments/aquatic-sciences-assessment/environment/pesticide_monitoring

4. France, uses the metric of Number of Unit Doses (NODU) which makes it possible to estimate an average number of treatments per hectare and thereby measure how intensely pesticides are being used[75].

Options for funding

It appears to PAN UK that one of the obvious sources for funding for a monitoring system would be the introduction of a pesticide tax or levy. PAN UK has talked extensively about the use of a tax as a driver for pesticide reduction (see https://foodresearch.org.uk/publications/brexit-pesticides-crossroads/ pages 14, 15).

Denmark first introduced a pesticide tax in 1996. In 2013, its tax was adjusted so that it no longer just reflected a proportion of the price paid but is calculated on the basis of the toxicity to health and environment of specific pesticide products. In other words, the amount of tax applied to pesticides varies according to the potential each substance has for harming the environment and/or human health. The most toxic pesticides – those that haven't been filtered out by the hazard criteria during the initial risk assessment, or those that drive the most dam-aging impacts such as contaminating water courses – have the highest rate of tax applied to them. Making more toxic pesticides more expensive for the end user works as a disincentive to use them and, as has been shown in Denmark, helps to drive down the use of the most toxic pesticides.

Thus introducing a tax based on pesticide toxicity could serve two functions – reducing the use of the most toxic or persistent pesticides and contributing to the funding of a monitoring system.

Given that the polluter pays principle is a tenet supported by the Government this would seem to be an elegant solution to the question of funding.

Useful resources for further research:

- Swedish Water monitoring model
- https://dl.sciencesocieties.org/publications/jeq/articles/0/0/jeq2019.02.0056
- https://www.slu.se/en/departments/aquatic-sciences-assessment/environment/pesticide_monitoring/

[75] Institute for European Environmental Policy, Effective policy options for reducing environmental risks from pesticides in the UK, May 2016, p77, https://ieep. eu/archive_uploads/2211/IEEP_PANUK2016_RSPB_ pesticides_report.pdf

- Pesticide Load—A new Danish pesticide risk indicator with multiple applications[76]
- French Ecophyto plan including information on NODU[77]

Response from Royal Society for the Protection of Birds:

1. What information do stakeholders have on available methods and approaches for monitoring pesticide exposure and effects in the terrestrial environment?

A combination of laboratory and field studies is a must and should assess the variation in presence, persistence and accumulation of products. This should be assessed in soil, sediment, plants and animals, including a variety of invertebrates and vertebrates representative of different ecological food chain levels.

2. What is the appetite for more comprehensive post authorisation environmental monitoring?

Yes definitely required - so long as it's done as just one part of a package of mitigation improvements. An environmental monitoring program is a good idea to fill some gaps in knowledge about persistence, presence and accumulation of chemicals in the environment and in plants and wildlife. Hopefully it is part of a bigger package of improved regulations around initial testing of effects before regulated use. It would be very useful to have social science evidence of how the most effective mitigation advice is given, heeded and monitored.

Whatever the outcome of the monitoring review (and whatever the post Brexit approvals process for pesticides looks like) – the precautionary principle should remain central, and indeed be strengthened. A monitoring scheme, however robust, doesn't negate the importance of a hazard based approach. A monitoring system both pre and post approval that looks at 'downstream' and non-lethal effects (in addition to what is currently assessed pre-approval) will be key to this.

3. Did stakeholders have views on potential frameworks for an "idealised" scheme

Across the board, there should be a way of mapping use (so improved usage data) with potential environmental impacts. This should highlight any immediate cause for concern.

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[76] https://www.sciencedirect.com/science/article/abs/pii/S0264837717306002

[77] http://www.endure-network.eu/de/about_endure/all_the_news/france_unveils_new_national_action_plan#3

In terms of a more specific suggestion for a monitoring scheme, the following is the bare-bones of a system that could be designed to test for exposure of various and key taxonomic groups and trophic levels to what would be a potentially large group of compounds and their breakdown products. It shows the sorts of plants and animals that would need to be monitored and how samples might be obtained. It would need to be done at regular intervals and across a defined range of strata (trophic levels, land use and regions) and need to be regularly revised in the light of new evidence

Scope:

- Environmental exposure (soil and water)
- Ecological exposure (plants and primary and secondary consumers)
- Ecological impact (change in occurrence / abundance / activity in space and time, in relation to environmental and ecological exposure)

Requirements:

- Stratified sampling program – across land use types (including certified organic land and non-agricultural land-uses), vegetation soil and water
- Testing for a wide range of active compounds, adjuvants and breakdown products of these.

Water

Stratified by: Proximal and distal location of water bodies, field drains, ditches and permanent water courses

Soil

Stratified by: Regional land use; Soil type

Plants

Stratified by: life history and regional land use; Perennial species such as Hawthorn, grasses; Annual/biennial species like dandelion, common grasses

Invertebrates

Taxa known to be primary or secondary consumers of agricultural pests or involved in their population control – aphidopagous species – hoverflies, carabids (e.g., Pterostichus spp), Coccincellids (ladybirds), Stahylinids (e.g., Philonthini), parasitoid wasps (e.g., Collyriinae).

Carabids (appropriate genera) can also be used to monitor transport via the seed-feeding guilds (e.g.,Amara, which seem to be vulnerable to pesticide use, indirectly at least)

Crop pollinators – hymenoptera, coleoptera, diptera, lepidoptera (appropriate genera)

Care with trapping methods that killing/collecting media do not confound residue detection; need to select species which are sufficiently abundant, widespread, identifiable and trappable.

