Impact Assessment Framework with Specific Protection Goals (SPGs) for Non-Target Terrestrial Plants (NTTPs)

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Impact Assessment Framework with Specific Protection Goals (SPGs) for Non-Target Terrestrial Plants (NTTPs)

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This study was carried out by Wageningen University & Research and Ramboll UK Ltd and financed by the European Crop Protection Association

Wageningen University & Research
Wageningen, October 2020

REPORT
2020-074
ISBN 978-94-6395-583-6

Bright ideas. Sustainable change.

Johan Bremmer, Samantha Deacon, Lara Alvarez, Gertie Arts, Hilfred Huiting, Bert Smit, 2020. *Impact Assessment Framework with Specific Protection Goals (SPGs) for Non-Target Terrestrial Plants (NTTPs).* Wageningen, Wageningen University & Research, Report 2020-074. 76 pp.; 7 fig.; 9 tab.; 25 ref.

In dit rapport stellen we een voorlopig effectbeoordelingskader (IA) voor, dat kan worden toegepast op de regulering van gewasbeschermingsmiddelen (PPP's) en voldoet aan de eisen van de Better Regulation Guidelines. Kaderontwikkeling was gericht op het gebruik van gewasbeschermingsmiddelen voor onkruidbestrijding en de bescherming van niet-doelsoorten terrestrische planten (NTTP's). Vier onkruidbestrijdingsscenario's werden beschreven als casestudy's, waaronder (I) een referentiescenario met de nadruk op chemische onkruidbestrijding, (II) een scenario met focus op bescherming van NTTP's, in het perceel (III) een scenario gericht op bescherming van NTTP's buiten het perceel, en (IV) een scenario met volledige bescherming van ecosysteemdiensten. Zes ecosysteemdiensten werden geëvalueerd: voedselproductie (voedsel en grondstoffen), wildvoeder, watervoorziening (grondwater en oppervlaktewater), erosiepreventie en instandhouding van bodemvruchtbaarheid en leefgebied voor soorten. Het kader en de specifieke beschermdoelen zijn getest aan de hand van zes casestudies die een reeks gewassen en EU-lidstaten vertegenwoordigen.

In this report we propose a preliminary Impact Assessment (IA) Framework that may be applied to the regulation of plant protection products (PPPs) and that fulfils the requirements of the Better Regulation Guidelines. Framework development focused on the use of PPPs for weed control and the protection of non-target terrestrial plants (NTTPs). Four weed control scenarios were described as case studies including (I) a reference scenario with emphasis on herbicidal weed control, (II) a scenario with focus on in-field protection of NTTPs, (III) a scenario oriented at off-field protection of NTTPs, and (IV) a scenario with full protection of ecosystem services. Six ecosystem services were evaluated: Crop provision (food and raw materials), wild foods, fresh groundwater, fresh surface water, erosion prevention and maintenance of soil fertility and habitat for species. The framework and Specific Protection Goals (SPGs) were tested using six case studies representing a range of crops and EU Member States.

Key words: Ecosystem services, impact assessment, sustainability, crop protection, weed control, plant protection products

This report can be downloaded for free at https://doi.org/10.18174/532843 or at www.wur.eu/economic-research (under Wageningen Economic Research publications).

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Wageningen Economic Research Report 2020-074 | Project code 228200408

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Preface

Sustainable crop production is increasingly the focus of European policy, such as the recent Farm to Fork Strategy at the heart of the European Green Deal aiming to make food systems fair, healthy and environmentally-friendly. In addition, existing environmental legislation influences the way crops are produced, such as the use of no-spray zones adjacent to surface water bodies for their protection under the Water Framework Directive. In order to meet policy requirements, a balance needs to be struck between the secure and commercially-viable provision of high-yielding crops for food, fodder, fibre, biofuels and raw materials, and protection of the environment. Many factors influence sustainable farming, not least pest and weed control, in which plant protection products (PPP) play an important role.

The European Commission (EC) is modernising legislation by application of Better Regulation Guidelines. This matches with the need to update the legislation regulating the sale and use of PPP and, for example, to bring their authorisation process in line with the socio-economic impact assessment of industrial chemicals in Registration, Evaluation, Authorisation & restriction of Chemicals (REACH) regulation. In this context the EC invited the European Crop Protection Association (ECPA) to participate in a consultation process and requested manufacturers to develop an Impact Assessment Framework, compliant with the Better Regulation Guidelines of the European Commission. In these guidelines environmental and socio-economic impacts are simultaneously addressed in a balanced way to protect non-target organisms and to safeguard the competitiveness of European agriculture.

The development of the Framework has been executed by a consortium of Wageningen Research and Ramboll with support from RPA Ltd, and experts in research institutes located in the case study countries. The research team wants to thank Zbigniew Anyszka (Inhort, Poland), Richard Hull (Rothamsted Research, UK), Anneli Lundkvist (SLU, Sweden), Donato Loddo (CNR-IPSP, Italy), Gino Angeli (Fondazione Edmund Mach, Italy) and Ludovic Bonin (Arvalis, France) for executing the case studies. Furthermore, we thank Teresa Fenn and Rocio Salado from RPA, Justus Wesseler, Silke Gabbert and Bert Lotz from Wageningen UR for reviewing the results. We thank the representatives of ECPA and their members who have guided the project and commented on the output of this study. Finally, we want to thank Virginie Ducrot from ECPA for the open and involved manner in which she supervised this project.

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Summary

The European Crop Protection Association (ECPA) was invited by the European Commission to participate in the consultation process for defining specific protection goals (SPGs) for cropped areas and adjacent marginal habitats using an ecosystem services approach. ECPA, therefore, initiated the development of an Impact Assessment Framework, compliant with the Better Regulation Guidelines of the European Commission. In these guidelines environmental and socio-economic impacts are simultaneously addressed in a balanced way to assess trade-offs between services underpinned by the cropped habitat and non-target organisms and to safeguard the competitiveness of European agriculture.

In this report we propose a preliminary Impact Assessment (IA) Framework that may be applied to the regulation of plant protection products (PPPs) and that fulfils the requirements of the Better Regulation Guidelines. Framework development focussed on the use of PPPs for weed control and the protection of non-target terrestrial plants (NTTPs). The framework is based on The Economics of Ecosystems and Biodiversity (TEEB) approach. This provides an ecosystem cascade of biophysical structures or processes, functions, services, benefits and values to facilitate the analysis of trade-offs implied by environmental management strategies. TEEB definitions for each ecosystem service (each linked to a specific protection goal) were used as the starting point for this IA Framework; however, each description was adapted to focus on NTTPs for assessment. The framework follows a step-wise process, as follows:

- define each crop scenario and develop a conceptual model (CM);
- identify ecosystem services relevant to each crop scenario;
- define SPGs, indicators and metrics for each ecosystem service;
- measure potential impacts on ecosystem services and farm economics from crop protection actions (e.g. PPP, mechanical weeding, marginal habitat); and
- compare trade-offs between ecosystem services across crop production scenarios.

Scenarios
Four weed control scenarios were described as case studies including (I) a reference scenario with emphasis on herbicidal weed control, (II) a scenario with focus on in-field protection of NTTPs, (III) a scenario oriented at off-field protection of NTTPs, and (IV) a scenario with full protection of ecosystem services.

A CM was introduced as part of the screening process and drives the assessment to aid understanding of the ecological risks from chemical (PPP) and physical (mechanical weed control) impacts associated with a selected weed control strategy. Through the model, impact pathways describe the potential for changes in ecosystem service providing units (SPUs) from weed management practices.

Ecosystem services
Six ecosystem services were evaluated: Crop provision (food and raw materials), wild foods, fresh groundwater, fresh surface water, erosion prevention and maintenance of soil fertility and habitat for species (functioning of ecological components of the agro-ecosystem) as these are expected to materially change in ecosystem service provision level with the choice of weed control method. For each prioritised ecosystem service and associated SPU, preliminary quantitative specific protection goals (SPGs), indicators and metrics were defined for in-field and off-field land uses. The framework was extended with indicators measuring economic and social impacts such as changes in yield, costs associated with weed management and employment.

Case studies
The framework and SPGs were tested using six case studies representing a range of crops and EU Member States. A questionnaire was developed for local agronomists to draw upon their knowledge of farming practices in each crop and country. The case studies executed by local experts qualitatively

assessed the impact of the four weed control scenarios on ecosystem services (with different levels of in-field and off-field protection for NTTP); one case study (winter wheat) was undertaken quantitatively. The initial Framework was updated with the results of the case studies and informed discussions with ECPA and other public and private stakeholders involved in the application of the EU Better Regulation Guidelines in EU legislation related to crop protection.

Findings

Based on the evaluation of the case studies it is concluded that the Impact Assessment Framework is applicable to the regulation of the sustainable use of PPP with the following conclusions:

- The Impact Assessment Framework is applicable for the qualitative and quantitative assessment of the environmental, social and economic impacts, benefits and trade-offs when adjusting a diverse weed control toolbox;
- A local agronomist is needed to frame an assessment (choice of scenarios);
- A quantitative assessment of environmental and socio-economic impacts is feasible and requires a multi-disciplinary approach with expertise in agronomy, risk assessment, ecology, ecosystem services, environmental economic and socio-economic analysis and sustainability. It also requires sufficient data, which may not be readily available in some areas. Local knowledge and experience are valuable, but assumptions should be supported by published scientific and other authoritative data (e.g. national statistics);
- A holistic assessment can be achieved through the application of ecosystem services frameworks that enable the monetary quantification of impacts to farmers (e.g. farm income) and to society (e.g. food prices). This can be derived from the choice of weed management practices, and the non-monetary valuation of ecosystem service delivery for the society as used in this study;
- Further research is required to continue developing the impact assessments through the ecosystem services perspective towards benefits and their associated values, to be comparable with the SEA (Socio-Economic Assessment) approach used in REACH chemical authorisation. This is particularly relevant as the benefits derived from the various ecosystem services and their associated value are usually non-linear and are location and context dependent. Consequently, decisions made without consideration of the beneficiaries and the anticipated impacts on ecosystem service benefits could lead to unintended consequences and trade-offs;
- The six case studies used to illustrate the Framework are based on single crops grown in one year. Future case studies could be more complex to fully test the Framework, such as introducing crop rotation, other PPP products and other non-target wildlife (trophic levels);
- Digitalising impact assessments could enable the deployment of the full quantitative potential of the Framework, facilitating (i) data acquisition (e.g. automatic pick-up from EFSA dossier endpoints or authoritative data), (ii) comparison of more ecosystem services and/or environmental or socio-economic indicators across scenarios, and (iii) the identification of most promising scenarios;
- The overarching direction must be towards developing more holistic assessments and aligning policies to optimise broader ecosystem management and protection across the landscape to protect multiple public goods of societal importance, whilst minimising impacts on farm income and maintaining food prices; and
- The ultimate challenge for policies and regulations is to maximise the potential of this Framework by breaking down the silos between European Food Safety Authority (EFSA) SPGs in PPP risk assessment and providing integrated SPGs for the management and protection of crops and the protection of the whole ecosystem, whilst contributing to human well-being.

Recommendations

In order to build on the results provided by this study and refine the SPGs it is recommended that the approach is discussed with relevant stakeholders and policy makers to invite their input and adjust, if needed, the SPGs and the way they are measured. The application of the Framework may be extended to other crop scenario contexts through discussion with agronomists; also, to expand to other groups of PPPs such as insecticides, fungicides and acaricides to include other SPGs or ecosystem services than those focused on NTTPs.

1 Introduction

The EU has set high requirements regarding the quality of their regulatory framework. In order to operationalise these higher requirements, 'Better Regulation Guidelines' have been developed to improve existing and new legislation setting out the principles that ought to be followed for any legislative initiative. The introduction of the 'Better Regulation Guidelines' states the following: '*The European Commission is determined, therefore, to ensure that its proposals meet policy goals at minimum cost and deliver maximum benefits to citizens, businesses and workers while avoiding all unnecessary regulatory burdens. This is key to support growth and job creation – allowing the EU to ensure its competitiveness in the global economy - while maintaining social and environmental sustainability.*'

Regulation (EC) 1107/2009 (hereafter Regulation 1107) governs the risk assessment and placement on the market of plant protection products (PPPs). To be approved, PPPs have to comply with regulatory criteria aimed at General Protection Goals (GPGs): environment, efficacy and human and animal health. However, the Better Regulation Guidelines[1] require adequate, preferably quantitative economic, social and environmental impact assessment of decisions in each stage of the policy cycle. Such assessments require the application of Specific Protection Goals (SGPs). So far, SPGs for ecosystem services have not been operationalised for PPPs. The EFSA has made a first step in defining SPGs based on ecosystem services for Pollinators, Non-Target Terrestrial Plants (NTTPs), Non-Target Arthropods, Soil Organisms and Amphibians, and it has provided guidance for developing SPGs (EFSA Scientific Committee, 2016). Currently the European Commission is exploring the best way to select SPGs, given the complexities faced with selecting SPGs for Pollinators. According to the Terms of Reference of this study, the current assessment of PPPs has three limitations:

1. The assessment of the risks of PPPs is performed in isolation, without considering the reason PPPs are applied. PPPs are applied in order to provide treatment and protection of a crop against diseases, competitive weeds and pests that may compromise the crop success or the production of economically viable yields, and thus ensure quality to produce sufficient and safe food for consumers. Regulation 1107 does not require socioeconomic or cost-benefit analyses before the authorisation process of a PPP. The benefits of application of a PPP have been limited to the technical efficacy of the PPP. Thus, neither the potential economic importance of a PPP is considered, nor its relative importance regarding potential alternatives. Since sustainable and careful application of PPPs contribute to plant health, higher yield and higher quality of agricultural produces, application of PPPs contribute significantly to food security and quality.
2. It does not consider the effects of trade-offs between relevant protection goals e.g. between Non-target Terrestrial Plants and Soil Organisms. Trade-offs can occur due to human behaviour. Farmers and growers search for the best strategies and inputs to make their production process as efficient as possible. Successful implementation of SPGs can only take place if the SPGs defined for a given area of environmental risk assessment (e.g. Non-target Terrestrial Plants) include all relevant trade-offs (e.g. trade-off with SPG for soil organisms) in a balanced way, and if all SPGs are applied simultaneously and consistently. In this context, a holistic view is required, one that considers PPP use as well as other farming practices that can affect the SPG. If not, the uses of PPPs can be too quickly selected as being in conflict with SPGs, particularly if they are undefined or not well-defined. Beyond crop protection products, other aspects linked to crop management may also conflict with the SPG.
3. It focuses only on the negative impacts and does not account for beneficial ecosystem services effects on Ecosystem Services that can occur through application PPPs as an embedded part of Integrated Pest Management (IPM) or other Good Agricultural Practices, such as crop rotation, crop diversification or conservation tillage.

[1] https://ec.europa.eu/info/sites/info/files/better-regulation-guidelines.pdf

The ECPA has been invited by the EU to participate in the consultation process for defining SPGs based on ecosystem services. The ECPA, therefore, initiated the development of an Impact Assessment Framework, compliant with the Better Regulation Guidelines of the European Commission, in which both environmental and socioeconomic impacts are simultaneously addressed in a balanced way, to protect non-Target Organisms and to safeguard competitiveness of EU agriculture.

The objective of this study is to develop an Impact Assessment Framework that can be applied on the assessment of PPPs and fulfils the requirements of the Better Regulation Guidelines. In this document, we propose an initial conceptual Impact Assessment Framework, which has been applied to six case studies relevant to the risk assessment for Non-Target Terrestrial Plants (NTTP), in line with the request of the EC. The case studies investigate the impact of various weed control scenarios on ecosystem services (with different levels of in-field and off-field protection for NTTP) in the context of six crops grown in different parts of the EU. Based on the results of the case studies, main findings and follow-up discussions with the ECPA and other public and private stakeholders involved in applying the EU Better Regulation Guidelines in EU legislation related to crop protection, the Framework was adjusted.

The structure of this report is as follows. In Chapter 2, the main structure of the IA framework as well as the main components is elaborated on. Chapter 3 describes how the framework has been applied to case studies, it presents their results and elaborates on the conclusions drawn about the applicability of the framework. Chapter 4 includes a final discussion, conclusions and recommendations.

The specific focus and content of this report requires the use of technical terms. It is likely these terms are not familiar to all disciplines. Thus, we note here that, in the execution of this project, we have used the glossary developed by the EFSA and the ECPA, version 2018-03-20 (EFSA 2016[2], Dollacker et al., 2018)[3]. However, some often-referred terms are additionally explained in Appendix 1.

[2] EFSA Scientific Committee 2016: Glossary, in: Guidance to develop specific protection goal options for environmental risk assessment at EFSA, in relation to biodiversity and ecosystem services, pp. 36-39, EFSA Journal, Vol. 14 (6), e04499, available online at https://efsa.onlinelibrary.wiley.com/doi/full/10.2903/j.efsa.2016.4499

[3] https://www.ecpa.eu/sites/default/files/documents/ECPA%20BESS_Resource-paper_BEG_Publication_vs_2018_03_20_0.pdf

2 Structure of the proposed IA Framework

2.1 General structure

In this project, we investigate four weed control scenarios in order to illustrate how the IA Framework can be used. The level of protection required in-field and off-field for NTTPs varies across scenarios. For some of the chosen scenarios, meeting the protection goal for NTTPs implies that farmers will adjust their weed control practices, including through use of herbicides. The general structure of analysing impacts of adjustments in the weed control toolbox to meet specific protection goals is presented in Figure 2.1.

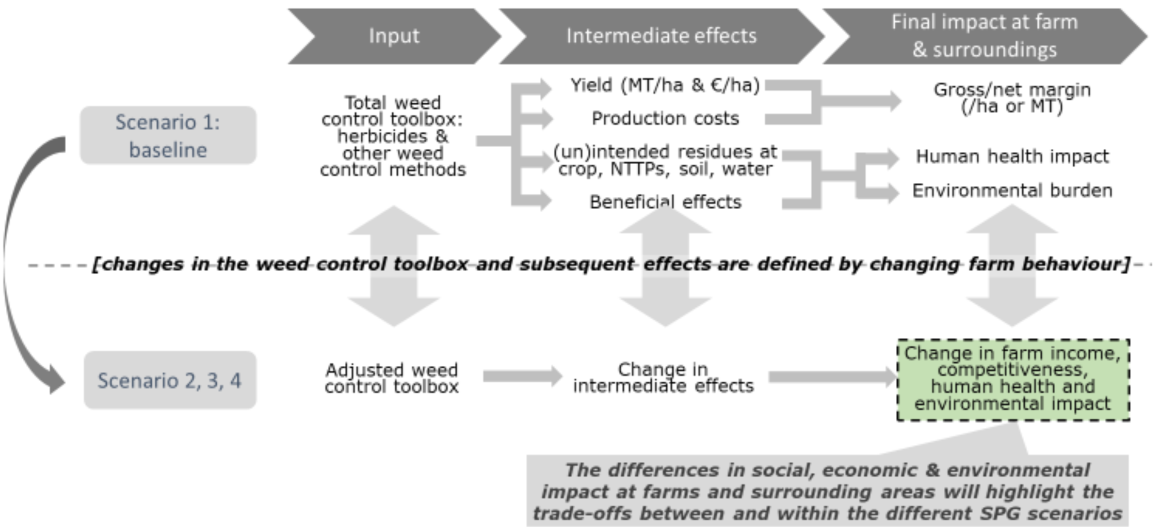

Figure 2.1 *Conceptual model for analysing impacts of adjustments in the weed control toolbox for various specific protection goal scenarios for NTTPs*

The IA framework contains two basic dimensions:

- The horizontal dimension addresses the basic steps for how the applied weed control measures are linked by intermediate effects to the final social, economic and environmental impacts.
- The vertical dimension includes the alternative weed control scenarios and corresponding adjustments in the applied weed control measures differentiating in levels of NTTP protection in-field and off-field.

The IA framework enables the comparison of different types of impacts of applied weed control measures under different scenarios containing specific requirements to protection goals.

The four scenarios and corresponding specific protection goals for NTTPs have been defined in greater detail as well as other social and economic impacts. In Section 2.2, the four elaborated scenarios are defined; 2.3 elaborates on the ecosystem services framework and the identification of priority ecosystem services and how the scenarios have been connected to measurable environmental impacts and specific protection goals using an ecosystem services-based framework. In Section 2.4, the anticipated social and economic impacts are defined.

2.2 Weed control Scenarios

The IA Framework is evaluated using a range of crop production and weed management scenarios applied in six case studies (see Chapter 3). The crops included cereal, vegetable and fruit production (perennial apple orchard), covering a range of northern, central and southern European countries. Four weed management scenarios for arable field crops (rather than vegetables or orchards) were used as examples in this project. They are adapted from previous literature on the topic (EFSA 2014, Arts et al. 2017).

1. Scenario 1 reflects the **minimum legal requirements** to weed control, which implies that weed control is largely executed by **application of herbicides**. In this scenario, the focus for the in-field is on the ecosystem service crop/food production. So, ecosystem services provided by non-crop plants in the field are given a lower priority during crop protection activities. In-field NTTPs will not be protected from the effects of herbicides. This scenario refers to the status quo for in-field/off-field NTTP protection goals in the EU. This scenario does not necessarily mean that fields are completely cleaned from wild plants.
2. Scenario 2 focuses on an **increased in-field protection of non-target terrestrial plants** (compared to Scenario 1), which is accomplished by a minimum weed reduction approach focused on differentiation between weed species. Weed reduction is applied according the economical yield loss scenario, which means that weed control is only applied if the costs for weed control are lower than the yield reduction caused by the weeds. This ensures herbicide application is focused on the parts of the field with greatest weed pressure. Flower strips can be added which bolster the community of NTTPs and other wildlife. In-field ecosystem services provided by NTTPs (for example, food for selected herbivores, such as over-wintering geese in arable fields) can be maintained in this scenario. Natural enemies are protected as much as possible.
3. Scenario 3 reflects in-field the minimum legal requirements to weed control (this is the same as with Scenario 1) and adds an **increased protection of off-field non-target terrestrial plants** via spray drift reduction technology and precision machinery. The ecosystem service crop production is fully maintained in-field, and increased protection of off-field NTTPs requires the use of highly protective nozzles in case of PPP use, in order to reduce drift with at least 95%. Compensation areas (e.g. set-aside areas) can be added which contribute to the conservation of NTTPs.
4. Scenario 4 aims to optimise the **protection of ecosystem services** in-field as well as off-field. In-field, all ecosystem services except food production have high priority, so yield losses are accepted. This optimization is achieved through a mix of weed control technologies. The scenario aims to show the trade-offs in ecosystem services between increased NTTP protection and weed control. This scenario employs mechanical weeding, targeted use of herbicides and precision agriculture. Compensation areas (e.g. flower strips and buffer zones) can be added in-field in order to contribute to the conservation of NTTPs.

The potential impact of herbicide use on crop production and NTTPs needs to be disentangled from baseline environmental and socioeconomic conditions that will (naturally) vary. Defining weed control scenarios may include the following considerations:

- Define the type of weed management, such as a specific herbicide product or type of mechanical weed control
- Consider the beneficiaries
- Think holistically about potential impact pathways that may affect the environment, social factors or farm economics
- Describe the habitats, including management or compensatory actions such as buffer strips or flower margins
- Define the weed community for a crop production scenario
- In a crop rotation context, consider the influence of a preceding crop on weed pressure and the efficacy of weed treatment
- Consider how weeds and weed control may change over time--for example, weed shift and resistance to a herbicidal product, application rates and frequency of weed management.

