MTT REPORT 105

How to measure the environmental risks from uses of plant protection products for achieving the IPM requirements and risk communication

– A case study on the production chain of cereal farming in Finland

Kati Räsänen, Riikka Nousiainen, Sirpa Kurppa, Sari Autio, Sanni Junnila, Kari Tiilikkala, Janne Kaseva, Pauliina Laitinen

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This report is a combination of two deliverables that were originally named in the project plan:

1) A synthesis report on definition of the role of pesticide issues in vertical food chains, assessing pesticide ecotoxicological impact in LCA, facts to be taken into account in policy development

2) A synthesis report on definition of the role of pesticides in horizontal (watershed) approach, assessing ecotoxicology in horizontal scale, facts to be taken into account in policy development

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How to measure the environmental risks from uses of plant protection products for achieving the IPM requirements and risk communication

– A case study on the production chain of cereal farming in Finland

Räsänen, Kati[1], Nousiainen, Riikka[1], Kurppa, Sirpa[1], Autio, Sari[2], Junnila, Sanni[1], Tiilikkala, Kari[1], Kaseva, Janne[1], Laitinen, Pauliina[2]

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Abstract

Indicators are needed in the monitoring of risk reduction actions according to the EU strategy, where the aim is to reduce health and environmental risks via integrated pest management (IPM). The actions are based on EU legislation by the directive for sustainable use of plant protection products (PPPs) (2009/128/EC). PPP sales data are examples of present indirect indicators, which do not reflect the actual risks caused by various types of pesticides. In this study, we introduce a novel approach, the procedure, to specifically assess the progress of IPM in reducing environmental risks, and for achieving sustainable development as required. The study was done as part of the PesticideLife project (2010–2013) coordinated by MTT Agrifood Research Finland and co-financed by EU LIFE+ programme.

With the procedure the field usage of PPP effects were demonstrated in two dimensions. In the vertical dimension, the demonstration of potential PPP environmental impacts was assessed in terms of the food chain with the ecotoxicity impact of LCA. PestLCI 2.0 was used to estimate the emissions assuming average Finnish field conditions and the SETAC consensus LCIA model for ecotoxic impacts – USEtox™ – was used for characterisation factors. In the horizontal dimension, the demonstration of environmental risks on the landscape were evaluated using the aquatic risk indicators of EU HAIR2010 (HArmonised environmental Indicators for pesticide Risk).

The data for the demonstrations was based on PPP usage and sales in Finland. The field scale PPP usage data (kg of active ingredient per hectare) was obtained from a case study carried out by the Finnish Information Centre of the Ministry of Agriculture and Forestry (Tike), covering data from 2007 and crop farms in Finland. Sampling of the case data by Tike was also a pilot study to prepare for collecting pesticide usage data regularly in the future by Finnish authorities. The PPP sales data was obtained from the Finnish Safety and Chemicals Agency (Tukes). Three model crops of spring wheat, feed barley and oats, and four model substances of MCPA, glyphosate, prothioconatzole and α-cypermethrin were used in this work. In performing the vertical impact and horizontal risk demonstrations with the procedure, the three following steps were taken: 1. mapping of the PPP usage, 2. impact and risk assessment calculations at a countrywide scale in Finland, and 3. impact and risk assessment calculations at the regional scale (ELY-centres in Finland).

In the future, the results of this procedure, i.e. results obtained from different time periods, would describe impacts of the choices for the farmers working in the frame of IPM. In this study, we suggest to provide the authorities with this procedure for assessing of performance of IPM actions. Additionally, the proposed procedure and results can be used for different risk communication purposes. Further work is necessary for drawing more general conclusions on the patterns of environmental risks and IPM processing induced by the usage of plant protection products in Finland.

Keywords:
integrated pest management, IPM, indicator, environmental risks, ecotoxicity, life cycle assessment, PestLCI, USEtox™, HAIR risk indicators, plant protection product, active ingredient, risk communication

Hur mäter man miljöriskerna vid användning av bekämpningsmedel för att uppnå IPM-kraven och kommunicera riskerna?

– En fallstudie på produktionskedjan vid odlingsjordbruk i Finland

Räsänen, Kati[1], Nousiainen, Riikka[1], Kurppa, Sirpa[1], Autio, Sari[2], Junnila, Sanni[1], Tiilikkala, Kari[1], Kaseva, Janne[1], Laitinen, Pauliina[2]

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Abstrakt

Indikatorer behövs för att övervaka åtgärder för riskreduktion i enlighet med EU:s strategi, som går ut på att minska hälso- och miljöriskerna genom integrerat växtskydd (IPM). Åtgärderna bygger på EU-lagstiftningen i direktivet för hållbar användning av bekämpningsmedel (2009/128/EG). Försäljningsdata för bekämpningsmedel är exempel på befintliga indirekta indikatorer, som dock inte återspeglar de faktiska riskerna med olika typer av bekämpningsmedel. I denna studie introducerar vi en ny metod som ger en bättre helhetsbild av IPM-arbetets framsteg, genom att den inkluderar både möjligheten att bedöma utvecklingen inom hållbar användning av bekämpningsmedel samt riskarbetet kring bekämpningsmedel. Studien utfördes inom projektet PesticideLife (2010–2013) som samordnas av Forskningscentralen för jordbruk och livsmedelsekonomi MTT i Finland och samfinansieras av EU-programmet LIFE+.

Denna metod gör det möjligt att demonstrera effekterna som orsakats av de bekämpningsmedel som använts i fältstudien i två dimensioner. I den vertikala dimensionen bedömdes bekämpningsmedlens potentiella miljöinverkan på livsmedelskedjan och livscykelanalysens (LCA) ekotoxicitetsinverkan. PestLCI 2.0 användes för att uppskatta utsläppen utifrån genomsnittliga finska odlingsförhållanden, och modellen USEtox™ – SETAC:s LCIA-model för ekotoxisk inverkan – utnyttjades för att få fram karaktäriseringsfaktorer. I den horisontella dimensionen bedömdes miljöriskerna per landskap med akvatiska riskindikatorer från EU HAIR2010 (HArmonised environmental Indicators for pesticide Risk).

Uppgifterna byggde på användningen och försäljningen av bekämpningsmedel i Finland. Uppgifterna om bekämpningsmedlens användning på fältet (antal kilo aktiv ingrediens per hektar) erhölls från en fallstudie som utfördes av finska Jord- och skogsbruksministeriets informationstjänstcentral (Tike), och som innehöll uppgifter från 2007 från odlingsjordbruk i Finland. Denna datainsamling som Tike genomförde var en pilotstudie med syftet att myndigheten i framtiden regelbundet ska kunna samla in användningsinformation gällande bekämpningsmedel. Uppgifterna om försäljning av bekämpningsmedel erhölls från finska Säkerhets- och kemikalieverket (Tukes). I studien användes tre modellväxter, vårvete, foderkorn och havre, och fyra bekämpningsmedel: MCPA, glyfosat, protiokonazol och α-cypermetrin. Metodens vertikala och horisontella risker har demonstrerats i tre steg: 1. kartläggning av bekämpningsmedelsanvändningen, 2. bedömning av inverkan och risk på nationell nivå i Finland, 3. bedömning av inverkan och risk på regional nivå (ELY-centraler i Finland).

I framtiden kommer resultaten från denna metod som erhållits under olika år att återspegla de val odlarna gjort vad gäller integrerat växtskydd. I studien vill vi även erbjuda myndigheter att använda metoden i fråga. Metoden i fråga samt resultaten den ger kan även användas för olika typer av riskkommunikation. Det krävs ytterligare studier för att kunna dra slutsatser gällande vilka miljörisker bekämpningsmedel orsakar, samt hur arbetet med IPM-metoden fortskrider i Finland.

Nyckelord:
integrerat växtskydd, IPM, indikator, miljörisk, ekotoxicitet, livscykelanalys, PestLCI, Usetox, HAIR-riskindikator, växtskyddsmedel, aktiv ingrediens, riskkommunikation

Miten kasvinsuojeluaineiden käytön ympäristöriskejä mitataan IPM:n vaatimusten ja riskiviestinnän saavuttamiseksi?

– tapaustutkimus viljan viljelyn tuotantoketjussa Suomessa

Räsänen, Kati[1], Nousiainen, Riikka[1], Kurppa, Sirpa[1], Autio, Sari[2], Junnila, Sanni[1], Tiilikkala, Kari[1], Kaseva, Janne[1], Laitinen, Pauliina[2]

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Tiivistelmä

EU:n terveys- ja ympäristöriskejä vähentämään pyrkivän, integroidun kasvinsuojelustrategian (IPM = integrated pest management) mukaisen toiminnan seuraamiseen tarvitaan indikaattoreita. Toiminnat perustuvat EU:n lainsäädännön direktiivillä (2009/128/EC) tapahtuvaan ohjaukseen, jonka tarkoituksena on kasvinsuojeluaineiden kestävä käyttö. Kasvinsuojeluaineiden myyntitiedot ovat yksi esimerkki indikaattoreista, mutta ne eivät tosiasiassa kuvaa erilaisten aineiden aiheuttamia todellisia riskejä. Tutkimuksessamme esittelemme uuden menettelytavan, jolla voidaan arvioida kasvinsuojeluaineiden kestävän käytön kehittymistä ja kasvinsuojeluaineita koskevan riskinhallinnan tilaa eli kokonaisvaltaisemmin IPM:n edistymistä. Tutkimus on tehty PesticideLife -hankkeessa (2010–2013), jota koordinoi Maa- ja elintarviketalouden tutkimuskeskus MTT ja joka on osittain rahoitettu EU LIFE+-ohjelman kautta.

Menettelytavassa peltolohkon kasvinsuojeluaineiden käytöstä aiheutuvia vaikutuksia demonstroidaan kahdessa suunnassa (dimensiossa). Vertikaalisessa demonstraatiossa kasvinsuojeluaineiden ympäristövaikutuksia arvioidaan ruokaketjun suuntaan elinkaariarvioinnin (LCA = life cycle analysis) ekotoksisella ympäristövaikutusluokalla. Tutkimuksessa käytettiin PestLCI 2.0 -mallia arvioimaan Suomen pelto-olosuhteista saatuja keskiarvoisia päästöjä sekä ekotoksisen SETAC LCIA -vaikutusluokan USEtox™ –mallia karakterisointikertoimien laskemisessa. Horisontaalisessa demonstraatiossa ympäristöriskejä arvioitiin alueellisesti EU:n HAIR2010 (HArmonised environmental Indicators for pesticide Risk) akvaattisilla riski-indikaattoreilla.