Vertebrates

These are at risk from direct exposure either lethal or sub-lethal, but also to risks through bioaccumulation.

Birds – could use feathers and/or failed eggs from regular ringing / nest-monitoring activities

Game birds from shoots/roadkill

Bats – fur or blood samples during other ringing/capture activities

Knowledge still needed:

- The range of compounds to be tested (primary compounds, breakdown products or metabolites, secondary adjuvants and possible effects of admixtures)
- Levels of detectability vs levels that may be implicated in sub-lethal or secondary ecological effects
- Is use of indicator compounds sufficient to reduce the range of tests needed and give an index of exposure?
- More evidence of the role of some candidate groups in natural control/trophic links in agro-ecosystems to determine candidate 'sentinel' groups?

4. Options for funding.

Polluter pays principle means that there is a case for the manufacturers to be liable for the costs of an environmental monitoring program. We have done some work published[78] on how voluntary measures do not work and so there needs to be more impetus on regulation and on discouraging use financially, e.g., a pesticide tax which could then generate income for monitoring impacts.

[78] https://theecologist.org/2015/nov/16/voluntary-schemes-cannot-replace-environmental-regulation

Response from Soil Association:

Soil Association initial response to the Defra call for evidence on the pesticides environmental monitoring review

Appetite for more comprehensive post authorisation environmental monitoring

We strongly support the assertion made in a recent *Science* paper by Professor Ian Boyd and Dr Alice Milner that "*Without knowledge of safe environmental limits, the total pesticides used — and therefore the total environmental dose — is governed by market demand rather than by a limit on what the environment can endure. There is little information about where, when, and why pesticides have been used, making it very difficult to quantify potential environmental effects*"[79].

A major part of tackling this issue, aside from improved pesticide regulation, is a move towards what Boyd and Milner called a 'pesticidovigilance system". Currently the lack of a systematic monitoring system of pesticide residues in the environment, or consideration of safe pesticide limits at landscape scales, is of huge concern. We will be urging the UK Government to adopt an ambitious pesticide reduction target, something which has been shown in other EU countries to have a powerful effect in shifting farming practices, igniting farmer innovation and shifting the focus of R&D. Without a monitoring system that can track such a target and provide much needed evidence, the market will continue to drive pesticide use regardless of what the environment can endure.

We therefore see a comprehensive post authorisation environmental monitoring system as absolutely vital to the aspirations set out in the 25 Year Environment Plan and repeated by Secretary of State, Michael Gove.

Potential frameworks for an "idealised" scheme *and* available methods and approaches for monitoring pesticide exposure and effects in the terrestrial environment

We need a better measure of pesticide use and an estimate of the full toxic load applied to our environment. Currently the focus on weight is misleading as pesticides are becoming more powerful (less is needed for the same toxic impact) and more complicated mixtures of interacting toxic chemicals. Instead we recommend the use of the Treatment Frequency Index and Number of Doses, such as used by Denmark and France[80]. This could support a measure of the landscape scale use of pesticides which is currently completely missing,

[79] Milner, A. M. & I. L. Boyd (2017) 'Toward Pesticidovigilance', *Science*,357(6357): 1232-1234 DOI: 10.1126/science.aan2683

[80] For example see the report by Pesticide Action Network UK https://www.pan-europe.info/old/Resources/Reports/Pesticide_Use_Reduction_is_Working.pdf

which would ensure that the environmental impact of pesticides can be assessed in a more rounded way.

We identify two key areas where monitoring could target environmental residues and their impacts on wildlife (soil biota and insects), where none currently occurs. 1) the monitoring of pesticide residue levels in agricultural soils and soil biota to detect changes over time. Considering the number of different types of pesticides used on the typical farm field over the course of a year, such monitoring would inform a greater research focus on the effect of these pesticides on soil life and soil health, as well as persistence and fate information for key pesticides and mixtures. 2) the monitoring of residues in wildflower pollen around agricultural fields. If residues levels could be analysed in conjunction with information on insect population changes in the same areas, this could be used and to inform more real-world level exposure experiments. This would lead to much greater understanding of the links between pesticide and pollinator declines.

Monitoring could focus on pesticides of key concern but would also need to look at estimating the total pesticide toxic exposure to wildlife. The Soil Association in combination with PAN UK is currently reviewing unforeseen harm from multiple pesticide residues. We have concluded that the exposure of wildlife, including life in soils, to multiple pesticide residues is of real concern and must no longer be overlooked in pesticide policy or regulations. We currently know of only two independent scientific studies that have looked at multiple residues in wildflowers[81] and soils[82].

Options for funding

Ideally the funding of a comprehensive post monitoring system should be paid for by the companies selling the products and users, following the ‘polluter pays’ principle. How this could be done in a way that avoids any perverse outcomes needs to be fully explored by the government, including the potential for a pesticide taxation scheme, such as used in Denmark. It is further suggested that any surplus from such a scheme should be reinvested into support for farmers to reduce pesticide use. In terms of data collection, farms already collate and record their pesticide use in software packages. Better national analysis of this data, without compromising on data protection issues, should be fully investigated to improve understanding of usage and products used.

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[81] David, A., Botias, C., Abdul-Sada, A., Nicholls, E., Rotheray, E. L., Hill, M. E. & Goulson, D. (2016) ‘Widespread contamination of wildflower and bee-collected pollen with complex mixtures of neonicotinoids and fungicides commonly applied to crops’, *Environmental International,* **88:** (169-178) https://www.sciencedirect.com/science/article/pii/S0160412015301161

[82] Silva et al 2018 https://www.sciencedirect.com/science/article/pii/S0048969718343420

These are only initial thoughts. We would therefore welcome any opportunities to be further engaged in this issue, including sharing our conclusions findings on pesticide mixtures when we have concluded this project.