The IA Framework needs to account for the outcome of detailed assessment of risks to NTTPs from potential exposure from PPP and mechanical weed management strategies. EFSA (2016) has recommended that an ecosystem services approach is useful for putting risks into a wider socioeconomic context, which is operationalised in the following sections of this report.

2.3 A Framework for Ecosystem Services in Socioeconomic Assessment

In order to operationally connect the four scenarios for NTTP protection to their measurable environmental benefits, impacts and trade-offs to other areas of the ecological risk assessment (e.g. protection of soil organisms), an ecology-focused ecosystem services approach as recommended by EFSA (EFSA Scientific Committee, 2016) was used. Biophysical structures and processes interact and generate ecological functions, and these ecological functions in turn generate ecosystem services that are measurable entities. Valuing the services provided by ecosystems is a rapidly evolving science, with several published frameworks available. These frameworks were reviewed in this project to identify the best fit for NTTP protection in agricultural ecosystems across Europe. However, it should be noted that in crop production, abiotic ecosystem services are crucial, in addition to biotic ones addressed in the ERA. These services need to be considered in order to evaluate the health of agro-ecosystems.

- **Millennium Ecosystem Assessment (MA) classification of ecosystem services (2005)** (Millennium Ecosystem Assessment, 2005) is the first and thus one of the most cited and widely applied frameworks and is the basis on which subsequent ecosystem service classifications have been developed. The MA defines ecosystem services as 'the benefits people obtain from ecosystems' and groups them into four ecosystem service categories: supporting, provisioning, regulating and cultural services. The MA ES framework is the reference point for EFSA guidance on specific protection goals (EFSA Scientific Committee, 2016).

- **Common International Classification of Ecosystem Services (CICES) (2018)**[4] is recognised internationally and has been designed to help measure, account for and assess ecosystem services. CICES was designed for environmental accounting purposes and offers a structure that links with the framework of the United Nations System of Environmental-Economic Accounts (SEEA). SEEA defines ecosystem services as 'contributions that ecosystems make to human well-being, and distinct from the goods and benefits that people subsequently derive from them' following the cascade model that links the environment and the social and economic system. CICES aims to classify the contributions that ecosystems make to human well-being that arise from living processes and builds on existing classifications (MA). CICES only considers final services; it does not attempt to identify or classify supporting and intermediate services, as it considers such services to either be part of the processes and functions that characterise ecosystems to be consumed or be used by people indirectly, and these supporting and intermediate services may simultaneously facilitate many final ecosystem outputs. Therefore, intermediate or supporting services are considered to determine the capacity of the ecosystem to deliver particular final services, and they are measured as part of the ecosystem accounts in terms of measures of ecosystem condition as the structures, processes and functions that give rise to provisioning, regulating and cultural services. The focus of the CICES framework on final services avoids double-counting when valuing the benefits in ecosystem accounts, but since the aim of this IA Framework is to measure marginal changes in ecosystem service provision for the comparison of alternative scenarios rather than developing full ecosystem accounts, certain intermediate services such as soil erosion, which are important in agricultural systems and the assessment of changes across scenarios, would not be captured in this IA.

- **The Economics of Ecosystems and Biodiversity (TEEB) Approach (2010)**[5] builds on the MA (2005) by further demonstrating the economic significance of biodiversity loss and ecosystem degradation in terms of negative effects on human well-being. TEEB uses a tier-based approach to

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[4] Towards a Common International Classification of Ecosystem Services (CICES) for Integrated Environmental and Economic Accounting. Available at: https://cices.eu [Accessed 07/01/2020]

[5] TEEB - The Economics of Ecosystems and Biodiversity for Local and Regional Policy Makers (2010). Available at: http://www.teebweb.org/media/2010/09/TEEB_D2_Local_Policy-Makers_Report-Eng.pdf http://www.teebweb.org [Accessed 14/01/2020]

analysing problems and suitable policy responses. Similar to CICES, TEEB is presented as an ecosystem cascade of biophysical structures or processes, functions, services, benefits and values to facilitate the analysis of trade-offs (in biophysical structures or processes, functions, services, benefits or value) implied by environmental management strategies. For the latter, **TEEB was chosen as the most suitable framework for agro-ecosystems, and in particular for NTTP protection here.** A main advantage of this framework is the availability of processes regarding the prevention of soil erosion and maintenance of soil fertility, a key ecosystem service in crop production. Soil type influences the plant community found in an agricultural system, and soil fertility influences the growth of NTTPs and crops. Soil erosion prevention may be adversely affected under mechanical weed management, for example when soil structure is affected. It is important to note that the TEEB for Agriculture and Food (TEEBAgriFood) Evaluation Framework and the UK National Ecosystem Services (UK NEA) assessment (Chapter 7, Enclosed farmland) were also reviewed, and they informed this assessment.

The TEEB definitions[6] for each ecosystem service were used as the starting point for this IA Framework; however, each description was adapted to focus on NTTPs for assessment (Table 2.1). While the focus for SPG evaluation was on NTTPs (vascular plants), consideration of indirect effects from NTTP protection on other ecosystem components (for example, improvements in water quality or soil health) were part of a screening process to prioritise ecosystem services for assessment.

2.3.1 Ecosystem Services prioritisation

A useful tool in ecological risk assessment and ecosystem services analysis is a conceptual site model (CSM), which was used in this project to operationalise TEEB for European crop production scenarios. A CSM used as part of the screening process aids understanding of the ecological risks from chemical (PPP) and physical (mechanical weed control) impacts associated with each scenario. The focus of the CSM is to identify impact pathways that may lead to marginal changes in ecosystem service providing units (SPUs) from weed management practices. These changes in SPUs may in turn lead to changes in ecosystem service provision that are non-material; or, they may substantially increase or decrease the level of ecosystem service provision relative to an alternative scenario. The CSM is focused on changes associated to weed management practices (i.e. herbicide use and alternatives) and assumes all other farm crop protection products (e.g. insecticides, fungicides) and crop management practices remain constant across scenarios. Development of the CSM helps to describe the crop scenario and wider environmental setting, the identification of the sources of risks or impacts, likely SPU or ecosystem service being affected, exposure pathways and the frequency and magnitude of a potential impact via an exposure pathway, along with anticipated environmental recovery conditions across scenarios. An example of a conceptual field and receptors is illustrated in Section 3.3 (UK Winter Wheat case study).

It is noteworthy in this project that the project team tried to consider the range of crop scenarios when prioritising ecosystem services for assessment, so that the Framework accounts for a 12-month arable crop cycle and permanent crops, such as apple orchards, although both are very different in term of weed management.

For the assessment of impacts on NTTP, the CSM focused on the following impact pathways:
- Chemical impacts from the herbicides used based on the environmental fate and the toxicity profile to terrestrial plants
- Indirect herbicide impacts to other organisms, such as soil fauna
- Physical impacts associated with mechanical weed control, such as removal of NTTPs by cutting tools
- Indirect influences of mechanical weed control (such as timing and frequency of disturbance) to other organisms, such as soil fauna, and on abiotic ecosystem services upon which crop production depend, such as maintenance of soil structure and prevention of soil erosion

[6] http://www.teebweb.org/resources/ecosystem-services

Prioritisation of ecosystem services for assessment was made using the following criteria and was based on professional judgement:

1. Anticipated presence or absence of ecosystem service in-field and/or off-field (relevance to NTTPs in agro-ecosystems)
2. Relevance to beneficiaries who may include the farmer, local community or consumer (relevance to those who may be affected by the change in ecosystem service provision)
3. Anticipated changes in ecosystem service across scenarios (relevance to NTTP protection in crop production, the assessment should only focus on services likely to be subject to material changes)
4. Regulatory requirements (relevance to legal requirements)

The presence/absence of ecosystem services, baseline service levels and beneficiaries are presented in Table 2.1. The judgement on potential ecosystem service changes across scenarios relied on knowledge of baseline service provision levels (high, medium, low), impact pathways and the anticipated magnitude of change across scenarios (material change presented as 'Y' for yes or non-material change as 'N') (Table 2.2). Data availability and regulatory requirements were outlined as part of the case studies. Information sources and professional judgement informed the prioritisation process, but data availability in itself was not used as a criterion for prioritisation, as a lack of data should not be equated to a lack of impact. In the event of data gaps that prevent a full quantitative valuation of changes associated with the choice of weed control method, a qualitative assessment should be conducted and uncertainties and data gaps identified. Sensitivity analysis may help inform whether further research may be needed to address data gaps.

Ecosystem services incurring a material change were prioritised for further assessment. Non-material changes were screened out from further assessment. Some services were bundled or grouped together to avoid double-counting closely related services. In-field and off-field ecosystem services were considered separately, but it is worth noting that some services occur in both locations. The outcome of the screening process is summarised in the last two columns of Table 2.2.

Key for Tables 2.1 and 2.2

	In-field: material change in service provision and potential for change across scenarios
	Off-field: material change in service provision and potential for change across scenarios
	In-field and off-field: material change in service provision and potential for change across scenarios
	Not prioritised: only non-material change anticipated OR considered as part of another ecosystem service to avoid double counting across services

'n/a' in the table means not available

'ES' is an abbreviation of ecosystem services

Table 2.1 *Anticipated presence or absence of ecosystem services in-field and off-field*

ES code	Ecosystem Service (ES)	TEEB definition *(Project context)*	SPU (agroecosystems)	In-field Presence (Y/N)	Baseline service provision (low/moderate /high)	Beneficiaries	Off-field Presence (Y/N)	Baseline service provision (low/moderate/ high)	Beneficiaries
Provisioning Services (ES that describe the material or energy outputs from ecosystems, including food, water and other resources)									
ES1a	**Food (in-field crop production)**	Ecosystems provide the conditions for growing food. Food comes principally from managed agro-ecosystems but marine and freshwater systems or forests also provide food for human consumption. *This Project: This ES includes the harvest from crops for human consumption (from crops grown for fodder are considered raw materials, ES1b). Food may be fresh or processed (to be defined for each case study)*	Crop	Y	High	Farmer, consumers	N	n/a	n/a
ES1b	**Raw materials (in-field)**	Ecosystems provide a great diversity of materials for construction and fuel including wood, biofuels, fodder and plant oils that are directly derived from wild and cultivated plant species. *This Project: Although crops such as oilseed rape (OSR) can be grown for human nutrition, for the purposes of this study we are considering only industrial uses (e.g. biofuel, lubricating oil or raw material in the chemical industry; following oil extraction, the expeller cake is a high protein and animal feed source). Other raw material crops include Brassica grown as raw materials for fertiliser or biocontrol pellets, and fodder maize*	Crop	Y	High	Farmer, consumers	N	n/a	n/a
ES2	**Wild foods (off-field)**	Ecosystems provide the conditions for growing food. Wild foods from forests are often underestimated. *This Project: Wild foods in off-field include berries, nuts, wild garlic, watercress, herbs, nettles, etc, providing food for humans*	Wild species foraged for food (or medicine)	N	n/a	n/a	Y	Low to high (context dependent)	Collectors (local community, recreational users) and consumers
ES3	**Freshwater (groundwater)**	Ecosystems play a vital role in the global hydrological cycle, as they regulate the flow and purification of water. Vegetation and forests influence the quantity of water available locally. *This Project: NTTP contribute to the infiltration of stormwater runoff and regulation of ground water quality.*	Plants (crop and NTTPs) and soil organisms supporting them	Y	Potentially high	Farmers, local community	Y	Low to high (context dependent)	Local community

ES code	Ecosystem Service (ES)	TEEB definition *(Project context)*	SPU (agroecosystems)	In-field			Off-field		
				Presence (Y/N)	Baseline service provision (low/moderate/high)	Beneficiaries	Presence (Y/N)	Baseline service provision (low/moderate/high)	Beneficiaries
ES4	**Freshwater (surface water)**	Ecosystems play a vital role in the global hydrological cycle, as they regulate the flow and purification of water. Vegetation and forests influence the quantity of water available locally. *This Project: NTTP in regulating flow and stormwater runoff quality. Also, NTTP in off-field aquatic habitat (runoff)*	Plants (crop and NTTPs)	Y	Low to high (context dependent)	Local community, recreational users	Y	Low to high (context dependent)	Local community, recreational users
ES5	**Medicinal resources (off-field)**	Ecosystems and biodiversity provide many plants used as traditional medicines as well as providing the raw materials for the pharmaceutical industry. All ecosystems are a potential source of medicinal resources. *This Project: NTTP with medicinal uses, such as elder (Sambucus nigra) used in home remedies for centuries as an antiseptic and anti-inflammatory*	Wild species foraged for medicinal uses	N	n/a	-	Y	Low to moderate (context dependent)	-
Regulating Services (services that ecosystems provide by acting as regulators, such as, regulating the quality of air and soil or by providing flood and disease control)									
ES6	**Local climate and air quality**	Trees provide shade whilst forests influence rainfall and water availability both locally and regionally. Trees or other plants also play an important role in regulating air quality by removing pollutants from the atmosphere. *This Project: Crops and NTTP contribute to air quality and removal of pollutants from the atmosphere*	Plants (crop and NTTPs)	Y	Low to moderate	Local and regional population	Y	Low to high (context dependent)	Local and regional population
ES7	**Carbon sequestration and storage**	Ecosystems regulate the global climate by storing and sequestering greenhouse gases. As trees and plants grow, they remove carbon dioxide from the atmosphere and effectively lock it away in their tissues. In this way, forest ecosystems are carbon stores. Biodiversity also plays an important role by improving the capacity of ecosystems to adapt to the effects of climate change. *This Project: carbon sequestration by crops and NTTPs and soil carbon storage*	Plants (crop and NTTPs) and soil organisms (soil fauna and microorganisms)	Y	Low to moderate	Global population	Y	Low to high (context dependent)	Global population

ES code	Ecosystem Service (ES)	TEEB definition *(Project context)*	SPU (agroecosystems)	In-field			Off-field		
				Presence (Y/N)	Baseline service provision (low/moderate /high)	Beneficiaries	Presence (Y/N)	Baseline service provision (low/moderate/ high)	Beneficiaries
ES8	**Erosion prevention and maintenance of soil fertility**	Soil erosion is a key factor in the process of land degradation and desertification. Vegetation cover provides a vital regulating service by preventing soil erosion. Soil fertility is essential for plant growth and agriculture and healthy functioning ecosystems supply the soil with nutrients required to support plant growth. *This Project: Role of crops (e.g. cover crops) and NTTP to reduce soil erosion and impacts of herbicide and mechanical weed control practices on soil fertility*	Rooted plants (crop and NTTPs) and soil organisms supporting them (microorganisms, macro-organisms such as earthworms)	Y	Low to moderate	Farmer	Y	Low to high (context dependent)	Other farmers/ landowners, local community
ES9	**Moderation of extreme events**	Extreme weather events or natural hazards include floods, storms, tsunamis, avalanches and landslides. Ecosystems and living organisms create buffers against natural disasters, thereby preventing possible damage. For example, wetlands can soak up flood water whilst trees can stabilize slopes. Coral reefs and mangroves help protect coastlines from storm damage. *This Project: Moderation of extreme events by crops and NTTP*	Rooted plants (crop and NTTPs) in flood plains	Y	Low to moderate	Local communities	Y	Low to high (context dependent)	Local communities
ES10	**Waste-water treatment**	Ecosystems such as wetlands filter both human and animal waste and act as a natural buffer to the surrounding environment. Through the biological activity of microorganisms in the soil, most waste is broken down. Thereby pathogens (disease causing microbes) are eliminated, and the level of nutrients and pollution is reduced. *This Project: Effect of herbicides on biological activity in the soil and role of NTTP in the absorption of soil and water pollutants*	Plants, fauna, macrofauna, bacteria and fungi	Y	Low to moderate	Farmer	Y	Low to high (context dependent)	Other farmers/ landowners, local community

ES code	Ecosystem Service (ES)	TEEB definition *(Project context)*	SPU (agroecosystems)	In-field Presence (Y/N)	Baseline service provision (low/moderate/high)	Beneficiaries	Off-field Presence (Y/N)	Baseline service provision (low/moderate/high)	Beneficiaries
ES11	**Pollination**	Insects and wind pollinate plants and trees which is essential for the development of fruits, vegetables and seeds. Animal pollination is an ecosystem service mainly provided by insects but also by some birds and bats. Some 87 out of the 115 leading global food crops depend upon animal pollination including important cash crops such as cocoa and coffee (Klein et al, 2007). *This Project: Effect of herbicides on the availability of habitat and food for pollinators. The service is pollination by wild insect pollinator species, and the role they provide for pollinator-dependent crops and NTTP biodiversity (e.g. mediating seed, fruit and seeds of plants that in turn feed invertebrates, birds and mammals). This service focuses on habitat availability and food for pollinators, not the agronomic relevance of crop pollinators and their impact on commercial food production (as this varies from crop-to-crop, with crop rotation and inter-cropping, use of domesticated pollinators, etc)*	Habitat and food that supports pollinators (arthropods such as bees, hoverflies, butterflies and other pollinator species)	Y	Low to moderate	Farmer, local communities, consumers	Y	Low to high (context dependent)	Other farmers/ landowners, local communities
ES12	**Biological control**	Ecosystems are important for regulating pests and vector borne diseases that attack plants, animals and people. Ecosystems regulate pests and diseases through the activities of predators and parasites. Birds, bats, flies, wasps, frogs and fungi all act as natural controls. *This Project: Role of NTTPs in the provision of habitat for predators of crop pests*	Habitat that supports beneficial arthropods (natural enemies such as ladybirds, ground beetles, true bugs, lacewings, spiders, parasitic wasps), vertebrate predators and fungal species	Y	Low to moderate	Farmer, consumers	Y	Low to high (context dependent)	Other farmers/ landowner, local community

ES code	Ecosystem Service (ES)	TEEB definition *(Project context)*	SPU (agroecosystems)	In-field Presence (Y/N)	Baseline service provision (low/moderate /high)	Beneficiaries	Off-field Presence (Y/N)	Baseline service provision (low/moderate/ high)	Beneficiaries
Cultural Services (non-material benefits people obtain from contact with ecosystems, including aesthetic, spiritual and psychological benefits)									
ES13	**Spiritual experience and sense of place (off-field)**	In many parts of the world natural features such as specific forests, caves or mountains are considered sacred or have a religious meaning. Nature is a common element of all major religions and traditional knowledge, and associated customs are important for creating a sense of belonging. *This Project: degree to which marginal gains in biodiversity and habitat value from reduced impact on NTTP contribute to the provision of meaningful places for individuals and the preservation of traditional knowledge, including foraging and use of wild foods*	Particular plant species (crop and NTTPs), trees, patches of vegetation and ecosystems as landscape features, landscape elements/habitats	Y	Moderate to high	Farmers, local community	Y	Low to high (context dependent)	Local community, recreational users, wild food consumers
ES14	**Tourism**	Ecosystems and biodiversity play an important role for many kinds of tourism which in turn provides considerable economic benefits and is a vital source of income for many countries. In 2008 global earnings from tourism summed up to US$ 944 billion. Cultural and eco-tourism can also educate people about the importance of biological diversity. *This Project: degree to which marginal gains in biodiversity and habitat value from reduced impact on NTTP contribute to tourism*	Attractive plants and vegetation, plant species that provide habitat to vertebrates (e.g. bird watching) and attractive invertebrates (crop and NTTPs)	Y	Low to high (context dependent)	Tourists, farmers, local communities	Y	Low to high (context dependent)	Tourists, local communities
ES15	**Aesthetic appreciation and inspiration for culture, art, design**	Language, knowledge and the natural environment have been intimately related throughout human history. Biodiversity, ecosystems and natural landscapes have been the source of inspiration for much of our art, culture and increasingly for science. *This Project: degree to which marginal gains in biodiversity and habitat value from reduced impact on NTTP contribute to art, culture and science*	Particular plant species such as flowering plants (also attractive invertebrates and vertebrates attracted by the habitat provided by those plant species), structures constructed and/or modified by their typical biota (crop and NTTPs)	Y	Low to high (context dependent)	Local populations, recreational users	Y	Low to high (context dependent)	Local populations, recreational users

ES code	Ecosystem Service (ES)	TEEB definition *(Project context)*	SPU (agroecosystems)	In-field Presence (Y/N)	In-field Baseline service provision (low/moderate /high)	In-field Beneficiaries	Off-field Presence (Y/N)	Off-field Baseline service provision (low/moderate/ high)	Off-field Beneficiaries
ES16	**Recreation and mental and physical health**	Walking and playing sports in green space is not only a good form of physical exercise but also lets people relax. The role that green space plays in maintaining mental and physical health is increasingly being recognized, despite difficulties of measurement. *This Project: degree to which marginal gains in biodiversity and habitat value from reduced impact on NTTP contribute to recreational and mental and physical health values, including increased availability of wild food for recreational foraging*	Appreciated agricultural landscapes (e.g. fields bordered by hedgerows) and semi-natural habitats, wild foods providing foraging opportunities for local population and recreational users (crop and NTTPs)	Y	Low to high (context dependent)	Local populations, recreational users	Y	Low to high (context dependent)	Local populations, recreational users, wild food consumers
Habitat or supporting services (underpin almost all other services. Ecosystems provide living spaces for plants or animals; they also maintain a diversity of different breeds of plants and animals)									
ES17	**Maintenance of genetic biodiversity**	Genetic diversity is the variety of genes between and within species populations. Genetic diversity distinguishes different breeds or races from each other thus providing the basis for locally well-adapted cultivars and a gene pool for further developing commercial crops and livestock. Some habitats have an exceptionally high number of species which makes them more genetically diverse than others and are known as 'biodiversity hotspots'. *This Project: Role of NTTPs to support genetic diversity*	Habitats large enough to contain a sufficient number of effectively mating and reproducing species to prevent reduction of genetic biodiversity and maintain evolutionary processes to safeguard their potential for continuous adaptation. Genetic biodiversity of crop plants is acknowledged but is not considered relevant for this assessment as it is not affected by the choice of weed control methods and remains unchanged across scenarios.	Y	Low	Farmer (e.g. greater resilience in crop production such as maintaining predator-prey relationships), local community	Y	Low to high (context dependent)	Local communities
ES18	**Habitat for species (functioning of ecological components of the agro-ecosystem)**	Habitats provide everything that an individual plant or animal needs to survive: forage; water; and shelter. Each ecosystem provides different habitats that can be essential for a species' lifecycle. Migratory species including birds, fish, mammals and insects all depend upon different ecosystems during their movements. *This Project: Role of crops and NTTPs in the provision of habitat for animal and plant species which enable structures, processes and functions that give rise to provisioning, regulating and cultural services.*	Habitats large enough to support organisms or communities of organisms. Includes ecosystem engineers (e.g. earthworms, plants) and large plants and animals that provide surfaces for periphytic organisms, hedgerows.	Y	Low to moderate (note: in-field, the crop defines the habitat during the cropping season, NTTPs provide habitat and food for herbivores after harvest)	Farmer, local community	Y	Low to high (context dependent)	Local communities