Demonstraatioissa käytetty aineisto perustui kasvinsuojeluaineiden käyttö- ja myyntitietoihin vuodelta 2007. Peltolohkojen kasvinsuojeluaineiden käyttötiedot (kg tehoainetta hehtaaria kohti) saatiin Suomen Maa- ja metsätalousministeriön tietopalvelukeskukselta (Tike). Tike:n tekemä käyttötietojen keruu oli heille samalla pilottitutkimus, jonka tavoitteena jatkossa on kerätä torjunta-aineiden käyttötietoja säännöllisesti Suomen viranomaisena. Kasvinsuojeluaineiden myyntitiedot saatiin Suomen Turvallisuus- ja kemikaalivirastosta (Tukes). Tutkimuksessa käytettiin kolmea mallikasvia (kevätvehnä, rehuohra, kaura) ja neljää ainetta (MCPA, glyfosaatti, protiokonatsoli, α-sypermetriini). Menettelytavan vertikaaliset ja horisontaaliset riskit demonstroitiin kolmella tasolla: 1. kasvinsuojeluaineiden käytön mallintaminen kartalla, 2. vaikutusten ja riskien arviointien laskeminen koko Suomen tasolla, 3. vaikutusten ja riskien arviointien laskeminen aluetasolla (ELY-keskukset Suomessa).

Tulevaisuudessa menetelmällä eri vuosilta saadut tulokset tulevat kuvaamaan viljelijöiden tekemiä kasvinsuojeluvalintoja IPM:n toteuttamisessa. Tutkimuksessamme halusimme myös tarjota kyseisen menettelytavan viranomaiskäyttöön IPM -toimien arvioimiseen. Kuvattua menettelytapaa ja sen tuloksia voidaan käyttää erilaisiin riskiviestinnän tarkoituksiin. Lisätutkimusta tarvitaan, jotta voidaan tehdä johtopäätöksiä kasvinsuojeluaineiden aiheuttamista ympäristöriskeistä ja IPM:n edistymisestä Suomessa.

Avainsanat:
integroitu kasvinsuojelu, IPM, indikaattori, ympäristöriskit, ekotoksisuus, elinkaariarviointi, PestLCI, USEtox™, HAIR-riski-indikaattorit, kasvinsuojeluaine, tehoaine, riskiviestintä

Abbreviations

EC	= European Commission
EFSA	= European Food Safety Authority
GIS	= Geographic Information System
HAIR	= HArmonised environmental Indicators for pesticide Risk, http://www.hair.pesticidemodels.eu/home.shtml
IPM	= integrated pest management
LCA	= Life Cycle Assessment
MTT	= MTT Agrifood Research Finland, Coordinating Beneficiary, www.mtt.fi
NAP	= National Action Plan on the Sustainable Use of Pesticides
PPP	= Plant Protection Product
SYKE	= Finnish Environment Institute, www.environment.fi
Tike	= Information Centre of the Ministry of Agriculture and Forestry, www.mmmtike.fi
Tukes	= Finnish Safety and Chemicals Agency, Associated Beneficiary 2011–2013, http://www.tukes.fi/en/
USEtox™	= a model for characterizing human and ecotoxicological impacts of chemicals in life impact assessment, http://www.usetox.org/

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1 Introduction

1.1 The purpose of this study

Finland's agriculture is the northernmost in the world. Our country lies between the 60th and 70th parallels. There are still cultivated fields in Lapland up to the Arctic Circle, because the Gulf Stream makes our climate milder compared to other areas of the world on the same latitude, such as Siberia or Northern Canada. However, the growth season is very short; the number of suitable crop varieties and cultivars are limited and must have been adapted to the Northern conditions (long day length) very well.

In Finland, agriculture occurs near the water systems because of their abundance (9% of the total land is covered by freshwater distributed largely to small lakes and rivers, Statistics Finland 2012). Finnish total arable and horticultural land is 2,300,000 ha (Tike 2010), which is about 5.9% of the total land area (Statistics Finland 2012). Plant production covers about two thirds of the total arable and horticultural land, from that cereals are cultivated on about 60 %, grasslands comprise about 30 % and the other crops only ca 10 %. From the area of other crops the main cultivated are turnip and oil seed rapes on over 40 % and potato on over 10 % in years 2003-2009 (Tike 2010). About 9% from the agricultural land is under organic cultivation in 2012 (EVIRA 2012).

Herbicides and fungicides are the most commonly used plant protection products (PPP), in Finland. Insecticides are less needed because of the short summers and cold winters, which can limit the population growth of the noxious organisms naturally. In addition, the disease pressure is lower in some cases compared to warmer climate conditions. However, climate change may threaten the good situation. In recent years, the introduction of new cultivation methods, like direct sowing, have led to an increased need for plant protection, when the fungal diseases and weeds remain in the plant remnants and topsoil, and are able to conquer the fields at an earlier stage of the growth season compared to tilled soils.

The total sales of plant protection products in Finland was 1707.5 tonnes in 2011, or 0.7 kg/ha if calculated for the total agricultural land of the country (Tukes 2012, Tukes = Finnish Chemical and Safety Authority). Sales data of agricultural plant protection products between 2000-2011 in Finland is shown in Figure 1. The sales of biological plant protection products in Finland have constantly been ca. 1% of the amount of chemical products. Therefore, comparison is difficult. The relation between the sales amounts of biological and chemical products has been quite constant (Savela 2013).

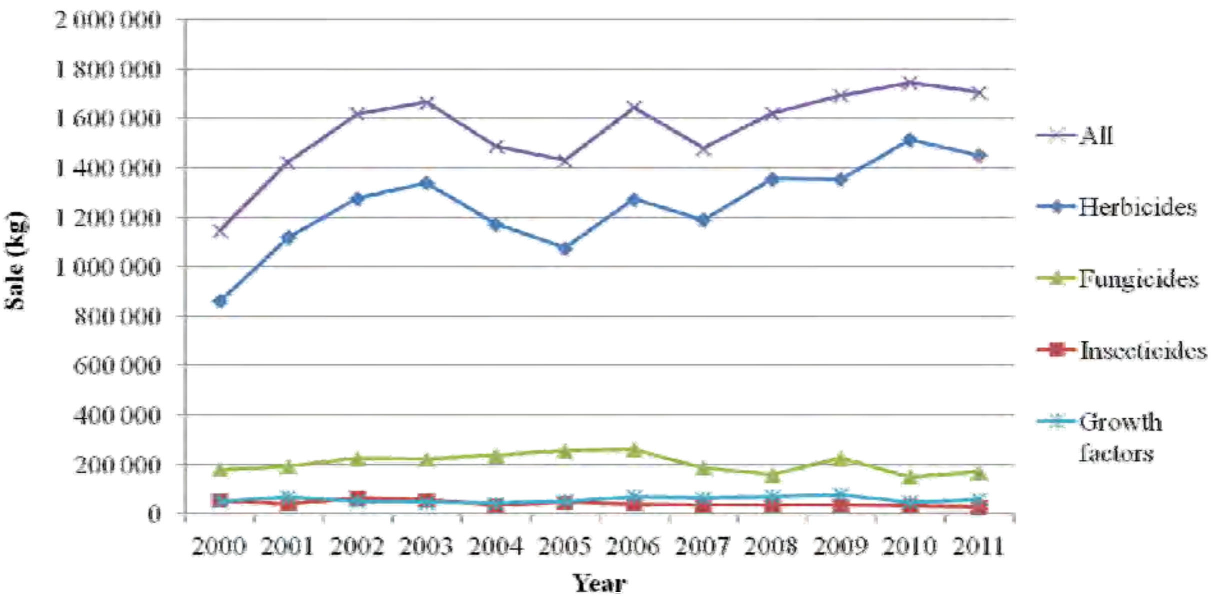


Figure 1. Sales data of agricultural plant protection products in Finland 2000-2011.

This demonstration study, comply package 4 of the PesticideLife project, is partly financed by EU LIFE+ financing programme (2010-2013). The aim of this part was to demonstrate the role of pesticide issues in vertical food chains, assessing the pesticide ecotoxicological impact in LCA, and the role of pesticides from a horizontal (watershed) approach, and assessing ecotoxicology on the horizontal scale to the aquatic environment. The aim was to communicate the results to the authorities, advisory organisations and farmers both in Finland and in the Northern zone. The aims were conducted via a procedure, more details of which are in section 2.

1.2 Legal obligations of plant protection products

1.2.1 Legal background

In Europe, the use of plant protection products is regulated as a part of the Thematic Strategy for the Sustainable Use of Pesticides (2009/128/EC). As a special group of chemicals, the placing on the market and use of plant protection products is only allowed following the approval of active substances and authorisation of each plant protection product. The EC regulation (1107/2009/EC) lays down uniform rules on the evaluation, authorisation, placing on the market and control of PPPs and the active substances they contain within the European Union. Legislation of plant protection products is based on the protection of human health and the environment from the possible risks posed by the use of PPPs. The approval of pesticides as well as the monitoring of residues in food, feed and the environment was already legislated on before 2009, when also the use of pesticides was legislated by the EU's new framework directive 2009/128/EC on the sustainable use of pesticides (SUD). The directive must be implemented in the national legislation in EU Member States, as was done in Finland in 2012. The Finnish Act on plant protection products (1563/2011) covers the provisions of the SUD and the regulations concerning the placing of plant protection products on the market (1107/2009). The regulation of plant protection products are shown in Figure 2.

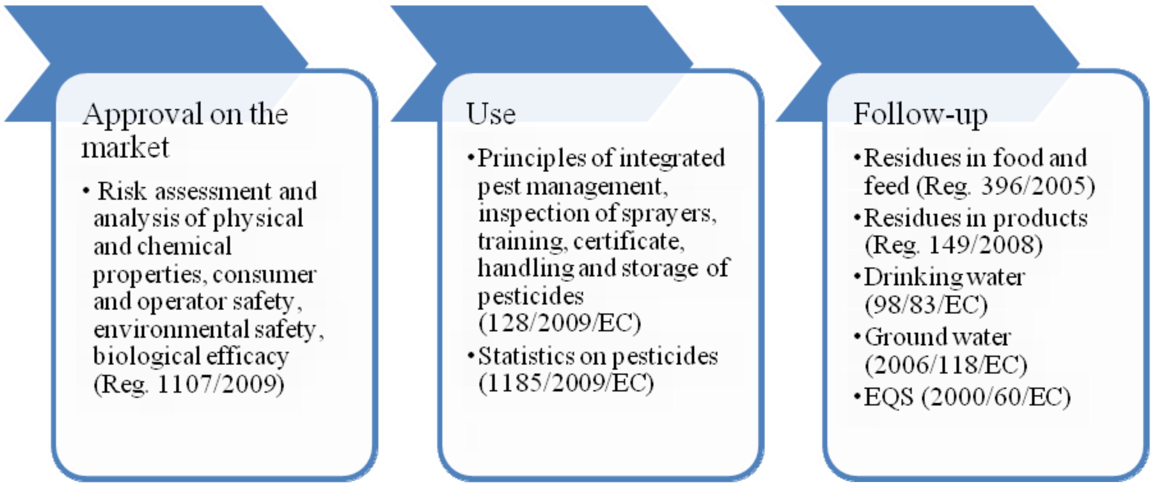


Figure 2. Plant protection products are regulated through the life cycle of the product, from the approval process and use to the follow-up of the residues in food, feed and the environment.