Please contact Louise Payton at lpayton@soilassociation.org with any enquiries on this response.

Soil Association, 3/7/19

11.5 Comments from industry and user community stakeholder workshop

Table 7.3 Attendees of industry and user community stakeholder workshop.

Nomination	Affiliation
Janet Williams	Bayer
Chris Leake	Bayer
Ian Barber	Corteva Agriscience
Andrew Eatherall	Corteva Agriscience
Silke Steiger	BASF
Chris Hartfield	National Farmers Union
Hazel Doonan	Agricultural Industries Confederation
Neal Evans	The Voluntary Initiative
John Moverley	The Amenity Forum
Peter Campbell	Syngenta
Project team:	
Gen Madgwick	Natural England
Lee Walker	UK Centre for Ecology & Hydrology
Richard Shore	UK Centre for Ecology & Hydrology
Libby Barnett	Fera Science
Jane Lakey	DEFRA

Questions and comments arising from the initial presentation

1. What does an adverse effect/good status look like?
2. Language of Levels and compartments is confusing/imprecise

Element: Usage

Action: Change picture of crop spraying from aerial application to another image on the usage

3. Quality of data going into application maps is key,
4. Limitations of PUS data may well be an outcome of this review
5. Applications in non-farming would not be captured in farm application data (e.g., farmgate)

Element: Soils

6. Could inform on non-PPP related changes in status.

Element: Earthworms.

7. Caution on including earthworm in scheme as other drivers are dominant.

Action: Remove the ‘p’ from Rothampsted.

8. Importance of other drivers recorded in “effects” schemes was stressed.
9. New scheme coming into effect for exposure assessment in risk assessment procedures.
10. Caution over schemes that could be a flag without strong evidence for links to PPP use.

Element: Pollinators

11. Colony loss data could be included.
12. Food survey data for honey could be a source of data.
13. WIIS’s sensitivity as a reactive scheme is problematic.

Element: Vertebrates

14. Invertebrate in header for vertebrate slide.

15. Any scheme with effects metrics needs to be clear and communicate what they are being used for (e.g., as a flag that something has changed but not necessarily due to PPP exposure.
16. Support for approach of building on what is already being used.
17. It would be good to explain why broader population status and trend indicators are excluded from the scheme.

Next steps

Action: Use Darren Mingo as an intermediary for combining feedback on report.

Action: Pass on contact details of this group to Jane Lakey.

Action: Forward feedback from breakout group to rapporteurs to check notes prior to circulation to group for scoring.

Breakout questions and responses from Industry Stakeholder Workshop

21st January 2020

Question A - Will post-registration monitoring (as or similar to the scheme outlined) help identify unexpected consequences of PPP use at different scales? Give your reasons.

Response	Sum Score
1. Provides more realistic information on scale of use and exposure	3
2. Potentially flag issues where potential concerns and where further investigations were needed	7
3. Identify presence of what type of mixtures may be present in the environment	1
4. Public realisation of presence of any residues – will be a challenge for public communications	6
5. Need to be clear on definition of unexpected 'consequences' – be more specific whether it relates to environmental exposure. ie What consequences and what would be unexpected	17
6. Need long-term monitoring to identify temporal and spatial changes beyond background	4
7. Define long-term	0
8. Need to establish baseline – otherwise you cannot determine whether or not a 'consequence' is 'unexpected'	13
9. Define scale scheme and limitations of elements	0
10. It's a good start and an improvement from current evidence	0
11. Careful terminology needed in report and when presenting results of monitoring	3
12. What do you base expected metrics on?	

Question B - Are there missing elements that should be included in the proposed scheme and how would they be of value?

Response	Sum Score
1. **The report needs to be transparent about the reasons why prospective elements have been excluded from the scheme**	3
2. **It is important to manage expectations for the scheme defining purpose and scope of scheme. The scheme needs to be clear from the outset that it is not going to be able to identify that pesticide X is causing impact Y. It can only flag that occurrence of pesticide X is outside what you would expect, then then would trigger separate investigative work to determine why, and the relevance**	15
3. **Communications around report and any subsequent scheme are important. Be clear about what the 'flag' means**	3
4. **The scheme raises questions/issues for further investigation rather than providing a definitive answer and so acts as a cue for more detailed investigation**	4
5. **Consistency in frequency of monitoring is important**	3
6. **More granularity of PUS data would enhance the usefulness of the scheme and use of Environmental Land Management Scheme (ELMS)**	14
7. **The baseline (including historical exposures) from which unexpected results will be compared needs to be clear**	6
8. **Collect other potential exposure contaminants that could be involved e.g., fertilisers and micro-nutrients**	3
9. **Information on Amenity (and allotment/home and garden) use is a gap**	3

Question C - Are there elements of the draft monitoring scheme considered not of value? State which and why.

Response	Sum Score
1. Number of applications isn't a useful indicator in PUS	13
2. Presence of PPPs alone is not helpful, particularly with sensitive technique detecting at ppb/ppt level – residues need to be assessed in context of potential for effects/risk based on available ecotox data	26
3. Fitting analysis to exposure assessment	4
4. How have current elements fed into regulatory assessment, e.g., WIIS – how successfully have issues identified as resulting from approved use fed back into the regulatory assessment process	7
5. Use of state of the art usage data requires clear data management	4

Question D. What do you perceive to be the barriers to any implementation of such a scheme?