Table 2.2 Anticipated changes in ecosystem service delivery across scenarios

ES code	Ecosystem Service (ES)	Scenario 1 Minimum requirements (herbicide use)		Scenario 2 Weed reduction according to economical yield loss threshold scenario		Scenario 3 Minimum requirements scenario with further reduced drift exposure off-field		Scenario 4 Full protection of ES		Ecosystem data availability	Prioritised for assessment IN-FIELD (Y/N)	Prioritised for assessment OFF-FIELD (Y/N)
		Presence (Y/N)	Impact pathways	Change (Y/N)	Impact pathways	Change (Y/N)	Impact pathways	Change (Y/N)	Impact pathways			
Provisioning Services (ES that describe the material or energy outputs from ecosystems, including food, water and other resources)												
ES1a	**Food (in-field crop production)**	Y	**Herbicide is anticipated to reduce NTTPs in-field (herbicidal action). Protection of NTTPs off-field conforms with current legal requirements.** Yield optimised.	Y	**Alternative weed control is anticipated to be spatially selective or to have a reduced impact on NTTPs in-field for some crops. Protection of NTTPs off-field, conforms with current legal requirements. Economical yield loss threshold - yield reduction accepted if offset by cost reduction, or innovative technology (less drift; vegetative growth protection goal).** Yield loss anticipated.	Y	**Herbicide is anticipated to reduce NTTPs in-field (herbicidal action). Protection of off-field NTTPs anticipated via >95% drift reduction.** Yield loss anticipated due to wider buffer strip with no option to grow crop in buffer zones (as compensation).	Y	**Alternative weed control is anticipated to be spatially selective or to have a reduced impact on NTTPs in-field for some crops. Protection of off-field NTTPs anticipated via >95% drift reduction.** Yield loss anticipated: no crop in buffer zone	EU and country level statistics (tonnage, acreage, yield, PPP use, crop cycles, etc.)	**Y**	**N (ES not present)**
ES1b	**Raw materials (in-field)**	N	See Food above	Y	See Food above	Y	See Food above	Y	See Food above	See Food above	**Y**	**N (ES not present)**
ES2	**Wild foods (off-field)**	Y	**Protection of NTTPs off-field, conforms with current legal requirements.** Temporary reductions of available quantities of some wild food NTTP may occur. Note: collected by at least 65m EU citizens and consumed by at least 100m (20% of the population), wild foods constitute a	Y (non-material change anticipated)	**Alternative weed control is anticipated to have a reduced impact on NTTPs** off-field owing to drift reduction from lower herbicide application, with potential beneficial effects for wild food NTTP.	Y	**Protection of off-field NTTPs anticipated via >95% drift reduction,** with potential beneficial effects for wild food NTTP.	Y	**Protection of off-field NTTPs anticipated via >95% drift reduction.** Reduced herbicide application (comparatively greater reduction than that of scenario 2) and drift reduction nozzles lead to more NTTP in-field and off-field, with potential	Wild food data - specific to each case study (off-field description in conceptual model); occurrence distribution and abundance, demand and benefits from published and grey literature, national statistical offices	**N (ES not present)**	**Y**

ES code	Ecosystem Service (ES)	Scenario 1 Minimum requirements (herbicide use)		Scenario 2 Weed reduction according to economical yield loss threshold scenario		Scenario 3 Minimum requirements scenario with further reduced drift exposure off-field		Scenario 4 Full protection of ES		Ecosystem data availability	Prioritised for assessment IN-FIELD (Y/N)	Prioritised for assessment OFF-FIELD (Y/N)
		Presence (Y/N)	Impact pathways	Change (Y/N)	Impact pathways	Change (Y/N)	Impact pathways	Change (Y/N)	Impact pathways			
			source of income and food for a portion of the EU population and is more common in low-income areas and in regions with low access restrictions or low collection regulations/ enforcement; their cultural value (i.e. use in traditional cuisine, recreational activity and sense of place/cultural identity) may be even greater in a European context, but is more difficult to quantify (i.e. intangible).						beneficial effects for wild food NTTP.	and databases, spatial data (Atlas Flora Europaea). See Schulp, C.J., Thuiller, W. and Verburg, P.H., 2014. Wild food in Europe: A synthesis of knowledge and data of terrestrial wild food as an ecosystem service. Ecological Economics, 105, pp.292-305.		
ES3	**Freshwater (groundwater)**	Y	Applied according to label. Note: under the current legal requirements, no contamination of groundwater above 0.1 µg/l is expected to occur	Y	Applied according to label dose, reduced herbicide use anticipated	Y	Applied according to label dose, reduced herbicide use anticipated	Y	Applied according to label dose, reduced herbicide use anticipated	EU and country level statistics (for WFD water bodies); Ecotoxicity test and environmental fate data from dossier	**Y**	**Y**
ES4	**Freshwater (surface water)**	Y	Following legal requirements (non-spray zones and dose)	Y	Following legal requirements (non-spray zones) and doses, reduced herbicide use anticipated	Y	Wider buffer zones and >95% drift reduction anticipated	Y	Wider buffer zones, reduced herbicide use and >95% drift reduction anticipated	EU and country level statistics (for WFD water bodies); Ecotoxicity test and environmental fate data from dossier	**Y**	**Y**

ES code	Ecosystem Service (ES)	Scenario 1 Minimum requirements (herbicide use)		Scenario 2 Weed reduction according to economical yield loss threshold scenario		Scenario 3 Minimum requirements scenario with further reduced drift exposure off-field		Scenario 4 Full protection of ES		Ecosystem data availability	Prioritised for assessment IN-FIELD (Y/N)	Prioritised for assessment OFF-FIELD (Y/N)
		Presence (Y/N)	Impact pathways	Change (Y/N)	Impact pathways	Change (Y/N)	Impact pathways	Change (Y/N)	Impact pathways			
ES5	**Medicinal resources (off-field)**	N	Provisions under in-field food crop production and raw-materials would be largely applicable to medicinal crops, however medicinal plant crops are not the focus of the case studies. Off-field foraging of medicinal plants (e.g. nettle) is considered alongside wild foods ES to avoid double-counting.	Y	Potential beneficial effects for off-field medicinal NTTPs anticipated; off-field foraging of medicinal plants (e.g. nettle) is considered alongside wild foods ES to avoid double-counting.	Y	Potential beneficial effects for off-field medicinal NTTPs anticipated; off-field foraging of medicinal plants (e.g. nettle) is considered alongside wild foods ES to avoid double-counting.	Y	Potential beneficial effects for off-field medicinal NTTPs anticipated; off-field foraging of medicinal plants (e.g. nettle) is considered alongside wild foods ES to avoid double-counting.	-	**N (ES not present)**	**N (to avoid double counting with wild food and cultural ES)**
Regulating Services (services that ecosystems provide by acting as regulators e.g. regulating the quality of air and soil or by providing flood and disease control)												
ES6	**Local climate and air quality**	Y	**Herbicide is anticipated to reduce NTTPs in-field (herbicidal action). Protection of NTTPs off-field conforms with current legal requirements. Application according to label dose and MRL. Standard nozzles.** Vapour drifts dependent on climatic conditions, but these are assumed constant across scenarios. Baseline drift.	Y (non-material change anticipated)	**Alternative weed control is anticipated to be spatially selective or to have a reduced impact on NTTPs in-field for some crops,** leading to higher NTTP density in-field and reduced drift, all other conditions being equal. Emission reduction (albeit low) and greater biomass & flower and seed generation of NTTPs are anticipated, to filter pollutants (mainly in-field but also gains off-field). Air emissions (NOx, particulate matter) from mechanical weed control anticipated.	Y (non-material change anticipated)	**Protection of off-field NTTPs anticipated via >95% drift reduction**. Emission reduction (greater than scenario 2 for off-field) is anticipated to lead to greater NTTP biomass & flower and seed generation off-field to filter pollutants. Also wider buffer zones (= compensation), with NTTP gain anticipated relative to baseline.	Y (non-material change anticipated)	**Alternative weed control is anticipated to be spatially selective or to have a reduced impact on NTTPs in-field for some crops. Protection of off-field NTTPs anticipated via >95% drift reduction.** Reduced herbicide application (comparatively greater reduction than that of scenario 2) and drift reduction nozzles are anticipated to lead to further reductions in	Scientific literature on deposition and dispersion rates per type of habitat/vegetation.	**N (non-material change in-field ES anticipated from variations in weed management)**	**N (non-material change in-field ES anticipated from variations in weed management)**

ES code	Ecosystem Service (ES)	Scenario 1 Minimum requirements (herbicide use)		Scenario 2 Weed reduction according to economical yield loss threshold scenario		Scenario 3 Minimum requirements scenario with further reduced drift exposure off-field		Scenario 4 Full protection of ES		Ecosystem data availability	Prioritised for assessment IN-FIELD (Y/N)	Prioritised for assessment OFF-FIELD (Y/N)
		Presence (Y/N)	Impact pathways	Change (Y/N)	Impact pathways	Change (Y/N)	Impact pathways	Change (Y/N)	Impact pathways			
									drift, all other conditions being equal (lowest air emissions scenario). Greatest biomass of NTTP & flower and seed generation in-field and off-field are anticipated to filter pollutants. Air emissions (NOx, particulate matter) from mechanical weed control.			
ES7	**Carbon sequestration and storage**	Y	**Herbicide is anticipated to reduce NTTPs in-field (herbicidal action). Protection of NTTPs off-field conforms with current legal requirements. Application according to label dose and MRL. Standard nozzles.** Vapour drifts dependent on climatic conditions. Baseline drift. Traditional farming methods per country/crop (e.g. tillage).	Y (non-material change anticipated)	**Alternative weed control is anticipated to be spatially selective or to have a reduced impact on NTTPs in-field for some crops,** leading to higher NTTP density in-field (increased biomass, flower and seed generation = more carbon sequestered), and some gains off-field (although more limited; owing to drift reduction from lower herbicide application); impact of mechanical weed control on carbon storage (compaction) is anticipated, all other conditions/farming methods being equal. GHG emissions from mechanical weed control are anticipated.	Y (non-material change anticipated)	**Protection of off-field NTTPs anticipated via >95% drift reduction.** Greater NTTP biomass, flower and seed generation off-field anticipated to capture CO_2. Also wider buffer zones (= compensation), with NTTP gain anticipated relative to baseline.	Y (non-material change anticipated)	**Alternative weed control is anticipated to be spatially selective or to have a reduced impact on NTTPs in-field for some crops. Protection of off-field NTTPs anticipated via >95% drift reduction.** Reduced herbicide application (comparatively greater reduction than that of scenario 2) and drift reduction nozzles are anticipated to lead to higher NTTP in-field and off-field (increased biomass,	Scientific literature (average carbon sequestration and storage rates per type of habitat and anticipated changes owning to soil properties - pore space, and land management practices).	**N (non-material change in-field ES anticipated from variations in weed management)**	**N (non-material change off-field ES anticipated from variations in weed management)**

ES code	Ecosystem Service (ES)	Scenario 1 Minimum requirements (herbicide use)		Scenario 2 Weed reduction according to economical yield loss threshold scenario		Scenario 3 Minimum requirements scenario with further reduced drift exposure off-field		Scenario 4 Full protection of ES		Ecosystem data availability	Prioritised for assessment IN-FIELD (Y/N)	Prioritised for assessment OFF-FIELD (Y/N)
		Presence (Y/N)	Impact pathways	Change (Y/N)	Impact pathways	Change (Y/N)	Impact pathways	Change (Y/N)	Impact pathways			
									flower and seed generation = more carbon sequestered); impact of mechanical weed control on carbon storage (compaction) is anticipated. GHG emissions from mechanical weed control are anticipated.			
ES8	**Erosion prevention and maintenance of soil fertility**	Y	**Herbicide is anticipated to reduce NTTPs in-field (herbicidal action). Protection of NTTPs off-field conforms with current legal requirements. Application according to label dose and MRL. Standard nozzles.** Baseline erosion and soil fertility (fertilizer input remains constant across scenarios).	Y	**Alternative weed control is anticipated to be spatially selective or to have reduced impact on NTTPs in-field for some crops,** leading to higher NTTP density in-field (increased biomass), and some gains off-field (although more limited; owing to drift reduction from lower herbicide application), leading to fertility gains and reduced erosion are anticipated; however, these potential benefits may be offset by impacts of mechanical weed control on soil erosion and fertility (compaction), all other conditions/ farming methods being equal. The outcome will be dependent on the intensity	Y	**Protection of off-field NTTPs anticipated via >95% drift reduction.** Greater NTTP biomass, flower and seed generation off-field anticipated, all other conditions being equal, leads to increased soil organic matter levels and reduced erosion. Also wider buffer zones (compensation) anticipated, with NTTP gain relative to baseline.	Y	**Alternative weed control is anticipated to be spatially selective or to have reduced impact on NTTP in-field for some crops. Protection of off-field NTTPs anticipated via >95% drift reduction.** Reduced herbicide application (comparatively greater reduction than that of scenario 2) and drift reduction nozzles are anticipated to lead to higher NTTP in-field and off-field (increased biomass, flower and seed generation = greater soil organic matter	Soil monitoring data (Government databases/maps, research, etc.)	**Y**	**Y**

ES code	Ecosystem Service (ES)	Scenario 1 Minimum requirements (herbicide use)		Scenario 2 Weed reduction according to economical yield loss threshold scenario		Scenario 3 Minimum requirements scenario with further reduced drift exposure off-field		Scenario 4 Full protection of ES		Ecosystem data availability	Prioritised for assessment IN-FIELD (Y/N)	Prioritised for assessment OFF-FIELD (Y/N)
		Presence (Y/N)	Impact pathways	Change (Y/N)	Impact pathways	Change (Y/N)	Impact pathways	Change (Y/N)	Impact pathways			
					of the alternative weed control applied.				levels and reduced erosion); however, these potential benefits may be offset by impacts of mechanical weed control on soil erosion and fertility (compaction), all other conditions/ farming methods being equal. The outcome will be dependent on the intensity of the alternative weed control applied.			
ES9	**Moderation of extreme events**	Y	Context dependent: plant cover, root architecture, drainage and field and watercourse boundary management contribute to speeding up or slowing the movement of water across farmland at local level although these effects are masked at the catchment scale.	Y	Linked to soil erosion and sedimentation, which can block channels and increase flood risk. **Assessed as part of soil erosion (ES9) to avoid double counting.**	Y	Linked to soil erosion and sedimentation, which can block channels and increase flood risk. **Assessed as part of soil erosion (ES9) to avoid double counting.**	Y	Linked to soil erosion and sedimentation, which can block channels and increase flood risk. **Assessed as part of soil erosion (ES9) to avoid double counting.**	Flood risk databases, soil monitoring data	**N (to avoid double counting with soil erosion prevention and maintenance of soil fertility - ES9)**	**N (to avoid double counting with soil erosion prevention and maintenance of soil fertility - ES9)**
ES10	**Waste-water treatment**	Y	Baseline biological activity in activated sludge.	Y	Reduced herbicide use could have beneficial effects on soil microorganisms. **Assessed as part of soil fertility (ES9) to avoid double counting.**	Y	**Protection of off-field NTTPs anticipated via >95% drift reduction.** Emission reduction (greater than scenario 2 for off-field) could have beneficial	Y	**Alternative weed control is anticipated to be spatially selective or to have reduced impact on NTTP in-field for some**	Soil monitoring data (Government databases/maps, research, etc.). Ecotoxicity data from activated	**N (to avoid double counting with soil erosion prevention and maintenance**	**N (to avoid double counting with soil erosion prevention and maintenance**

ES code	Ecosystem Service (ES)	Scenario 1 Minimum requirements (herbicide use)		Scenario 2 Weed reduction according to economical yield loss threshold scenario		Scenario 3 Minimum requirements scenario with further reduced drift exposure off-field		Scenario 4 Full protection of ES		Ecosystem data availability	Prioritised for assessment IN-FIELD (Y/N)	Prioritised for assessment OFF-FIELD (Y/N)
		Presence (Y/N)	Impact pathways	Change (Y/N)	Impact pathways	Change (Y/N)	Impact pathways	Change (Y/N)	Impact pathways			
							effects on soil microorganisms. Also reduced exposure to fertilizers in-field anticipated owing to wider field margins. Reduced erosion anticipated owning to greater NTTP biomass, flowers and seed generation. **Assessed as part of soil fertility (ES9) to avoid double counting.**		**crops. Protection of off-field NTTPs anticipated via >95% drift reduction** Reduced herbicide application (comparatively greater reduction than that of scenario 2 and drift reduction nozzles could have beneficial effects on soil microorganisms and lead to higher NTTP in-field and off-field (greater soil organic matter levels and reduced erosion); impact of mechanical weed control on biological activity anticipated. **Assessed as part of soil fertility (ES9) to avoid double counting.**	sludge tests in dossier)	**of soil fertility - ES9)**	**of soil fertility - ES9)**
ES11	**Pollination**	Y	**Herbicide is anticipated to reduce NTTP in-field (herbicidal action). Protection of NTTPs off-field conforms with current legal requirements.** Baseline pollination.	Y	Greater biomass & flower and seed generation of NTTP to support pollinators is anticipated, possibly reduced support from the crop (in case of yield losses).	Y	Greater biomass & flower and seed generation of NTTP to support pollinators is anticipated.	Y	Greater biomass & flower and seed generation of NTTP to support pollinators is anticipated, possibly reduced support from the crop (in case of yield losses).	Data on distribution and abundance of pollinator species (country level, e.g. via voluntary recording societies)	**N (assessed as part of ES18 - Habitat for Species)**	**N (assessed as part of Habitat for Species)**

ES code	Ecosystem Service (ES)	Scenario 1 Minimum requirements (herbicide use)		Scenario 2 Weed reduction according to economical yield loss threshold scenario		Scenario 3 Minimum requirements scenario with further reduced drift exposure off-field		Scenario 4 Full protection of ES		Ecosystem data availability	Prioritised for assessment IN-FIELD (Y/N)	Prioritised for assessment OFF-FIELD (Y/N)
		Presence (Y/N)	Impact pathways	Change (Y/N)	Impact pathways	Change (Y/N)	Impact pathways	Change (Y/N)	Impact pathways			
ES12	**Biological control**	Y	**Herbicide is anticipated to reduce NTTPs in-field (herbicidal action). Protection of NTTPs off-field conforms with current legal requirements.** No IPM principles applied. Low level of baseline biological control.	Y	Natural enemies (soil dwelling predators as opposed to flying predators) anticipated	Y	Focus on ES production. The more NTTP, the better the anticipated distribution of the predators. In line with Scenario 1	Y	Natural enemies (soil dwelling predators as opposed to flying predators) anticipated	Farm business surveys, national statistics	**N (assessed as part of ES18 - Habitat for Species)**	**N (assessed as part of Habitat for Species)**
Cultural Services (non-material benefits people obtain from contact with ecosystems, including aesthetic, spiritual and psychological benefits)												
ES13	**Spiritual experience and sense of place (off-field)**	Y	**Existing crop and landscape**	Y (non-material change anticipated at landscape level but could have an impact on the availability of wild foods off-field)	Limited impact on the crop landscape anticipated, although it could have a higher value due to the addition of heterogeneous features. Increased NTTP biomass, flower and seed generation off-field owing to drift reduction from lower herbicide application <u>could increase sense of place value, however no changes at landscape level are anticipated</u>	Y (non-material change anticipate d at landscape level but could have an impact on the availability of wild foods off-field)	Limited impact on the crop landscape anticipated; increased biomass, flower and seed generation of NTTPs in-field and off-field <u>could increase sense of place value, however no changes at landscape level are anticipated</u>	Y (non-material change anticipated at landscape level but could have an impact on the availability of wild foods off-field)	Limited impact on the crop landscape anticipated; increased biomass of NTTP off-field <u>could increase sense of place value, however no changes at landscape level are anticipated</u>	Context specific - published and grey literature	**N (non-material change in in-field ES anticipated from variations in weed management)**	**N (non-material change in off-field ES anticipated; cultural identity and heritage value of wild foods foraged by local population and used in traditional cuisine assessed as part of wild foods, provisioning services to avoid double-counting)**
ES14	**Tourism**	Y	**Existing crop and landscape**	Y (non-material	Limited impact on the crop landscape anticipated, although it could have a	Y (non-material	Limited impact on the crop landscape anticipated; increased	Y (non-material	Limited impact on the crop landscape anticipated;	Tourism statistics at EU and country	**N (non-material change in in-**	**N (non-material change in off-**

ES code	Ecosystem Service (ES)	Scenario 1 Minimum requirements (herbicide use)		Scenario 2 Weed reduction according to economical yield loss threshold scenario		Scenario 3 Minimum requirements scenario with further reduced drift exposure off-field		Scenario 4 Full protection of ES		Ecosystem data availability	Prioritised for assessment IN-FIELD (Y/N)	Prioritised for assessment OFF-FIELD (Y/N)
		Presence (Y/N)	Impact pathways	Change (Y/N)	Impact pathways	Change (Y/N)	Impact pathways	Change (Y/N)	Impact pathways			
				change anticipated)	higher value due to the addition of heterogeneous features. Increased NTTP biomass, flower and seed generation off-field owing to drift reduction from lower herbicide application could increase value for agro-tourism and rural tourism, however not changes at landscape level are anticipated.	change anticipated)	biomass, flower and seed generation of NTTPs in-field and off-field could increase value for agro-tourism and rural tourism, however no changes at landscape level are anticipated.	change anticipated)	increased biomass of NTTP off-field could increase value for agro-tourism and rural tourism, however no changes at landscape level are anticipated.	level, published and grey literature	**field ES anticipated from variations in weed management)**	**field ES anticipated from variations in weed management)**
ES15	**Aesthetic appreciation and inspiration for culture, art, design**	Y	**Existing crop and landscape**	Y (non-material change anticipated)	Limited impact on the crop landscape anticipated, although it could have a higher value due to the addition of heterogeneous features. Increased NTTP biomass, flower and seed generation off-field owing to drift reduction from lower herbicide application could increase aesthetic and inspiration value for culture, art and design, however not changes at landscape level are anticipated.	Y (non-material change anticipated)	Limited impact on the crop landscape anticipated; increased biomass, flower and seed generation of NTTPs in-field and off-field could increase aesthetic and inspiration value for culture, art and design, however not changes at landscape level are anticipated.	Y (non-material change anticipated)	Limited impact on the crop landscape anticipated; increased biomass of NTTP off-field could increase aesthetic and inspiration value for culture, art and design, however not changes at landscape level are anticipated.	Published and grey literature, local cultural data	**N (non-material change in in-field ES anticipated from variations in weed management)**	**N (non-material change in off-field ES anticipated from variations in weed management)**
ES16	**Recreation and mental and physical health**	Y	**Existing crop and landscape**	Y (non-material change anticipated at landscape level but could have	Limited impact on the crop landscape anticipated, although it could have a higher value due to the addition of heterogeneous features. Increased NTTP biomass, flower and seed generation off-field owing to drift reduction from	Y (non-material change anticipate d at landscape level but could have	Limited impact on the crop landscape anticipated; increased biomass, flower and seed generation of NTTPs in-field and off-field could increase recreational, mental and physical health value,	Y (non-material change anticipated at landscape level but could have	Limited impact on the crop landscape anticipated; increased biomass of NTTP off-field could increase recreational, mental and physical health value, however not changes	Published and grey literature, local recreation and visitor surveys; see Wild Foods above.	**N (non-material change in in-field ES anticipated from variations in weed management)**	**N (recreational value of wild foods foraged by local population and recreational users assessed as part of wild**

ES code	Ecosystem Service (ES)	Scenario 1 Minimum requirements (herbicide use)		Scenario 2 Weed reduction according to economical yield loss threshold scenario		Scenario 3 Minimum requirements scenario with further reduced drift exposure off-field		Scenario 4 Full protection of ES		Ecosystem data availability	Prioritised for assessment IN-FIELD (Y/N)	Prioritised for assessment OFF-FIELD (Y/N)
		Presence (Y/N)	Impact pathways	Change (Y/N)	Impact pathways	Change (Y/N)	Impact pathways	Change (Y/N)	Impact pathways			
				an impact on the availability of wild foods off-field)	lower herbicide application could increase recreational, mental and physical health value, however not changes at landscape level are anticipated.	an impact on the availability of wild foods off-field)	however not changes at landscape level are anticipated.	an impact on the availability of wild foods off-field)	at landscape level are anticipated.			**foods, provisioning services, to avoid double-counting)**
Habitat or supporting services (underpin almost all other services. Ecosystems provide living spaces for plants or animals; they also maintain a diversity of different breeds of plants and animals)												
ES17	**Maintenance of genetic biodiversity**	Y	The assessment focuses on one crop cycle. **Herbicide is anticipated to reduce NTTPs in-field (herbicidal action). Protection of NTTP off-field conforms with current legal requirements.** Baseline biodiversity	Y	Greater number of species of NTTP can lead to increased genetic biodiversity. **Assessed as part of habitat for species (ES19) as a proxy.**	Y	Greater number of species of NTTP can lead to increased genetic biodiversity. **Assessed as part of habitat for species (ES19) as a proxy.**	Y	Greater number of species of NTTP can lead to increased genetic biodiversity. **Assessed as part of habitat for species (ES19) as a proxy.**	Published and grey literature	**N (ES18 - Habitat for species, used as a proxy)**	**N (ES19 - Habitat for species, used as a proxy)**
ES18	**Habitat for species (functioning of ecological components of the agro-ecosystem)**	Y	The assessment focuses on one crop cycle. **Herbicide is anticipated to reduce NTTPs in-field (herbicidal action). Protection of NTTP off-field conforms with current legal requirements.** Baseline habitat services	Y	Greater number of species of NTTP can lead to increased habitat value.	Y	Greater number of species of NTTP can lead to increased habitat value.	Y	Greater number of species of NTTP can lead to increased habitat value.	Published and grey literature, land cover data (for example, *Felix Herzog, Philippe Jeanneret, Youseff Ammari, Siyka Agelova, Michaela Arndorfer, et al. 2013. Measuring farmland biodiversity. Solutions, vol. 4(N 4), pp.52-58)*	**Y This service is used as a proxy for pollination (ES11), biological control (ES10) and maintenance of genetic biodiversity (ES17)**	**Y**

The prioritised ecosystem services were assessed in the crop production case studies (Section 3). It is noted that the baseline level of service provision and magnitude of change are context-dependent (i.e. landscape and specific crop e.g. arable crop vs. perennial crop) and will vary across the case studies, therefore, as previously noted not all the prioritised ecosystem services will be equally relevant for all the crops and off-field settings. Indeed, some ecosystem services may not be relevant or change little when applied to other contexts; however, this shortlist of prioritised ecosystem services provides the starting point.