1.2.2 Placing on the market

When applying for approval and authorisation for a plant protection product, the manufacturer is obliged to submit a large dossier of studies related to physical and chemical properties, methods of analysis, human toxicology, operator safety, residues and consumer safety, fate and behaviour in the environment and ecotoxicological effects and biological efficacy (EU 2013 a, EU 2013 b). In the first place, the active substances must be approved at the EU level and secondly, the formulated products containing those active substances must be authorised in the Member States within the three EU zones (Northern, Central and Southern) cooperating in the evaluation of the plant protection products within each zone. The Northern zone consists of the Nordic and Baltic countries.

As conditions for authorisation, Member States may set different risk mitigation measures on the basis of environmental risks, for example, as restrictions of use in sensitive areas like ground water areas. The plant protection products are authorised for a maximum of ten years. The Finnish authority responsible for the approval of plant protection products is the Finnish Safety and Chemicals Agency Tukes.

1.2.3 Regulations of use

The use of plant protection products is regulated by the directive on the sustainable use of pesticides (SUD, 2009/128/EC). The directive is concerned with the training of all professional PPP users, the inspection of sprayers, awareness raising, aerial sprayings, the protection of waters and the handling and storage of pesticides, among other things. All Member States are obliged to adopt a national action plan (NAP), through which the objectives, targets, measures and timetables of the directive are set. The Finnish Safety and Chemicals Authority (Tukes) is responsible for the implementation of Finnish NAP (MMM 2011).

1.2.4 Monitoring the sales and use of pesticides

Yearly sales data on plant protection products have been collected in Finland since the 1950s. The sales statistics are published on the Tukes website (http://www.Tukes.fi/fi/Toimialat/Kemikaalit-biosidit-ja-kasvinsuojeluaineet/Kasvinsuojeluaineet/Myyntitilastot/). Sales data from the last 12 years are presented in Figure 1.

In the thematic strategy on the sustainable use of pesticides, the EU recognised the need for a detailed, harmonised way of collecting statistical data on sales and the use of plant protection products at the EU level. Such statistics are necessary for assessing EU policies on sustainable development and for calculating relevant indicators in the risk to health and the environment related to pesticide use. Therefore, the regulation concerning the statistics on pesticides (1185/2009) was given and the first round of data collection is ongoing. The sales were reported to EUROSTAT for the first time in 2012. For the usage data, Member States can choose the most representative year in a five-year time window, and the methods for collecting the usage data can be variable. Validation of the data collection methods used in different Member States has not taken place yet.

1.2.5 Monitoring of residues

Plant protection products are synthetic chemicals which are purposely spread in the environment during the production of food and feed. The approval process and instructions for use are necessary for protecting the consumers and the environment. The maximum residue levels (MRL) of PPPs in or on food and feed (396/2005) and products (149/2008) have been set for different food commodities at the EU level in order to protect consumers. MRLs are based on research results and are set at a level that ensures that the consumption of each food commodity is safe to all consumer groups. The same principle is used in the monitoring of pesticide residues in drinking water (98/83/EC) and groundwater (2006/118/EC) as well as in environmental monitoring by environmental quality standards, EQS (2000/60/EC). National authorities run monitoring programmes and report on the results nationally and at the EU level.

1.3 Plant protection products and the environment

When plant protection products are spread on field, non-target organisms and the environment are exposed at least to a certain extent following the application. As plant protection products are not usually intended to be readily degradable, those may remain in the environment for a longer period. Certain substances may also be transported from the site where they have been used via the air, surface and groundwaters and the exposed organisms (e.g. Laitinen 2009, Ruuttunen and Laitinen 2008, Seppälä 1997, Turunen 1985). The fate, exposure and effects of pesticides in the environment are illustrated in Figure 3.

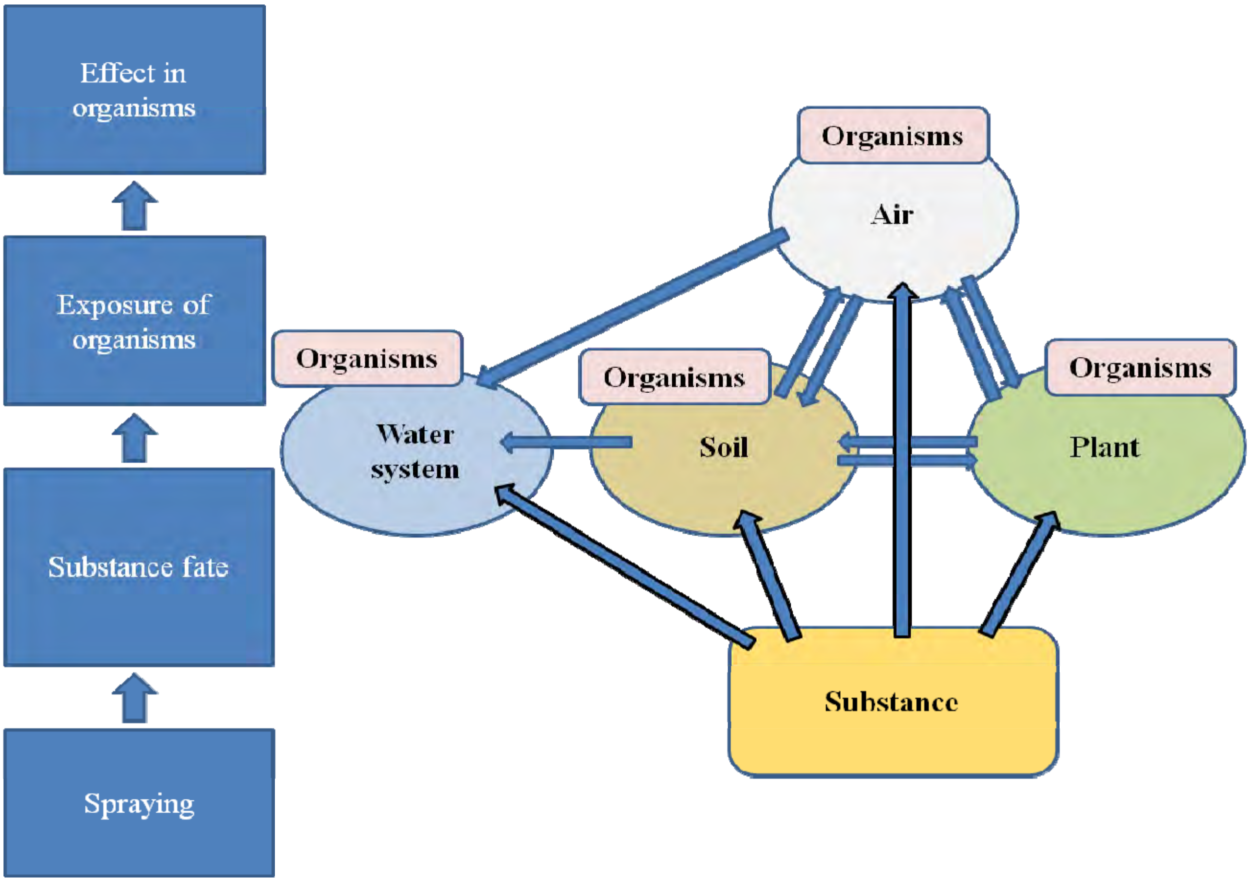


Figure 3. The fate, exposure and effects of pesticides in the environment

Plant protection products can cause a risk to non-target organisms. The risks induced by PPP are defined as a relationship between toxicity and exposure. Therefore, a risk assessment is needed to quantify whether the risks are acceptable following the intended uses of the product. The risk assessment of plant protection products according to the regulation 1107/2009 is performed on two levels: for active substances at the EU level, and for the products containing active substances at the zonal level, including the mutual recognition of authorisation at Member State level. The approval and authorisation applications need to be supported by a large amount of studies on the active substance and the product. Detailed data requirements are set in the annexes of the regulation, and the risks are assessed according to the EU guidance documents.

The European Union has been divided into three zones for cooperation in the risk assessments of plant protection products. The Northern zone includes Denmark, Sweden, Lithuania, Latvia, Estonia and Finland, while Norway and Iceland are cooperating with EU Member States within the zone. However, the agricultural and environmental conditions differ a lot, even within the Northern zone in the Nordic and Baltic countries. For national purposes, additional research data may be required to ensure that the environmental conditions of the studies are relevant for the intended uses and the proposed risk mitigation measures are applicable in the area in question.

Nordic countries have a long tradition in cooperation concerning the risk assessment and authorisation of plant protection products, since the 1950s. We were already used to sharing the workload of risk assessments of active substances in the 1980s, before some of the Nordic countries joined the EU the following decade. Therefore, the zonal evaluation of active substances is not a new idea in the Nordic countries. Today, the Baltic countries also participate actively in the Northern zone cooperation.

Guidance on the application, data requirements and risk assessment for plant protection products in the Northern zone is available from the Tukes website http://www.Tukes.fi/Tiedostot/Kemikaalituotteet/kasvinsuojeluaineet/Northern_Zone_work-sharing_guidance_April_2013.pdf (Anon 2013). The guidance will be updated regularly according to the latest research results, following the discussions and agreements between the experts of each section. For this purpose, the experts organise yearly cooperation meetings and teleconferences with funding from the Nordic Chemicals Group of the Nordic Council of Ministers.

1.3.1 Environmental risk assessment

The environmental risk assessment is necessary prior to the authorisation of plant protection products and it is performed using the guidance available in the EU and the Member States. The aim of the risk assessment is to demonstrate that the product fulfils the criteria of the uniform principles agreed in the EU and the intended use of the plant protection product does not pose any unacceptable risks to the environment.

In the Table 1 below, the different guidance documents available for this area are presented. Because the guidance documents are living documents and are occasionally amended to take into account the current scientific developments of the area, the table should not be considered as a complete list but only as an example of the various requirements.

