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The Silent Spring – On the need for sustainable plant protection

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The Leopoldina Discussions series publishes contributions by the authors named. With the discussion papers, the Academy offers scientists the opportunity to present thought-provoking ideas and to encourage and guide discussions, flexibly and outside of formal working group processes.

Contents

1. The framework

1.1 Environmental chemicals and global change

Chemicals end up in the environment in many different ways, intentional and unintentional. Plant protection products, hereinafter referred to interchangeably as pesticides, make up the quantitatively largest share of harmful substances which are used deliberately. Chemical pesticides are used to protect crops and plant products from harmful organisms and the diseases they cause, and contain one or more chemical and usually synthetically manufactured active substances. Pesticides combat animals acting as pests, e.g. insects (insecticides) or rodents (rodenticides), offer protection from diseases such as fungal infestations (fungicides) or simplify production methods and decrease the related costs through reducing the number of hours worked. Pesticides also include herbicides which are used to control weeds. Other applications include plant growth regulation and the conservation of plant products.

Alongside climate change, major changes to global nutrient cycles, the destruction of habitats and other factors, pesticide contamination plays a significant role in the concept of planetary boundaries, which suggests that crossing critical thresholds leads to profound disturbances in the Earth system processes.[1]

The fact that an intact, species-rich environment means much more than upholding aesthetic or moral standards has been internationally recognised and supported through national strategies since the Rio Summit in 1992 at the latest.[2] This is based on the premise that ecosystems and the organisms living within them render numerous services which are vital for life on earth. These range from the production of oxygen and food, to the provision of drinking water which is purified in the process of filtering through soils and bedrock. Ecosystems sustain es-

1 Rockström et al. (2009), Persson et al. (2013), Steffen et al. (2015).

2 BMUB (2007).

sential material cycles, e.g. for carbon storage or climatic alteration and the decomposition of natural, organic materials as well as synthetic and often toxic chemicals. Nutrient cycles such as the nitrogen and phosphorus cycles are equally important. The variety of stressors mentioned above, which now impact ecosystems simultaneously, has caused such a dramatic decrease in biodiversity in Germany and around the world[3] that it is referred to as a mass extinction.[4] This also has an impact on the services performed by communities in ecosystems.

In 1962, US biologist Rachel Carson published the book "Silent Spring"[5] in which she scientifically substantiated the adverse environmental effects of chemical pesticides, which were just becoming established at that time. The title refers to the almost complete absence of birdsong as a result of severe population declines in parts of the USA. The book made Carson one of the most significant people to draw attention to the undesirable consequences of pesticide use. She contributed to a popularisation of the scientific representation of environmental problems which had already been described at the end of the 19th century by Raabe in "Pfister's Mill"[6] and re-entered public consciousness in 1972 with the report by the "Club of Rome"[7]. Since then, the ecological, environmental chemical and ecotoxicological research has experienced enormous growth and also addresses other products such as biocides, pharmaceuticals, industrial chemicals and synthetic nanomaterials in addition to pesticides.

The problem of synthetic agrochemicals and a broad range of other industrial chemicals in the environment due to continual increases in their worldwide usage[8] is now a cause of growing concern. And this remains the case in spite of increased public awareness, multiple drastic improvements to the legal framework, considerable gains in competencies and increased capacities in regulatory and enforcement authorities, as well as huge advances in research into environment and risk.

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3 Cardinale et al. (2012), Hooper et al. (2012), Newbold et al. (2016), Ceballos et al. (2017).

4 Dirzo et al. (2014).

5 Carson (1962), p. 100 et seqq.

6 Raabe (1884).

7 Club of Rome (1972).

8 Bernhardt et al. (2017).

As part of a Leopoldina workshop, environmental scientists from the fields of chemistry, ecotoxicology, ecology, agriculture, environmental legislation and regulatory affairs met in March 2017 to describe their perspectives on the current chemical-related environmental situation with a view to the situation in Germany, in order to identify discernible negative developments and draft suggestions for solutions. Although the wide variety in chemicals pertinent to the environment was discussed in general terms at first – e.g. human and animal pharmaceuticals, biocides, fertilisers, hormone (endocrine) disrupting industrial chemicals, poorly degradable (persistent) chemicals – the discussion then focussed on pesticides used in agriculture. Due to their intentionally high potential to cause a biological impact and their large-scale use in agriculture, pesticides have a special status among the chemicals which pose grave environmental problems. The decision was therefore taken to limit the present discussion paper to pesticides. As this group of active substances covers a wide variety of chemical structures, in the following, only selected pesticides will be discussed as specific examples.

This paper makes a contribution to the further development of the **risk assessment of pesticides**, describes the **environmental problems and causes** which arise through the use of these active substances, offers **recommendations for action** for a sustainable use of chemicals in line with conservation objectives, identifies **gaps in research** and formulates a **plea for environmentally sustainable plant protection** by way of conclusion.

1.2 Legal framework for the authorisation and use of pesticides

Pesticide authorisation

Pesticides may only be placed on the market once they have undergone numerous tests. This applies both at EU level to the approval of active substances permitted in the EU, and within the member states to the approval of pesticide products which contain other chemicals in addition to the active substances. A much debated example is the product Roundup containing the active substance glyphosate, which is regulated by consistent European legislation in European administrative cooperation (EC Regulation on Plant Protection Products No. 1107/2009).[9] The manufacturers of the active substances and products are obliged to carry out a comprehensive range of examinations. These include, among others, analytical methods for detecting the substances in soils, water, plants and animals, environmental behaviour, for example, degradation, distribution between soil, water and air, and an estimation of the *exposure*[10]. In addition, the manufacturers are required to provide ecotoxicological and toxicological information, that is, to estimate the *effects*[11] on organisms and ecological communities as well as the impact on the people exposed. The authorising authority for pesticides in Germany is the Federal Office of Consumer Protection and Food Safety (BVL) which is part of the Federal Ministry of Food and Agriculture (BMEL). The Federal Ministry becomes involved after an EU Community procedure has been laid down on the authorisation of active substances. Fundamentally, pesticides may only be authorised in EU member states if their active substances feature on the positive list of active substances approved by the EU[12].

The BVL works together with three federal regulatory authorities: the Julius Kühn Institute (JKI) tests the effectiveness, compatibility for plants, regulations for practical application and the toxicity to bees; the

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9 Köck (2012).

10 Exposure refers to the amount of a given pesticide which an organism in the environment can come into contact with.

11 “Effects” are the toxic impact of exposure to pesticides – or other environment-relevant chemicals – on organisms, populations, ecological communities and ecosystems.

12 European Commission. EU Pesticide Database.

Federal Institute for Risk Assessment (BfR) assesses the potential impact on the health of people and livestock; and the German Environment Agency (UBA) evaluates possible consequences for the environment. On the basis of the evaluation reports from these authorities, the BVL then issues a temporally restricted authorisation for a pesticide product in Germany. Authorisation is usually granted for a period of ten years. Through this, the BVL stipulates the crops in which the pesticide may be used, as well as the harmful organisms which it may be used against. Furthermore, the BVL defines the pre-harvest intervals the farmer must maintain between the final pesticide application and harvest in view of the permitted maximum residue level in the crop. Where necessary, the BVL also issues restrictions to be upheld by the farmer which aim to manage risks to users, local residents and the environment (so-called rules of application, e.g. to protect bees and bodies of water).