Response	Sum Score
1. Funding – who is going to pay	3
2. Dissemination of findings and level of detail of finding – who, what they see and when – stakeholder groups	3
3. Scope of project has to be agreed	6
4. PUS limitations – if used as basis need to be comfortable with data produced by PUS. Is it enough, given low number of farms sampled? Amenity sector not covered frequently	12
5. Monitoring of PPP residues in vertebrate carcasses – how representative are they of populations	1
6. Receipt of data – digital labels will provide detailed data – need to define ownership of data and use (IPR)	6
7. Ability to record targeted and precision applications of PPPs, rather than whole field applications	4
8. Sufficient resources to look at further detail following flag?	9
9. When to report to public	0
10. Granularity of data (e.g., PUS only statistically robust to regional scale – so how do your follow-up unexpected findings?)	11
11. GLP – Quality Assurance requirements	0
12. Is analytical capacity missing? My group mentioned this at the workshop	0

Question E - How should any post-registration monitoring scheme be resourced?

Response	Sum Score
1. Existing Pesticide finance levy should be a start. There could perhaps be a mistrust in the outcomes if industry was seen to fund the project	17
2. Public funding – Government sources	19
3. Water monitoring includes EA monitoring – terrestrial should take a similar approach	5
4. Long term funding would be needed	1
5. Some additional funding may be needed – in particular to address 'flags', if identified	6
6. Potential issues – the authorisation holder may be needed to provide funding – but that would require the issue being tied to a specific active substance. I think we went as far as saying if it was tied to a specific active the authorisation holder may want to resource further work. There may be a public perception issue with this though	2
7. Multi-stakeholder funding, including industry and environmental groups	1
8. Volunteer experts to provide some data, although would need to ensure volunteers are adequately 'trained'	0
9. Data sources may be available for use	1
10. Reward for data provision from farmers through ELMS	2

Question F - How/where do you think the results from monitoring should be disseminated?

Response	Sum Score
1. Need for careful dissemination – need for carefully handled public communication through a mechanism that understands the consequences of reporting issues	14
2. Frequency and scale of reporting yet to be defined, (monthly, annual, farm, regional, country, UK-wide?)	2
3. Content of report would be important – just the flag, the in- depth analysis or high level public report showing trends with interpretation	5
4. Amenities protecting use of those PPPs	3
5. Availability of initial results – freely available – transparency being key here, but need science and evidence based expert interpretation with that	13
6. Useful to have stakeholders involved in initial review of reporting	14
7. For ECP use only to help provide evidence on PPPs	0
8. Analysis and interpretation of data is key thing to communicate.	3

Question G – List any other key issues not addressed elsewhere.

Response	Sum Score
1. Why for example were farm bird index, Rothamsted Insect Survey and butterfly survey and other perceived 'relevant' data not included? Report needs to explain why these were excluded from scheme	13
2. Need mechanism to promote use of this evidence in public debate	0
3. Incorporating new data from other data needs to be highlighted and presented in a clear way	1
4. The comparability of the data needs to be explained	4
5. Consistent and traceability of metrics is important	8
6. Cognisance of other stressors on signal change	15
7. Adoption of a control area would be necessary, if possible – bearing in mind what it could be	0
8. Missing things not regarded as PPPs e.g., comparison of organic v conventional	2
9. Sources of other uses of actives e.g., veterinary meds, biocides, pharmaceuticals	9
10. Gap in information on amateur and amenity use is of concern	3

11.6 Comments from conservation bodies and NGOs stakeholder workshop

Table 7.4 Attendees of conservation body and NGOs stakeholder workshop

Nomination	Affiliation
Matt Shardlow	Buglife
Nick Mole	Pesticide Action Network UK
Josie Cohen	Pesticide Action Network UK
Thomas Lancaster	Royal Society for the Protection of Birds
Stephanie Morren	Royal Society for the Protection of Birds
Louise Payton	Soil Association
Paul De Zylva	Friends of the Earth
David Buckingham	Royal Society for the Protection of Birds
Jonathan Newman	Environment Agency
Project team:	
Gen Madgwick	Natural England
Lee Walker	UK Centre for Ecology & Hydrology
Richard Shore	UK Centre for Ecology & Hydrology
Libby Barnett	Fera Science
Andrew House	DEFRA

Breakout questions and responses Conservation bodies and NGOs Workshop

29th January 2020

Question A - Will post-registration monitoring (as or similar to the scheme outlined) help identify unexpected consequences of PPP use? Give your reasons.

Response	Sum Score
1. **Need to decide who is going to use the data and what would they do with it**	6
2. **Who is to do the coordination?**	0
3. **Challenge in collating data and how to interpret where there is conflicting information**	0
4. **Better data where there are particular gaps would be useful**	5
5. **A lot of data would need to be collected in order to be useful to identify "fine-brush" consequences**	2
6. **Needs a mechanism to trigger policy change or registration status**	11
7. **Need to decide whether monitoring scheme and analysis (interpretation) of resulting data are separated**	0
8. **Who has responsibility for taking further action, e.g., commissioning in-depth studies?**	8
9. **There is a fear that it could be used by industry to defer some registration processes**	0
10. **Need to change title of scheme to clarify purpose**	3
11. **Need to clarify in report the value of monitoring scheme to renewal process**	1

Question B - Are there missing elements that should be included in the proposed scheme and how would they be of value?