Table 1. Examples of the guidance documents on the environmental risk assessment used in Finland

Guidance documents	Link to the original document
FOCUS groundwater and surface water scenarios	http://ec.europa.eu/food/plant/plant_protection_products/approval_active_substances/focus_en.htm
RA for soil-dwelling organisms, the Finnish PECsoil calculator	http://www.Tukes.fi/en/Branches/Chemicals-biocides-plant-protection-products/Plant-protection-products/Data-dossier-requirements-and-risk-assessments-/PEC-soil-calculator/
EC RA on the aquatic ecotoxicology	http://ec.europa.eu/food/plant/protection/evaluation/guidance/wrkdoc10_en.pdf
EC RA on terrestrial ecotoxicology	http://ec.europa.eu/food/plant/protection/evaluation/guidance/wrkdoc09_en.pdf
EFSA RA for birds and mammals	http://www.efsa.europa.eu/en/efsajournal/pub/1438.htm
Exposure of PPP via air	http://ec.europa.eu/food/plant/plant_protection_products/approval_active_substances/focus_en.htm
links to all EU guidance	http://ec.europa.eu/food/plant/pesticides/approval_active_substances/guideline_documents_en.htm
Northern zone guidance document on work-sharing	http://www.Tukes.fi/Tiedostot/Kemikaalituotteet/kasvinsuojeluaineet/Northern_Zone_work-sharing_guidance_April_2013.pdf

The behaviour of the plant protection product in the environment is mainly evaluated based on the data of the active substances and their significant degradation products. The exposure depends greatly on how and where the product will be used. Predicted environmental concentrations (PEC) must be calculated in soil, groundwater and surface waters, based on realistic worst-case scenarios. For the ecotoxicology, effect studies on aquatic and terrestrial organisms with the product are required in addition to those with active substance(s). The risks are then defined as toxicity exposure ratios (TER) comparing the toxicity of the plant protection product to tested organism with the PEC values in the representative compartment (e.g. in surface water), following the actual use rates, application times and other use instructions of the product, as applicable in Finland.

In case the first tier risk assessment fails to demonstrate the safe use, a higher tier risk assessment will be performed. The higher tier may mean a more realistic test design in the ecotoxicological studies, e.g. mesocosm or field studies in order to achieve a more realistic toxicity endpoint, or it may include risk mitigation measures in order to reduce the environmental load of the substance, e.g. buffer zones along the watersheds. So the higher tier risk assessment may need to be repeated to find out the conditions where the use can be demonstrated to pose a negligible risk. Risk mitigation options available in the Northern zone are presented in Appendix VI of the Northern zone guidance document on work sharing (Anon 2013).

1.3.2 Challenge of the risk mitigation

A challenge for the regulatory authorities in the Northern zone is to perform the environmental risk assessment of plant protection products according to the PPP regulation, to maintain the high level of protection of the environment and at the same time to prove that in the market there is an adequate selection of products available for the farmers.

Currently the authorisation decisions of plant protection products include the necessary restrictions of use, e.g. the buffer zones for protecting the aquatic organisms; restrictions of use on the same field in consecutive years; prohibition to spray during the daytime when pollinating insects are active; or restrictions of use on groundwater areas. These restrictions are based on the risk assessment of each product and they are always product-specific, and products including the same active substance may have different restrictions due to different composition or use conditions. These restrictions and the use instructions of each product are part of the labelling of the products and must be followed by the users.

However, the agricultural and environmental conditions differ a lot, even within the Northern zone in the Nordic and Baltic countries. Differences in product selection, authorisation systems, cultivation methods and conditions of use may make the harmonisation of PPP authorisation very difficult. Certain products have quite big differences in their use instructions, use rates and application times, etc. in the Nordic and Baltic countries. For instance, when they start to spray their winter cereals in Denmark, we still have the skiing season in Finland. Therefore, the automatic mutual recognition of approvals within the zone seems not to lead to the best environmental and agricultural practice for each country. Therefore, use instructions and risk mitigation measures may be different even for the same product in different Member States within the zone. Risk mitigation options available in the Northern zone are presented in Appendix VI of the Northern zone guidance document on work sharing (Anon 2013).

For example, Denmark supplies most of its drinking water from groundwaters and must therefore be very restrictive for pesticides with high leaching properties, whereas surface water is more important for the drinking water supply in other Nordic countries. Due to the introduction of the restriction of use on groundwater areas in Finland, we may authorise products which may leach in certain conditions, provided that they are not used in the defined groundwater areas.

For reducing the risks to surface waters, Finland has recently revised the buffer zones according to the PPP risk assessment, leading to buffer zones from 3 to up to 50 metres. In addition, drift reducing nozzles can be used to reduce the width of the required buffer zones. There will be a transition period (2013-2014) for moving towards the new buffer zone system.

The user of each plant protection product is responsible for following the labelling, use instructions and possible restrictions of use thoroughly. The knowledge and skills of the farmers are essential when controlling the exposure and mitigating the risks of plant protection products to the environment. The user is always responsible for the appropriate choice of product on certain crops and pests, and for following the use instructions and possible restrictions of use. Using a pesticide that is not effective or is otherwise unsuitable for the pest in question means unnecessary load to the environment with a hazardous chemical. Therefore, the user first needs to identify the pest and find the most effective product for the circumstances in question. The user should get to know the user instructions and restrictions of the product already before purchasing the product. The label texts can be found in the register of plant protection products on the Tukes website: http://www.Tukes.fi/en/Branches/Chemicals-biocides-plant-protection-products/Plant-protection-products/Authorised-products/Plant-Protection-Product-Register/.

1.3.3 Reducing the risks of plant protection products – National Action Plan (NAP)

Since 2011, Finland has an officially approved national action plan for reducing the risks of plant protection products (Ministry of Agriculture and Forestry 2011). A national action plan (NAP) supports the implementation of the EU directive on the Sustainable Use of Pesticides (SUD, 128/2009/EC, EU 2009).

The action plan was preceded by a PPP reduction programme in the 1990s, although the programme was never officially approved. Later, certain measures from the reduction programme have been taken into the agri-environmental support programmes (1995-1999, 2000-2006 and 2007-2012), which aimed to a) reduce the environmental load caused by agriculture, especially the load into surface and groundwaters and into the air; b) protect the biodiversity; and c) take care of the rural landscape. Measures concerning the use of PPPs form one part of the programme, yet the main focus has been on the reduction of nutrient releases so far. In Finland, about 90% of all farmers get EU agri-environmental subsidies, meaning that more than 95% of the agricultural area has been cultivated according to the agri-environmental rules. As it covers almost all farmers and all cultivated land, this is the instrument to influence farmers' behaviour concerning environmental issues most extensively.

The Finnish approval authorities have prioritised new, less harmful products in order to substitute older, possibly more harmful ones. Plant protection products should be used according to established need only. To determine the need for control thresholds, forecasts and specialist systems have been developed. The emphasis has been put on crop rotation and integrated pest control.

All agricultural spraying equipment must be tested regularly every five years. Training courses need to be available and an examination system will be created for the professional users and retailers of plant protection products. The farmers have to attend training every five years. Furthermore, the programme includes the extension service, advice to and training of the persons using pesticides.

A project called "Balanced Crop Protection" formed the basis for the training between 2000 – 2006. A group of scientists, advisers, industrialists, farmers and administrators jointly produced booklets for 24 different crops (A Balanced Crop Protection on wheat, on barley, on potatoes, etc.) as well as a book on crop protection in ecological farming (http://www.kasvinsuojeluseura.fi/Tasapainoinen/tabid/1875/Default.aspx). Every farmer had to buy the booklets for the crops he or she grew. The booklets cover crop protection measures in a wide sense, starting from the selection of the right variety, field, crop rotation, and cropping techniques to actual crop protection. These booklets mainly cover the general IPM criteria which were published by IOBC-WPRS, and are available at: http://www.kasvinsuojeluseura.fi/Tasapainoinen/tabid/1875/Default.aspx.

Based on fifty-year-old regulations, every farmer also has to keep records on the use of plant production products, used amounts and application times on each field parcel. These records must be presented for the supervisory authorities whenever required.

The monitoring of the concentrations of plant protection products in surface and groundwaters has not been organised to cover the whole country in regular time series, but the situation has been surveyed in agricultural areas. Traces of several plant protection products have been found in surface and groundwaters in Finland, especially near old nursery gardens and railway yards (http://www.ymparisto.fi/default.asp?contentid=180536&lan=fi , http://www.ymparisto.fi/default.asp?contentid=276110&lan=fi).

The risk indicator calculated on the basis of sales amounts indicates the growing trend of the environmental load from plant protection products (http://www.ymparisto.fi/default.asp?contentid=249462&lan=fi&clan=fi#a0).

The users of plant protection products are responsible for choosing the right product and using it properly in order to minimise the unnecessary load into the environment. Therefore, the level of education and certification of the users are essential.

1.3.4 Risk indicators and sales of plant protection products in Finland

Several attempts have been made internationally to develop risk indicators for calculating the risks related to agricultural uses of plant protection products in the recent years (e.g. Anon 2012, OPERA 2011, Nummivuori 2007). The achievements of the National Action Plans will be measured by using risk indicators.

In Finland, data necessary for calculating the risk indicators are collected by Tukes and Tike (Information Centre of the Ministry of Agriculture and Forestry) collectively. Tukes is responsible for collecting the sales data, while Tike is in charge of the usage data. The data covers the amount of active substances and the amount of products sold every year. The data is published every year (http://www.Tukes.fi/fi/Toimialat/Kemikaalit-biosidit-ja-Kasvinsuojeluaineet/Kasvinsuojeluaineet/Myyntitilastot/). Tike will collect the first round of pesticide usage data before 2016 according to Regulation (EC) No 1185/2009 concerning statistics on pesticides.

There are remarkable yearly variations in the sales amounts of plant protection products in Finland. In the 1990s, the sales of plant protection products went down for several years in Finland and reached a level of about 1,000 tonnes of active substance per year, which corresponded to a use of approximately 0.5 kg/ha. However, the sales rose again later on. At the beginning of 2012 there were some 350 approved plant protection products on the market in Finland containing around 150 active substances

A national risk indicator was developed in the Finnish Environment Institute SYKE (Seppälä and Nummivuori 2004, Seppälä and Nummivuori 2005, Nummivuori and Seppälä 2006, Nummivuori 2007). Intrinsic properties of the active substances like persistence, bioconcentration, leachability and ecotoxicological properties are accounted for and linked with the sales data in the Finnish risk indicator. It indicates that the environmental risks of PPPs are growing together with the sales amount (Figure 4). Changes in cropping techniques, increasing farm sizes and the more professional use of PPPs, a larger part of the cultivated area used for grain production and falling prices for glyphosate have been suggested as reasons for the growing sales trend. The indicator is published at: http://www.biodiversity.fi/en/indicators/farmlands/fa4-pesticide-use.