Regulating the use of pesticides

The use of plant protection products forms a regulation level in addition to the authorisation level. While the authorisation level answers the question of whether an active substance or a pesticide may be used, the regulations for use govern how a pesticide should be used. Paragraphs 3 and 6 et seqq. of the German Plant Protection Act (Pflanzenschutzgesetz) contain a list of basic provisions, including the so-called good plant protection practice.[13] This means that the treatment of plants or plant products with pesticides in accordance with the conditions of their authorised usage, are selected, dosed and timed to ensure acceptable efficacy with the minimum quantity necessary, taking due account of local conditions and the possibilities for control using suitable cultivation methods and biological means. However, as agricultural tillage is not subject to any authorisation processes, the monitoring of these regulations is already deficient when they are put into practice. In particular, there are no incentives to minimise the preventive use of pesticides. In addition to this, the so-called “cross compliance” controls in European agricultural policy cover some environmental regulations, for example the standardised European limit on nitrate usage, but not pesticide use. [14]

13 Pflanzenschutzgesetz (2012)

14 Möckel et al. (2014).

However, with the EC directive on sustainable use of pesticides, an overriding European political objective for chemical plant protection was put in place in 2009. This framework directive requires the EU member states to draw up National Action Plans aimed at "setting quantitative objectives, targets, measures, timetables and indicators to reduce risks and impacts of pesticide use on human health and the environment and at encouraging the development and introduction of integrated pest management and of alternative approaches or techniques in order to reduce dependency on the use of pesticides".[15] The directive was formally implemented in Germany through the "National Action Plan for Sustainable Use of Plant Protection Products" (NAP) passed by the Federal Government on April 10, 2013.[16] The UBA, which was involved in drawing up the NAP in accordance with its responsibility for environmental issues within the authorisation process, criticised the objectives and measures in the NAP for being too unspecific, too non-binding and too unambitious.[17]

Deficiencies

Thus, before a pesticide can be brought into circulation, it has to face the relatively high regulatory hurdles laid down by the legislative authority in the form of the authorisation process. But although the authorisation process has repeatedly been expanded and refined over the past decades, particularly when it became necessary to close obvious loopholes in the authorisation or make (periodic) adaptions in keeping with the development of scientific knowledge, the authorisation process does not depict all the ecological impact scenarios in the field by far.

There has been an authorisation process for plant protection products in Germany since 1968,[18] but it has only explicitly covered the effects on environmental resources (water, the environment) since 1986[19]. The current structure for pesticide authorisation has its main origins in a European directive from 1991, which in 2009 became a

15 EU (2009a).

16 BMELV (2013).

17 UBA (2016).

18 German Plant Protection Act (PflSchG) of 10 May 1968.

19 German Act on Crop Protection (Plant Protection Act – PflSchG) of 15 September 1986.

regulation that was immediately applicable to the entire EU. One of the most well-known examples from the earlier period of risk assessment for chemicals is the insecticide DDT, which was only banned in Europe and the USA in the 1970's after the concentration of the substance in organisms came to light.

In view of the administrative process, there is a need for more stringent monitoring of the restrictions on the use of plant protection products. This is also an important demand in the NAP. Unfortunately, the federal states are currently not able to meet this demand due to massive reductions in staff in the plant protection authorities. We have identified a nationwide deficiency in implementation which requires a systematic reaction, e.g. establishing a pesticide tax to create an incentive for a decreased use of pesticides, and/or to fund the administrative process and other costs of pesticide use borne by society. Furthermore, the European and national concept for the authorisation and monitoring of pesticides must be safeguarded through consistent defence against illegal pesticide imports.

Industrial chemicals, biocides, pesticides as well as pharmaceuticals for humans and animals are each assessed and regulated according to their own specific procedures. Here, it may occur that a substance's impact on the environment is assessed and regulated differently in the various procedures on account of its multiple areas of application (e.g. use as a biocide and a pesticide), as there is some variation in the rules of application and/or legal regulations.

1.3 Environmental risk assessment

If pesticides are used correctly, there should be no harmful effects on human and animal health, nor on groundwater, and no unjustifiable effects on the environment (with the exception of the target species) should emerge. This demand is articulated in the EC regulation[20]. Supplementary legislation and comprehensive technical guidelines (guidance documents) contain detailed specifications for the legal data requirements, performance of the risk assessment and uniform decision-making criteria. A summary of such investigations is found in the sources cited in the appendix.[21]

The environmental impact is assessed in a tiered process which aims to efficiently organise the evaluation work using a filter system. The fundamental principle here is the comparison of the expected concentration of the substances in the environment (PEC – predicted environmental concentration), or the expected exposure of non-target organisms to be protected, following the proposed use of a pesticide, with corresponding concentrations below which no adverse effects on the non-target organisms have been observed (e.g. RAC values – regulatory acceptable concentration). On the first, lowest tier of the authorisation process, the data collected on exposure and ecotoxicity under realistic worst-case conditions as well as conservative model assumptions and/or increased safety factors are taken into account, reflecting the uncertainty of the data generated at this level. If the expected concentration is sufficiently below the threshold above which an effect can be expected when exposed on field sites, the risk can be deemed acceptable. If an unacceptable risk is determined at a lower tier, the applicant companies have the option of refining the investigations for risk assessment by carrying out tests under more realistic circumstances (higher tier assessment). Refinements can be made to the exposure assessment, e.g. through more sophisticated exposure modelling or considerations

20 EU (2009b).

21 Information on the risk assessment can be found here, for example: https://ec.europa.eu/food/plant/pesticides/approval_active_substances_en
https://ec.europa.eu/food/plant/pesticides/authorisation_of_ppp/application_procedure_en
https://www.bvl.bund.de/DE/04_Pflanzenschutzmittel/psm_faq.html

of the results of complex field studies, and/or to the impact estimation, e.g. through investigations of additional species or investigations into the effects on complex ecological communities in mesocosm[22] or field studies. In general, the more realistic the risk assessment, the lower the certainty factor to be applied, and thus the higher the exposure rated as acceptable. In such complex systems, indirect effects (adverse effects downstream) can emerge which are fundamentally undiscernible in studies performed on individual organisms.[23]

The detailed empirical data in the exposure assessment, i.e. particularly the metabolic pathways and degradation rates of the pesticides in soil and water, is collected in laboratory test procedures (standard data) and also in complex field studies (refined evaluation under natural conditions). The empirical data used in the impact estimation is gathered in studies designed to determine the acute and chronic toxicity on the non-target organisms to be protected (including, among others, birds, small mammals, honey bees and other terrestrial arthropods, earthworms, fish, aquatic invertebrates, terrestrial and aquatic plants). These studies are predominantly performed with “model organisms”, in other words, species which are easy to rear under laboratory conditions (e.g. the water flea *Daphnia magna*, tiger worm *Eisenia fetida*). Most of these test procedures are heavily standardised and defined in the guidelines laid down by the Organisation for Economic Co-operation and Development (OECD), which have proven successful in long-term comparison tests of laboratories around the world.

The differing sensitivities of different model organisms are a cause for concern:[24] For example, the certainty factor applied in the regulatory process does not compensate for the differing sensitivities of different species of earthworms. This also applies to aquatic test systems, at least in connection with neonicotinoids.[25]

Potential effects on human health, which will not be further ad-

22 Mesocosms are model systems spanning up to a cubic metre with environmental compartments such as soil columns or water/sediment systems, where the retention and effects of chemicals on the organisms living in the compartment can be investigated in the laboratory or under field conditions.

23 Halstead et al. (2014), Gessner & Tlili (2016).

24 Frampton et al. (2006).

25 Morrissey et al. (2015).

dressed in this paper, are tested on mammalian model organisms – often on rats – through experiments on metabolism, acute and chronic toxicity, irritation on the skin and eyes, impact on the genetic makeup and reproduction, as well as carcinogenic properties. Consumers, users and people who spend time as pedestrians or residents in close proximity to areas treated with pesticides are considered potentially exposed people.