Subsequent assessments should validate this shortlist through a context-specific screening and justify the final prioritisation of ecosystem services, documenting the reasons for screening further ecosystem services out. However, as noted above, data gaps should not be a justification for screening out an ecosystem service if material changes are anticipated.

2.3.2 Specific Protection Goals

An aim of this project is to operationalise an ecosystem services approach for decision-making as part of Environmental Risk Assessment. The EFSA and others (e.g. TEEB) recognise that ecosystem services are complex and challenging when measuring directly. To make these frameworks usable and drive towards quantitative assessment, indicators and metrics that are measurable are generally used as proxies for ecosystem services. The 'operational goal' these measures are compared against are referred to as Specific Protection Goals (SPGs). For each prioritised ecosystem service and associated service providing unit (SPU), preliminary quantitative SPGs, indicators and metrics were defined for in-field and off-field land uses and considered the following:
- Legal frameworks and guides (e.g. SPGs from EU Regulations/Directives, EFSA guidance documents, workshops, publications)
- Ecological characteristics of the SPUs and the surrounding environment
- SPG dimensions from the EFSA guidance

The framework proposes a comprehensive list of indicators and relevant data sources. Subsequent assessment should select the most appropriate indicators based on data availability. Refer to Table 2.3 for an overview of SPGs, indicators and metrics.

The interpretation of SPG dimensions as defined by EFSA is as follows and in Table 2.3:
- Ecological entity to protect
  a. Ecosystem service provision (measured through indicators)
- Attribute to protect
  a. For population of SPUs: survival, growth, reproduction, abundance, biomass, genetic biodiversity
  b. For habitat SPU: habitat structure
- Magnitude of relevant events
  a. No change, minor (negligible to small), moderate (medium to large), major
- Temporal scale of effects
  a. Crop cycle
- Spatial scale of the effect
  a. In-crop, in-field but off-crop, off-field, landscape, watershed, region
- PPP application frequency varies across scenarios (crop-dependent) and needs to be defined on a case-by-case basis.

In this project, SPG attributes have been qualitatively defined. The magnitude of SPG effects for each category is anticipated to vary based on crop and landscape context and should be quantitatively defined on a case-by-case basis.
The following policies were considered for the definition of SPGs:
- EU Common Agricultural Policy (CAP)
- EU Bioeconomy Strategy
- EU Soil Thematic Strategy Soil
- EU Drinking Water Standards (DWS)
- EU Water Framework Directive (WFD)
- EU Biodiversity Strategy to 2020

- No Net Loss Initiative
- UK Biodiversity Net Gain (with ambition to extend to Environmental Net Gain)
- EU & MS Air Quality Standards
- Kyoto Protocol (LULUCF)

The policy map is evolving and recent developments include a new European Farm to Fork Strategy. The strategy is at the heart of the European Green Deal aiming to make food systems fair, healthy and environmentally-friendly. Its aims are to accelerate our transition to a sustainable food system in the following ways:

- have a neutral or positive environmental impact
- help to mitigate climate change and adapt to its impacts
- reverse the loss of biodiversity
- ensure food security, nutrition and public health, making sure that everyone has access to sufficient, safe, nutritious, sustainable food
- preserve affordability of food while generating fairer economic returns, fostering competitiveness of the EU supply sector and promoting fair trade

These principles for sustainable crop production underpin this SPG framework. Testing of the SPG framework was conducted on UK winter wheat production (refer to Section 3.3):

1. Assessment and definition of SPU and quantification of ecosystem services flows (i.e. level of ecosystem service provision) in the baseline (minimum requirements scenario)
2. Assessment and quantification of changes in SPU (NTTP and other organisms) and ecosystem services flows in the different Weed control scenarios relative to the baseline (minimum requirements scenario)
3. Description of ecosystem services to show trade-offs

Table 2.3 Proposed in-field and off-field specific protection goals

ES code	Ecosystem Service (ES)	ES Indicators	Index or metric	In-field SPG (gain or loss)	Off-field SPG (gain or loss)	Legal Requirement	Summary of SPG Attributes: Ecological entity to protect	Attribute to protect	Scale: Magnitude of effects	Scale: Temporal scale of effects	Scale: Spatial scale of effects	PPP application frequency
Provisioning Services (ES that describe the material or energy outputs from ecosystems, including food, water and other resources)												
ES1a	**Food (in-field crop production)**	– Yield (food security) – Quality for fresh produce influence of quality on price is reflected in Socioeconomic Analysis (SEA)	Crop yields (ton/ha; ton dry matter/ha; MJ/ha) Quality (tons per class) Crop area, buffer zone and margin	~ No net loss in yield (marginal contribution to food security); ~ No loss in crop quality associated with the application of herbicides	n/a	Various policy instruments, including PPP legislation, CAP and EU Bioeconomy Strategy; Regulation EC 1107/2009 – sustainable use of PPPs; economic value of production and market value of crop; quality thresholds for some crops.	In-field food production (population)	Crop yield (biomass)	Negligible to small	Whole year	In crop Region/ continent	Crop dependent
ES1b	**Raw materials (in-field)**	– Yield (fuel security) – Quality for fuel - influence of seed contamination on price is reflected in SEA	Crop yields (ton/ha; ton dry matter/ha; MJ/ha) Quality (% of weed seed contamination) Crop area, buffer zone and margin	~ No net loss in yield (marginal contribution to energy security); ~ No loss in raw material quality associated with the application of herbicides	n/a	Renewable Energy Directive (EU) 2018/2001	In-field raw material production (population)	Crop yield (biomass)	Negligible to small	Whole year	In crop Region/ continent	Crop dependent
ES2	**Wild foods (off-field)**	Availability of wild foods	Area or plant cover of indicator species used as a proxy for harvested quantities, unless data is available for most commonly foraged wild foods in each area (kg collected or traded)	n/a	No net loss on wild foods associated with the application of herbicides	None	Off-field populations of wild food species	Wild food species survival, NTTP biomass (and reproduction for scenario 4)	Negligible to small	Weeks to months for survival and biomass, season for reproduction	Field margin to nearby off-crop	Crop dependent

ES code	Ecosystem Service (ES)	ES Indicators	Index or metric	In-field SPG (gain or loss)	Off-field SPG (gain or loss)	Legal Requirement	Summary of SPG Attributes					
							Ecological entity to protect	Attribute to protect	Scale			PPP application frequency
									Magnitude of effects	Temporal scale of effects	Spatial scale of effects	
ES3	**Freshwater (groundwater)**	Groundwater quality (drinking water resource)	Groundwater impact or risk index; failures of the European Drinking Water Standard (groundwater monitoring data)	No deterioration of drinking water standards (WFD status) associated with the application of herbicides	No deterioration of drinking water standards (WFD status) associated with the application of herbicides	Directive 2000/60/EC (Water Framework Directive) Council Directive 98/83/EC of 3 November 1998 (Drinking Water Directive) Directive 2009/128/EC (Sustainable Use of Pesticides)	In-field and off-field NTTPs populations that contribute to the infiltration of stormwater runoff and regulation of ground water quality	NTTP survival, biomass (and reproduction for scenario 4) as indicators for population health	As above	As above	Field to watershed	Crop dependent
ES4	**Freshwater (surface water)**	Surface water quality and reduction of aquatic plants;	Surface water risk index, EQS failures (field monitoring data or aquatic plant growth in ecotoxicity tests)	No exceedance of maximum allowed concentration in ditches and deterioration of WFD status in large water body associated with the application of herbicides	No exceedance of maximum allowed concentration in ditches and deterioration of WFD status in large water body associated with the application of herbicides	Directive 2000/60/EC (Water Framework Directive) Council Directive 98/83/EC of 3 November 1998 (Drinking Water Directive) Directive 2009/128/EC (Sustainable Use of Pesticides)	In-field and off-field NTTPs populations that regulate flow and stormwater runoff quality. Also, NTTP populations in off-field aquatic habitat (runoff).	NTTP survival, biomass (and reproduction for scenario 4) as indicators for population health	As above	As above	Field to watershed	Crop dependent

ES code	Ecosystem Service (ES)	ES Indicators	Index or metric	In-field SPG (gain or loss)	Off-field SPG (gain or loss)	Legal Requirement	Summary of SPG Attributes: Ecological entity to protect	Attribute to protect	Scale: Magnitude of effects	Temporal scale of effects	Spatial scale of effects	PPP application frequency
Regulating Services (services that ecosystems provide by acting as regulators e.g. regulating the quality of air and soil or by providing flood and disease control)												
ES8	**Erosion prevention and maintenance of soil fertility**	Plant cover and rooting linked to soil erosion prevention, soil erosion vulnerability, soil loss	Index relating to soil erosion prevention provided by agro-ecosystem Total amount of soil retained (ton ha^{-1} $year^{-1}$) Percentage of soil covered in cropland, zero tillage, winter crops, cover crop or intermediate crop, plant residues Density of hedgerows Soil health index relating to the five[1] overarching parameters indicative of soil fertility, including; general biodiversity, microbial biomass and activity, plant growth, soil fauna and soil physical/chemical assessment Soil loss rates in arable land (t ha^{-1} yr^{-1}) Very low (<1) Low (1-2) Moderate Low (2-5) Moderate (5-10) Moderate high (10-20) High (<20)	No net increase in soil erosion rates No net loss in soil organic matter (SOC) No decline in soil health index No net increase in soil compaction	No net increase in soil erosion rates No net loss in soil organic matter (SOC) No decline in soil health index No net increase in soil compaction	Soil Thematic Strategy and Proposed Soil Framework Directive; various legislative acts at MS level	In-field and off-field NTTPs that reduce soil erosion and promote soil fertility.	NTTP survival, biomass (and reproduction for scenario 4) as indicators for population health NTTPs contribution to soil fertility (organic carbon, soil structure); consider also impact of soil compaction from mechanical weed control	Negligible to small	Weeks to months for survival and biomass; season for reproduction	Field margin to nearby off-crop	Crop dependent
Habitat or supporting services (underpin almost all other services. Ecosystems provide living spaces for plants or animals; they also maintain a diversity of different breeds of plants and animals)												
ES18	**Habitat for species (functioning of ecological components of**	NTTPs as habitat and food for herbivores (bees), predators (spiders) and detrivores (earthworms) Farm composition (plot/patch	**Species diversity indicators:** Number and amount of vascular plant species. Indicators should be expanded to be more representative of the whole	Biodiversity net gain	Biodiversity net gain	EU Biodiversity strategy to 2020 & No Net Loss Initiative UK Biodiversity Net Gain (with	NTTPs populations that provide habitat and food for species	NTTP survival, biomass (and reproduction for	Moderate to large in-field Negligible to small effects at the edge of	Weeks to months for survival and biomass; season for reproduction	Field margin to nearby off-crop	Crop dependent

ES code	Ecosystem Service (ES)	ES Indicators	Index or metric	In-field SPG (gain or loss)	Off-field SPG (gain or loss)	Legal Requirement	Summary of SPG Attributes					
							Ecological entity to protect	Attribute to protect	Scale			PPP application frequency
									Magnitude of effects	Temporal scale of effects	Spatial scale of effects	
	the agro-ecosystem)	type and geometry) Indicators for species diversity and habitat diversity (interpretation is contextual: higher percentage of shrubs implies more biodiversity on intensive farms, but abandonment on extensive farms)	habitat, pollination ES and biological control ES. For species indicators these may include diversity and abundance of wild bee and bumblebee species; invertebrates, herbivorous birds, etc.; and for biological control ES, could be yield loss due to pest (tn/ha). **Habitat diversity indicators:** Habitat impact index, habitat richness, habitat diversity, average size of habitat patches, length of linear elements; crop richness, percentage of farmland with shrubs, percentage of farmland with trees			ambition to set Environmental Net Gain) Directive 2009/128/EC (Sustainable Use of Pesticides)		scenario 4) as indicators for population health	the field/field margin			

2.4 Definition of social and economic impacts

The objective of the IA Framework is to include all significant intended and unintended environmental, social and economic impacts from a change in specific protection goals based on the associated changes in farming practice. PPPs are applied to protect plant health with the intention of safeguarding the quality and yield of the products to be harvested. Application of PPPs has by consequence direct economic impacts (Wesseler and Smart, 2014), but it can also impact the health of the applicant and bystanders (Beckmann and Wesseler, 2003; Rola and Pingali, 1993) and/or the consumer eating the products containing PPP residues (Fleischer and Waibel, 1998). Therefore, indirect impacts on human health and direct economic impacts should be included in an assessment.

Regarding the economic impacts, in this proof-of-concept study we limit the framework to the costs and revenues affected by adjustment of the crop protection toolbox. We have therefore included the following direct intermediate effects:

- Changes in costs
  - PPPs applied (price and quantity, based on composition of PPP mix and volumes to be applied)
  - Labour applied in weed control
  - Capital costs, i.e. costs for machinery and equipment
  - Change in the amount of land used for crop production
- Changes in revenues
  - Crop quality, reflected by adjustment of the price
  - Yield reduction compared to the minimum requirements scenario
  - Change in the amount of land used for crop production

Impacts should be calculated as relative change in costs and relative change in revenues compared to the minimum requirements scenario.

Regarding impacts on human health, we assume that applying PPPs according to the rules laid down in existing regulation (Scenario 1, the minimum requirements scenario) will not affect the health of users, bystanders and consumers.

Another social impact addressed is change in employment levels, e.g. due to the shift from chemical weed control to mechanical weeding. Change in employment has been measured in terms of changes in labour input.

3 Application of the Impact Assessment Framework on case study crops

3.1 The questionnaire

In order to enable testing through application of the IA framework in practice by experts in weed control in specific crops, we developed a questionnaire in Excel. The questionnaire contains four sheets aimed at collecting detailed information on farming practices for a given crop/country case study (see Appendix 2).

The first sheet contains generic questions. The main objective of this section is to get a good understanding of the context (cultivation, landscape, farm structure, etc.) in which the case study is executed. The main topics are indication of the case crop, the location, description of the landscape, the land use, description of the farm structure, field margins, applied machinery, description of the main crops and fields and the applied crop protection strategy.

In the second sheet, we zoom into applied weed control strategy. We ask for a description of the herbicides applied, the machinery used and the relative share of labour hours spent on weed control. Furthermore, we ask for a description of all non-crop plant species present in-field and off-field, making a distinction between weeds (affecting yield and/or quality) and Non-Target Terrestrial Plants (NTTPs) which do not harm to crop production. We conclude this sheet with questions describing the weed control measures in greater detail, such as method of weed control, frequency, timing, etc.

In the third sheet, we pay attention to elaboration of all four scenarios, with respect to the applied weed control measures and the social and economic impacts. The minimum requirements scenario can be considered a realistic worst-case scenario to fit the purpose of the risk assessment. The minimum requirements scenario does not necessarily reflect common practice. Indeed, in the minimum requirements scenario we refer to the legal baseline from regulation (EC) No 1107/2009, whereas the weed control strategies applied in reality by farmers are more diverse than the use of a single herbicide, in line with integrated pest management approaches (EU legal requirement since 2014). For all four scenarios, the expert was asked to describe adjustments in the applied weed control measures, the intermediate effects, and differences between the scenarios. The final questions relate to social and economic impacts.

In the fourth sheet, the consequences of all scenarios in a subset of the prioritised ecosystem services (refer to Table 2.2 above) are assessed. The subset contains wild foods (ES2), fresh water (ground water, ES3), fresh water (surface water, ES4), erosion prevention and maintenance of soil fertility (ES8) and habitat for species (functioning of ecological components of the agro-ecosystem, ES18). Information on the other prioritised ecosystem service, food provisioning (ES1), was collected in previous sheets and thus a decision was made to not duplicate the information here. The questions address if those ecosystem services are present in the farm investigated in each specific case, and if they are, whether they will be affected by the applied weed control measures. Due to constraints in time, expertise and data, the experts were asked to provide qualitative answers.

To facilitate information, explanatory sheets were also added to assist with the completion of the questionnaire. One sheet contains further explanations about the scenarios. Another sheet contains a simplified CSM to visualise in-field and off-field land uses, such as field boundaries and margin strips. This sheet has been added to support consistency in the understanding of the separation between in-field and off-field situation. The last sheet provides the opportunity to add supplementary information e.g. climatic data per month, if this information contributes to the explanation of the selected alternative weed control measures.

3.2 Case studies

3.2.1 Selection and execution

In order to get a good understanding of how the IA framework can be applied, and what the environmental, social and economic impacts are from shifting to alternative scenarios, we have chosen several case studies that are diverse with respect to their growing system, cultivation duration, herbicide use, harvested product and geographic spread. Each case study refers to a particular crop. In all these crops, weed control plays an important role varying from direct competition with the crop for water, light and nutrients in crops like wheat, to prevention of frost damage in fruit production. We selected four commodities and three horticultural crops important in the EU, and their respective main countries of cultivation. Afterwards, we selected the countries where the cultivation of this crop is of considerable importance. Then we also considered variation across regions. Finally, we chose the crop and country combination: one crop in Scandinavia, two crops in northwest Europe, one crop in eastern Europe and two crops in southern Europe. This has led to the selection of case studies as presented in Table 3.1.

Table 3.1 *Overview of case studies*

Case crop	Country	Zone (EU)	Zone (project)	Region (off-field habitat)
Maize	France	South	South	Dijon
Onions	Poland	Mid	East	Central Poland
Oil Seed Rape	Sweden	North	North	Southern Sweden
Ware potato	Netherlands	Mid	Northwest	Flevoland
Apple orchard	Italy	South	South	Sud-Tirol
Winter wheat	UK	Mid	Northwest	South East England

The questionnaires relating to the crop case studies were answered by local experts. These local experts were selected from our professional networks, which are mainly employed by research institutes with focus on agriculture in general or on specific areas of agriculture (see Appendix 3 for an overview). After sending off the questionnaire (in the form of an excel file), the local experts were provided with more detailed explanations and instructions during a Skype meeting with members of the project team. During the execution of the case study questionnaire, the local expert was able to contact the responsible team member for additional guidance. This occurred in some of the case studies. After submission of the filled-in questionnaire to the team member, the team member assessed the answers and asked for clarification or additions. The revised questionnaires were discussed during meetings of the project team. Afterwards, the local experts were also asked to fill in an evaluation form about the working process, etc.

In some cases (onions (Poland), oilseed rape (Sweden) and maize (France)), experts in agronomy employed by companies that are members of the ECPA were asked to review the filled-in questionnaires. This led to some additional information, but did not result in adjustments of the analyses.

The winter wheat case study in the UK has been elaborated in greater detail in order to explore quantitative application of the Framework. The expected environmental impacts have been quantified, applying the indicators as presented in Table 2.3 and making use of statistical data. The approach and the results are presented in Section 3.3.

3.2.2 Applicability

The finalised questionnaires were assessed by the responsible project team member. The assessment related to the correctness of interpretation as evidenced by adequacy of the answers and the level of detail.

In general, the answers showed that the local experts had in general a good understanding of the objectives of the project, and of the case study in particular, although there were some gaps in the knowledge of ecosystem services. A comparison of the case studies showed some key differences in interpretations, such as the distinction between weeds and NTTPs in-field, although the differences were described. In other words, in some case studies, almost all non-crop plants were considered as weeds by the local expert, whereas in other cases, a wider variety of plant species were considered as NTTPs. Another difference was observed regarding the interpretation of the scenarios. Compared to the minimum requirement scenario, Scenario 2 emphasises further protection of NTTPs in the in-field situation, whereas Scenario 3 emphasises further protection of the plants off-field. In one case (oilseed rape, Sweden), the adjustment of the weed control toolbox did not show the requested difference. Scenario 2 and 3 could be interpreted as interpolation between Scenario 1 (the minimum requirements scenario) and Scenario 4 (full protection scenario), with Scenario 2 closer to Scenario 1 and Scenario 3 closer to Scenario 4.

The level of detail of the answers was sufficient to test the IA Framework. Most local experts provided all information requested in a clear and straightforward manner. So the information density is adequate for further analyses. In a few cases, qualitative information was provided where quantitative figures were asked (e.g., % cost reduction) but still provide an insight into the direction of change.