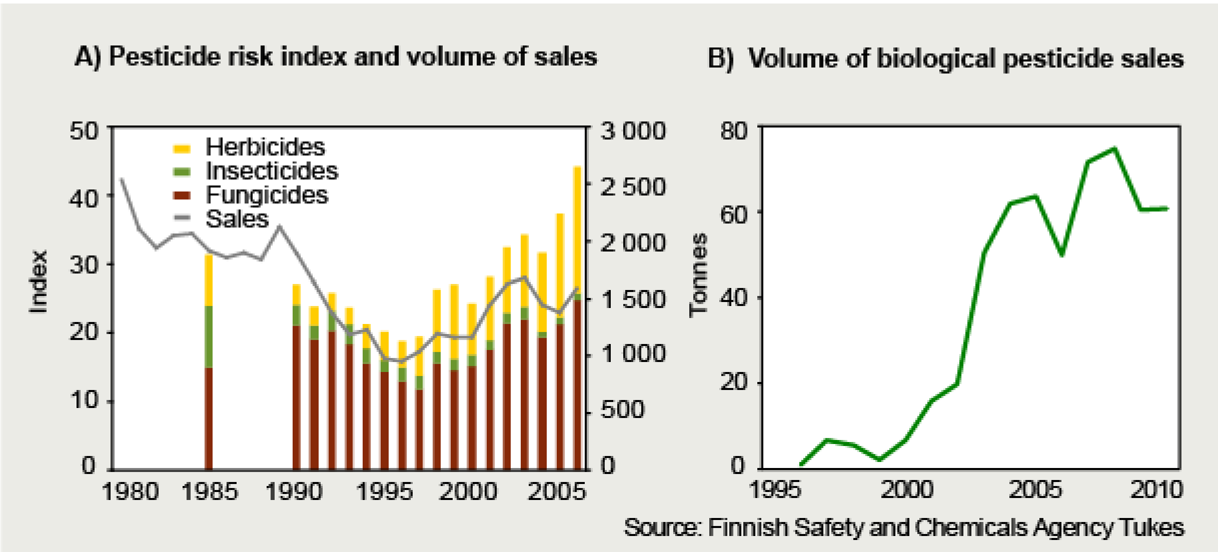


Figure 4. Risk indicator and sales of pesticides as active ingredients in Finland 1985 – 2004 (SYKE and Evira)

In the EU the calculation tool HAIR (HArmonised environmental Indicators for pesticide Risk) has been developed for the Member States of the European Union (Kruijne et al. 2011, HAIR2010 2013). The first version of HAIR was developed within a project funded under the framework of the sixth Environmental Action Programme. The aim of the original HAIR project was to develop and integrate European scientific expertise on the agricultural use, emissions, environmental fate and the impact of pesticides on the environment and human health. The HAIR consortium developed a set of indicators. In 2009, the

European Commission DG RTD and Alterra Wageningen UR agreed that Alterra would develop a software package and user manual in 2010. Now the HAIR2010 (Version 1.2.4, 10-01-2012) is available at: http://www.pesticidemodels.eu/. The primary aim of the HAIR instrument is to calculate the trends in aggregated risk resulting from pesticide use in agricultural crops within the European Union. The calculated trend can be compared for example with risk reduction targets set in national policy plans. A research group is developing the HAIR instrument.

HAIR2010 input data is stored in different types of databases. The Usage database contains the regional pesticide use data collected by the Member States. The Compound database contains the intrinsic properties of the active ingredients of plant protection products. The HAIR2010 database contains the crop maps, soil and climate maps, crop definitions and all other input data required for calculating the risk indicators. The user is responsible for the Usage database and the Compound database. The HAIR2010 database does not need to be edited by the user. The software has a modular structure so that existing indicators can be updated or new risk indicators can be added later, when necessary. The crop interception model has a central place in the HAIR concept. For each application, the crop interception is determined based on crop characteristics and climate assumptions.

HAIR2010 contains a set of 29 risk indicators expressed by their exposure toxicity ratio. The aquatic indicators express the potential risk to the aquatic ecosystem in a standard volume of surface water in a field ditch with standard cross-sectional dimensions. Considering loadings by spray-drift, runoff and erosion, separate risk indicators with different exposure concentration are calculated for standing and flowing water conditions, and for acute and chronic exposure regimes. These exposure conditions are related to toxicity data for different aquatic organisms. The indicator for the risk of leaching towards deep groundwater layers is based on the long-term average leaching concentration in the soil solution. The terrestrial risk indicator group includes acute and chronic indicators for birds and mammals and earthworms, as well as acute hazard quotient for bees. The set of occupational indicators comprises acute and chronic indicators of risk to operators, re-entry workers, adult and child bystanders and residents.

The HAIR instrument can be used with more refined usage input data originating from farm or field-based case data collected in Member States. It is up to the Member States how their Usage databases are created. As for all mathematical models, the reliability of the results obtained with this instrument is highly dependent on the liability of the input data.

1.4 Cultivation practices, the basis of risk management

1.4.1 Integrated Pest Management (IPM)

Integrated Pest Management (IPM) represents a consolidated means to manage a wide range of agricultural pests and diseases. Preventative, mechanical and chemical means are employed in a single package when needed. The use of pesticides and other inputs is kept to an economically justifiable level and risks to the environment are minimised (e.g. Junnila 2012).

There are tens of definitions for IPM, and that of the FAO (Food and Agriculture Organization of the United Nations 2013) is the following: "Integrated Pest Management (IPM) means the careful consideration of all available pest control techniques and subsequent integration of appropriate measures that discourage the development of pest populations and keep pesticides and other interventions to levels that are economically justified and reduce or minimise risks to human health and the environment. IPM emphasizes the growth of a healthy crop with the least possible disruption to agro-ecosystems and encourages natural pest control mechanisms."

According to the directive (128/2009/EC), farmers must adopt the general principles of IPM practices from 2014. Preventative methods like choice of tillage method, crop rotation, healthy seed, resistant cultivars and accuracy in selecting sowing time are essential to securing a good crop yield. Chemical control will be used only if preventative measures do not adequately suffice for plant health and crop growth. Monitoring pests and diseases and using threshold values and forecasting systems, if available, will support decision-making. Observing the amount and quality of the yield and the effectiveness of plant protection by using unsprayed parcels bring knowledge and experience for choosing the best methods in the coming years. Training and diversified data transmission is an essential part of IPM.

Farmers, scientists and advisers share their knowledge and experiences about plant protection at regular events organised by Tukes (Tukes 2013).

1.4.2 Comparison of conventional, integrated and organic farming systems

No clear definitions are available for all the farming systems although the words – conventional – integrated – organic – have often been used in the literature. The easiest one to define is organic farming and the most difficult to describe is conventional farming. An organic farming system, according to the Codex Alimentarius Commission (http://www.fao.org/docrep/005/Y2772E/Y2772E00.HTM), is designed to increase biodiversity and soil biological activity, to conserve long-term soil fertility, to recycle plant and animal waste, to minimise non-recyclable inputs and pollution from cultivation practices, to control pests and diseases with non-chemical methods, to manage animals extensively and with a focus on their well-being, and to retain the integrity and qualities of the products during processing. Historically, organic farming in the EU was established in 1991 under Regulation (2092/91) for organic farming, complemented by Reg. 1804/99 for organic livestock. The new regulations (834/2007 and 889/2008) set the current rules for production standards and for placing signs and advertising organic products. The IFOAM (International Federation of Organic Agriculture Movements) defines organic farming differently (http://www.ifoam.org/growing_organic/growing_organic_main.php). A description of organic farming in Finland has been reported by the Finnish Food Safety Authority Evira (http://www.evira.fi/portal/fi/tietoa+evirasta/asiakokonaisuudet/luomu/).

The international organisation for biological and integrated control of noxious animals and plants (IOBC-WPRS) has described integrated farming as follows: "Integrated Production – is a concept of sustainable agriculture developed in 1976 which has gained international recognition and application. The concept is based on the use of natural resources and regulating mechanisms to replace potentially polluting inputs. The agronomic preventative measures and biological/physical/chemical methods are carefully selected and balanced taking into account the protection of health of both farmers and consumers and of the environment." The IOBC has renewed the IP guidelines several times (http://www.iobc-wprs.org/ip_ipm/IOBC_IP_principles.html).

The term "conventional farming" is used to describe a wide range of agricultural practices and it is hard to put a single definition on conventional farming. In general, it is assumed to be any type of agriculture that requires high external energy inputs to achieve high yields, and generally relies upon technological innovations, uniform high-yield crops, and high labour efficiencies (Gold 1999). Conventional farming describes any farming not dedicated to alternative methods. Fundamentally, it is the kind of farming which dominated the 20th century and which accounts for most farming today. The term industrial farming can be also used for that. There huge amount of food is attempt to be produced and chemical plant protection products, chemical fertilizers and intensive mass animal farming are common. Production has been arranged to match to the local markets and national agricultural policy. Very often, large scale monocropping has been possible (Horrigan et al. 2002).

The use of inputs in conventional farming is not overly limited. All kinds of nationally registered agrochemicals can be used, including synthetic fertilizers and pesticides. In integrated farming the aim is to achieve sustainable agriculture and there the use of agrochemicals should be based on a well-justified need to protect a plant or a crop. The use of biological, mechanical or cultural control methods is highly recommended if effective methods are available. In organic farming no fossil oil-based products or synthetic chemicals can be used except for the fuel for machinery and plastic covers or mulches.

1.4.3 IPM progress in different production sectors

MTT has been involved in IPM research and the development of different crops since the 1990s. In Finland, IPM principles were largely introduced in 1993 when the guidelines "Good farming methods" were published by an expert team working for the Ministry of Agriculture and Forestry (Korkman et al. 1993). The term "balanced plant protection" was first mentioned in the official guidelines. After that, IP farming based on IOBC guidelines have been developed for horticultural crops. As early as in 1995, Raisio Group made contracts with cereal farmers to start IP farming. About 200 vegetable farmers from the company Apetit (http://www.lannen.fi/en/default.asp) attended an "IP farmer field school" between 1997-1999. Farmers and IPM experts of MTT produced joint IP guidelines for the company. Similarly, IP technologies were developed for apple and berry production. In 2000, official guidelines for "balanced plant protection" were published for all the crops grown in Finland and all farmers had to attend an official plant protection course. In 2003, INEX Partners (http://www.inex.fi/english/) organised IP training for all the contract farmers producing vegetables for the market chain. During all the IP courses and projects, "the first generation" of farmers became familiar with IPM principles, monitoring methods, threshold values and biological control, etc. The same farmers and production chains with the IP know-how will be the first to be able to implement IPM principles according to the SUD directive.