1.4 Pesticide use

The prominent increase in pesticide use in agricultural production around the world over the past decades, despite stagnating use in some regions,[26] has come with an increased impact on the environment. In parallel to the growth in populations and global trade, the variety, production volumes and efficacy of pesticides have also increased.

Application methods

Pesticides predominantly reach arable crops and soil directly via application to the fields using spray nozzle technology and enter the atmosphere close to the ground through volatilisation. Pesticides can get into the surface water through drift, surface runoff and drainage, and into the groundwater through water seepage. These processes are influenced by the respective environmental conditions such as the climate and soil properties. Another widespread form of application is through seed dressing. Here, seeds are treated with a coating containing a pesticide (fungicide and/or insecticide) prior to sowing. After being sown, the active substances disseminate into the soil around the seed corn and are then taken up by the seedling and dispersed throughout the plant to ensure protection (in the case of systemic active substances).

Active substances and products

Around 280 *active substances* are currently approved for chemical plant protection in Germany.[27] The number of *formulations* (or *agents* or

26 Bernhardt et al. (2017).

27 BVL (2017).

products) is considerably larger than the number of active substances, which in addition to active substances mostly contain *co-formulants*, such as carriers or preservatives, which perform a variety of technical functions, for example improving the properties and effect of the active substances. The volume of pesticide active substances sold in Germany alone reached approximately 32,000 tons in 2016 (excluding inert gases used for storage protection); this quantity corresponds to around 110,000 tons of pesticide products and approximately one hundredth of the amount used worldwide. Although the current application rate of pesticides is considerably lower than it has been and sometimes is just a few grams applied per hectare, there is great potential for side effects to emerge in the environment as a result of increases in effectiveness together with unparalleled increases in the selectivity of modern pesticides. During the growing season, the repeated applications of single pesticides and spray sequences of different pesticides come to an average application rate of 2.8 kg of active substance per hectare per year in Germany. If the co-formulants are included in the calculation, it amounts to 8.8 kg per hectare of arable land per year.[28] Repeated applications have become standard: Fruit cultivation sites lead the way and are often sprayed up to 20 times or more per year.[29]

28 UBA (2016).

29 Roßberg & Harzer (2015).

2. Environmental consequences of intensive pesticide use

2.1 The situation in general

Diverse research groups have frequently demonstrated that the present use of pesticides has a significant adverse impact on ecosystems and biodiversity.[30] In terrestrial systems, herbicides reduce the diversity (the variety of species) and abundance (number of individuals in a given species) of flowering plants and there are also significant adverse effects for weeds on arable land. In conjunction with this loss of food resources, the insect diversity is also not only reduced in biotopes on the field boundaries,[31] but throughout the entire agricultural landscape. The vast reduction in biomass, micro habitat structures and food resources does not only affect insects but also consumers of insects such as small mammals and birds (the effects on the food web, see below).[32] In aquatic systems, insecticides change the structure,[33] biodiversity[34] and function of water communities.[35] The worldwide invertebrate population has fallen by approximately 45%, and similarly, the number of species has declined dramatically,[36] though other causes such as habitat loss also play a role. This discussion paper focuses on the environmental consequences of pesticide use. The effects on human health are not explored, although enormous costs are generated in Europe and the USA by the adverse effects of pesticide use on human health.[37]

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30 Sachverständigenrat für Umweltfragen (2016).

31 Roß-Nickoll et al. (2004), Ottermanns et al. (2010), Legrand et al. (2011), Schmitz et al. (2014), Hahn et al. (2015).

32 Hallmann et al. (2014), Goulson (2015), Rundlof et al. (2015), Woodcock et al. (2016), Hallmann et al. (2017), Vogel (2017).

33 Liess & von der Ohe (2005).

34 Beketov et al. (2013).

35 Schäfer et al. (2011), Schäfer et al. (2012).

36 Dirzo et al. (2014).

37 Grandjean & Bellanger (2017).

2.2 Examples of effects on organisms and ecological communities

Neonicotinoids: Weaknesses in the authorisation system

We illustrate different fundamental environmental problems using two active substance groups as examples. The example of *neonicotinoids* is used to demonstrate weaknesses in the pesticide authorisation system. This class of substances affects the nervous system of insects. The active substances bind to neural receptors and change micromorphological structures in the central nervous system of insects, thereby causing a long-term disruption to the transmission of stimuli which is fatal for the pests, but also for non-target organisms and beneficial organisms such as bees and bumblebees. In addition to its effectiveness, the systemic effect is the distinctive feature of this insecticide, which has been authorised since the mid 1990's with continuously increasing sales figures – according to statistical analyses, the quantities applied quadrupled from 2000 to 2014[38]. As already described, seeds are treated ("dressed") with neonicotinoids before being sown on arable land. This does not only offer the seed protection from pests, but the plant as well, as it absorbs the active substance after germination and transports it to other parts of the plant. The plant is then protected against insect damage over a longer period.

Alternatively, crops can be sprayed with the active substance. When sprayed, part of the water-soluble neonicotinoids is taken up by the plant and the remainder reaches the soil, and can then be carried by surface water runoff or wind into water bodies. It has now been proven that the use of neonicotinoids has long-lasting adverse effects on organisms such as honey bees and other insects.[39] Numerous studies have demonstrated that neonicotinoids affect the behaviour and communication of honey bees and wild bees, which perform a vital function in agriculture as pollinators. The resultant reduction in pollination does not only adversely affect agricultural yields, but also the wild plants pollinated by wild bees.[40] Other studies show a correlation between the

38 Milner & Boyd (2017).

39 EASAC (2015).

40 Biesmeijer et al. (2006), ipbes (2017).

quantity of pesticides used and the population decline of wild bees, butterflies, birds and aquatic organisms.[41] The contribution of pesticides – not only neonicotinoids – to species loss and the resultant negative impact on essential functions such as pollination has been widely acknowledged by scientists.[42] The EU has reacted to these reports and in 2013 it laid down restrictions on the use of three neonicotinoid active substances: clothianidin, imidacloprid and thiamethoxam. Consequently, the EU recently banned the use of several neonicotinoid insecticides everywhere except in greenhouses.

There is currently increasing evidence that the active substances of several neonicotinoids remain in the soil for long periods and are also absorbed by non-target plants. This means that their toxic effect inadvertently persists in the soil during green manuring, for example, as well as in flower strips or even in neighbouring areas of land.[43] This finding is extremely alarming and counteracts many attempts in nature conservation to counter the loss of biodiversity through the use of flower strips.

Glyphosate: Disturbances to food chains

The large-scale *broad-spectrum herbicide* glyphosate present in the product Roundup serves as a second example. It is actually degradable, but the reports on the speed of its degradation vary considerably from 3 to 500 days,[44] though smaller time spans of 2 to 53 days have also been reported[45]. The same applies to AMPA[46], the primary degradation product of glyphosate which has no effect as a pesticide (40 to 300 or 26 to 45 days). Glyphosate and AMPA, which are extremely soluble in water, were found to be in the surface water and groundwater in Germany and other countries in quantities exceeding the stipulated upper limit of 0.1 micrograms per litre, despite the fact that the standard leaching tests and modelling had not forecast a high leaching potential.[47] In an attempt to find an explanation,

41 Budge et al. (2015), Münze et al. (2017), Vogel (2017).

42 Liess et al. (2005), Geiger et al. (2010), Hallmann et al. (2014), Pisa et al. (2015), Vogel (2017).

43 Mogren & Lundgren (2016).

44 EFSA (2015).

45 Bento et al. (2016).

46 Aminomethylphosphonic acid

47 EFSA (2015).

some authors speculate that the abnormally high concentrations could be attributed to incorrect use by farmers, but the situation remains unclear.