3.2.3 Results

In Table 3.2, the results of all six case studies have been summarised. The following information is needed for a correct interpretation of this table. Variables listed in rows are as follows:

1. The way weed control is applied, distinguishing between herbicide use and alternative methods
2. Social impacts, with special attention to labour input (employment)
3. Economic impacts at farm level, with special attention to labour costs, machinery costs, yield and price effects
4. Environmental impacts, including the ecosystem services prioritised for assessment based on the anticipated material changes in service provision and the potential for change across scenario (refer to Section 2.3.1)
   a. Food (ES1)
   b. Wild Food (ES2)
   c. Fresh water (ground water, ES3)
   d. Fresh water (surface water, ES4)
   e. Soil Fertility (ES8)
   f. Habitat for wild species (ES18)

The six case studies (crop and country) are listed in columns. In the table we present the results as estimated by the local experts who answered the questionnaire by making a comparison of Scenario 2 (increased in-field protection of non-target terrestrial plants), Scenario 3 (focus on an increased protection of off-field non-target terrestrial plants) and Scenario 4 (optimising the protection of ecosystem services in-field and off-field) relative to Scenario 1 (minimum requirements scenario), which served as reference scenario. The environmental impacts of the winter wheat case study are not presented in Table 3.2, as no responses were provided by the UK expert. However, this case study has been elaborated in more detail and quantitative results are presented in Section 3.3. Finally, we have used colours to indicate the impacts. Red text implies negative impacts and green text implies positive impacts, whereas the black text refer to no impact.

When we compare the scenarios, we find the following observations:

- The change in the protection goals both in-field and off-field leads to a reduction of pesticide use up to 100% in Scenario 4 and a mix of weed control technologies. Little attention is paid to alternative measures in-field that differentiate between weeds and NTTPs, although applying precision technology can control weeds at places with a high weed density saving NTTPs. It is theoretically also possible that this distinction could be applied during hand weeding (mainly applied in Scenario 4), but it has not been reported by the experts. It would require hand weeding with the help from skilled botanists and trained growers, which does not reflect the reality of the practice and of the costs of weed management.

- Greater in-field protection of NTTPs (as per Scenarios 2 and 4) leads to increased labour input in weed control measured in work hours, up to an increase of 150% in the most stringent scenario, such as Scenario 4 (full protection of ES) for apple cultivation in Italy.
- Regarding the economic consequences, we see in most case studies a reduction in yield (%) in Scenarios 2, 3 and 4 (generally between 10 and 30%), with the highest reduction (up to 50%) in the most stringent scenario (full protection of ES). The yield reduction is caused by competition of weeds with the crop for resources, such as water, light and nutrients. The only exception to yield reduction is potato in The Netherlands. There was a low weed pressure and good soil fertility in this case study. Moreover, the use of advanced digital farming tools (e.g. spot spraying of the herbicides based on camera views) is already a common practice in this case study, so that no mechanical weed control was needed as an alternative to herbicide use to enable meeting even the most stringent protection goals. Therefore, the change in weed control practice did not have a large impact on yields. Furthermore, in most case studies, increase in machinery costs (up to +20%) is reported.
- When we look at the qualitative changes in the Ecosystem Services (environmental impacts), we expect some positive effects in scenarios protecting NTTPs, regarding providing habitat for wild species, such as bees and pollinators, birds and mammals in the cases of maize, potato and apple production, both in-field and off-field. However, we also see additional potential risks for ecosystem services. The shift from herbicide application to only mechanical weed control can increase the risk of loss of soil fertility through increased tillage and the risk of erosion through harrowing. A mix of weed control technologies is preferred.

Table 3.2 *Overview of results of the case studies: impacts of adjusted weed control measures according to Scenarios 2, 3 and 4 (Scenario 1 is used as the reference for comparison)**

Category	Variables	Maize, France	Onions, Poland	Oilseed rape, Sweden	Potato, The Netherlands	Apple, Italy	Winter wheat, UK
Weed control	Herbicide use and alternative weed control	1: two times herbicide use: pre and post emergence 2: one time herbicide use, one pass hoeing 3: one time herbicide use with anti-drift nozzles and 2 m buffer zone; 4: tine harrowing pre-emergence, hoeing post-emergence	1: three to five times herbicide use. 2: reduced herbicide use, hoeing, hand weeding 3: reduced herbicide use, hoeing, hand weeding, burning 4: no herbicide use, hoeing, hand weeding, burning	1: four to five treatments 2: two to three treatments, soil cultivation, row hoeing, weed harrowing; 3: two to three treatments, soil cultivation, row hoeing, weed harrowing; 4: no herbicide use, soil cultivation before sowing and hand weeding	1: One treatment with herbicides 2: Reduced herbicide use, due to band spraying 3: Reduced herbicide use, due to no spraying on outer rows 4: Reduced herbicide use due to camera patch spraying	1: 4 times herbicide use 2: reduced herbicide use; mowing in the rows and along the rows 3: reduced herbicide use; mowing in the rows and along the rows, the outer 5 m of the orchard is not sprayed. 4: no herbicide use, mowing in the rows and along the rows, periodic soil tillage	1: three times herbicide use 2: reduced herbicide use due to patch spraying linked to weed mapping 3: reduced herbicide use due to adjusted nozzles; 4: single application pre-emergence, in-crop mechanical weeding
Social impacts	Employment	2,3,4: higher labour input due to mechanical weeding	2,3,4: higher labour input especially due to hand weeding	In scenario 2,3, and especially 4: higher labour input	In scenario 2 and 4; up to 5% increased labour input compared to scenario 1 (and 3)	In scenario 2,3,4: higher labour input up to 150% in scenario 4.	4: higher labour input
Economic impacts	Change in labour costs	2,3,4: increased costs due to hoeing and tine harrowing	In scenario 2: +10-15% In scenario 3: +5% In scenario 4: +15-25%	In scenario 2: +5-10% In scenario 3: +20-25% In scenario 4: +30-40% or more	In scenario 2 and 4; up to 5% increased labour costs compared to scenario 1 (and 3)	In scenario 2: +50% In scenario 3: +35% In scenario 4: +150%	4: could be higher
	Change in machinery costs	2,3,4: no data	In scenario 2: +10% In scenario 3: +5% In scenario 4: +20%	In scenario 2: +5-10% In scenario 3: +10-20% In scenario 4: +30-40%	No data	In scenario 2: +10% In scenario 3: +10% In scenario 4: +20%	2,4: higher costs
	Yield	2,3: 10% yield reduction 4: 30-50% yield reduction	In scenario 2: -5% **In scenario 3: 0%** In scenario 4: -10%	In scenario 2: -5-10% In scenario 3: -10-20% In scenario 4: -35%	No change	**In scenario 2: 0%** In scenario 3: -5% In scenario 4: -5-10%	2,3,4: reduction up to 30% in 4
	Price reduction (related to lower quality of yield)	No difference in price between scenarios	No difference in price between scenarios	Yes, up to 35% in scenario 4 due to decreased quality	No change	No change	Yes, up to 30% due to decreased quality
Environ-mental impacts	Food (in-field crop production (ES1)	Refer to yield reduction above	Refer to yield reduction above	Refer to yield reduction above	Refer to yield reduction above	Refer to yield reduction above	Refer to yield reduction above
	Wild foods (ES2)	No data for all scenarios	In Scenario 1 wild foods have no value because of residues; in Scenario 2,3 and 4 they have value for human consumption	No impact, since in most cases berries, if present, will not be picked	No change	No impact in all four scenarios	See section 3.3 for case study
	Fresh water groundwater (ES3)	In scenario 1,2: impact of herbicide use on groundwater expected; in scenario 3,4: no impact expected	In all four scenarios no impact on ground water expected	No data	No data	No data	

Category	Variables	Maize, France	Onions, Poland	Oilseed rape, Sweden	Potato, The Netherlands	Apple, Italy	Winter wheat, UK
	Fresh water surface water (ES4)	In scenario 1,2: emission of herbicides due to drift possible 3,4: less impact of herbicide use expected, but turbid water following rainfall possible	The impact on fresh surface water reduces increasingly moving from scenario 1 to 3 to 2 to 4, in which it has the lowest impact.	No data	In Scenario 1 and 2, pollution through evaporation can occur; in Scenario 3 and 4 no impact	It is expected that the reduced herbicide use in scenario 2 and 3, and the additional measures in scenario 3 reduce the likelihood of contamination of the surface water.	
	Soil quality (ES8)	In scenario 3,4: increased risk of erosion compared to scenario 1 and 2	Impact expected in scenario 2 and 4, although not specified	In scenario 2 and 3, there is an increased risk of erosion due to hoeing	No difference compared to scenario 1	2,4: possible loss of soil organic matter due to tillage	
	Habitat for wild species (ES18)	3,4: improved habitat compared to scenario 1 and 2 because of presence of more plant species	No specific impacts for the scenarios have been reported	No data	Negligible impact on habitat expected	2, 3 and 4 improvement of habitat expected because of presence of more plant species	

*Scenario 1: Minimum requirements scenario, Scenario 2: Weed reduction according the economical yield loss threshold scenario, Scenario 3: Minimum requirements scenario with focus on off-field, Scenario 4: Full protection of ecosystem services (ES). Colours: Green: Impact more positive compared to Scenario 1; Red: Impact more negative compared to Scenario 1; Grey: no difference in impact with Scenario 1; yellow: no or insufficient data

In summary, according to the opinion of the local experts, a more stringent policy aimed at the protection of NTTPs (especially in-field) would result in reduced herbicide use and increased mechanical weed control. Weed control methods, both chemical or mechanical, often do not differentiate between weeds and NTTPs. Both weeds and NTTPs present in-field and off-field take profit from the reduced pesticides. However, both weeds and NTTPs will be removed at the places where weed control is applied. Thus, replacing one weed control method by another will not enable the establishment of in-field non-crop plants over longer periods. Application of a more stringent policy will have negative economic consequences from the farmer's perspective (lower yield, higher costs), unless compensation is offered for NTTP conservation and for the provision of ecosystem services that support farm productivity (e.g. soil health, water retention), and both positive and negative consequences for those priority ecosystem services identified. The increased labour input could also deliver social benefits from more jobs or more pay for workers. However, since these findings are first estimates of local experts, more investigation is necessary to study the effects on ecosystem services in more detail.

3.3 UK Winter Wheat Case Study

Winter wheat is an important arable crop in the UK, comprising 1,823,336 hectares and 44% of the area of all arable crops grown in 2016 (UK Pesticide Usage Survey (PUS), 2018). Data from the survey reported the primary reasons for herbicide use were control of general weeds (no single species dominates), black grass and broad-leaved weeds (PUS, 2018). Only 0.3% of wheat area is untreated. The most extensively used herbicide formulation contained glyphosate, and a broad-spectrum herbicide is used as an example in this case study for the quantitative assessment of impacts on ecosystem services delivery. These data reflect UK specific herbicide usage and may not be reflective of other countries (highlighting the importance of geographical context in these assessments).

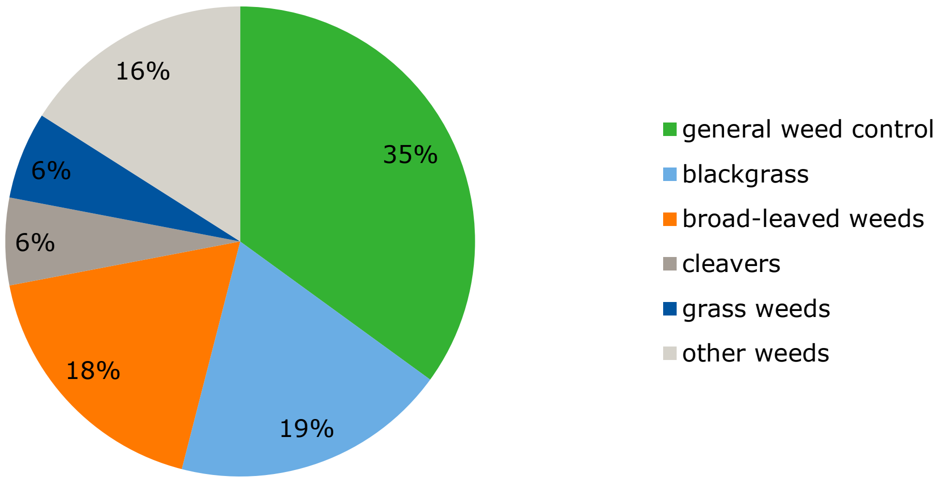


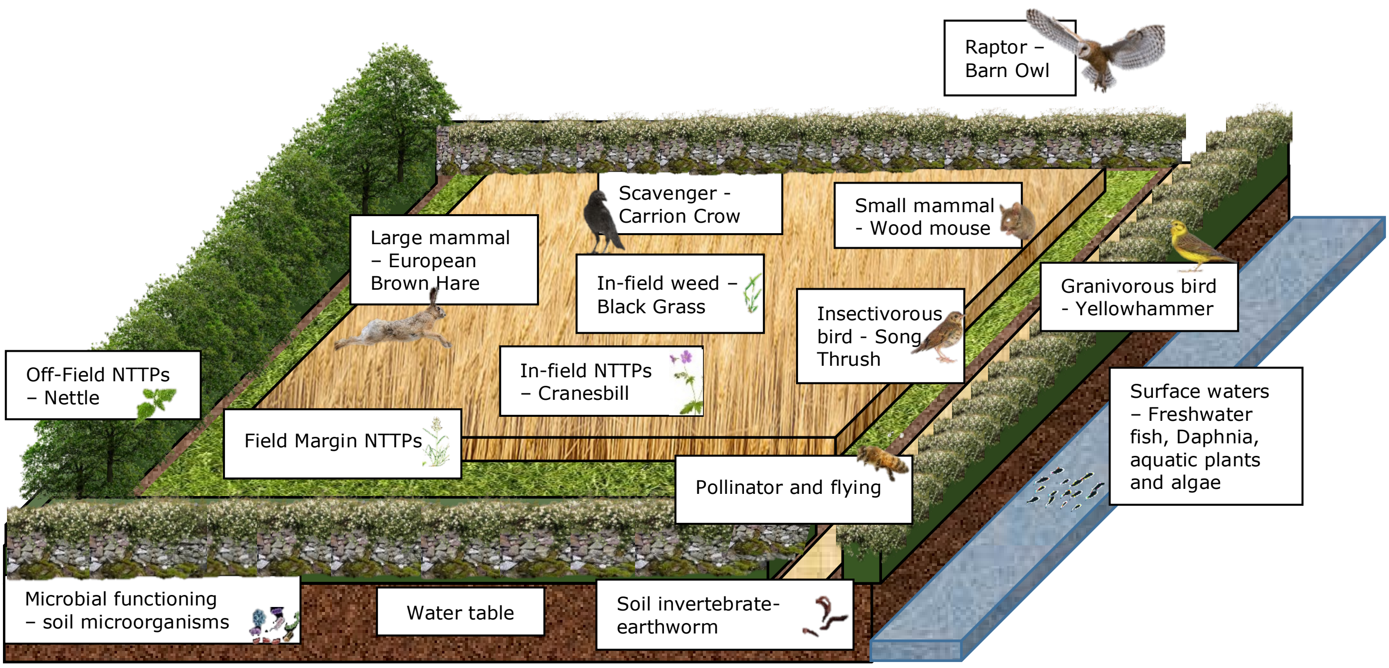
Figure 3.1 *Overview of percentages of weed species mentioned as reason for herbicide use in UK wheat protection in 2016 (from Pesticide Usage Survey, 2018)*

In the UK, wheat receives on average three applications of herbicide per crop cycle at approximately half of the label rate, according to the Pesticide Usage Survey (2018). Most applications take place in the autumn (approximately 55%) with the majority in October (approximately 35%). A further application takes place in spring, with approximately 35% of applications taking place between March and May. The damage to the winter wheat crop posed by weeds depends on the weed species, their density, the competitive ability of the winter wheat and the growth stage when weeds compete. The most competitive weed for winter wheat in this case study is blackgrass, whereas other species such as chickweed are moderately competitive. Other highly competitive species include barren brome, cleavers, Italian rye grass and wild oat. Black grass will reduce crop yields through competing for nutrients, particularly nitrogen.

The survey is consistent with advice to growers in the Wheat Growth Guide from the Agriculture and Horticulture Development Board (AHDB) and consistent with responses from the UK expert in this study. The AHDB recommends three herbicide applications:

- pre-emergence in October (between growth stage GS00 and GS10 using BBCH scale)
- six weeks after sowing in early-November when leaves are emerging on main shoot
- six months after sowing between foundation and construction phases in mid-April

These timings are used in this case study. Scenarios 1 to 3 involve three herbicide applications in autumn and spring. Scenario 4 has one pre-emergence herbicide application in October followed by four mechanical weeding passes fortnightly in the autumn (with three passes between October and November), none in winter (due to wet weather conditions, in order to avoid soil compaction and crop damage) and one pass at the end of January/beginning of February. The reproductive phase of plants is protected in Scenario 4, so no further weeding is undertaken in the spring or summer. The scenarios are described in more detail below. A conceptual site model was developed for this case study based on information provided by the UK expert (Figure 3.2).



	Off-Field		In-Field		Off-Field		
SPUs	Mature woodland	Hedgerow	Grass field margin (Scenarios 1 to 3)	Wheat crop	Public footpath	Hedgerow	Surface water
NTTPs	Nettle; dock; hedge garlic; mustard; ground ivy; speedwells; dandelion; cleavers; bryony; hedge bindweed		Bromes (sterile & soft); couch; creeping thistle; dock; creeping bent; perennial sow thistle; rye grass; red fescue; bristle ox tongue	Blackgrass and less -noxious weeds such as chickweed, groundsel, meadow cranesbill, poppy	see field margin	see hedgerow	Not part of assessment
% Area	5% (all sides)		5-10%	85%	-	-	-

Figure 3.2 *Example of a conceptual site model (CSM) for the UK winter wheat case study*

3.3.1 Spatial and temporal context

The case study is based on the locality of the UK weed expert consulted as part of this project, Rothamsted in the south east of England. A typical arable field size is 10 hectares (100,000 m^2). This was used in the calculation of relative changes between scenarios in ecosystem services by habitat. It was assumed that the field is a square with each side being 316 m in length. The field includes grass margins and hedgerows on all sides and off-field surrounding habitats include surface water bodies and woodland. Arable fields can also include public footpaths. The footpath and woodland were not included in the spatial calculations in this assessment as there were no impacts or changes between scenarios. The proportions of each feature are as follows:

- Cropped area in Scenarios 1 to 3 is 94,308 m^2 (9.43 ha) and 93,359 m^2 in Scenario 4
- In-field field margin is 3 m wide, equivalent to 3,795 m^2
- In-field flower strip (Scenario 4) is 6 m wide, equivalent to 1,897 m^2
- Off-field hedgerow is 1.5 m wide, equivalent to 1,897 m^2

The total non-cropped area is 6% in Scenarios 1 to 3 and 7% in Scenario 4, which is within the range advised by the UK weed expert.

The temporal scale for this case study is a one-year winter wheat crop cycle.

3.3.2 Scenarios

The basic aims behind each scenario are described in Section 2.2 of this report. For the winter wheat case study, the scenarios are as follows:

- Scenario 1 reflects the common current practice in the UK with three herbicide applications using 75% spray drift reduction nozzles and the in-field field margin is 3 metres wide.
- Scenario 2 is similar to Scenario 1 and in addition it uses precision technology to manage the parts of the field with greatest weed pressure: this leads to a reduced herbicide usage overall.
- Scenario 3 has the same weed control strategy as Scenario 1, but using 95% (instead of 75%) spray reduction nozzles for reducing exposure to field margin and off-field habitats.
- Scenario 4 employs a single pre-emergence herbicide application using 95% drift reduction nozzles, then mechanical weeding at fortnightly intervals post-emergence in October and November. A further pass of the mechanical weeder is made at the end of January. In addition, a 6-metre flower strip replaces a 3-metre grass margin along one edge of the field.

The ecosystem services evaluated in this case study are presented in Table 3.3 and Figure 3.3 below shows the crop cycle timeline. Timings are indicative for this case study and in reality may vary depending on weather conditions, crop growth (indicated by the growth stage code according to the BBCH scale) and weed pressure.

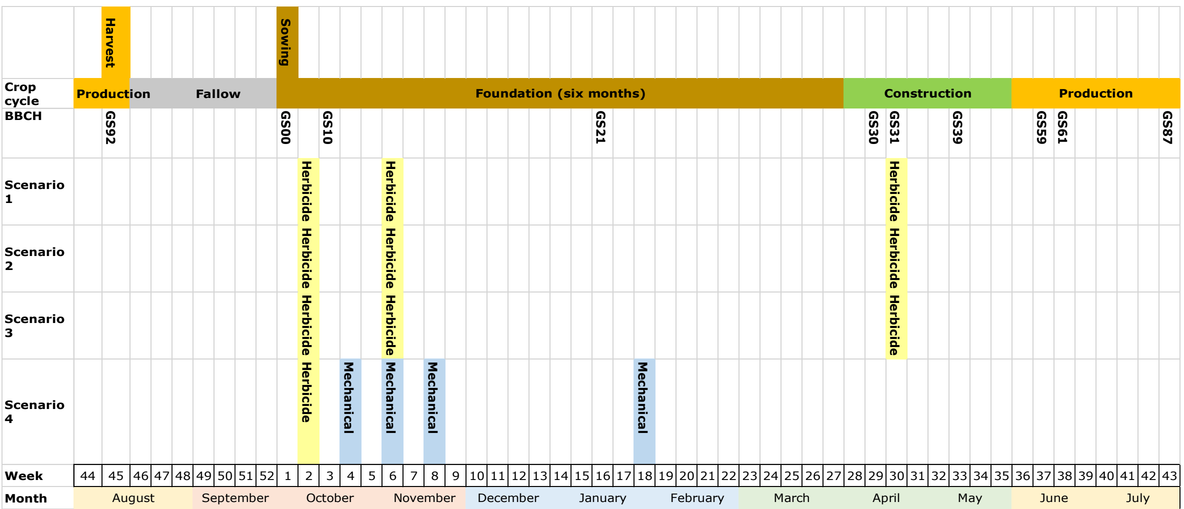


Figure 3.3 *Winter wheat crop cycle and timings of weed management*

3.3.3 Priority ecosystem services

Taking as a starting point the shortlist of prioritised ecosystem services presented in Section 2, context-specific indicators and metrics for ecosystem services were identified (Table 3.3). These are displayed in an ecosystem services cascade (TEEB, 2010) of biophysical structures or processes (service providing units, SPU), functions, services, benefits and values to facilitate the analysis of trade-offs implied by weed management strategies. The focus of this study is biophysical changes in ecosystem services; further research is needed to continue the impact assessment towards the associated changes in benefits and their associated values, such as farm income, to be comparable with socioeconomic assessment in REACH chemical authorisation.