However, the idea about IP farming has not become very popular in cereal farming and recommended crop rotations have been poorly followed (Jauhiainen and Keskitalo 2012). The implementation of IPM principles is still incomplete. On a policy level, one of the main goals should be the improvement of crop rotation and the use of new technologies such as that of legume-based farming, intercropping, etc. Earlier decisions made by politicians have made animal-based cropping very rare in Southern Finland and thus grass plant cropping is missing from the main areas of cereal production. This kind of short-sighted policy has decreased regional land use diversity and environmental sustainability of agriculture in Finland.

2 Procedure for demonstrating the impacts and risks

PPP can affect the quality of all environments (air, soil, water), when emissions run into the environment and affect organisms there. Thus, risks induced by PPP usage and IPM implementation affect both the food chain (vertical implementation of IPM) and the landscape environment (horizontal implementation of IPM).

The basic aim of this research was to study PPP risks, more details of which are presented in section 1.1. In addition, the aim was linked with the EU strategy on the sustainable use of pesticides, where attempts are made to reduce the health and environmental risks via integrated pest management (IPM). Indicators are also needed for the measurement of the risk reduction actions (OECD 2011). At this moment, in many EU countries, only PPP use volumes and/or sales data are used as indicators of the risks. Thus, for achieving the aims, in this study a demonstration procedure was developed for the measurement of risk reduction actions via IPM.

This demonstration procedure is a combination of two methods. In it the effects of actual field usage of plant protection products, data obtained from one case study, are calculated with these two methods leading to two dimensions. The effects on the food chain are studied with ecotoxicity impact of life cycle analysis (LCA) in the vertical dimension. The effects on the landscape environment are studied with HAIR risk indicators, available in the EU, in the horizontal dimension. IPM implementation influences two dimensions, thus both dimensions were used for obtaining a larger or more realistic picture of the environmental actions. So, two different risk values from two dimensions are obtained as a result of this procedure. In the future, the results obtained from different time periods will describe the progress of the risk and thus IPM development. This procedure can be applied and used in risk communication purposes with different stakeholder groups. The procedure is shown in Figure 5.

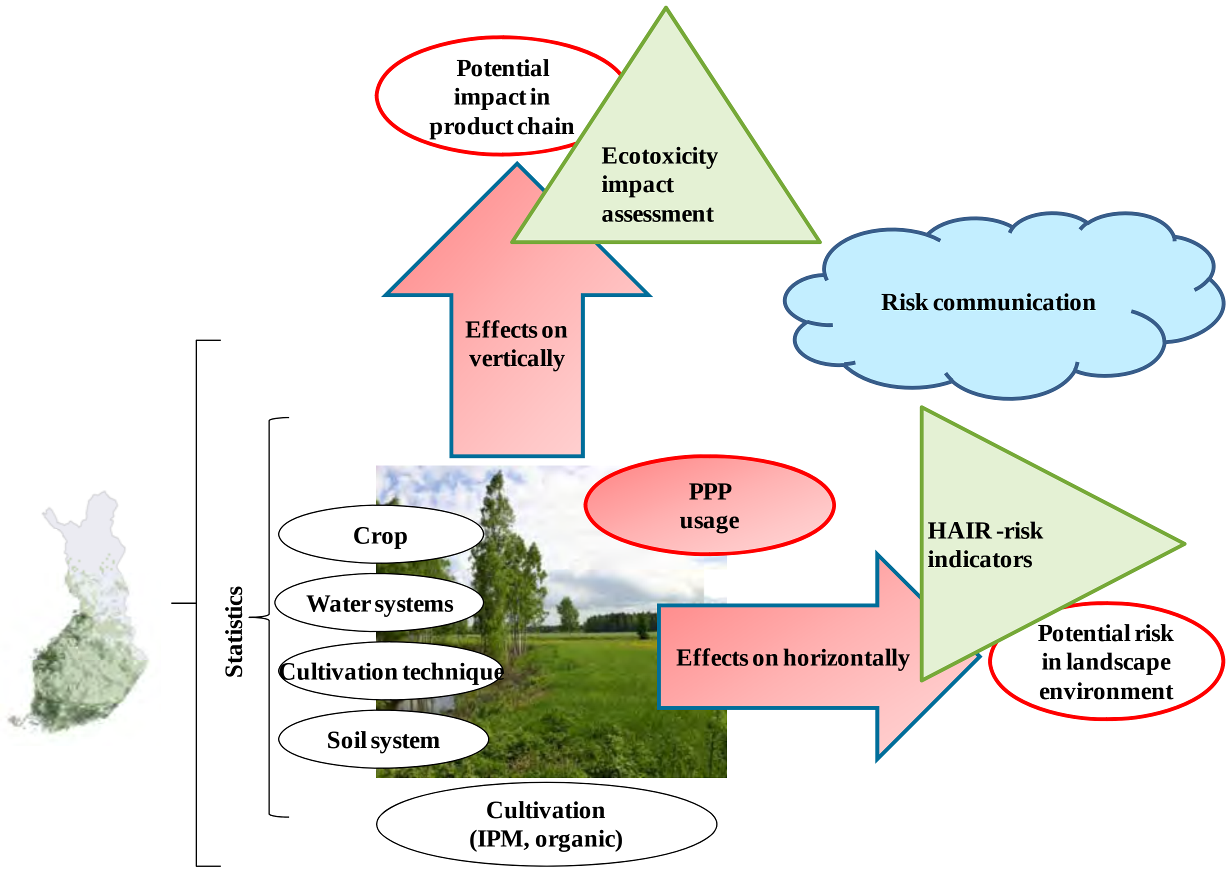


Figure 5. A proposed procedure to study the progress of IPM in vertical and horizontal dimensions.

This study utilised a case data where the actual plant protection product usage data was collected from Finnish cereal farms. Cereals were chosen as model crops because of their large cultivation area in Finland and in the larger Baltic-Nordic region. Cereals were also chosen for demonstration crops for the other PesticideLife actions for 2010-2012. More details are available from our project web pages (PesticideLife 2010-2012). There is a need to demonstrate the success of IPM choices made by cereal farmers, because non-chemical control is less developed in field production than in horticulture or in greenhouse cultivation.

3 Data for this study – a case study

Data for this research was received from a case study covering plant protection product usage data in Finland. It covered the field scale data (kg of active ingredient per hectare) in 2007 from Finnish crop farms. The case study was carried out by the Finnish Information Centre of the Ministry of Agriculture and Forestry (Tike), whilst also aiming to prepare for the collection of PPP usage data regularly in the future by the Finnish authorities (EY N:o 1185/2009).

3.1 Cereals

In this study, three spring cereals – feed barley, spring wheat and oats – were chosen for the model crops from the case study (Figure 6). Model cereals contained the main part of the total crop growing area in 2007 in Finland, about 1,079,500 ha, that was about 92% of the total cereal area and 53% of the total arable crop area (Tike 2010), shown in Figure 7.

Figure 6. Feed barley in summer (photo: Marja Jalli – MTT), Feed barley in autumn (photo: Peppi Laine – MTT), Spring wheat in summer (photo: Aino-Maija Mustalahti - MTT), Spring wheat in autumn (photo: MTT image database/Tapio Tuomela), Oats in summer (photo: Marja Jalli – MTT), Oats in autumn (photo: Marja Jalli – MTT).

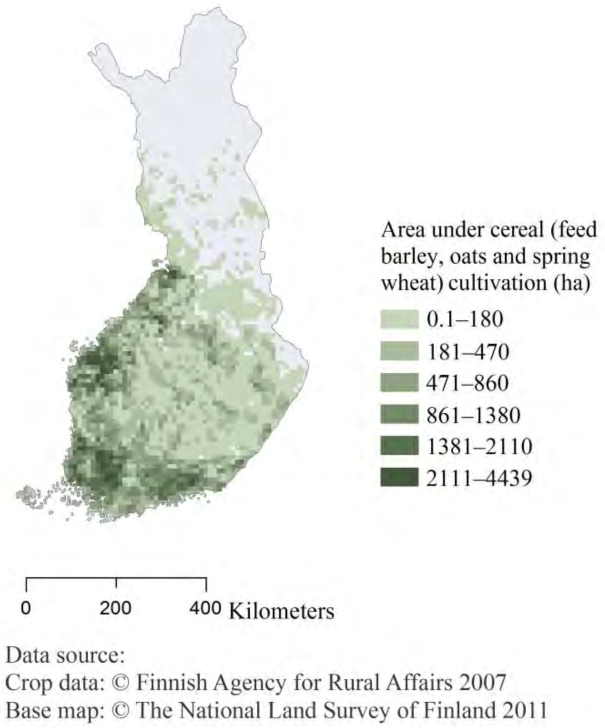


Figure 7. Model cereals (feed barley, spring wheat and oats) of this study covering 53% of the total cultivated crop area in 2007 in Finland.

3.2 PPP usage and model substances

The data covered a total of 1,128 cereal fields over 5,427 ha (Figure 8). There were 471 feed barley fields over 2,317 ha, 500 oats fields over 2,086 ha, and 157 spring wheat fields over 1,025 ha. The average field parcel area in the data set was 4.83 ha (median 3.95, lower quartile 2.53, upper quartile 6.35). Correspondingly, in Finland the average field parcel area was 1.94 ha (Tike 2013), whereas in the average spring the wheat parcel area was 3.32 ha, barley 2.67 ha and oats 2.18 ha (Tike 2013).

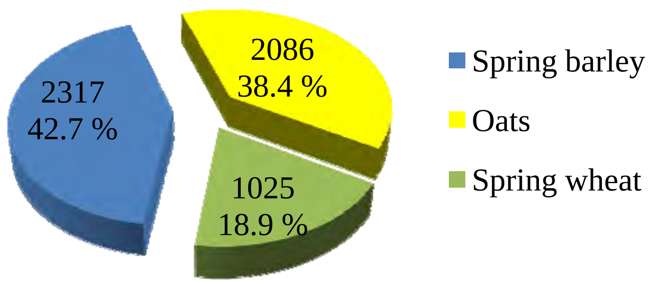


Figure 8. Cereal fields (ha, and% from the total study area) used in the case data (total 5,427 ha).

The data covered the parcel level usage data of plant protection products in 963 fields from the total of 1,128. In 14% (N=165) of the fields, no plant protection products were used. Data fields on model cereals are shown in Figure 9. Thus, this study is also the first attempt to demonstrate the use of plant protection products in different parts of Finland on the map. The usage was calculated as kilograms per hectare of active ingredient used. Applications for plant protection products were performed during the growing season 2007 between 1 April and 30 October.