From an ecotoxicological standpoint – based on tests using the standard model organisms – glyphosate and AMPA are often less critical than other herbicides. Nonetheless, the high level of glyphosate use around the world is problematic for a variety of reasons: Firstly, an increasing number of glyphosate-resistant weeds has been reported.[48] In addition, broad-spectrum herbicides such as glyphosate exterminate almost all wild plants growing on arable land. Since this deprives insects and vertebrates of part of their livelihood, such agents have a negative impact on biodiversity,[49] as has been shown for plants and animals.[50] This means that the disturbances to food chains caused by glyphosate are a problem for species in intensively farmed landscapes, as the density of the agricultural land leaves hardly any alternative feeding grounds. According to the German Federal Environmental Agency, pesticides containing glyphosate are applied at least once a year to approximately 40% of fields, and even up to 90% of rape fields. If the cultivation of energy crops such as rape and maize, which were heavily subsidised in the past years, continues to increase, further declines in diversity of plants, insects and vertebrates must be expected on agricultural land.

2.3 Pesticide accumulation in soil and water

Deficiencies in predictive models

Models are used to estimate the expected concentration of pesticides in the environment, taking into account the pesticide quantity and type applied, climatic parameters, the chemical and environmental properties as well as soil or water type. It has however been shown that such predictive models are in many cases erroneous.

48 Bonny (2011), Breckling & Verhoeven (2010).

49 Schütte et al. (2017).

50 Firbank et al. (2003), Heard et al. (2003a), Heard et al. (2003b), Squire et al. (2003), Bohan et al. (2005), Squire et al. (2009).

- *Pesticide residues in soils*

  Taking the example of neonicotinoids, it is evident that these are detected in the soil[51] for a longer period than was predicted in the studies used for authorisation. A recent monitoring study in Switzerland showed that of 80 selected pesticides applied along with others to 14 agricultural areas between 1995 and 2008, a large proportion (80%; half of which as transformation products) can still be detected in low concentrations in soil samples taken now – on average, 10 to 15 pesticides per agricultural field investigated.[52] This indicates that these substances remain in the soil for decades, although significantly shorter retention times, often in the range of weeks or months, were anticipated in the authorisation documents. A similar result has been observed with the herbicide atrazine, which is still present in soil over 20 years after being banned (to protect groundwater).[53] Numerous pesticides have also been detected in Portuguese, Spanish and Finnish soils long after their usage and much longer than the expected degradation half lives.[54]

- *Pesticide residues in water*

  Pesticide residues can also be found in water in higher concentrations than were predicted in the exposure assessments. For example, neonicotinoids are present in the groundwater[55] and bodies of water in concentrations which have ecological impact as a result of surface runoff and water treatment plants,[56] although this should have been ruled out in the authorisation. For lipophilic (fat-soluble) insecticides, it was shown that the standard models for prospective exposure assessment (so-called FOCUS scenarios) used in the EU needed to be replaced by models which factor in regional features such as location-specific climate data, so as to make improved predictions and guaran-

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51 Bonmatin et al. (2015).

52 Chiaia-Hernández et al. (2017).

53 Jablonowski et al. (2011).

54 Goncalves & Alpendurada (2005), Laitinen et al. (2006), Sanchez-Gonzalez et al. (2013), Masia et al. (2015).

55 Huseth & Groves (2014).

56 Münze et al. (2017).

tee better environmental protection.[57] Investigations showed[58] that across Europe, critical environmental quality standards for chemicals including pesticides are exceeded in water. This phenomenon has also been observed outside Europe.[59] The search criteria for analysing pesticides were expanded in a study in Switzerland, which then revealed over 100 different pesticides and numerous transformation products in rivers.[60] The positive effect of vegetated leave strips for reducing pesticide emissions, e.g. through surface runoff and spray drift, has often been described, which is why such measures should be increasingly introduced.[61]

- *Deficient measuring programmes*
  It is of fundamental importance that the monitoring programmes to determine the water pollution load of harmful substances, performed on behalf of the federal states of Germany as part of the European Water Framework Directive, are not even close to representatively recording the spectrum of active substances used in current agricultural practice. In most cases, the measurement parameters are based on just a few pesticides from the list of so-called priority substances. Only active substances which have exceeded the environmental quality standard in a measurement campaign are examined more frequently. This dissatisfactory situation is explored in a monitoring initiative by the German Federal Environmental Agency (Umwelt Bundesamt) within the scope of the National Action Plan for plant protection (NAP).

57 Knaebel et al. (2012), Stehle et al. (2013).

58 Malaj et al. (2014).

59 Stehle & Schulz (2015).

60 Moschet et al. (2014).

61 Bereswill et al. (2014), Weissteiner et al. (2014), Chen et al. (2016), Otto et al. (2016).

3. Deficiencies in the current pesticide authorisation process

Pesticide manufacturers are required to expound the expected environmental impact of their products as part of the authorisation process. There are however considerable differences between the expected and the actually observed impact on the environment.
In the following, we discuss the most important aspects that are neglected in the current assessment procedure for environmental risks from pesticide use that may explain this difference.

3.1 Exposure predictions and the persistence assessment of the persistence of chemicals in the environment are insufficient

In the case of many substances that were initially authorised but later prohibited, it was not only the toxicity that proved critical, but also their long-term retention (persistence) in the environment. The presence of a wide range of residues in soils and waters that were not predicted by the increasingly complex models clearly demonstrates that predictions based exclusively on models are not reliable. To further minimise the unforeseen effects of pesticides, the evaluation models underlying such predictions must undergo a validation, more strongly informed by real world conditions than has been the case until now. However, real-world conditions are extremely difficult to model in standardised procedures on account of the complexity described. A more comprehensive monitoring of pesticides after authorisation (post-authorisation phase) might provide the data required to validate the models. In addition to pollution of water bodies by spray drift, surface runoff and drainage, such a monitoring process should include the soil in the target areas (the arable land) and the nearby non-target areas (the leave strips, hedges, etc.), which play a vital role for biodiversity. To give an historical example: the active substance and degradation products of the herbicide atrazine can still be detected in groundwater, approximately 25 years after the ban on the herbicide in Germany. This shows a discrepancy between the several hundred days estimated as maximum time for the active substance to be metabolised to half of its original amount (the half-life), and real-world measurements. One reason is that the active substance can be stabilised in the soil matter or underlying rock for a long time, including in the form of so-called non-extractable residues,[62] and can then be gradually released. In locations with potential for seepage, and where larger amounts of the herbicide had been used, this stabilisation causes low quantities of the herbicide to continue to enter the groundwater.[63] Further examples of the phenomenon of pesticide stabilisation in soil are noted in the chapter “Pesticide accumulation” (2.3). Repeated contamination from atrazine-loaded agricultural imports can be another possible explanation for the presence of atrazine residues in at least some water bodies.

Assessment of environmental persistence of pesticides

Pesticide residues which can no longer be extracted from the soil are considered as degradation products in the assessment of environmental persistence. All chemicals create such residues in quantities varying from a few percent to over 90 percent of the amount used. Studies have shown that non-extractable residues are made up of different components; those sequestered in pores of the soil matrix are slowly released again, and may contain the parent compound and/or its degradation products. It is therefore necessary that these components be factored into the assessment of environmental persistence.[64]

Pesticides can degrade more slowly in the presence of other active substances than if occurring alone. For example, the half-life of the herbicide pendimethalin approximately doubles in the presence of the fungicide mancozeb compared with the degradation of pendimethalin alone.[65] To date, there are only a few examples of studies on the degradation under realistic conditions, for example, with a lack of nutrients,

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62 Kaestner et al. (2014).