Response	Sum Score
4. Could UK Pollinator Monitoring Scheme (POMS) be included? What would need to be done to include this data in the scheme? Potential source of samples for analysis. Needs to increase sample numbers (larger number of sites).	11
5. Rothamsted moths and aphids sampling could be a source of samples. Limited spatial extent.	0
6. Forestry use not picked up by PUS reporting.	4
7. Amenity use not picked up by PUS reporting.	9
8. Coordination with Aquatic monitoring – picking up terrestrial signals.	2
9. The proposed scheme could be extended to veterinary medicines.	2
10. Sales data.	3
11. Coordinate outputs with data on residues in UK food produce.	0
12. Farmer collected field-level data on use	1
13. Including collection of IPM data in PUS.	0
14. Pesticide load indicator project outputs – Uni of Hertfordshire	1
15. University of Reading work on individual based models on exposure and impacts	1
16. Spatial data in National Biodiversity Network (NBN) and Biological Records Centre (BRC) – changes in distribution compared to pesticide use/exposure. Probably a Level 3 approach.	2

Question C - Are there elements of the draft monitoring scheme considered not of value?-state which and why.

Response	Sum Score
1. **Caveat of value of WIIS as it is a reactive scheme.**	15
2. **PUS in current form of limited value compared to alternatives data sources.**	15

Question D. - What do you perceive to be the barriers to any implementation of such a scheme?

Response	Sum Score
1. **Political will.**	12
2. **Willingness to adopt addition reporting needs on farmers – around additional data collection (see 4).**	0
3. **Issues around commercial confidentiality around some of the data suggested.**	0
4. **Social capital risk for users of PPPs – around additional data collection (see 3).**	0
5. **Size of datasets will be too big and complicated to analyse.**	0
6. **Securing long-term funding for monitoring and short burst funding for intensive investigations.**	10
7. **Having mechanisms in place to act upon signals from monitoring scheme and commission intensive studies.**	4
8. **Having mechanisms in place to feed into renewal of registration.**	0
9. **Need clear governance and ownership of the monitoring scheme to ensure it is fit for purpose.**	2

Response	Sum Score
10. Adequate Quality Assurance of data.	0
11. Challenge would be to get buy-in from multiple providers of data, capacity to meet needs and scope of information being gathered.	3
12. Longevity of funding of platforms.	0
13. Clarity on where this monitoring sits in the policy landscape.	3
14. Accountability for monitoring scheme.	1
15. Flexibility of scheme to evolve.	0
16. What to do if critical components stop.	0
17. Currently no overarching regulatory requirement for this monitoring.	1

Question E - How should any post-registration monitoring scheme be resourced?

Response	Sum Score
1. Public purse – share of agri environment money	7
2. Research Councils – UKRI.	7
3. Hypothecated Pesticide Industry through pesticide tax on product.	12
4. Cost through registration.	1
5. User - Pay per spray.	1
6. Pesticide industry levy – charge to users or distributors – licencing approach.	7
7. Charge for use certification.	0

Question F - How/where do you think the results from monitoring should be disseminated?

Response	Sum Score
1. Open data and transparency.	15
2. Transparency of what the data is being used for.	2
3. Impartial reporting is important.	4
4. Annual reporting or ongoing dissemination of data, or both.	6
5. Go to ECP, anybody discussing renewals including CRD.	2
6. The results should inform roll-out or further roll-out of IPM.	2
7. Dissemination into agricultural training and agronomy advice, industry and departmental lit.	4

Question G – List any other key issues not addressed elsewhere.

Response	Sum Score
1. Currently no overarching regulatory requirement for this monitoring.	14
2. No monitoring of efficacy of PPP use, would need yield data.	3
3. Is there space for monitoring of PPP-resistance, for mapping.	0
4. Include in report that will not even in part replace RA requirements.	8
5. The range of PPPs analysed would need to be considered carefully.	0
6. Use of combination of target and non-target scanning.	2
7. Point 3 on page 5 relating to informing Risk Assessment process – what would need to be in place in order for this feedback to happen?	5
8. Encompass flexibility to address specific questions.	4

11.7 Written Responses to Draft Report from Stakeholders – March 2021

In addition to the written responses below, editorial notes and comments were also received from the National Farmers Union, the Voluntary Initiative, Agricultural Industries Confederation, Natural England and Defra's Chemicals Regulation Division.

Crop Protection Association response to the 'proposal for terrestrial monitoring of authorised pesticides (TEMPEST)'

The Crop Protection Association (CPA) welcomes the Centre for Ecology and Hydrology (CEH) report regarding the proposal for terrestrial monitoring of authorised pesticides (TEMPEST) as it is the first report to identify and draw together all ongoing terrestrial environmental monitoring activities and schemes within the UK. In this regard however, the statement '*The lack of monitoring of PPPs in the terrestrial environment...*' in the executive summary (paragraph 3 on page 3) is not factually correct and is inconsistent with claims made later in the report. The report goes on to highlight (page 4) that there are a wide variety of existing terrestrial environmental monitoring activities and that these schemes compare favourably with those employed by other countries. And if collated appropriately these existing monitoring schemes will provide a good starting point to base any further investigations.

The report focuses mainly on PPPs but also includes some reference to other pesticides and other factors, whereas the Defra commission uses the term pesticides when it is referring to PPPs. CPA considers it helpful to consider the full range of factors that can impact the environment when appraising potential policy approaches, but it is also important for terminology to be used accurately.