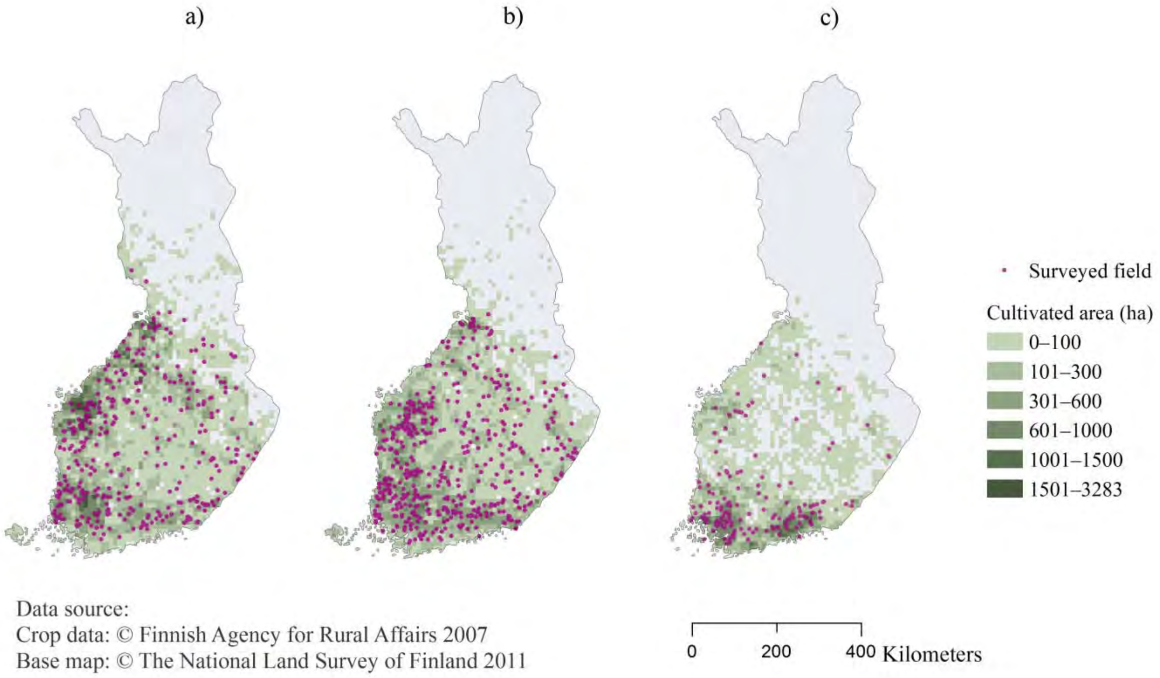


Figure 9. Locations of cereal fields (purple dots) in the case data of a) feed barley (471 fields), b) oats (500 fields) and c) spring wheat (157 fields) (total 1,128 fields ha).

For clarity and simplicity, in our study only two herbicides (glyphosate, MCPA), one from the fungicide group (prothioconazole) and one active ingredient from the insecticide group (α-cypermethrin) were chosen as model substances in oats, feed barley and spring wheat fields. Glyphosate and MCPA were chosen because they are the most commonly used active substances (Figure 10, showing substance sales) in Finland. Glyphosate is also a target of many other research interests. Prothioconazole and α-cypermethrin were chosen for this study because they are known to be toxic to aquatic organisms in low concentrations, despite their low usage in farms (Figure 10, substance sales).

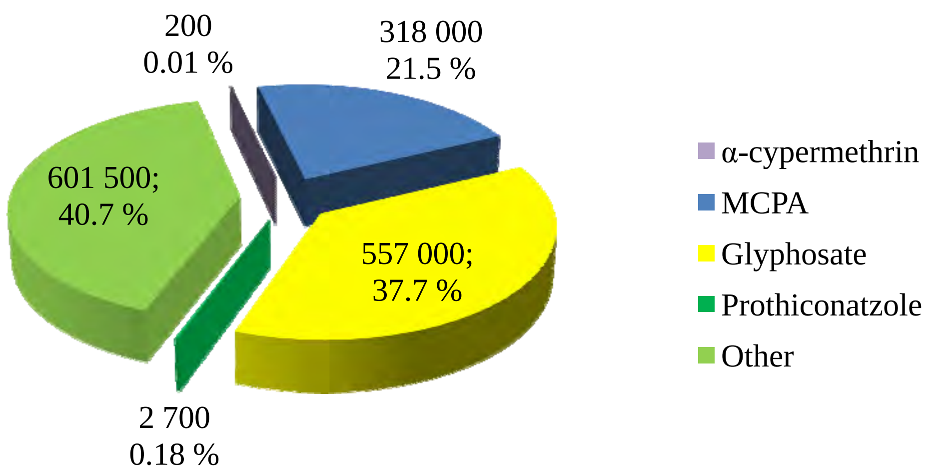


Figure 10. Sales data (kg;% from the total sales) of the model substances in Finland 2007. Total agricultural active ingredient sales were 1,479,000 kg. The sales data for individual active substances are rounded, and publishing is permitted by the authorisation holders. ‘Other’ means active ingredients sold other than the model substances.

The total active ingredient usage in the case data was 3,535 kg as presented in Figure 11. In the total data model, substances (glyphosate, MCPA, prothioconazole, α-cypermethrin) were used on 619 fields; glyphosate was applied on 125 parcels, MCPA on 486 parcels, prothioconazole on seven parcels and α-cypermethrin on one parcel. Glyphosate treatments were performed generally once per season on each field with the exception of one parcel, where glyphosate was applied twice on one field. Out of the seven parcels treated with prothioconazole, three parcels were treated twice during the growing season. α-cypermethrin was used on only one parcel in our data. Thus, no statistical calculations could be done on it. Active ingredients other than the model substances (= other) were used on 797 fields. There was no information of the PPP usage on 165 fields. Usage data of the active substances per treated area is presented in Table 2.

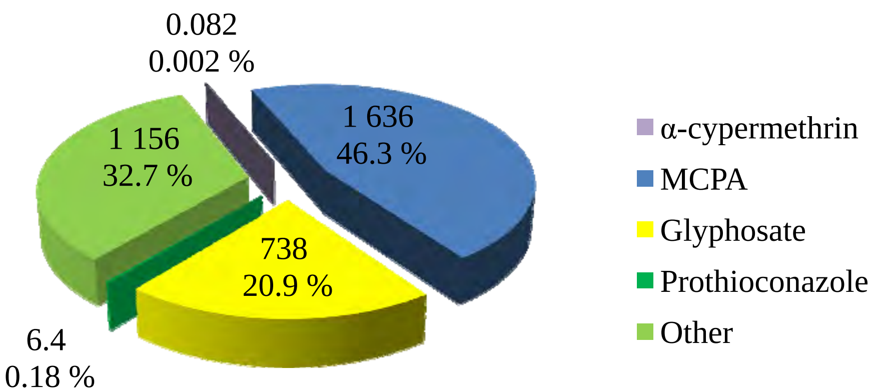


Figure 11. Total usage (kg;% from the total usage) of the model active substances on model cereals (feed barley, oats and spring wheat) in the case data (total 3,535 kg in 963 fields). 'Other' means active ingredients used other than model substances.

Table 2. Total treated field areas (ha) and active ingredient usage (kg) in case data. 'Other' means active ingredients used other than model substances.

Active ingredient	**Total field amount**	**Field area in median (ha)**	**Total area (ha)**	**% of total area**	**Active ingredient usage in median (kg)**	**Total active ingredient usage (kg)**	**% of total usage**
α-cypermethrin	1	8.2	8.2	0.2	0.1	0.1	0.0
Glyphosate total	125	5.0	712.5	13.1	4.8	737.6	20.9
Glyphosate *spring applications*	39	5.5	231.8	4.3	4.6	193.2	5.5
Glyphosate *autumn applications*	86	5.0	468.6	8.6	4.8	544.4	15.4
MCPA	486	4.2	2436.0	44.9	2.3	1635.9	46.3
Prothioconazole	7	7.4	48.4	0.9	0.5	6.4	0.2
Other	797	4.4	4148.4	76.4	0.1	1155.5	32.7
None	165	3.0	597.8	11.0	-	-	-

3.3 Statistical analysis of usage data

3.3.1 Models used in statistics

SAS 9.3 software (SAS Institute, Inc., Cary, NC, USA) was used for the statistical analysis of the data.

The use of all active ingredients in the fields was analysed with logistic regression (any substance used vs. no substance used). In addition, glyphosate and MCPA were similarly examined. The explanatory variables were crop (spring barley was feed barley in our study, oats, spring wheat), soil type (organic, sand, clay), cultivation method (reduced tillage, conventional tillage, no tillage), area (small < 3.5 ha, medium = 3.5-6 ha, large > 6 ha), nearest water system (river, lake, stream) and their two-factor interactions. Statistically significant interactions were searched for with the stepwise selection method. No interactions were included into the best fitting solutions. The dependence of PPP usage between fields was examined with spatial analysis.

The amounts of active ingredient usage in one field were modelled using a mixed model. The distribution of the dependent variable, active ingredient usage (kg ha^{-1}), was positively skewed so it was normalised by logarithmic transformation. Analyses were run using the MIXED procedure with Residual Maximum Likelihood (REML) estimation method, with the active substance (glyphosate, MCPA, prothioconazole, other), crop (spring barley was feed barley in our study, oats, spring wheat), soil type (organic, sand, clay), cultivation method (reduced tillage, conventional tillage, no tillage), area (small < 3.5 ha, medium = 3.5-6 ha, large > 6 ha) and nearest water system (river, lake, stream) denoted and their interactions in fixed effects. “Other” means the active ingredients used other than model substances. Farm, field and their interaction were used as random effects. In addition, the interactions between active substance and farm was relevant to the model.

The degrees of freedom were computed by a method described by Kenward and Roger (1997).

The model can be expressed in equation form as follows:

$$y_{ijklmn} = \mu + AS_i + G_j + ST_k + CM_l + A_m + NWS_n + ASG_{ij} + GA_{jm} + ASA_{im} + GNWS_{jn} + CMNWS_{ln} + ASFA_{io} + \varepsilon_{ijklmno},$$

where μ is the overall mean, ASi , Gj , STk , CMl and $NWSm$ are the fixed effects of the active substance, grain, soil type, cultivation method and nearest water system, respectively. $ASFA_{io}$ represents the random effect, and $\varepsilon_{ijklmno}$ is the residual error.

The appropriateness of the models was studied by residual analyses. The residuals were checked for normality using box plot (Tukey 1977). Comparisons between means were performed with the Tukey-Kramer post-hoc test.

α-cypermethrin was only used on one parcel in our data. Thus, no statistical calculations could be performed on it. The substance was sprayed onto spring wheat on about 8 ha (0.01 kg/ha) where reduced tillage was used.