63 Vonberg et al. (2014a), Vonberg et al. (2014b).

64 Kaestner et al. (2014).

65 Swarcewicz & Gregorczyk (2012).

at temperatures over or below the 20 degrees Celsius commonly used as a regulatory standard, or in the presence of other pesticides or other stressors (dryness, waterlogging, etc.).

Chemicals which were manufactured many decades ago and have since been prohibited can be released from their storage reservoirs, such as the soil or sediment, by climatic changes. This means that they are remobilised and therefore become detectable and potentially effective in the environment again.[66] The long-banned insecticide DDT is also an example of how contaminants can still be detected in the environment and continue to adversely affect the environment and human health even decades after its use. DDT can still be found in some soils and in the sediment layers of water bodies, although banned in Germany since 1972.[67]

3.2 Tank mixtures, sequential exposure and total loading are given inadequate attention

As part of its EU approval, the environmental risk assessment of a pesticide active substance basically constitutes the evaluation of a single substance. The evaluation is based on (eco)toxicological and environment-chemical information regarding the substance and a representative pesticide formulation for selected example applications. The approach to assessing individual substances deemed to be adequate in the EU active substance review programme has only limited relevance for the environmental risk assessment of pesticides in the national authorisation process. This is because a substantial proportion of the pesticide products under review contain more than one active substance, i.e. multiple active substances simultaneously. Mixtures of several products already represent – with a rising tendency – approximately one third of the pesticides approved in Germany. A key factor in the evaluation of the environmental impact is therefore the interaction between the active substances in the combination products including the other ingredients (co-formulants), i.e. the toxicity of the mixture expected to

66 Scheringer (2017).

67 Neitsch et al. (2016).

occur in the environment after it is applied. Accordingly, the European environmental risk assessment guidance for pesticides includes instructions for the consideration of combination effects and for the assessment of the environmental risk posed by combination drugs. Frische et al. (2014) provide an overview of the facts.[68]

However, the common agricultural application practice is not explicitly considered in the current assessment: On the one hand, the simultaneous use of several pesticides in the form of tank mixtures made by the farmer in the spray tank prior to application is not accounted for. On the other hand, the sequential use of different pesticides and/or tank mixtures over the spraying season (known as spray sequences). Clearly, the risk assessment ignores these issues. One exception to this are currently the tank mixtures that are explicitly prescribed or recommended by the manufacturer, which have to undergo an environmental risk assessment.[69]

In many cases, sequential contaminations have an increased effect if the organisms have not fully recovered from previous damage (see chapter 3.4).[70] Also, on the level of ecological communities (organisms from different species in a defined habitat), the effects of sequential contamination can culminate if the recovery of a population is slowed by competition for food and habitats with more tolerant species.[71]

Overall, the question arises of whether, and to what extent, the current regulatory tests correctly depict the environmental risk of pesticide use and whether the risk management measures derived from the tests actually guarantee the level of protection aspired in legislation.

68 Frische et al. (2014).

69 BVL (2015).

70 Ashauer et al. (2007).

71 Liess et al. (2013).

3.3 Shortcomings in the assessment of direct effects

Pesticide use in agricultural settings inevitably leads to substances ending up in non-target ecosystems such as forests, hedges, fields, field margins and water bodies. For this reason, the potential effects in non-target ecosystems are estimated during the authorisation process and if required, rules, limitations or even bans on application are prescribed to reduce the risks to an acceptable level. In past decades, it has become clear that these risk assessments were not always suitable for predicting the unintended direct effects on non-target organisms.

Overlooked groups of organisms

Potentially endangered organism groups such as wild pollinators and amphibians are still not given sufficient attention in effect estimations. An example is the abovementioned group of substances, namely neonicotinoids, where honey bees were exclusively used as test organisms in the authorisation process. Moreover, sublethal (non-fatal) effects on, for example, reproduction, food procurement behaviour and orientation capabilities were hardly considered. Field studies with realistic exposure scenarios found strong effects, such as the collapse of bumblebee and wild bee colonies, whereas effects on the larger honey bee colonies were not detectable.[72] Similarly, amphibians are hardly considered in the risk assessment, despite some high mortality rates were found in response to direct spraying at regular doses of authorised pesticides.[73] Amphibians presumably come into contact with pesticide residues in agricultural landscapes during their terrestrial life stages outside the spawning period, which in addition to other factors, may contributed to the global decline of amphibians.

Underestimation of the risks

The risks faced by certain groups of organisms are inadequately estimated, for example for stream organisms. Using the indicator system SPEAR, field studies were able to show that the effects of pesticides, at concentrations classified as safe in the authorisation process, are de-

72 Rundlof et al. (2015).

73 Brühl et al. (2013).

tectable in numerous natural landscapes, even at very low concentrations[74]. Such underestimations can lead to the loss of biodiversity on a landscape scale[75] and impair ecosystem functions.[76] The cause of these deficient risk estimations can be attributed to a lack of consideration of indirect effects and additional stressors described below.

3.4 Indirect effects insufficiently considered

Indirect effects of pesticides are caused by interactions between animal and plant organism groups in ecosystems, e.g. through competition, symbiosis or food webs.[77] The effects can be reinforced or propagated on the scale of populations and communities (see below). The recovery of populations after exposure to stress – an important criterion in the pesticide authorisation process – can take longer times under realistic conditions than assumed in the authorisation process. Already minor, statistically not detectable disturbances caused by pesticides can be intensified through the competition with more tolerant species for food and living space. If such events occur annually, these minimal effects can culminate, and in turn lead to the local extinction of a population.[78] Furthermore, impacts can emerge in later generations for the first time, or to a greater degree.[79]

The effects of pesticides can propagate at the community level. If, for example, herbicides – most notably broad-spectrum herbicides such as glyphosate – reduce plant biomass, the number of consumers, which are dependent on the plant population, will also decline due to the decreased availability of food. These indirect effects on the food chain are yet to be adequately considered in the regulatory authorisation process. The regulatory authorisation process focuses on individual populations without any reference to their role in the food chain. Moreover, from a

74 Liess & von der Ohe (2005), Schäfer et al. (2012).

75 Beketov et al. (2013).

76 Liess et al. (2008).

77 Halstead et al. (2014), Gessner & Tlili (2016).

78 Liess et al. (2013).

79 Campiche et al. (2007), van Gestel et al. (2017).

regulatory perspective, the effects of pesticides can be acceptable if the effects are not classified as negative, or the population recovers from initial direct effects within a certain timeframe. Temporary disturbance or reduction in a population can also have strong effects on the consumers of that population. In recent years, for example, the population decline of common bird species in the agricultural landscape[80,81] has been attributed to the use of pesticides and the indirect effects on the food web as described. Occasionally, this has even been attributed to individual active substances, as shown in the example of the neonicotinoid active substance imidacloprid.

On a population and community level, the effects described can result in gradual changes in the entire ecosystem.

3.5 Hardly considered to date: The impact of multiple stressors

In the real-world, active substances occur together with a range of other substances, e.g. other active substances (see chapter 3.2) that accumulate in soils, or other chemicals in water bodies, introduced via sewage effluents and incomplete removal during wastewater treatment. Interactions with natural and anthropogenic stressors also occur. Ecosystems have to compensate for anthropogenic stressors, such as restricted crop rotations and excessive nutrient inputs, but also natural stressors such as dry periods. The approval of pesticides and other chemicals tends to ignore the potential impact of such additional stressors.