__Table 3.3__ Prioritised Ecosystem Services

SPUs (agroecosystems)	Functional role	Ecosystem service	Benefit	Socio-economic value
Crop plants (winter wheat) In-field	Productivity, ability of the crop to generate a standing stock of biomass	Provisioning services Crops for food and for raw material (ES1) *Indicator: crop yield* *Metric: yield (tons per hectare)*	Food for healthy life, farm income, jobs, community dependence and perception of farming (in-field)	Direct use, monetary value: Market value of food crop (including subsidies) Indirect, non-monetary value: human diet quality, food security
Wild food plants (NTTPs) Off-field	Productivity, ability of the NTTPs to generate a standing stock of biomass	Provisioning services Wild plants for food (ES2) *Indicator: hedgerow fruiting plant* *Metric: plant biomass*	Foraged food to supplement diet (recreational, cultural identity and heritage values are also present but no changes anticipated at landscape level across scenarios) (off-field)	Direct use, monetary: market value of wild foods Indirect use, non-monetary: human diet quality, cultural values
NTTPs and soil organisms above groundwater aquifer In-field and off-field	Water retention and infiltration; regulation of groundwater quality by NTTPs	Provisioning services Freshwater (groundwater) (ES3) - Water recharge (quality and availability) *Indicator: clean groundwater resource* *Metric: failures in European Drinking Water standard for PPP (may also use PECgw)*	Fresh groundwater available for use	Direct use, monetary value: Groundwater value is conditioned by uses, such as agriculture, drinking water e.g. market price of water, averting cost
NTTPs (leading to surface water receptor) Off-field	Direct use, monetary values: Value is attributed to use (as for ground water)	Provisioning services Freshwater (surface water) (ES4) *Indicator: water quality* *Metric: failure in surface water EQS for PPP (may also use PECsw)*	Fresh surface water available for use (habitat value as healthy lakes and rivers could be considered as part of habitat services however they are outside of the scope of this assessment)	Direct use, monetary values: Value is attributed to use (as for ground water)
Rooted plants and soil organisms supporting them In-field and off-field	Role of NTTP to reduce soil erosion and mitigate impacts on soil fertility of herbicide and mechanical weed control practices	Regulating services Soil maintenance, including erosion potential and fertility (ES8) *Indicator: range of soil quality indicators, including bulk density, surface compaction, infiltration, organic carbon, total nitrogen, earthworm density and biomass, and total fungi* *Metric: range of metrics corresponding to indicators*	Stable and fertile soils for plant and crop growth, carbon sequestration (although changes are limited and conditioned by other farm management practices), nutrient cycling, water transport, aquifer recharge. This service is used as a proxy for moderation of extreme events (ES9) and wastewater treatment (ES10)	Direct use, monetary values crop yield gains (income), avoided cost of agricultural inputs Indirect, non-monetary value: food security
Habitats to support organisms and communities In-field and off-field	NTTPs as structural components of habitat and food source for other organisms	Habitat or supporting services Habitat for species (functioning of ecological components of the agro-ecosystem) *Indicator: plant growth for indicator species* *Metric: biomass (kg/ha)*	Habitat services underpin all ecosystem services (e.g. pollination), support whole food chains, contribute to people's interaction with environment (e.g. bird watching, recreation) and can improve ecosystem resilience This service is used as a proxy for pollination (ES11), biological control (ES10) and maintenance of genetic biodiversity (ES17)	Direct use values: increased yield or quality; avoided costs from artificial pollination for certain crops; avoided pesticide costs. Indirect use values: regulation of carbon cycles, cultural, recreational and aesthetic values. Non-use values: bequest, altruistic and existence values

3.3.4 Approach

Changes across scenarios were estimated for each prioritised ecosystem service as follows. All the results were expressed as percentage change (%) relative to Scenario 1. Also, where possible, the results are reported by habitat type as NTTPs in cropped area, margin, flower strip or hedgerow. Assessment of impacts from herbicide use and mechanical weeding were based on published literature (Owuor et al, 2016, Deacon et al, 2015, 2016; Haddaway et al, 2016; Hacket and Lawrence, 2014; Holden et al, 2019; Lautenbach et al, 2019; Pocock et al, 2010; Rothamsted Research, 2020; Rounsevell, et al, 2019; Spurgeon et al, 2013; Defra, 2020), the risk assessment dossier for an example general spectrum herbicide and professional judgement. Care was taken to focus on published literature relating to UK winter wheat (or cereals) production.

ES1: Food (in-field crop production)
Anticipated changes in crop yield across scenarios for one typical crop cycle were derived from the responses from the UK expert in this questionnaire developed for this project (see Section 3.1 and Table 3.2). According to the agronomist, yield reductions are anticipated in Scenarios 2, 3 and 4 (reduction up to 30% in Scenario 4), and a decrease of the economic value of the harvest is anticipated (up to 30%) due to decreased quality of the harvest.

Assumptions
When a range was provided by the expert, the upper range was used in the calculations in order to measure potential change. Yield impacts should be informed by a meta-analysis of field assessments in similar crop conditions.

This assessment considers a one-year winter wheat crop cycle. Assessments over longer timeframes are recommended to take account of the influence of changes in weed flora that may arise over time under each different protection goal scenario. For example, changes in the efficacy of in-field weed control will influence weed seed bank dynamics and the development of herbicide resistance over time. Both of these effects will have long-term consequences for crop production modelling tools could be used to predict long-term impacts of a change in protection goals.

ES2: Wild foods (off-field)
No information was provided by the UK expert on the potential changes in the availability of wild foods across scenarios. Therefore, the assessment of wild food followed a habitat equivalency analysis approach in which the above-ground biomass of NTTPs in a hedgerow was estimated (baseline condition) and compared with potential effects from weed control actions under the four scenarios. An indicator species was used to represent a woody shrub or fruiting tree in the hedgerow (apple tree). An assessment of changes across scenarios on the above-ground biomass of NTTPs in the hedgerow was predicted using spray drift data and potential ecotoxic effects on NTTPs from the herbicide risk assessment dossier. The same method was used in Habitat Services (ES18) for other field habitats.

Assumptions
It is assumed that the indicator species represents all NTTPs in a woody hedgerow that may bear fruit and be collected as a wild food by the local community.

ES 3: Fresh water – ground water (in-field and off-field)
Changes in impacts to ground water across scenarios were estimated based on the plant cover present each week in each field habitat and plan cover ability to allow precipitation to infiltrate into the soil. Plant growth was defined by growth (biomass) for indicator species in crop (wheat), margin, flower strip and hedgerow on a weekly basis. Growth was normalised to a score of 1 representing full growth. Descriptions of the condition of plant cover and metric used are presented below (Table 3.4). A score for the potential for water to infiltrate and recharge the ground water aquifer was assigned to each cover type, a score of 1 indicates a low infiltration potential, while a score of 5 indicates a high soil infiltration potential (SIP).

Table 3.4 *Land Cover Indices*

Land cover type	Description	Soil Infiltration Potential (SIP)
Infield		
Bare Soil	Heavy clay soil with flint over chalk, with little or no slope, uncultivated and left exposed	2
Weeded Soil	Soil compacted through mechanical weeding (mowing and drilling not considered unless these change across scenarios)	2
Emerging crop and NTTPs	Emergent vegetation in the cropped habitat (crop and NTTPs) at weeks 17/18 of the wheat cycle and NTTPs in grass margin and flower strip (off-crop)	3
Established crop	Soil held together by presence of shallow rooted crop and NTTPs	4
Grass margin (3 metres)	Shallow rooted grass margin presents an above-ground biomass greater than a score of 0.4 that suggests a slow the flow of water and increased infiltration	5
Flower strip (6 metres)	Shallow rooted wildflower strip presents an above-ground biomass greater than a score of 0.4 likely to increase infiltration. Flower strips are not as efficient as grass margins at increasing infiltration, but the difference is offset by the greater width compared to grass margin	5
Off-field		
Hedgerow (1.5 metres)	Deep rooted hedgerow (woody shrub/fruiting tree)	3

Notes

Infiltration scale: 5 high potential; 1 low potential

Average precipitation from the Rothamsted Meteorological Station (Harpenden, Hertfordshire) was obtained from Rothamsted Research[7]. The monthly averages were used to create a weekly estimate of rainfall and this used to create a five-point scale from 0mm per week to 25mm per week. Precipitation information is provided in Table 3.5 below.

Table 3.5 *Precipitation Metric Data*

PPT (mm)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
2019	34.8	43.2	60.4	13.2	42.8	70.8	45.0	45.2	75.0	109.6	91.0	111.6	742.6
2018	76.1	48.4	78.5	74.8	61.9	3.7	15.1	64.0	51.0	71.0	63.8	75.0	683.3
2017	70.2	38.7	40.4	10.9	70.5	39.1	72.6	66.6	86.9	31.2	53.5	110.8	691.4
2016	92.3	46.9	84.3	62	39.4	84.8	27.1	30.1	70.3	30.1	85.7	26.2	679.3
2015	81.9	54.6	26.1	31	68.4	26.7	132.6	83.2	45.5	64.6	84	81.8	780.5
Mean (2019 to 2015)	**67.5**	**46.1**	**53.1**	**29.0**	**55.0**	**29.7**	**44.6**	**54.5**	**63.9**	**54.3**	**74.1**	**72.4**	**714.3**
Weekly Average PPT (mm)	**15.3**	**11.5**	**12.0**	**6.8**	**12.4**	**6.9**	**10.1**	**12.3**	**14.9**	**12.3**	**17.3**	**16.3**	**13.7**
PPT metric	**3**	**3**	**3**	**2**	**3**	**2**	**2**	**3**	**3**	**3**	**4**	**4**	**3**

Notes

PPT Metric 0-5mm = 1   6-10mm = 2   11-15mm = 3   16-20mm = 4   21-25mm = 5

The potential for impacts to ground water to occur were estimated by multiplying the PPT metric (Table 3.5) with the SIP metric (Table 3.4) and aligned to a five-point scale (Table 3.6).

Table 3.6 *Potential impacts to ground water*

PPT x SIP	0-4	4-8	9-12	13-16	17-20
Groundwater impact index	5	4	3	2	1

[7] https://www.rothamsted.ac.uk/

The resulting index for each habitat type and scenario was multiplied by its respective area to account for the spatial differences across scenarios.

Assumptions
The SIP score was informed by a literature review on soil infiltration (e.g. Owuor et al, 2016; Haddaway et al, 2016) and is based on professional judgement.

ES 4: Fresh water – surface water (off-field)
It is assumed in the CSM that the surface water body lies outside of the field boundary beyond the hedgerow. Changes in risk to surface water across scenarios were estimated by taking account of the following factors:

- Herbicide application: total herbicide dose for each scenario based on the number of applications and area covered (advised by UK expert questionnaire)
- Drift reduction: anticipated drift based on the drift reduction nozzles in each scenario
- Margin: additional spray drift reduction provided by the field margin, based on Hackett and Lawrence (2014)
- Distance beyond the hedgerow: incorporates spatial considerations to account for the greater width of the flower strip which further attenuates drift (this difference was not considered for the grass margin in order to avoid double-counting)

Values for potential impacts to surface water were calculated by multiplying these factors together for each scenario: *Herbicide application x drift reduction x margin x distance beyond the hedgerow.* The habitat equivalency approach was not used for this ecosystem service valuation, as the risk assessment dossier included detailed fate and exposure modelling, resulting in a low risk to surface water. It was not the intention to repeat the risk assessment here.

In addition, surface water data for the UK covering the period 2001 to 2019 was obtained from the Defra Data Services Platform (2020) and screened by Ramboll against the EQS value (196 μg/l) and the global PEC (104.81 μg/l). After adjustment for anomalies (unbounded '<' values), only three exceedances out of a total of 1238 monitoring results were found to exceed the EQS and PEC thresholds.

Assumptions
The assessment was informed by a literature review on drift attenuation provided by margins (Hackett and Lawrence, 2014) and adapted for this case study using professional judgement.

ES8: Soil erosion prevention and maintenance of soil fertility (in-field and off-field)
The assessment of soils followed a habitat equivalency analysis approach in which the above-ground biomass of NTTPs (plant cover), a soil index in the field habitats (baseline condition) and weekly rainfall (Table 3.5) were combined. Impacts to soil index and plant cover from weed control actions under the four scenarios (and rainfall) were combined and compared against the baseline. The primary information source for the soil index was Holden et al (2019) who reported a range of soil quality indicators in a study of a UK wheat field for arable crop, grass margin, hedgerow and pasture habitats. Pasture was taken to be indicative of the flower strip conditions. Indicators used in this case study included bulk density, surface compaction, hydrology (Ks), soil organic carbon, total nitrogen, earthworm density and biomass and total fungi. These are considered to be representative of soil erosion prevention (with the addition of rainfall and plant cover) and soil fertility. Impacts of herbicide use were accounted for by referencing the risk assessment dossier (e.g. ecotoxicity to earthworms, microbial activity) and professional judgement. The potential effects of mechanical action were informed by studies such as Spurgeon et al (2013) and professional judgement. Scores for each habitat and scenario combination were multiplied against spatial area.

A similar method was used in Habitat Services (ES18) for other field habitats. To avoid double-counting, this ecosystem service was used as a proxy for the following ecosystem services:

- ES9: Moderation of extreme events (in-field and off-field)
- ES10: Wastewater treatment (in-field and off-field)

Assumptions
It was assumed that the wheat field in the study by Holden et al (2019) was typical and equivalent to the conceptual field in this case study. It was assumed that Holden's fields and the case study field are subject to other management actions, such as fertiliser application and other pest control measures – these form the baseline condition, so that only the action (and potential impacts) of the herbicide and mechanical weeding are evaluated.

ES18: Habitat for species (functioning of ecological components of the agro-ecosystem) (in-field and off-field)
As above, the assessment of habitat services followed a habitat equivalency analysis approach in which the above-ground biomass of NTTPs (plant cover) was estimated for baseline conditions. The potential impact of herbicide use and mechanical weeding over one year on a week-by-week basis were estimated and compared against the baseline. Potential impacts from herbicide use were extracted from the risk assessment dossier and considered dose, environmental fate, plant ecotoxicity and spray drift. Information on the efficacy of mechanical weeding was provided by the UK expert. Baseline plant growth on a weekly basis was derived for indicator species from a number of information sources including Pocock et al (2010). The crop cycle, timing of herbicide applications and the biomass of wheat crop were provided by the UK Wheat Guide produced by the Agriculture and Horticulture Development Board (AHDB). The indicator plants for the other field habitats were as follows:
- Crop comprises winter wheat (AHDB)
- In-crop NTTP indicator is an annual species *Papaver rhoeas (*Pocock et al, 2010)
- Margin indicator species are grass species (Pocock et al, 2010)
- Flower strip incorporates perennials and is an average of *Geranium dissectum*, *Trifolium pratense/repens*, *Ranunculus repens, Cirsium arvense* and grass species (Pocock et al, 2010)
- Hedgerow indicator is an apple tree (Zanotelli et al, 2012)

Scores for each habitat and scenario combination were multiplied against spatial area. To avoid double-counting, this ecosystem service was used as a proxy for the following ecosystem services:
- ES11: Pollination (in-field and off-field)
- ES10: Biological control (in-field and off-field)
- ES17: Maintenance of genetic biodiversity

Assumptions
It was assumed that the risk assessment modelling and evaluations for the example herbicide (dossier) were relevant to the timings and doses simulated in this case study.

Scenario 4 is intended to be protective of reproductive endpoints in NTTPs. Information on flowering times and duration were gathered as part of this study, but the residual levels of herbicide in the soil at flowering time were below lethal and sublethal levels. The herbicide was applied once and pre-emergence stages of crop development. Mechanical weeding was also undertaken in the autumn and winter months and it was concluded that there was no effect on plant reproduction from weed control measures defined in this scenario.

3.3.5 Results

The results show that a quantitative approach can be taken to ecosystem services valuation for PPP regulation. The results for soil maintenance and habitat services are presented for each habitat type, in-crop NTTPs, field margin NTTPs (and flower strip in Scenario 4) and NTTPs in the off-field hedgerow habitat (Figures 3.3 and 3.4).
- Scenario 2 (precision technology) provides greater protection to in-crop NTTPs than in Scenario 1 and as a consequence there are more NTTPs in the adjacent margins.
- Scenario 3 provides similar NTTP protection in crop to Scenario 1, but using 95% reduction spray drift nozzles (compared to 75% in Scenarios 1 and 2) result in a reduced herbicidal impact to field margins and more NTTPs.
- Scenario 4 provides the greatest gain in NTTPs compared to conventional weed control (Scenario 1). Using high-quality nozzles (95%) for herbicide application reduce spray drift to the field margins and

off-field habitats compared to Scenario 1. In addition, the mix of herbicide and mechanical weed control maximise NTTP habitat within and around the cropped area. Adding a flower strip in Scenario 4 further enhances the in- and off-crop NTTPs.

- It should be noted that in absolute terms the impacts to hedgerows are marginal in all scenarios compared to the cropped habitat.
- NTTP habitat services are considered a proxy for other services such as pollination, biological control and maintenance of genetic diversity, which are considered to follow the same trends. Also, it is used for the assessment of anticipated changes in wild food provision in the off-field habitat.

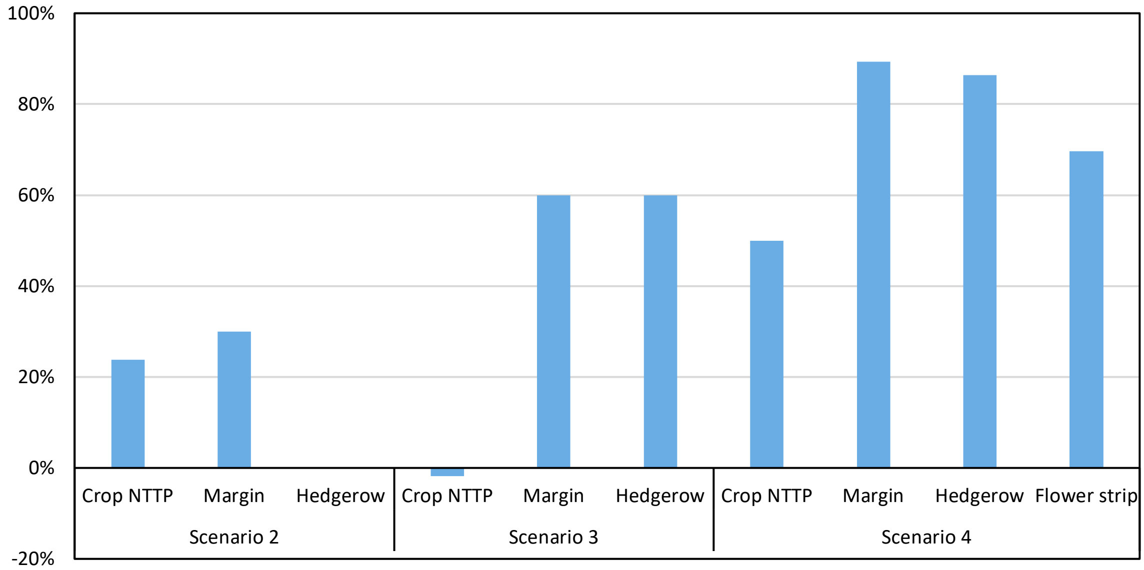


Figure 3.3 *Benefits to NTTPs in each habitat type across weed management scenarios relative to Scenario 1 (baseline)*

The results for soil maintenance services were similarly described by habitat:

- All scenarios provide greater protection for soil maintenance services in the grass margin compared to Scenario 1.
- However, Scenarios 2, 3 and 4 perform the same or worse than Scenario 1 for soils in the cropped habitat for the choices of weed control strategies. For example, the use of mechanical weed control in Scenario 4 repeatedly breaks up the soil structure adversely affecting soft-bodied invertebrates, fungal systems and may cause soil loss depending on weather conditions, which will also affect water quality in adjacent water bodies via runoff.
- Changes to soils in the hedgerow vary across scenarios but are the same or better than in Scenario 1. This is driven by plant cover. Scenario 2 provides greater protection to in-crop NTTPs than in Scenario 1, and as a consequence there are more NTTPs in the adjacent margins, leading to higher quality soils.
- Field margins and hedgerows have been shown to have higher quality soils than arable land (Holden et al, 2019), which is borne out in Scenario 3. In addition, these habitats provide greater protection to NTTPs, which allow for greater rainfall infiltration, provide more soil organic matter and greater density and biomass of earthworms relative to Scenario 1.
- Scenario 4 provides the healthiest soils across all scenarios in the margin, flower strip and hedgerow, although not the crop (as discussed). The greater protection of NTTPs in-crop, margins and off-field are coincident and related to improved soils.

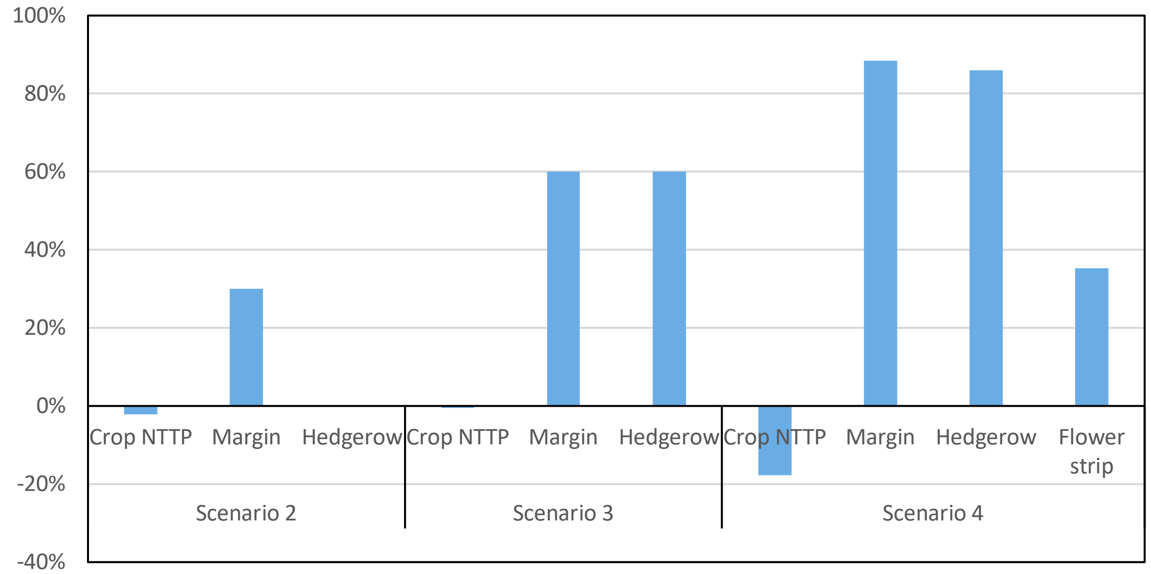
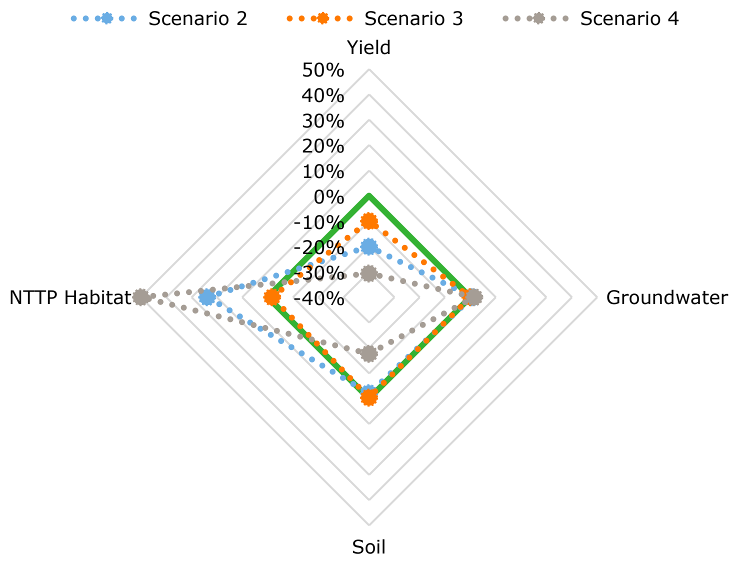


Figure 3.4 *Benefits to soil maintenance by habitat across weed management scenarios relative to Scenario 1 (baseline)*

Figure 3.5 compares changes in ecosystem services relative to Scenario 1 in each type of habitat:



In-field cropped habitat

It can be seen that maximising the protection of NTTPs in the cropped habitat will also benefit pollinators, genetic diversity and other organisms (habitat and food).