The aim of the review (as commissioned by Defra 29/05/2019) was 'to develop a proposal for an environmental monitoring programme to monitor the effects of pesticides on wildlife and the terrestrial environment'. However, as acknowledged in the report itself, the proposed monitoring scheme (TEMPEST) will not in most cases provide data that will determine whether PPPs or other factors are having an effect, or not, at the population, community, or ecosystem level. Instead, it aims to utilise the available monitoring schemes to identify changes in the status of the terrestrial environment and then use any observed changes to trigger further review and investigation. This is an efficient and pragmatic proposal, but any additional investigations would have their own challenges, most notably cost.

The report makes several suggestions for possible additional monitoring. Whilst these suggestions could add to the breadth of existing data collection, it is not clear that they would meet the Defra aim of determining causation of any environmental effects observed. A policy appraisal should consider the cost/benefit of different approaches. Government should ensure that funding reflects the purpose and value of the monitoring systems in the round.

One area stated in the report that requires careful consideration is the communication of findings of any monitoring scheme outcomes. The report acknowledges that careful terminology will be needed when presenting the results of monitoring. Too often the mere presence of a residue is used in a negative or emotive context regardless of whether there are any effects from that residue. There is a need to understand the context of the origin of any residue and attributed effects. For example, is the source from PPP, biocide, veterinary use or other source. If the source is PPP use, was this because of misuse or an unexpected effect from an authorised use? These considerations must be clearly highlighted in the communication of monitoring data. TEMPEST monitoring data could be used to provide useful information on label compliance e.g. identify misuse, and identify where further user training, stewardship or compliance activity is required.

Another useful aspect is that TEMPEST should be able to confirm the robustness of the PPP regulatory regime in the UK by illustrating whether the exposure predictions carried out in our regulatory risk assessments are - as predicted - highly precautionary and overestimate actual environmental exposure. Over time, data from TEMPEST could possibly be used to monitor the impact of Integrated Pest Management (IPM) and precision technologies in agriculture, as promoted in the National Action Plan for the Sustainable Use of Pesticides.

Since the implementation of harmonised PPP regulation, growers have experienced the withdrawal of many active substances and products, with additional restrictions placed on others, mainly as a consequence of increasingly conservative environmental requirements. Furthermore, the PUS data clearly shows that overall application rates of active substances have reduced over this period of time.

Changes and impacts on biodiversity is a multifactorial issue. The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES)[83] identified that the main direct drivers of changes in nature, in descending order, are (1) changes in land and sea use; (2) direct exploitation of organisms; (3) climate change; (4) pollution and (5) invasive alien species. Therefore, any further environmental monitoring needs to be focused on determining the causes of impacts, and must consider land management and changes in biodiversity in a more holistic way, especially if we are to meet the many goals of the 25 Year Environment Plan.

[83] IPBES (2018): The IPBES assessment report on land degradation and restoration. Montanarella, L., Scholes, R., and Brainich, A. (eds.). Secretariat of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, Bonn, Germany. 744 pages. https://www.ipbes.net/sites/default/files/2018_ldr_full_report_book_v4_pages.pdf

Draft proposal for Natural England's approach post registration monitoring of pesticides in the terrestrial environment (TEMPEST)

Combined response: Friends of the Earth, PAN-UK, RSPB, Soil Association

March 2021

Introduction

CEH has requested a combined response from conservation and environment NGOs to its draft report for Natural England on a proposed new system for the monitoring of pesticides (aka plant protection products) following their registration for use, and their effects on wildlife.

The request has come at an especially busy time for all concerned and not all NGOs have been able to consider the report in depth to make a comprehensive response, and some NGOs have not been able to contribute at all.

Given the relatively short amount of time provided for comment, CEH and Natural England are requested to be proactive in checking whether each of the named NGOs has any subsequent comments to provide on top of this composite submission before the proposals are finalised.

Response

1. Confidence in a new system

The lack of monitoring of PPPs in the terrestrial environment is a serious gap in the ability to track and make decisions about the real time use of pesticides.

Given past failures in addressing safety concerns and the tendency of government and regulators to stand behind testing regimes which were then found to be unfit for purpose, it is imperative that the public has confidence in any new system.

Such confidence will depend not on official reassurances but on the robustness and credibility of the scheme's design and how effective it is both in use and in reporting.

The report concludes that current post registration monitoring of pesticides in the UK's terrestrial environment based on pesticide usage data (PUS) and investigations of poisonings (WIIS) "compares favorably (sic) with those employed by other countries".

That is far from a comfort given the UK's deleterious state of nature including soils, water bodies, habitats and species, and the need to thoroughly improve data and ensure it is used to inform better, faster decisions and policies is long overdue.

As advised at the 29 January 2020 workshop it would be useful if the report set out the extent to which the elements of the proposed approach addressed the key questions and the degree of confidence that risks will be properly assessed. Instead, the report states in a very top level, almost throw away manner, that:

“The proposed monitoring scheme (TEMPEST) will not in most cases provide data that will be able alone to provide diagnostic answers as to whether pesticides are having an impact at the population, community or ecosystem level. Instead the ambition would be that any program should be able to identify changes in the status of our terrestrial environment, or particular parts of it, at an earlier level of organization *(sic)*. Any observed changes in status of TEMPEST components should be viewed as a trigger for further review and investigation.”

That does not instil confidence and it would be more helpful if the assessment of the efficacy of the components of the approach were fully laid out.

2. **Inadequacy of current monitoring schemes**

There appears to be an overconfidence in the current ability of WIIS and PUS monitoring.

WIIS over-relies on third party reporting of incidents and lacks the resources to effectively investigate incidents which are reported.