Temperature increases associated with climate change, which is already impacting ecosystems, will likely increase pesticide use as plant diseases thrive in warmer conditions and spread more easily.[82] Organisms can also become more sensitive to chemicals at higher temperatures.[83] Climate change is associated with more frequent extreme weather events. Periods of drought, during which the degradation

80 Sudfeldt et al. (2013).

81 Hallmann et al. (2014), Jahn et al. (2014), Hallmann et al. (2017).

82 Kattwinkel et al. (2011).

83 Patra et al. (2015).

of chemicals by microorganism may be slowed,[84] will be followed by more intense rainfall, which will increase the surface runoff.[85] This is expected to lead to increased water contamination from pesticides. In general, natural stressors make organisms more sensitive to pesticides and other chemicals. A meta-analysis has shown that the presence of other abiotic stressors such as a lack of oxygen or biotic stressors such as competition with other species increases populations' sensitivity by a factor of between 10 and 100.[86,87] Other anthropogenic activities in addition to pesticide use also act as stressors, for example soil compaction by agricultural vehicles, and have long-term consequences for the organisms that live there.[88] The effects of multiple stressors can reinforce each other – and compensating for each stressor incurs certain energetic costs for the ecosystems, apparent, for example, through increased respiration and therefore increased carbon dioxide emissions from the soil, which have consequences for the climate.[89] Similar interactive effects have also been identified in freshwater ecosystems.[90]

3.6 Social and political aspects

The question of the most environmentally sustainable use of pesticides is complex[91] when accounting for multiple criteria such as short-term risk, long-term effects of resistances, internal and external labour costs. In addition, an economic assessment of the alternatives for crop protection is required (e.g. crop rotations, mechanical tillage, fallow periods). Although the trade-off between the various criteria differs greatly from farmer to farmer, it is clear that pesticide use is often seen as the first choice as it has a direct benefit and is easy to use, cost effective and well-suited to "modern" agriculture. In addition, lobbying likely has a

84 Geng et al. (2015).
85 Gagnon et al. (2016).
86 Koehler & Triebskorn (2013).
87 Liess et al. (2016).
88 Schaeffer et al. (2016).
89 Filser et al. (1995).
90 Alexander et al. (2016), Gardeström et al. (2016).
91 Sexton et al. (2007).

massive influence over both political decision makers and regulators of pesticide use.[92] Early warning signs of pesticide contamination from independent research were either considered too late or not at all, despite the fact that in 2013, the European Environment Agency synthesised studies on numerous environmentally dangerous substances and processes to show that these warnings were overwhelmingly justified.[93]

Range, production and use of pesticides are increasing (worldwide) and stagnating at a high level (Germany)

The range and production volumes of pesticides and many other synthetic chemicals has dramatically increased around the world over the last 50 years,[94] while in Germany, the sales volume of the pesticides used on field sites has remained more or less constant since 1990.[95] Compared with the rest of Europe, the sales volume in Germany is the fourth highest after Spain, France and Italy. In relation to agricultural land, i.e. the quantity of pesticide applied per hectare, Germany ranks eighth among the 28 EU member states.[96] This is associated with soil, water and air pollution[97] as well as occasional cases of food contamination.[98] A representative survey carried out by the German Federal Environment Agency in 2016[99] shows that the population responds with increasing concern.

Gaps in research

The ever more detailed understanding of the retention and effects of pesticides and other chemicals in the environment has taken centre stage in research, pushing identification of the overarching relationships into the background. Predictions for the exposure and impact in a wider spatiotemporal context, i.e. considerations at landscape level

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92 UNHRC (2017).

93 EEA (2013).

94 Bernhardt et al. (2017).

95 UBA (2017)

96 Eurostat (2014)

97 Scheringer (2017).

98 Bai & Ogbourne (2016), Dervilly-Pinel et al. (2017), Glorennec et al. (2017).

99 https://www.umweltbundesamt.de/sites/default/files/medien/376/publikationen/umweltbewusstsein_deutschland_2016_bf.pdf

and over longer periods of time, have consequently been neglected. A lack of overarching concepts also has an effect on the social response to pesticides and the link between scientific knowledge and societal options for action. This highlights the particular need for social scientific approaches, such as those utilised to some extent in studies of farmer behaviour and their estimations of short-term advantages of pesticide use and its long-term costs as well as alternatives.

Deficiencies in risk assessment

Why were early indications of the persistence of some neonicotinoids overlooked, although they were recognised prior to authorisation?[100] The early risk assessments of neonicotinoids (and of pesticides in general) fail to sufficiently consider the presence of residues in pollen and in the so-called guttation drops (dew drops) which plants exude,[101] as well as sublethal (non-fatal) effects such as the disturbance of the orientation capability of bees[102]. What changes would have to be made to the risk assessment in order to avoid environmental consequences such as those caused by neonicotinoids in the future?

100 Goulson (2013).

101 Bonmatin et al. (2015), Reetz et al. (2016).

102 Klein et al. (2017), Stanley et al. (2016).

4. Recommendations for action

In sections 2 and 3, manifest adverse environmental consequences caused by the intensive use of pesticides were described and their predominant causes were identified. They can be attributed to deficiencies in the risk assessment performed in the authorisation process, to the absence of any systematic gathering of knowledge of risk in the post-authorisation phases, as well as to continuous inappropriate application of plant protection products. In the following, recommendations for action are given for the three starting points mentioned above, as well as indications of the areas where further research is needed.

4.1 Recommendations for an improved risk assessment in the authorisation process

The purpose of pesticide risk assessment is to prospectively, that is, prior to authorisation and hence usage, estimate the risk posed by active substances and products for humans and the environment. In the absence of practical experience with newly developed active substances and formulations, the risk assessment uses model assumptions regarding the effect of an active substance on the resources to be conserved under the plant protection legislation. The model assumptions are based on findings for certain indicator species that were acquired on a laboratory scale and on occasion also on a mesocosm scale (mesocosm, see chapter 1.3). Uncertainties are taken into account with the help of uncertainty factors that differ according to the degree of uncertainty.

The research results referred to in section 2 show that the present risk assessment is often incapable of realistically representing pesticide residues in the environment and the effects on non-target organisms as well as other resources to be protected, for example, soil or water. This can be partly attributed to insufficient criteria in the risk assessment. For the detection of so-called "combinatorial effects", for example, the risk assessment is not geared towards the common agricultural usage (tank mixtures and spray sequences, see chapter 3.2), but – in this respect, unrealistically – towards the intended usage of the single pesticide for which authorisation has been requested. As already explained, indirect effects and multiple stressors are not taken into account in the evaluation process.

The examples reveal that the risk assessment requires a revision which gives greater consideration to the scientific findings concerning the actual substance characteristics and (side) effects of pesticides obtained in the recent years. Until such a revision process has been carried out, the safety margins (or: uncertainty factors) should be increased considerably for the evaluation of new active substances and products. In addition, there should be a review of the decision to authorise active substances and products in cases where inconsistencies have emerged between the actual findings and those used in the risk assessment. If the discrepancy is particularly significant, a temporary suspension of the authorisation is also recommended if appropriate substitutes are available.

4.2 Recommendations for the further development of systematic generation of risk knowledge in the post-authorisation phase

The decision to authorise newly developed active substances and products is invariably made under uncertainty. Therefore, a systematic chemical and biological monitoring in the post-authorisation phase is needed in order to compare the modelling results and estimations of the prospective risk assessment with the empirical findings under realistic practical conditions.