Greater protection of NTTPs leads to trade-offs against yield (up to 31% loss in Scenario 4) and soil protection (up to 18% loss in Scenario 4). The loss in crop yield may be partially explained by reduced crop area given over to the 6m wide flower strip, although spatially the area represents 2% of the cropped area. There are several options for mechanical weed control in wheat production and timings can be crucial for weed control and NTTP protection. It is possible that a mix of weed control strategies and timings may reduce the impact on soils.

Potential impacts to groundwater are negligible in all scenarios and habitats.

Note: the axis range differs in this figure from the two figures below.

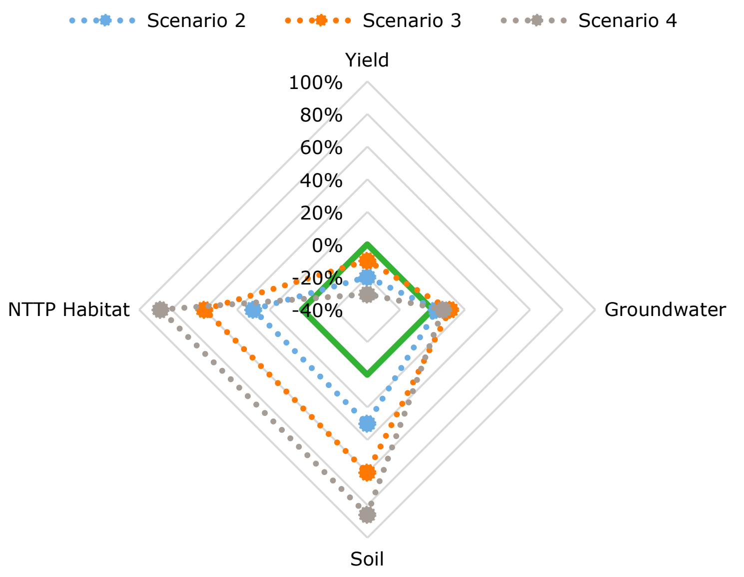
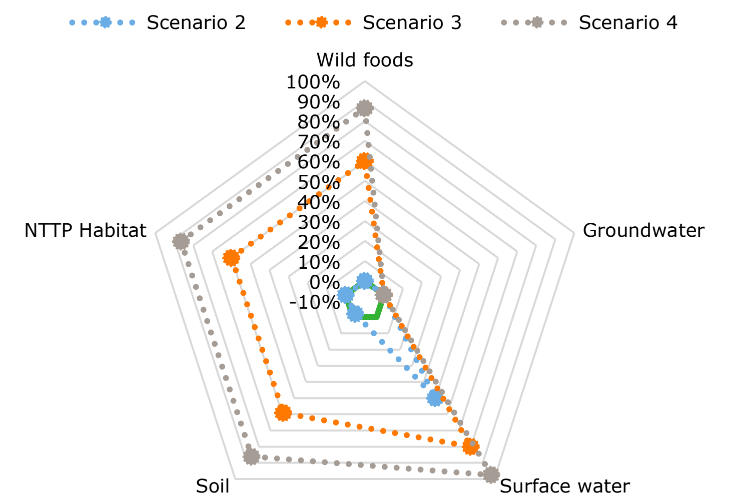
	**In-field margin habitat** The presence of field margins (and flower strips) increase NTTP protection, with Scenario 4 providing the greatest NTTP habitat services. Scenario 4 also has the largest area of margin NTTPs with the addition of the flower strip along one margin. Note, flower strips vary in species composition and whilst providing functional services may not fulfil conservation criteria. Margins achieving high functional and conservation stewardship may have increased value that can be counted in ecosystem services analysis (e.g. use of multiple indicator species or weighting factors).Soil maintenance is driven by plant cover in the field margins and follows a similar trend to NTTP habitat services. Soils are no longer negatively affected in the margins compared to the cropped habitat. Potential impacts to groundwater are negligible in all scenarios in the grass margin habitat. Scenario 4 provides the greatest overall benefits in ecosystem services for field margins, relative to Scenario 1, but Scenario 4 has the greatest yield trade-off (31% loss).
	**Off-field hedgerow habitat** Ecosystem services in off-field hedgerow habitat are consistently optimised in Scenario 4 compared to Scenario 1. The provision of clean groundwater changes little across scenarios in the hedgerow. Plant cover type strongly influences hedgerow services, including the provision of wild foods, which follow the same trend as NTTP habitat services. There are minimal impacts from herbicide or mechanical weed control in the hedgerow (often <2% from baseline plant growth with no impacts), but the relative changes appear greater compared to the other field habitats. The trade-offs in crop yield for Scenarios 2, 3 and 4 still apply.

Figure 3.5 *Changes in ecosystem services by habitat across scenarios relative to Scenario 1 (baseline)*

3.3.6 Conclusions

It is concluded that a quantitative approach can be taken to ecosystem services valuation for PPP regulation. The UK winter wheat case study operationalises the ecosystem services concept from a human welfare perspective and enables an understanding of the environmental trade-offs amongst services associated with different strategies to weed management. These scenarios are examples intended to demonstrate the IA Framework, but the method may also be used to predict and inform management decisions, such as method of weed control, timing of application, size of margin or compensatory area, and the method may ultimately inform stewardship payments.

There are two compromises with the case study that had to be made due to project constraints, but could (and should) be explored further:

- Agricultural ecosystems comprise a wide range of species that use the habitats for food, shelter and breeding. The focus of this study is terrestrial plants, but it is recognised that the case study would benefit from assessing the consequences to other wildlife of the losses or gains in NTTPs, such as farmland birds that rely on vegetation and plant seeds for food and insectivores that may be attracted to an increased abundance of invertebrates using flower strips. These benefits are currently not being realised in the case study.
- The IA Framework is designed to address environmental impacts and socioeconomic impacts; the current study has quantified the changes in ecosystem services; however, it has not monetised those impacts. To bring the study in line with other socioeconomic guidance (such as REACH Regulation), the study would need to consider trade-offs in farm income for the food provisioning service related to costs of machinery, maintenance, employment and other factors associated with weed control in wheat production, along with changes in societal welfare. It has been seen in other studies that consideration of ecosystem services alone does not provide the whole picture, particularly regarding the economic consequences of reduced pest control (Deacon et al, 2015 and 2016).

It is often possible to improve upon current levels of ecosystem service provision and current practice (i.e. baseline) scenarios. However, setting objectives for service provision and SPGs are not straightforward since the relationship between the ecosystem services provided and their value to society tend not to be linear (e.g. minimum supply levels are required for the benefit to be realised) and are context and location dependent (e.g. distance to beneficiaries) (Lautenbach et al, 2019, Rounsevell et al, 2019). In the UK winter wheat case study, maximising NTTPs in the cropped area benefits pollinators, genetic biodiversity, and supports food webs through the provision of habitat and food; however, it comes largely at the expense of food provision (crop yield) and, to a certain extent, soil protection. These trade-offs result in an economic loss to farmers and may lead to sub-optimal results in relation to food security and soil protection, with cumulative impacts on soil structure and soil organisms over time. As stated, there may be additional socioeconomic trade-offs in Scenarios 2 and 3 that have not been assessed in detail (refer to Table 3.2 for an overview of anticipated socioeconomic impacts).

The explicit understanding of these trade-offs enables more holistic decisions. However, while this case study demonstrates the value of ecosystem services frameworks to inform PPP strategies, the results presented remain indicative. A more holistic understanding of trade-offs that avoids unintended consequences and identifies synergistic and antagonistic effects requires further research to incorporate the following aspects:

- Longer timeframes to account for weed resistance, crop rotations, the impact of preceding crop and weed treatment on growth, weed seed bank build-up and existing weed pressure
- The influence of field scales and landscape complexity in order to account for the wider influence of landscape scale management options
- Also, other crop management practices, such as tilling, influence overall ecosystem service provision
- Indirect effects on other trophic levels (e.g. farmland arthropods, bird, mammals)
- Further trade-offs and synergistic effects on ecosystem services from other PPP product categories such as plant growth regulators, fungicides, insecticides, molluscicides, soil sterilant, nematicides and rodenticides
- Continue the impact assessment through the ecosystem services cascade towards changes in benefits and their associated values, such as farm income, to be comparable with socioeconomic assessment in REACH chemical authorisation
- Negative effects on soil, including soil compaction, soil biota, soil erosion and soil structure effects

4 Discussion, conclusions and recommendation

The objective of this study is to develop an Impact Assessment Framework that can be applied to the assessment of PPPs and that fulfils the requirements of the Better Regulation Guidelines. A key element of the work undertaken in this project regards the development of an Impact Assessment Framework. A major part of this Framework concerns the assessment of adjustment of the weed control toolbox on environmental changes. This has been based on the TEEB methodology that models the impacts on Ecosystem Services. We have screened eighteen ecosystem services, as presented in Tables 2.1 to 2.3, suggesting indicators and metrics to quantify the impact as prescribed by the Better Regulation Guidelines. The proposed framework is in line with recommendation from EFSA (2016), and thereby allows (i) to evaluate which ecosystem services are likely to be modified by the use of PPP or alternative weed control, and (ii) to relate the environmental impacts on ecosystem service delivery to quantitative indicators (including some endpoints from the current regulatory risk assessment of PPPs).

4.1 Discussion

Measuring changes in ecosystem services
In the case studies, we have assessed impacts across six ecosystem services: food (in-field crop production, ES1), wild foods (ES2), fresh water (ground water, ES3), fresh water (surface water, ES4), erosion prevention and maintenance of soil fertility (ES8) and habitat for species (functioning of ecological components of the agro-ecosystem, ES18), which are expected to suffer material changes in ecosystem service provision associated to the choice of weed control method.

Furthermore, because of time constraints, we have limited most case studies to a qualitative assessment of impacts on ecosystem services, with only one quantitative assessment of changes in ecosystem service provision for the UK winter wheat case study. The cases studies have been executed under the assumption that if herbicides are used less, more targeted or with higher percentage drift reduction, the risk of off-crop plants to be exposed to herbicides will be reduced. Economic impacts and impacts on labour input have been quantitatively assessed.

Finally, we could not collect quantitative baseline information on the extent to which ecosystem services are delivered in each crop/country. Therefore, we have defined the reference scenario (i.e. Minimum Requirements Scenario, Scenario 1) on the basis of current regulatory objectives for protection of Non-Target Organisms as delineated in Regulation (EC) No 1107/2009. Because of the focus on weed control and the qualitative testing of the prioritised ecosystem services in five of the six case studies, the IA Framework has not been completely tested. The exception concerns the winter wheat case study in the UK in which ecosystem service indicators have been quantitatively applied; however, the case study could be extended to include detailed quantification of social and economic impacts (refer to Section 3.3).

Therefore, additional case studies, not only limited to weed control and effects on NTTP, but also oriented at the protection of crops against plant pests and diseases, are necessary for a full test of the Impact Assessment Framework.

Developing scenarios
We have developed different examples of scenarios for specific protection strategies to safeguard ecosystem services in which Non-Target Terrestrial Plants (NTTPs) play a role. We have distinguished between in-field and off-field situation. In Scenario 2, which increased in-field protection of NTTP, we see that for some crops (maize, onions, oil rapeseed), herbicide use can be partly replaced by mechanical methods of weed control, such as hoeing, having less impact on some NTTPs or precision application (e.g. potatoes). The environmental impact of herbicide use can be reduced by application

of this scenario, especially when broad-spectrum herbicides are applied. However, the alternative weed control method is not selective and thus not able to distinguish between weeds (plants harming the production of the crop) and NTTPs which do not harm crop production. We see trade-offs between ecosystem services. For example, shifting weed control from chemical to mechanical methods can remove the potential risk of spray drift, but may increase the risk to soil organisms and other crucial abiotic ecosystem services essential for crop production and overall soil health. The use of significantly more mechanical weed control in Scenario 4 repeatedly breaks up the soil structure adversely affecting soft-bodied invertebrates, fungal systems and may cause soil loss depending on weather conditions and topography; these negative impacts on soil are not compensated by the increased NTTP density and should be thoroughly evaluated. Furthermore, increased mechanical weeding may also have a negative effect on nests of birds if applied during breeding season; mechanical weeding also disturbs birds and other species dwelling in the field through increased vegetation disturbance and noise. In addition, using increased mechanical weeding can lead to increased emission of greenhouse gases.

Socioeconomic analysis
Further development of the IA Framework is needed to evaluate the socioeconomic impacts of the changes in farming practice, where the decrease in yield and crop selling price can be considered jointly with the increase in labour and machinery costs and changes in ecosystem services. Economic consequences are a major driver in decision-making by farmers. In particular, it is needed to evaluate if the growing of a given crop under the different scenario would still be a viable option for the farmer, or if they would rather switch, or would have to be forced to switch their activities towards another crop, provided markets allow for it. It would also be interesting to check how the increase in costs for machinery, labour and time might affect different categories of farms, such as small farms, and farms with a high diversity of crops and look to which extend a requested change in farming practice to meet more stringent protection goals for NTTP would favour large agricultural businesses, which have more potential to invest in machinery, over smallholder farms (this has a potential to favour intensification).

Selection of the preferred scenario
The intention for using the IA framework is to enable a transparent and data-based identification of a 'win-win' scenario that allows for an increase in the protection of the environment and the delivery of key ecosystem services when/where needed and can be implemented at reasonable socioeconomic costs. In this study, we have not included an approach to select a preferred scenario, and we have not checked for the proportionality of the various proposed scenarios. However, it is possible to compare scenarios based on the results as presented in Table 3.2. For each of the scenarios, we compare the trade-offs between the positive and negative impacts of each scenario relative to Scenario 1. Negative impacts mainly regard additional labour costs and yield reduction and sometimes loss of soil fertility and erosion. Positive impacts mainly regard improved quality of ground water and surface water and improved habitats for wild species. In most cases, the qualitative assessment is too limited to select a preferred scenario. This would be possible only if one scenario can be identified based on qualitative data where all impacts of the preferred scenarios scores better or equal compared to the other scenarios. This is the case for Scenario 3 (focus on an increased protection of off-field non-target terrestrial plants) in the case of Dutch potatoes. No yield reduction or increase of costs are reported, but the quality of surface water improves when compared to Scenario 1.

The comparison can be largely improved by quantifying impacts, as has been conducted for the impacts on ecosystem services in the extended UK winter wheat case, described in Section 3.3. For a complete comparison, it is necessary to quantify and monetise the social and economic impacts as well, and to quantify the environmental impacts to be able to assess trade-offs based on a common metrics across scenarios. The challenges in providing monetary estimates of the total economic value for all ecosystem services is acknowledged, given data constraints, and some level of qualitative assessment is likely to be required for services and attributes whose welfare benefits cannot be fully monetised or quantified.

Results showed that differences between crops and local ecological/agronomical conditions (vulnerability to in-field weeds, field preparation and management, soil nature) have consequences on the possibility and costs for achieving an improved ecosystem service delivery and meeting certain

Specific Protection Goal options. The room for adjusting the weed control practice and how to best adjust it varies between crops and crop rotations; more conservatism is easier to achieve in less vulnerable crops. Overall, implementing measures from integrated weed management and adding a mandatory use of risk-reduction nozzles would already bring many ecological advantages and are associated with low socioeconomic costs. Finally, the consideration for risk mitigation measures where herbicide uses are performed can also allow for improvement of provision of some services (e.g. yields, soil erosion) while maintaining other services.

Skills requirement for ecosystem services assessment

All local experts and those employed by members of the ECPA who filled in the questionnaires (9 in total) were asked to fill in a short evaluation form at the end of the case study (see Appendix 4). The returned evaluation forms reported that the objectives, framework, definitions and questions were clearly formulated. The time spent filling in the form varied between 0,5 and 3 days.

An important aspect is the applicability of the IA framework in practice. One of the major takeaways from evaluation results of the case studies is the need for involvement of many fields of expertise from agronomy (by crop), crop protection, weed control, PPP risk assessment, ecology, ecosystem services and socioeconomic analysis. In most cases, local experts filling in the questionnaire invited other experts to contribute. Therefore, the assessment could benefit from further analyses and should be treated with caution. The part of the questionnaire dealing with ecosystem services' aspects of the case studies, in particular, need more elaboration and multi-disciplinary teams. The experts have interpreted the likely impacts from each scenario on the selected ecosystem services, but it is not clear that they fully understood the ecosystem services perspective, as even the ecosystem services language is not used in crop production. A key conclusion is that the ecosystem service element of the method needs to bring in a different/much wider range of expertise, and to balance this with agronomic realities. In particular, dually skilled people in conservation and agronomy are required to better understand the ecological linkages between NTTPs and ecosystem services. This is currently a significant gap in five of the six case studies.

Robustness of the IA Framework

We chose a large range of crops and countries to represent different agronomic and environmental situations. The value of the crop, its competitiveness to weeds, and the way it is planted and cultivated influences the range of weed control methods that can be used by the farmer. The degree of mechanical weed control already used in a given crop/country also influences the results on environmental and socioeconomic impacts. Furthermore, the impact can also vary between farms. If farmers have to invest in new technology, more machinery, or precision agriculture, the costs can be relatively bearable for large farms, but are not affordable for smaller farms. In the case of drift-reducing nozzles, which have been made compulsory in some EU countries, their policy promotion could however bear better risk mitigation and environmental outcomes. Access to labour when required may also be more difficult for smaller farms. Despite these differences, when we compare the different case studies, we also see many similarities. There is a consistent pattern across the case studies that have been executed independently, which reassures us about the robustness of the IA Framework. In all case studies, we see a shift from reduced or more precise herbicide use that increases the level of protection of NTTPs. It is a confirmation of the finding of the FAO Report on the Status of the World on Biodiversity and Ecosystem in food and agriculture, that good agricultural practices such as IPM and reduced tillage are on the rise (FAO 2019).

Accounting for other weed control measures

On about 80% of European cropland, Good Agricultural Practices (GAP) such as crop rotation cycles of up to 3 or 4 crops (including cover crops and crop diversification) are respected. GAPs not only enhance soil-related ecosystem services such as soil fertility--they are key Integrated Weed Management (IWM) strategies used by farmers to address disservices by avoiding weed build-up and hence are natural weed-regulating services applied in practice. Other IWM measures include mechanical harrowing of the seed bed, respecting economic weed threshold levels, or only applying herbicides to subfield areas where pressure of weeds is highest. This not only reduces costs (double row spraying, or precision application), all these measures imply that a certain level of weeds can be accepted in fields if they cause no damage to the crop. Some of these practices are considered in scenarios which were used for this analysis.

However, these practices are not considered in regulatory risk assessment: the regulatory scenario is a worst-case scenario covering incidence of high pest/weed pressure. Thus, there is a discrepancy between some assumptions of the regulatory risk assessment and real farming practice. These discrepancies need to be considered when setting new SPGs for risk assessment, e.g. in-field protection of NTTP as delineated in Scenario 2 is already at least partially met through implementing IWM (e.g. economic weed threshold level). Moreover, risk-reduction measures (e.g., PPP use reduction), good agricultural practices (crop diversification, cover crops) or the creation of semi-natural habitats (e.g., ecological focus areas beyond fields, set-aside subfield area or entire fields, flower areas in fields) are promoted and incentivised through EU CAPs (Common Agricultural Policy). Agri-Environmental Schemes as reflected in all three alternative scenarios have also already been applied (since the 1980s). These schemes can benefit cropland associated biodiversity at the local and wider scale, if (as in the case of semi-natural habitats) their creation is spatially properly configurated in the landscape (EC 2013; Früh-Müller et al 2018). The IA Framework therefore has the potential to highlight trade-off and synergies between different policies and regulations and contribute to more holistic EU protection goals.

Multi-year effects
One limitation of the current approach is that we look at the effects within one growing season. It is likely that effects of structural changes will not be stable over time. For example, adjustment of the weed control toolbox can lead to increased weed seed banks. In the short term, the impact on yield with consequences for food supply and income for the farmer can be limited, but in the long term the impact may accumulate with harming farm income and reducing the sustainability of farming. Also, weed seed banks will certainly change over time and in-field preservation of NTTPs could lead to new problematic weed species over time. The conceptual clear distinction between weeds and NTTP can be specific for crops and regions. Furthermore, resistance against herbicide can also affect the efficacy of herbicides in the long run. Therefore, we recommend addressing crop rotation cycles over several seasons for a reliable assessment of the impacts and of the different protection goal options. Similarly, there may be long-term benefits from build-up of NTTPs that can provide greater competition to weeds, especially where weeds are selectively controlled compared with NTTPs.

Links between PPP regulatory and agricultural management aspects
The proposed Impact Assessment Framework has the potential to include different weed control strategies, management and stewardship practices, such as PPP use and field margins and comply with the range of environmental and agricultural policies and regulations. In the absence of quantitative baseline information on the extent to which ecosystem services are delivered in each crop/country, we have defined the baseline scenario on the basis of current regulatory objectives for protection of Non-Target Organisms as defined in Regulation (EC) No 1107/2009. This benchmark specifically addresses the use of PPP and risk mitigation measures that are operational at Member State level. Moreover, Integrated Weed Management practices were embedded in the alternative scenarios. They influence cropping systems' environmental performance through the adherence to crop rotation cycles, crop diversification, and economic threshold levels for PPP use. They are thus directly relevant in the context of the Directive EC 2009/128 (Sustainable Use Directive) and with regard to providing pest and disease prevention through crop rotation and reduced PPP use. Stewardship under the EU Common Agricultural Policy, such as crop rotation cycles enhancement or subsidies paid, can be accounted for when looking both at the environmental and socioeconomic impacts. Finally, the framework also allows for accommodation of national policy objectives (e.g. biodiversity net gain policy in the UK could be considered in the winter wheat case study to ensure impacts were compensated, including an additional measurable 10% gain in biodiversity). Therefore, the framework enables a transparent appraisal of where various policy and regulatory layers come into play.

It should be further elaborated for targeted evaluation on how these different layers interact to identify the optimum leverages for the implementation of scenarios that are favourable both from the environmental and socioeconomic points of view. For instance, the framework can identify the policy layer in which a certain SPG can be operationalised most effectively and with least negative feedback to other areas. Such a structured layering of operational SPGs may increase the efficiency of the PPP regulation (EC) No 1107/2009 while at the same time providing clearer guidance for the implementation of the provisions set out in Directive EC 2009/128 (Sustainable Use Directive), and for the choice of effective socioeconomic instruments within the Common Agricultural Policy.

The combination of the different legislative layers' objectives also speaks to more holistic, integrated approaches that are fundamental to implementing a full ecosystem services concept or other policy goal, such as mainstreaming biodiversity into crop production. In particular, the following aspects could be considered in order to identify the policy layer in which an SPG is most appropriately operationalised in the most efficient way, e.g. (i) impacts that can be avoided under productive farming without chemical weed control (relevant under Regulation EC 1107/2009), (ii) impacts that are intrinsic to the activities of productive farming and cannot be avoided by non-chemical weed control (relevant under the Sustainable Use Directive), (iii) impacts that result from farm management/farm structure decision-making based on the socioeconomic options a farmer has (relevant under the Common Agricultural Policy) and (iv) impacts on historical farmland structures and protected species (relevant for national conservation policies).