PUS depends on responses to surveys rather than the reporting of pesticide usage in all sectors including agriculture, amenity and forestry as a matter of law. The time lag in PUS reporting and lack of granular detail on the temporal and spatial use of pesticides undermine effectiveness.

If PUS and WISS are to be relied on the schemes must be overhauled because they are not currently fit for purpose.

Honey sampling may provide some useful data with regard to managed colonies of honeybees, but it should not be taken as a proxy for direct monitoring of impacts of other wild bees and pollinating insects, including via sampling of soils, plants, hedgerows, field margins and water which the majority of insects will visit as part of the very different behaviours.

The health of UK soils and soil life has been in general decline for a range of reasons, including the routine application of many different treatments. The need to know the role of pesticides in the health and functioning of soils is urgent.

The collection and interpretation of pesticides sales data can also give useful information on the use of pesticide products rather than just individual active substances. This data needs to be incorporated into a new monitoring system and not kept hidden by commercial confidentiality clauses.

3. **Monitoring that informs better decisions**

The ultimate test of monitoring is how findings inform good and timely decisions. The value of a monitoring scheme which does not link directly into the process for the approval and review of products, for example by pausing use while matters of concern are investigated, is of questionable benefit.

The proposed approach appears to be generically weak in an ability to provide a safety net for detecting unexpected impacts on terrestrial inverts, including wildlife and agriculturally beneficial taxa. Unless it directly relates to the way products are tested and reviewed, it will also continue to lag behind the product approvals process. It may also attract unfavourable scrutiny from planned independent research (e.g. NERC's ECORISK programme on pesticide fate/impacts). POMS is not considered in this context, given that this was raised as an opportunity in the stakeholder workshops.

4. **Shortcomings of the proposed approach**

The recommendations for monitoring scheme components have a number of shortcomings.

There are two types of monitoring measurements in the proposals:

- direct measurements of pesticide use/residues/exposure
- indirect response measurements (termed 'effects measurements').

Both sorts of measurement are necessary parts of a future monitoring scheme and they have different purposes, and they are not interchangeable. The report should be clear about this distinction as that would help address concerns expressed by both stakeholder groups about 'unexpected consequences', completeness of the proposed monitoring tool suite and the remit of the proposed scheme to make recommendations.

Direct usage/exposure measurements are necessary for two main purposes:

(i) to test whether residue levels remain within permissible risk-based levels set by the licensing process. This is a test of whether the permitted usage and mitigation measures are working. If they are not, this is a clear problem that has to be addressed and the monitoring scheme should as a minimum, raise an alert.

(ii) To contribute to secondary assessments of possible impacts by testing for spatial/temporal correlations between usage/exposure measurements and measurements of ecological responses. Evidence for correlations (positive or negative) should trigger an alert, highlighting the need for further research to confirm a causal link and to devise a solution.

Effects measurements only contribute information that can be used for correlative assessments of links to usage/exposure measurements. An additional level of new research has to be commissioned in order to confirm causality and solution of any problems highlighted in this way. It is unclear who will take responsibility for commissioning this action.

Both stakeholder groups have questioned the completeness and suitability of the proposed suite of effects measurements. Several suitable monitoring datasets with high spatial replication and rich datasets do not appear in the recommendations even though they would be of high relevance to screening for correlative relationships to usage/exposure measurements.

The Pollinator Monitoring Scheme (POMS), Rothamsted suction traps, the Breeding Bird Survey (BBS), etc. should be incorporated in secondary correlative assessments to test for potentially problematic associations with pesticide use or residues.

Two effects measurements included in the proposed scheme have high costs associated with the need to increase spatial replication before they can inform secondary correlative comparisons with pesticide usage/exposure (which they do not currently measure). The Chick Food Index (CFI) and the Rothamsted Earthworm Survey (RES) potentially contribute valuable effects measurements, to test for ‘unexpected’ associations with separate pesticide use/exposure measurements, but there are better ways in which these schemes can provide monitoring data.

A serious omission from the recommendations is that three of the effects measurements schemes (CFI, RES and POMS) could form the basis for valuable, carefully structured exposure measurements in important functional groups that are currently unrepresented (other than an unrealistic suggestion to expand WIIS to reactively monitor dead individuals).

All three schemes collect repeatable samples of invertebrates and process the samples, classifying individuals into taxonomic/functional groupings to produce index metrics. This processing is costly, but it is already resourced and coverage could be expanded to contribute to the future monitoring scheme.

The overlooked opportunity is that all three schemes could easily extract the classified invertebrates (rather than just counting them) to produce samples of individuals for residue testing. That could address systematic gaps in residue testing in the proposed scheme: namely wild pollinators (POMS), predators/parasitoids (POMS), indirect effects on wildlife at higher trophic levels (CFI) and soil functionality (RES).

Collectively these functional groups are relevant to both agricultural and environmental stakeholders’ aspirations to move to more sustainable use of pesticides. The proposed scheme currently does not provide exposure level (residues) monitoring for any of these groups. That should be contrasted with the high proposed monitoring standards for honeybees (commercial pollinators) where both exposure and response metrics will be adequately monitored.

The issue of “unexpected consequences” is not adequately addressed in the report, raising concerns from both stakeholder groups. Concerns focus on what consequences are monitored and how the scheme will respond to any detected consequences.