Introduction of a suitable measuring system (monitoring)

The post-authorisation phase is an integral part of safety legislation in other areas of hazardous substances legislation, such as authorisation for pharmaceutical products. However, pesticide authorisation can only partially draw on the experiences gained from authorisation for pharmaceutical products, as in the latter case the observation system is based on the observant physician passing on patient reports of side effects to the notification system. In contrast, for pesticide use, the observant farmer is predominantly helpful for reports regarding the effective protection of crops and the health of the user, but not regarding the protection of non-target organisms and other environmental resources. For this reason, there is a need for a suitable measuring system (monitoring) in the post-authorisation phase in order to be able to pick up on any unexpected effects. A monitoring system of this kind could be operated by the authorities responsible in conjunction with the federal states. A pan-European division of work according to the various forms of pesticide usage in the EU member states is also worth considering. The costs for maintaining such a monitoring system could be covered by an increase in the application fees for authorising a pesticide. A pesticide tax borne by the users would be another option (see chapter 4.3).

Advantages of a monitoring system

Setting up and running such as monitoring system would on the one hand guarantee that more knowledge about pesticide risks is systematically acquired, particularly regarding recently authorised pesticides, where the authorisation decision can then be reviewed in the case of significant findings. Curtailing the initial authorisation period of active substances to a few years to make it clear that the initial authorisation period serves the continued development of risk knowledge in particular would also pave the way for the revision. However, it would have to be clearly defined what level of certainty with regard to the justifiability of the environmental impact must be achieved in a prospective risk assessment before it is appropriate to issue an initial authorisation with subsequent post-authorisation monitoring. This is because authorisation as a large-scale outdoor trial is not acceptable on ethical grounds. A further advantage of systematic post-authorisation monitoring would be the continuous gathering of knowledge about the fundamental suitability of current evaluation models and concepts for meeting the aspired conservation objectives – a sort of “calibration”, that is, a review of their ability to provide protection.[103]

103 Vijver et al. (2017).

4.3 Recommendations for an improved use of plant protection products

The environmental safety of pesticide use is not only dependent on the improvement of the risk assessment and post-authorisation controls, it is also highly dependent on the concrete usage by farmers.

Training and further education for farmers

Training and further education for farmers is a key consideration in this context. The curriculum of the so-called Certificate of Competence for the purchase and application of pesticides does not adequately impart the fundamental ecological and ecotoxicological knowledge required for the most environmentally sustainable use of pesticides to farmers. The educational documents must be revised so that pesticide users are better equipped to judge the instructions on the package leaflet and avoid instances of accidental misuse. Training at agricultural colleges and universities should also include a critical discourse on the brochures from pesticide manufacturers.

Introduction of pesticide taxes and incentives

As the use of pesticides poses particular control problems, it seems sensible to use incentives in order to work towards an environmentally sound use of pesticides. One potential incentive could be to levy a pesticide fee or pesticide tax on people placing pesticides on the market such as traders, manufacturers and importers. A tax of this kind could be used to finance conservation measures and research into alternative plant protection concepts, and to create an economic incentive to reduce the use of plant protection products. Other countries such as Denmark have had positive experiences with similar measures,[104] such that the introduction of incentives should also be considered in Germany (see also a concrete suggestion from the field of environmental legislation[105]). However, some pesticides have become so cheap that the requirement to pay a tax may only have a minimal impact on the decision to use the pesticides.

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104 Hommel & Deike (2009).

105 Möckel et al. (2015).

Specific incentive schemes

In addition to this, specific incentive schemes would have to be put in place. The existing agricultural policy continues to make a substantial contribution to disincentives through its focus on intensive farming.[106] One option to counter this could be to contact collectives such as farmers associations in catchment areas and through them, set up farmer field schools for example, and remunerate them for offering training.[107]

At EU level, a Common Agricultural Policy reform (CAP reform) is planned for 2020 which should encourage a paradigm shift in European agricultural policy in line with the EU's environmental and conservation objectives. The aim must be that agricultural businesses receive subsidies if they take concrete measures to protect the environment. These efforts would have to go considerably beyond the statutory minimum standards currently in force, thereby providing added value for society. Regarding the use of pesticides, the farmers' efforts rewarded by society should – in the spirit of policy coherence – fulfil the objectives of the EC directive on sustainable use of pesticides (see chapter 1.2). At the same time, sufficiently high subsidy rates must guarantee that these measures are actually economically viable for the agricultural businesses.

Collective responsibility

We agree with the critical agricultural report published in 2010 which declares: "One-sided allocations of responsibility to the farmers, evoking a defensive reaction from the profession, do not constitute a solution: farmers' plant protection strategies are not only determined by economic and agrarian political conditions, but are influenced by many stakeholders. Expert systems from 'traditional agricultural science' influence decisions in agricultural businesses via university-educated consultants and long-established information dissemination pathways. Perspectives must be widened to include all the players involved, in order to develop possible solutions for the common goal of 'reduced pesticide usage'. There must be greater promotion of joint learning and implementation processes, in which everyone involved can contribute

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106 Sutherland et al. (2010).

107 Van den Berg & Jiggins (2007), Schneider et al. (2009).

their knowledge and competencies."[108] This also applies to alternatives such as mechanical weed control, changes to routines or conservation tillage.

4.4 Recommendations for the administrative process and research

Beyond authorisation, observation in the post-authorisation phase and pesticide use, action is also required in the area of administration and research. The next section summarises a number of suggestions for solutions and also related research needs to ensure a sustainable use of pesticides.

I) *Transparency of collected environmental data*: The results of the extensive environmental investigations performed during the authorisation process are stored in the databases of pesticide manufacturers. The majority of the investigations must be reported to the responsible authorities upon request. Such data ought to be disclosed for use in research into the assessment of environmental risk, but it is currently protected as confidential information. Even data from incomplete or abandoned tests which are not required to be reported could be of interest for research. A high level of transparency could be created by requiring all future environmental investigations into pesticides to be registered with the authorities before they are actually conducted.

II) *Risk management at the landscape level*: Substance residues in the surface water and natural habitats adjacent to the treatment area should be decreased through the consistent provision of vegetated leave strips and buffer strips – as designated in the National Action Plans for plant protection (NAP). Moreover, additional measures for improving ecological value are necessary for cleared, intensive agricultural landscapes (creation of "ecological infrastructure" such as hedges, dry stone walls, flower strips or extensive pesticide-free cultivation). Such measures make it possible to offset and curtail the

108 Jürgens & Fink-Keßler (2010).

unavoidable direct and indirect effects of pesticides on biodiversity in the agricultural landscape.[109]

III) *More monitoring programmes*: The monitoring programmes discussed in 4.2 must be introduced in greater frequency in order to gain an understanding of pesticide contamination in water and soil[110] and therefore to retrospectively review the validity of the models used to estimate pesticide exposure. For soil, this has only been performed very rarely within individual research projects.[111] The various actors involved should play a part in the monitoring, e.g. the manufacturer could participate in its financing.

IV) *Reduction in the use of pesticides – exploring possibilities and limits*: The 5-point programme published by the German Environment Agency (UBA)[112] calls, inter alia, for a reduction in the use of pesticides. On the other hand, this is contrasted by concerns of manufacturers and users that it will then become impossible to provide effective protection for arable crops. A study of 150 wheat fields in western France however has shown that herbicide use could be decreased by 50% without considerable consequences for the yield, while simultaneously having a favourable impact on the biodiversity of wild plants.[113] There is a substantial need for research to substantiate such studies and extend them to other active substances and agricultural landscapes.

V) *Increased focus on sublethal and indirect effects*: The described case studies of neonicotinoids and glyphosate showed that the present regulatory practice of prospective hazard assessment is not sufficiently grounded in ecology. For example, possible effects of pesticides on the behaviour of animals are not covered by the tiered authorisation process. Under real-world conditions, the processes involved are

109 UBA (2015).

110 Milner & Boyd (2017).

111 Chiaia-Hernández et al. (2017).

112 UBA (2016).

113 Gaba et al. (2016).

complex, which is why indirect effects must be factored into a risk estimation, at least conceptionally[114] or via more detailed scenario modelling[115].