4.2 Conclusions

Based on the evaluation of the case studies, we come to the following conclusions:

1. The Impact Assessment Framework developed in this project is applicable for the qualitative and quantitative assessment of the environmental, social and economic impacts, benefits and trade-offs when adjusting a diverse weed control toolbox within one growing season. The questionnaire to local experts in weed control provided the basis for framing the assessments (choice of scenarios), thus relating the scenarios to the real-world agronomic practices applied in crop production.
2. A quantitative assessment of environmental and socioeconomic impacts is feasible within the proposed Impact Assessment Framework. Such an assessment requires a multi-disciplinary approach with expertise in agronomy, risk assessment, ecology, ecosystem services, socioeconomic analysis and sustainability. It also requires sufficient data, which are not readily available yet in some areas. This study has illustrated the type of information it can bring into the discussions. It has also identified the potential shortcomings of just taking one expert's view and the risk that this may not adequately enable assessment of environmental aspects. Local knowledge and experience is valuable, but assumptions should also be backed up by published scientific data and other authoritative data (e.g. national statistics).
3. A holistic assessment of environmental and socioeconomic impacts can be achieved through applying ecosystem services frameworks that enable the monetary quantification of impacts to farmers (e.g. farm income) and to society (e.g. food prices). This can be derived from the choice of weed management practices, and the non-monetary valuation of ecosystem service delivery for the society as used in this study. Further research is required in order to continue developing the impact assessments through the ecosystem services perspective towards changes in benefits and their associated values, to be comparable with the SEA (Socioeconomic Assessment) approach used in REACH chemical authorisation. This is particularly relevant as the benefits derived from the various ecosystem services and their associated value are usually non-linear and are location and context-dependent. Consequently, decisions made without consideration of the beneficiaries and the anticipated impacts on ecosystem service benefits could lead to unintended consequences and trade-offs.
4. In the present study, the impact assessment framework was used in six case studies, which enables us to illustrate how it works through qualitative and quantitative examples. In a next step, it could be fully tested with greater complexity (and reality) in scenarios, other PPP products and other non-target wildlife (trophic levels) (Conclusions in Section 3.3). Digitalising the impact assessment matrix could enable the deployment of the full quantitative potential of the Framework, facilitating (i) data acquisition (e.g. automatic pick-up from EFSA dossier endpoints or authoritative data), (ii) the integration of a higher number of ecosystem services and/or

environmental/socioeconomic indicators for the comparison of scenarios and (iii) the identification of most promising scenarios.
5. The overarching direction must be towards developing more holistic assessments and aligning policies to optimise broader ecosystems' management and their protection across the landscape to reach multiple public goods of societal importance, while minimising impacts on farm income and maintaining food prices. The ultimate challenge for policies and regulations is to maximise the potential of this Framework by breaking down the silos between EFSA SPGs in PPP risk assessment and providing integrated SPGs for the management and protection of crops, the protection of plants, invertebrates, birds and mammals (the whole ecosystem), while contributing to societal and economic benefits.

4.3 Recommendations

In order to build on the results provided by this study and further inform the identification of SPGs we recommend the following steps moving forward:
1. Expand the involvement of interdisciplinary experts in such studies, to improve its robustness and reliability in assessing the impacts on ecosystem services, by capturing a variety of perspectives and opinions and providing a more rounded analysis. This will then enable the method to be applied and tested further so that the environmental impacts can be assessed with the same level of expertise as the economic and social impacts.
2. Discuss the approach with relevant stakeholders and policy makers to add their input and add relevance of such studies when used to refine SPGs, while ensuring that they understand the role of ecosystem services in PPP risk assessment.
3. Test the application of such studies to the assessment of other groups of PPPs such as insecticides, fungicides and acaricides, and see whether focus is on other SPGs and/or ecosystem services versus for NTTPs.
4. Continue the impact assessment through the ecosystem services framework towards changes in benefits and their associated values in order to be comparable with socioeconomic assessment in REACH chemical authorisation.
5. Test the application of the IA Framework to assess the long-term consequences of adjusting the weed control toolbox, considering the effects e.g. on the seed bank build-up, the impacts on soil-related ecosystem services (e.g., fertility, soil erosion and compaction, soil structure, soil biota health) and of effects of crop rotation schemes, as well as the changes over time of in-field and off-field habitats.

References and websites

Arts, Gertie, Jos Boesten, Theo Brock and Ivo Roessink (2017): Arable weeds and non-target plants in prospective risk assessment for plant protection products; Specific protection goal and exposure assessment options. Wageningen. Wageningen Environmental Research, Report 2836.

Beckmann, Volker and Justus Wesseler (2003): How labour organisation may affect technology adoption: an analytical framework analysing the case of integrated pest management. Environment and Development Economics 8(3): 437-450.

Deacon, S., Norman, S., Nicolette, J., Reub, G., Greene, G., Osborn, R. and Andrews, P., 2015. Integrating ecosystem services into risk management decisions: Case study with Spanish citrus and the insecticide chlorpyrifos. Science of the Total Environment, 505, pp.732-739.

Deacon, S., Alix, A., Knowles, S., Wheeler, J., Tescari, E., Alvarez, L., Nicolette, J., Rockel, M., Burston, P. and Quadri, G., 2016. Integrating ecosystem services into crop protection and pest management: Case study with the soil fumigant 1, 3-dichloropropene and its use in tomato production in Italy. Integrated environmental assessment and management, 12(4), pp.801-810.

Department for Environment, Food and Rural Affairs i(Defra), 2020. Defra Data Services Platform [online]. Available at: https://environment.data.gov.uk/ (accessed 17 July 2020)

EC [European Community] (2013). Regulation (EU) No 1306/2013 Of The European Parliament and of the Council of 17 December 2013 on the financing, management and monitoring of the common agricultural policy and repealing Council Regulations (EEC) No 352/78, (EC) No 165/94, (EC) No 2799/98, (EC) No 814/2000, (EC) No 1290/2005 and (EC) No 485/2008. OJ L 347, 549-607.

EFSA PPR (2014). Scientific Opinion addressing the state of the science on risk assessment of plant protection products for non-target plants. EFSA-journal 2014; 12(7)3800, 163pp.

EFSA Scientific Committee, 2016. Guidance to develop specific protection goals options for environmental risk assessment at EFSA, in relation to biodiversity and ecosystem services. EFSA Journal 2016; 14(6):4499, 50 pp. doi:10.2903/j.efsa.2016.4499

FAO [Food and Agricultural Organization of the United Nations] 2019. The State of the World's Biodiversity for Food and Agriculture, J. Bélanger & D. Pilling (eds.). FAO Commission on Genetic Resources for Food and Agriculture Assessments. Rome. 572 pp. (http://www.fao.org/3/CA3129EN/CA3129EN.pdf)

Früh-Müller A, Bach M, Breuer L, Hotes S, Koellner T, Krippes C, Wolters V, 2019. The use of agri-environmental measures to address environmental pressures in Germany: Spatial mismatches and options for improvement. Land use policy 84 347-362. Doi.org/10.1016/j.landusepol.2018.10.049

Haddaway, N.R., Brown, C., Eggers, S., Josefsson, J., Kronvang, B., Randall, N. and Uusi-Kämppä, J., 2016. The multifunctional roles of vegetated strips around and within agricultural fields. A systematic map protocol. Environmental Evidence, 5(1), pp.1-11.

Hackett, M. and Lawrence, A., 2014. Multifunctional role of field margins in arable farming. CEA report. Cambridge Environmental Assessments.

Holden J, Grayson RP, Berdeni D, Bird S, Chapman PJ, Edmondson JL, Firbank LG, Helgason T, Hodson ME, Hunt SF, Jones DT. The role of hedgerows in soil functioning within agricultural landscapes. Agriculture, Ecosystems & Environment. 2019 Mar 1;273:1-2.

Lautenbach, S., Mupepele, A.C., Dormann, C.F., Lee, H., Schmidt, S., Scholte, S.S., Seppelt, R., Van Teeffelen, A.J., Verhagen, W. and Volk, M., 2019. Blind spots in ecosystem services research and challenges for implementation. Regional Environmental Change, pp.1-22.

Millennium Ecosystem Assessment. 2005. Ecosystems and human well-being. Vol. 5. Washington, DC: Island press.

Owuor, S.O., Butterbach-Bahl, K., Guzha, A.C., Rufino, M.C., Pelster, D.E., Díaz-Pinés, E. and Breuer, L., 2016. Groundwater recharge rates and surface runoff response to land use and land cover changes in semi-arid environments. Ecological Processes, 5(1), p.16.

Pocock, M.J., Evans, D.M. and Memmott, J., 2010. The impact of farm management on species-specific leaf area index (LAI): farm-scale data and predictive models. Agriculture, ecosystems & environment, 135(4), pp.279-287.

Rothamstead Research, 2020. Yearly weather summaries [online]. Available at: https://www.rothamsted.ac.uk/ (accessed 17 July 2020)
Rola, A.C. and P.L. Pingali (1993), Pesticides, Rice Productivity, and Farmers' Health: An Economic Assessment, Washington, DC: World Resource Institute.
Rounsevell, M.D., Metzger, M.J. and Walz, A., 2019. Operationalising ecosystem services in Europe.
Spurgeon DJ, Keith AM, Schmidt O, Lammertsma DR, Faber JH. Land-use and land-management change: relationships with earthworm and fungi communities and soil structural properties. BMC ecology. 2013 Dec 1;13(1):46.
TEEB (2010), The Economics of Ecosystems and Biodiversity Ecological and Economic Foundations. Edited by Pushpam Kumar. Earthscan: London and Washington.
Waibel, H. and G. Fleischer (1998), Kosten und Nutzen des chemischen Pflanzenschutzes in der deutschen Landwirtschaft aus gesamtwirtschaftlicher Sicht. Kiel: Wissenschaftsverlag Vauk.
Wesseler, Justus and Richard Smart (2014): Environmental Impacts. In: Jose Falck-Zepeda, Karinne Ludlow, Stuart Smyth (eds.), Socio-economic Considerations in Biotechnology Regulation, pp. 81-95. Springer, New York.
Zanotelli, D. Montagnani, L. Manca, G. and Tagliavini, M. (2012). Net primary productivity, allocation pattern and carbon use efficiency in an apple orchard assessed by integrating eddy-covariance, biometric and continuous soil chamber measurements. Biogeosciences Discussions, 9, 14091–14143.

Appendix 1 Glossary

Non-target organism (NTO) such as non-target terrestrial plant (NTTP)	An organism (e.g. terrestrial plant) that is not intended to be affected by the potential stressor under consideration
Specific protection goal (SPG)	An explicit expression of the environmental components that need protection, the maximum impacts that is predicted or can be tolerated, where and over what time period. In this document, the concept of SPG is consistent with 'assessment endpoint'
Ecosystem service (ES)	The benefit people obtain from ecosystems. Ecosystem services include provisioning services such as food and water; regulating services such as flood and disease control; cultural services such as spiritual, recreational, and cultural benefits; and supporting services such as nutrient cycling that maintain the conditions for life on Earth
In-field area	The crop area and its boundaries that are managed by the farmer in the context of crop management
Off-field area	The area outside the managed in-field area
Plant Protection Product (PPP)	A substance (or device) used to protect (crop) plants from damage by killing or reducing pest organisms or by mitigating their effects
Service providing unit (SPU)	Structural and functional components of ecosystems, including biodiversity, necessary to deliver a given ecosystem service at the level required by service beneficiaries

Appendix 2 Questionnaire applied in case studies

Sheet 1 Generic Questions

Impact Assessment Framework for the definition of Specific Protection Goals	
Provide justification to explain why this is field/farm is "typical" for the selected crop and country:	
Question	**Comments**
What is the case crop?	
What is the location (town)?	Select the town where the experimental fields are located. Add the dimension (.. km by .. km) of that town or region
What are the GPS-coordinates of the experimental fields subject to this impact assessment?	This should be a real situation
Description of the landscape	
Is the landscape flat or is relief present? Please describe	Add a picture/photo.
	Slope
What are the most important crops grown?	both arable farming, horticulture and grassland
Indicate the percentage of the area of:	Area of influence of pesticides, at maximum 1 km
Cultivation of crops	
Grazing	
Wood	
other nature and protected area	
Surface water	
Description of the typical farm:	It is sufficient to describe an imaginary farm which is typical for that region
Which crops are grown at the farm	
What is a typical farm size measured in ha?	
What is a typical size of parcels, measured in ha?	
What are typical dimensions (length and width, measured in m x m?	relative square or rectangular
Field Margins	
Describe the typical field margin (e.g. hedgerow)	Field margin: vegetation present direct adjacent to cultivated crop
On-farm off-field area:	
what is the size of the off-field area?	Consider farm yards, field edges, ditches, roads, paths, wood patches
Which weed control management measures are applied in the off-field area?	Specify in which type of vegetation it is applied
Which machinery is present for:	
Tillage?	
Chemical weed control	
Mechanical weed control	hoe, etc
precision agriculture?	
Which cultivation operations are executed by a contract worker?	

Description of crop and field:	So this would be a real situation, following from the above.
What is the soil type?	
Normal sowing and planting time?	Mention week numbers
Normal harvesting time?	Mention week numbers
What type of soil tillage will be executed?	
Description of cultivation:	
Describe the complete rotation cycle	

Description of crop protection for the case crop:	
List the main problems for crop production (e.g. pests, diseases)	For example, list the main 5 pests, ranking them in order of decreasing importance (yield, quality)
List the main problems for NTTPs	
Diseases?	

What is the main crop protection strategy:	
chemical	
non-chemical measures: list machinery used, frequency, crop stage	
application of buffer strips?	
IPM-strategies? Please describe	
Other methods? Please describe	

Sheet 2. Existing weed control

Real situation	
Question	**Comments**
Which herbicides are generally used?	
Costs	
What share (%) of total production costs are the costs of:	
herbicides?	
Labour spent on weed control?	
Machinery used for weed control (energy, depreciation, maintenance)?	
Describe the vegetation by listing the top ten plants present, making distinction between weeds and NTTPs:	Weeds: plants with impact on yield and / or quality of the cultivated crop or increases costs. NTTPs: plants present infield and off-field that do not or hardly harm yield and quality of the cultivated crop
Infield	
in field margin: margin strip (if present) and unsprayed crop area (if present)	
in off-field area: plants or vegetation types present within distance that can be affected by herbicide use (10 m); taking drift and runoff into account	
What is typical yield with herbicide? (tonnes/ha/yr)	
What are high/low ranges of yield with herbicide?	
Weed Control	
Method of weed control	
Frequency of control	
Timing of weed control (week(s) of year)	
Crop stage at which weed control is applied	Use BBCH scale crop development
Duration of weed control (if takes more than 1 day)	
Describe method of application/control	
Which herbicides are generally used?	
Application rate?	
Is the herbicide applied with other chemicals? As a mixture?	
What is the distance of spray drift?	
Are there legal or policy requirements for no spray zones in the case study/crop country?	

Sheet 3 Impact assessment weed control to be filled in for each of the four scenarios
Aim of this section: Elaborate all scenarios for the case crop and the weed management control method. Describe deviations in Scenario 1 with starting situation (e.g. because IPM is applied in starting situation) Follow the instructions of the SPG definition Excel sheet. Aside from chemical weed control, mechanical weed control measures can be considered, including e.g. creating false seedbeds and application of cover crops, hand weeding, choosing crops or varieties with a quick start after seeding/planting and/or good weed suppressing characteristics. Please make use of the elaboration of the scenarios as presented in the sheet Protection scenarios. With respect to the impacts, pay attention not only to the environmental impacts, but also to social impacts, consumer health and economic impacts.

Food, biofuel or raw materials production	**Comments**
	See for explanation sheet 'Protection scenarios'
List the main weed species	List the main 10 weeds, ranking them in order of decreasing importance (yield, quality)
List the main NTTP species	
Method of weed control	
Frequency of control	
Timing of weed control (week(s) of year)	
Crop stage at which weed control is applied	
Duration of weed control (if takes more than 1 day)	
Describe method of application/control	
Which herbicides are generally used?	
Application rate?	
Is the herbicide applied with other chemicals? As a mixture?	
What is the distance of spray drift?	
Are there legal or policy requirements for no spray zones in the case study/crop country?	
What is typical yield (and range) without herbicide?	
How do weeds affect yield?	
What proportion of weeds are controlled? (%)	
How long does the control last? (weeks)	
What are the other alternatives to herbicidal weed control applied in scenario 2, 3 and 4?	
List differences (measures applied, herbicides used, adjusted doses, adjusted frequencies) of scenarios 2,3 and 4 on the one hand compared with scenario 1 (minimum requirements scenario) with respect to weed control measures	
Socio-economic questions:	
Employment for farmer	Relative change (%) in labour input
Employment for employees or contract workers	
Consumer health	Exceedance of prescribed Maximum Residue Limit
Change in costs	
Labour	relative change (%) in costs
Machinery (energy, depreciation, maintenance)	relative change (%) in costs; consider only new machinery that has to be applied additionally
Herbicides	relative change (%) in costs
Reduced land use	% net land use reduction
Yield	Relative yield reduction (%)
Price	Relative price reduction (%)
	Pay attention to the market

Sheet 4 Assessment with Ecosystem Services Framework

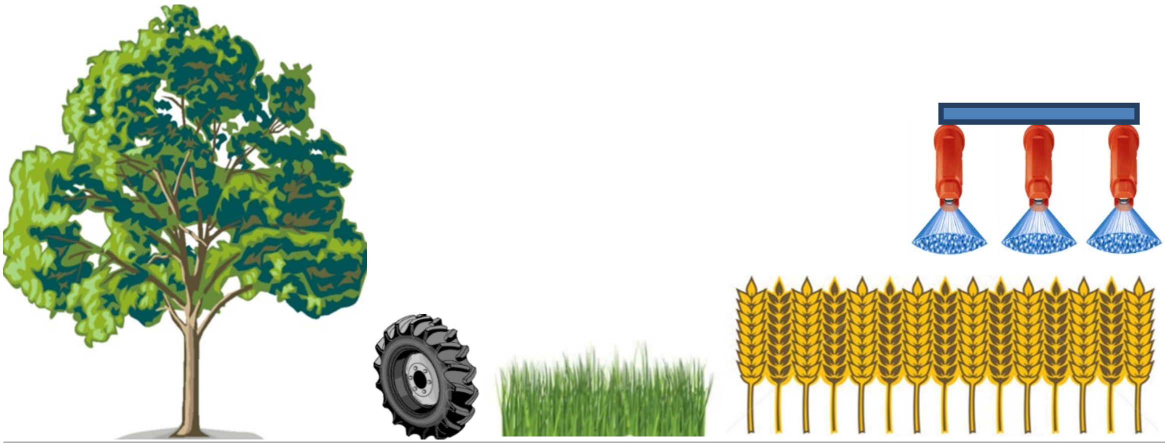
Ecosystem services
Question
Wild foods (off-field)
Are wild plant foods (e.g. berries) available in the off-field? What are they?
Are they important for the local community? (e.g. recreation, subsistence, festivals)
Do they have a value?
Freshwater (groundwater)
Are there protection policies for groundwater?
Do weed control actions affect groundwater resources?
Freshwater (surface water)
Are there protection policies for surface water?
Do weed control actions affect condition of surface waters?
Erosion prevention and maintenance of soil fertility
Are there protection policies for soil?
Do weed control actions affect soil quality?
Habitat for species (functioning of ecological components of the agro-ecosystem)
Do you have field monitoring studies that describe the ecology? Please also consider migratory or protected species
How do weed control actions affect wildlife?

Sheet 5 Background information: description of four scenarios

		Scenario 1	Scenario 2	Scenario 3	Scenario 4
Principles		Minimum requirements scenario	Weed reduction according the economical yield loss threshold scenario	Minimum requirements scenario with focus on off-field	Full protection of ecosystem services (ES)
Short explanation	**Infield, crop**	Focus on ES food production. Weed control by herbicides only	Reduced yield accepted if compensated by reduction in cost or innovative technology; mechanical harvesting	Focus on ES food production. Weed control by herbicides only but requires precision machinery (e.g. nozzles) to preserve the off-field area	Optimization of yield within the constraints of full protection of ES provided by NTTPs infield. So reduced yield can be a trade-off. Optimization means establishing the crop, without weed control afterwards. Focus on safeguarding NTTP species in-field, removal of some NTTP plants reducing yield accepted
	Infield, non crop	Other ES by non-crop plants no priority; no protection of NTTPs apart from the legal requirements	Flower strips (broader flower strips; also flower strips between rows); distinction between weed species on the basis of impact on yield reduction; natural enemies protected as much as possible	Other ES by non-crop plants no priority; protection of NTTPs off-field	All ES except food production have high priority; Protection of all NTTPs in and off-field; includes flower strips, buffer zones.
	Off-field	Following legal requirements for protection of off-field plants i.e. including the required use of nozzles	Following legal requirements for protection of off-field plants i.e. including the required use of nozzles	Full protection of off-field areas by maximum reduction of drift and use of nozzles > 95%; this option includes set-aside areas.	Focus on protection of ES in the off field area; drift reduction at least 95%

Sheet 6 Background information: Glossary

Definition of in field and off-field corresponding to farmer's interventions



Field boundary	Farm track	Margin strip	Unsprayed crop area	Sprayed crop area
Managed by farmer A				
Off-crop/off-field area-specific protection goals				**In-crop area-specific protection goals**
Risk mitigations applied strictly when the area is not managed by the farmer				
Risk mitigation applied as per boundary purpose when managed by the farmer				
Other legislations than Reg. 1107 may apply				

Glossary of definitions applied in the field of Ecosystem Services

https://www.ecpa.eu/sites/default/files/documents/ECPA%20BESS_Resource-paper_BEG_Publication_vs_2018_03_20_0.pdfhttps://www.ecpa.eu/sites/default/files/documents/ECPA%20BESS_Resource-paper_BEG_Publication_vs_2018_03_20_0.pdf

Appendix 3 Overview of institutes involved in case studies

Case crop	Country	Institutes
Maize	France	Arvalis
Oil Seed Rape	Sweden	Swedish University of Agricultural Sciences (SLU)
Onions	Poland	Inhort
Ware potato	Netherlands	Wageningen UR
Apple orchard	Italy	National Research Council (CNR) and Edmund Mach Foundation
Winter wheat	UK	Rothamsted Research

Appendix 4 Evaluation form for local experts

All local experts and those employed by members of the ECPA, who filled in the questionnaires were asked to fill in a short evaluation form at the end of the case study containing the following questions:

1. How much time did you spend to fill in the questionnaire?
2. Was the objective to fill in the questionnaire clear to you?
3. Were the frameworks and definitions clearly formulated and understandable?
4. Were the questions clearly formulated?
5. Did you have sufficient expertise to answer all questions? Pay attention to the fields of agronomy, crop protection – weed management, socioeconomic consequences, and Ecosystem Services.
6. Have you involved other colleagues from inside or outside your institute to answer the questions? If yes, for which reason and for which (type of) question?
7. In summary: how do you assess the applicability of the framework for the evaluation of herbicides?

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Wageningen Economic Research
REPORT
2020-074

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Report 2020-074
ISBN 978-94-6395-583-6

The mission of Wageningen University & Research is "To explore the potential of nature to improve the quality of life". Under the banner Wageningen University & Research, Wageningen University and the specialised research institutes of the Wageningen Research Foundation have joined forces in contributing to finding solutions to important questions in the domain of healthy food and living environment. With its roughly 30 branches, 6,500 employees (5,500 fte) and 12,500 students, Wageningen University & Research is one of the leading organisations in its domain. The unique Wageningen approach lies in its integrated approach to issues and the collaboration between different disciplines.