There are clear and achievable requirements that environmental stakeholders require monitoring schemes to address, recognising the limitations of risk based licensing approaches and providing a safety net to detect ineffective regulation/implementation and overlooked impact pathways. These are:

- Exposure tests: to test that safe residue levels set by the licensing process are not exceeded in practice, i.e., that permitted usage and proposed mitigation techniques are working (two major concerns with the existing licensing framework).

This test must also include monitoring exposure/residues in non-target habitats and taxa that have not been adequately tested in the licensing process – i.e., a safety net for problems that were unanticipated. There is plenty of precedent for problems with regulatory oversight and subsequent poor implementation.

- Impact tests: The available options for safety net testing are limited to reactive testing of acute wildlife incidents and correlative assessments of associations between exposure monitoring measurements and effects measurements. In most cases the detection of a potential problem should trigger an alert and the commissioning of research to confirm causality and to develop of a solution.

Recognition of the limits of inference from monitoring alerts and committing to a clear path to trigger more robust investigation of the apparent problem (and its solution) would address industry concerns about giving too much credibility to monitoring associations.

A three-stage approach to monitoring was openly discussed in the stakeholder meetings but this sensible framework is not given clear prominence in the report.

The stages were:

- collection of monitoring datasets (usage/exposure and effects measurements)

- secondary assessments of the monitoring datasets (looking for correlative associations between usage/exposure and effects measurements, which would suggest a pesticide impact, positive or negative)

- commissioning further research on emerging impacts (to confirm causality and to design solutions).

All three stages should also be able to generate alerts requiring action by regulators.

11.8 Natural England Science Advisory Committee (NESAC): Extract of Minute of Meeting held in London on 30th October 2019.

4 Pesticide Monitoring Review (Richard Shore)

4.1 Richard Shore of the Centre for Ecology and Hydrology (CEH) described work undertaken for Defra, Natural England and HSE to develop an integrated framework for monitoring the impacts of pesticides in the environment post-registration. Richard noted how hitherto registration has focused on standard tests undertaken before release and there has little systematic follow-up work to monitor impacts post-release across multiple environmental ‘compartments’. The project has therefore involved intensive desk-based research to:

- Review existing pesticide monitoring schemes of the terrestrial environment, focusing on pros, cons and gaps
- Undertake stakeholder engagement to access NGO and industry expertise
- Deliver workshops with technical specialists to understand how to enhance existing platforms, improve join up/reporting and identify gaps
- Develop a set of proposals, by Mar 2020 on what monitoring might be instigated, its scientific rationale and any constraints and logistical challenges.

4.2 NESAC was asked for its views on the emerging recommendations, prior to finalisation of the report, concentrating on:

- Whether they agreed with the need for and objectives of the work?
- Their views on the draft proposals?
- The role NE might have in the delivery of a monitoring programme once any subsequent recommendations are published? (c/f the roles of EA, HSE & Defra)
- The risks and opportunities we should be considering?

4.3 Members recognised this was a big piece of work and were enthusiastic about the development of a more effective monitoring approach. They felt that there needed to be greater clarity in the final report around the logic models describing and connecting evidence needs, desired outcomes, risks and pathways and mechanisms and to demonstrate how models could be used to prioritise and target environmental ‘compartments’ for gathering data. They suggested that we need to join up assessments throughout the ecosystem and not be afraid to pitch a ‘gold standard’ approach. The team was encouraged to be bolder around the language used to describe the objectives and potential impacts of the work. They were also keen that Natural England be involved in delivery, given the potential impacts on our core business, whilst recognising that engagement would need to be at a pragmatic level.

4.4 Members made various comments about detailed aspects of the proposals:

- They expressed surprise about the scale of evidence gaps in some areas, notably pesticides in soils, and asked about any experience or data from other countries.
- Could the human biomonitoring project offer insights into targeting pathways or receptors for monitoring?
- Do we know enough about the impacts of cumulative pressures?
- Forestry may need a bespoke pathway network.
- Could we assess against alternative systems (e.g. integrated pest management) and look for solutions at management level. Could Natural England contribute to ‘tests and trials’?
- Can taking a risk-based approach inform the focus of our monitoring effort?

11.9 Extract of Minutes of the meeting of the UK Expert Committee on Pesticides (ECP) held on 24 September.

Agenda item 7: Overview of new post-registration pesticide monitoring scheme project

7.1 A representative of this Defra-sponsored project gave a presentation to the Committee outlining the aims, scope and activities as well as potential outcomes and next steps.

7.2 It was reported that there are multiple existing monitoring schemes, but none monitor across multiple environmental compartments to identify potential adverse impacts of pesticide use at different scales. The project had identified and assessed the suitability of a number of schemes, ranking them in terms of readiness to provide relevant data/information.

7.3 The project had suggested there was a need to monitor: pesticide usage, residues in soil, chick-food availability; terrestrial invertebrates, pollinators and vertebrates. It was noted that the current arrangements do not enable all these issues/environmental components to monitored in depth. The project had identified potential gaps in the monitoring of: non-target plants and arthropods; amphibians and reptiles; long-tern reproductive effects; and consideration of urban and amenity pesticide uses.

7.4 The desired outcomes of the project are to facilitate a shift in focus from monitoring pesticide use and wildlife poisoning (currently monitored by the Wildlife Incident Investigation Scheme), to integrating measures and effects of exposure to provide a more holistic assessment. The aim was to develop a better understanding of normal agronomic practice, improve the ability to inform risk assessments, track risk mitigation outcomes and potentially have earlier warning of unexpected events.

7.5 Members were supportive of the approach being taken and observed that the project had the potential to improve detect

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ISBN 978-1-78354-777-7

Catalogue code: NECR377

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