VI) *Expanding the species spectrum*: There should be investigations into the impact of pesticides on previously neglected groups of species, for example amphibians, reptiles and selected insect groups, including those which are important as wild pollinators.

VII) *Investigating substance mixtures*: The ecotoxicity and environmental behaviour of substance mixtures in the environment (tank mixtures, spray sequences) must be examined in greater detail and appropriately included in the environmental audit.

VIII) *Influence of natural and anthropogenic stressors*: The influence of stressors such as temperature, precipitation/dryness, soil compaction and acidification, competition from less sensitive species should be factored into investigations exploring the impact of pesticides. It is clear that not all combinations of stressors can be covered and the complexity of the ecological reality cannot be conclusively modelled in the prospective risk assessment, so uncertainty factors will continue to be necessary when projecting the model results onto reality, even if data availability is significantly improved. The question here is how large the uncertainty factors should be in light of the many stressors. Retrospective observations are necessary to create a more solid scientific basis, i.e. monitoring data for substances which have already been brought onto the market, which can be used to "calibrate" or validate model approaches. Projects from the German Environment Agency are already in place to lay the foundations for a scientifically sound monitoring of the contamination and the ecological impact of pesticides in aquatic environments.

IX) *Studies in model catchment areas*: A meaningful extension to environmental studies would be to initially authorise the limited use of

114 Gessner & Tlili (2016), McKee & Filser (2016).

115 Filser et al. (2013), Wigger et al. (2015).

new substances in model catchment areas and to use this as a basis to gather more realistic data on the exposure and impact. The infrastructure for this exists in Germany, e.g. in the form of demonstration farms for integrated plant protection. An integration of existing institutional activities in environmental monitoring would enable this to be implemented without a significant increase to the resources required. This way, for example, studies into pesticide seepage “on the field” could be planned in collaboration with farmers and performed under agriculturally relevant conditions.

X) *Introduction of a tiered authorisation process*: Similarly, a modified, tiered authorisation process should be evaluated in model applications. One option would be to issue authorisation at an early stage but with strict limitations on the time span of the authorisation and cultivation area it may be applied to, accompanied by monitoring under field conditions. If no negative effects are observed after a certain period, the monitoring can be reduced and the authorisation be extended to other areas, and ultimately issued for long-term use over larger areas. Significant economic advantages could emerge, for the manufacturer at the very minimum, at comparatively low environmental risk, as products can be placed on the market earlier and the extent of costly prior testing processes might be reduced. The costs of the monitoring should be borne by the applicant who wants to market the product. The established post-authorisation phase for pharmaceuticals (known as post-market surveillance, pharmacovigilance) should also be systematically put in place for pesticides (pesticidovigilance), so that data on environmental factors and monitoring data are collected over a longer time frame after the introduction of a product.[116]

XI) *Interdisciplinary and transdisciplinary research*: There is a lack of consistent interdisciplinary and transdisciplinary research between natural scientists, social scientists and actors in politics, authorities, economics and public affairs for developing sustainable approaches to handling pesticides.

116 Milner & Boyd (2017).

5. Conclusion

The established agricultural plant protection practice has reached a turning point where important ecosystem functions and livelihoods are under serious threat.[117] Existing solutions have reached their limits and there is an urgent need to take action: this paper has outlined suggestions for ways to proceed. The critical scrutiny of long-accepted dogmata and practices as well as an interdisciplinary strategy are imperative for this.

On the whole, the manifold environmental effects of pesticides must be considered and dealt with within the wider framework of the European agricultural and chemical policies, where a fundamental rethink is required in both areas. Global aspects must also be taken into consideration, e.g. the vast quantities of imported soya animal feed whose production does not comply with local regulations and can bring in unknown quantities of problematic pesticides which are banned in Germany. Intensive, conventional agriculture cannot continue in its current form for a plethora of reasons; its adverse effects on the environment (e.g. nitrate contamination of groundwater, habitat loss for birds and insects, soil compaction, loss of biodiversity including the diversity of fruit plants) are too high, and yet the economic returns are too low for many farmers. The problem of pesticides must be seen as an important part of these systemic issues and their solutions.

The problem of industrial chemicals is similar, but extends beyond the problem of pesticides. The assessment procedures for industrial chemicals require – despite the introduction of REACH[118] – a fundamental rethinking. The key point here is that pesticides have to be viewed

117 Sánchez-Bayo & Tennekes (2017).

118 REACH is a regulation from the European Union which aims to improve the protection of human health and the environment from risks which could arise from the use of chemicals, and simultaneously enhance the competitiveness of the EU chemicals industry. Furthermore, it promotes alternative methods for identifying harmful effects of substances to reduce the number of trials performed on animals.

in conjunction with the presence of many other substances which humans and the environment are exposed to (pharmaceuticals, biocides, fertilisers, industrial chemicals). The combined effects of multiple substances that have a simultaneous or successive effect on an organism, such as in the cases of tank mixtures or through sequential applications (spray sequences) of pesticides, are systematically neglected in the risk assessment. This gives rise to a systematic underestimation of the risks posed by chemicals.

We firmly believe that the findings presented here on the adverse effects of pesticides must be considered crucial for the authorisation process and the use of pesticides, and that continued scientific observation of the effects of pesticides must be effectively introduced into the monitoring system. This means that the monitoring system must consistently contribute to a greater understanding of risk.

It should be in everyone's interest to develop crop cultivation and plant protection strategies which guarantee sufficient yields in the long term without permanently damaging the environment. The fundamental basics for this are ensured by, among other measures, a consistent, integrated and ecological cultivation of plants – i.e. pesticide usage as a last resort, a selection of crops and varieties suited to site conditions, the cultivation of species which are competitive and resistant to pests, and the most moderate use possible of the most specific, least persistent agrochemicals. To this end, we firmly advocate a participatory approach in conjunction with all parties involved. Broadly accepted societal values should form the basis of negotiations, particularly the provision of clean drinking water in the long term, food security and a diverse, species-rich and aesthetically pleasing environment.

All in all, we stand by the conviction that it would be completely inadequate to approach the question of pesticides with ad-hoc, selective measures. Pesticide usage is inextricably linked to multiple other factors and is therefore more difficult to deal with and solve than an isolated issue. We must therefore view the problem of pesticides as a systemic problem and treat it accordingly. If not, it will further exacerbate trends such as insect decline, extinction of bird species, groundwater and soil contamination by pesticide residues etc. Alongside specific and local measures, it is vital that new perspectives be found in the European agricultural and chemical policies.

6. Appendix

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Speaker: Prof. Dr. Detlev Drenckhahn (member of the Leopoldina).

ML = Mitglied der Leopoldina

6.2 Workshop programme

Environmental risk assessment of chemicals

23 – 24 March 2017

Venue:

National Academy of Sciences Leopoldina, Halle

23 March 2017

Welcome and introduction to the event

Andreas Schäffer

The impact of chemicals on the environment: What do we know?

Effects of plant protection products on freshwater ecosystems

Ralf B. Schäfer

Effects of plant protection products on terrestrial ecosystems

Juliane Filser

Mechanistic effect analysis as a basis for predicting the effects of pesticides on aquatic communities in the landscape

Matthias Liess

Effects, interactions and pathways of environmental chemicals in the environment

Rolf Altenburger

Prospective environmental risk assessment of plant protection products in the European authorisation process – a (self-)critical analysis

Tobias Frische

24 March 2017

Regulation on the modernisation of Swiss water treatment plants for the removal of micropollutants

Janet Hering

Exposure assessments

Bernd Stein

Closing discussion

Moderation: Andreas Schäffer

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