3.3.2 Results of statistical analysis

Results of logistic regression analysis

PPP was more likely to be used when the field size increased. The usage increased by 20% when the average area of the field was doubled from 4 ha to 8 ha (P<0.01). There was also a difference in usage between the crops; PPP usage was used the most in feed barley (26% more likely than in oats, P=0.01). There was more PPP usage in fields with reduced tillage (53% more likely than conventional tillage, however the difference was not statistically significant, P=0.09). There was spatial correlation in PPP usage with fields located nearer than 4.3 km to each other (p<.0001).

Glyphosate usage increased 40% (P<0.01), and usage of MCPA 14% (P=0.048), when the average field area (4 ha) doubled. There were also differences in glyphosate usage between cultivation methods; usage was 7.4 to 9.4 times higher when there was no tillage (P<0.001). Glyphosate usage occurred more nearer to rivers than streams but not significantly (73% more likely near to rivers P=0.09). Correspondingly, the use of MCPA occurred more near rivers and streams than lakes (being 53% more likely near rivers P=0.080, and 42% more likely near streams P=0.052, respectively).

Results of the mixed model

All interactions explaining the amounts of active ingredient usage per field are presented below (Table 3). Statistically significant fixed effects were taken into use in more specific examinations. Fixed effects having statistically significant pair-wise comparisons are presented in figures 12-13. The Tukey-Kramer method was used in pair-wise comparisons.

Table 3. Fixed effects to the amounts of active ingredient usage (Type III test)

Explanatory variable	P -value
Active ingredient	0.000
Area	0.537
Cultivation method	0.617
Crop	0.756
Nearest water system	0.993
Soil type	0.237
Active substance * Area	0.043
Active substance * Crop	0.000
Area * Crop	0.027
Cultivation method * Nearest water system	0.072
Crop * Nearest water system	0.023

The usage of glyphosate, MCPA and prothioconazole was consistent with crops; they were used the most intensively (kg ha^{-1}) on oats and the least on spring wheat (Figure 12). There was less usage (kg ha^{-1}) in other substances than the model ones, and the least with oats (***).

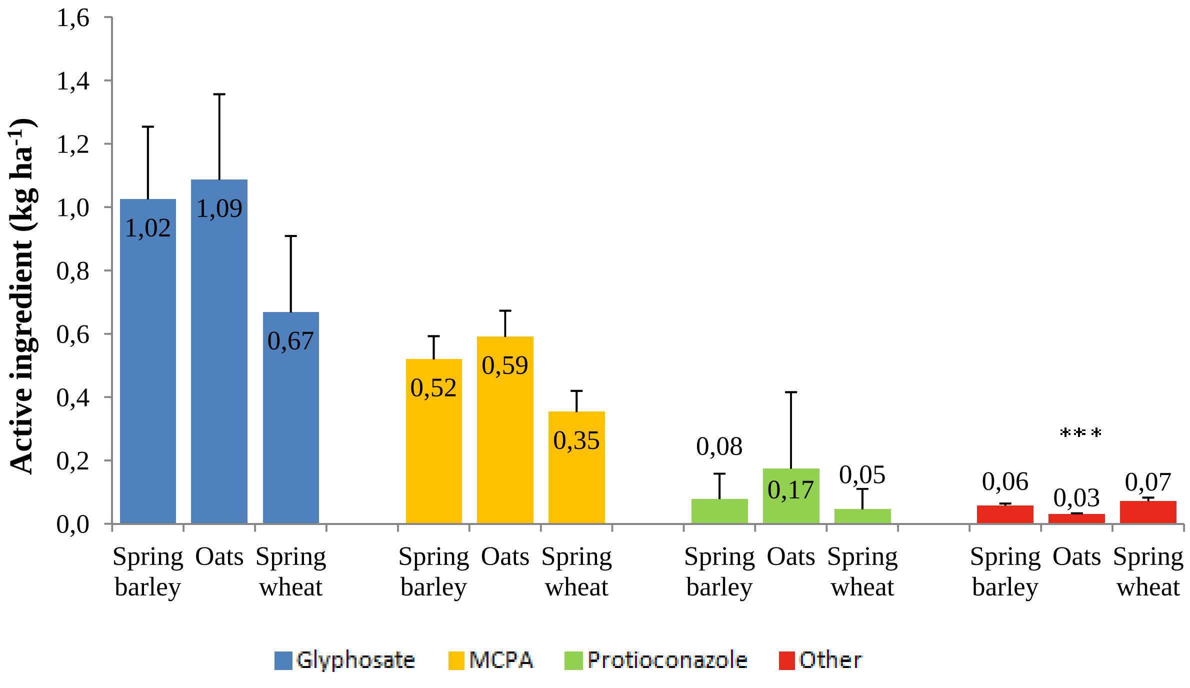


Figure 12. Active substance usage (kg ha^{-1}) on crops (with standard errors). The Tukey-Kramer method was used in pair-wise comparisons. 'Other' means active ingredients used other than model substances. In oats the usage of other active substance was least compared to other crops (***).

Active ingredient usage differed between the crops depending on size of area; on oats, active ingredient usage increased when the size of area increased, but on other crops active ingredient usage was highest in medium-sized areas. However, there were no statistical differences between crops (tested with Tukey-Kramer method).

The usage of active ingredients also differed depending on size of area, but it was the most in medium-sized areas with every active substance (Figure 13). Other active ingredients were used the least in small-sized areas (P<0.001). Prothioconazole usage differed a lot, but there were no statistical significance because of large standard errors.

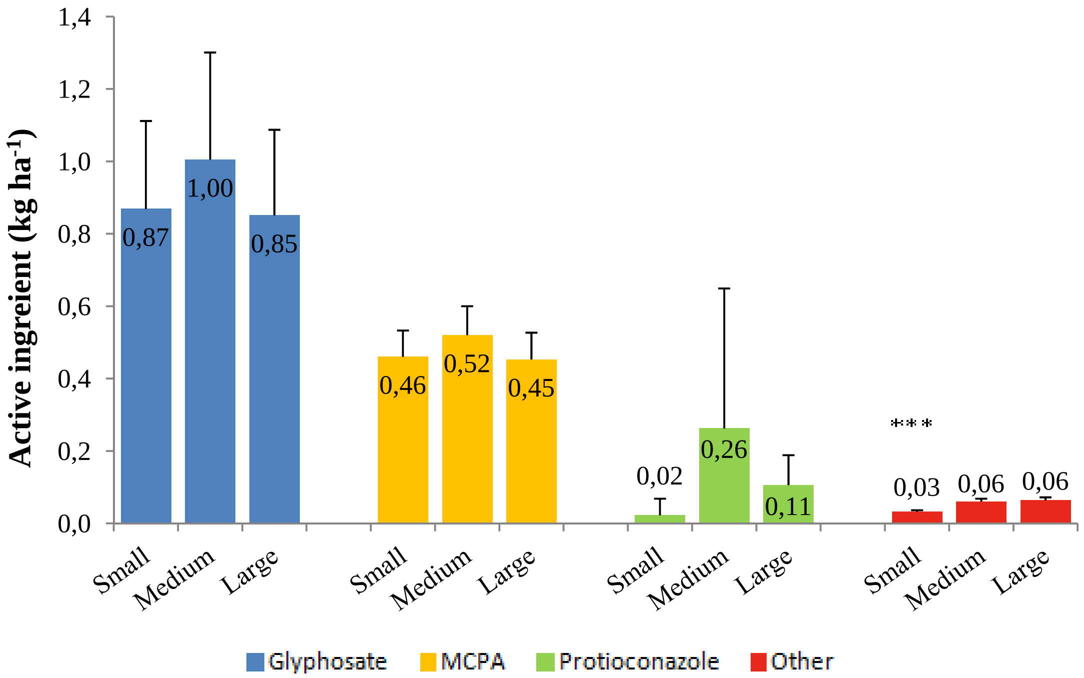


Figure 13. Usage of active substances (kg ha^{-1}) by size of areas. The Tukey-Kramer method was used in pair-wise comparisons. In small-sized areas, the usage of other substances was smaller compared to larger sized areas (***). Other = other used active ingredients than model substances. The size of area was classified as follows: small < 3.5 ha, medium = 3.5 - 6 ha, and large > 6 ha.

Active ingredient usage differed between crops depending on nearest water system. The usage occurred the most near to lakes with oats and spring barley, but the least with spring wheat. However, the differences between crops were not statistically significant (tested with Tukey-Kramer method).

Active ingredient usage also differed between cultivation methods, depending on the nearest water system. The biggest differences were within conventional tillage; usage near to lakes was the least. However, differences were not quite statistically significant (tested with the Tukey-Kramer method).

4 Stepwise demonstrations in this procedure

The vertical impact and horizontal risk demonstrations of the procedure were performed in three steps:

1. The first step: mapping of the PPP usage
2. The second step: impact and risk assessment calculations at countrywide scale
3. The third step: impact and risk assessment calculations at regional scale

The procedure is shown in Figure 5 in section 2.

In the first step, a GIS (geographic information system) approach was used to demonstrate PPP usage from the case data in 2007 on a map. Mapping of the usage describes potential regional exposure in Finland. In addition, this working step is also the first attempt to show PPP usage on a map of Finland.

In the second step, impact and risk assessment calculations were done on a countrywide scale. Impact and risk assessment calculations with used models describe the potential effects induced by the use of PPPs across the whole of Finland. Thus, on countrywide scale demonstrations the regional differences can be examined, effects of different substances can be compared to each other and the total sum of risks can be compared to different time periods. The last one describes the changes to risk over time.

In the third step, demonstrations were performed at the regional scale. The regional division was done using 15 ELY-centres (Centres of Economic Development, Transport and the Environment) in Finland. The ELY-centre regions used in this study are presented in Figure 15 in section 4.3. ELY-centres are tasked with promoting regional competitiveness, well-being and sustainable development, as well as curbing climate change. The regional centres are also responsible for organising the environmental monitoring and control measures of the use of plant protection products on their areas.

Impact and risk assessment calculations with used models describe a potential effect induced by the use of PPPs in smaller regions than whole of Finland. With these regional demonstrations, it was shown that impact and risk evaluations give more detailed information about the risks in regional differences and risks in different time period examinations than those from countrywide demonstrations. Substance usage and geographical differences, and thus risks can vary a lot between different regions. Regional demonstrations give information about the different use of PPPs and areas; some areas are probably more sensitive than others.

4.1 Mapping of PPP usage

At the first step, PPP usage was mapped using a GIS approach. Temporal patterns of PPP usage during the growing season were also visualised using animations (see animations on project web pages of PesticideLife project 2010-1013). The usage of each model substance in the surveyed fields is presented in Figure 14.

Products containing MCPA either had multiple active ingredients or MCPA was the only active ingredient in the product. The different cases were mapped separately as the amount of MCPA was lower in mixed products. Prothioconazole was used twice in the one field that is marked differently in Figure 14.

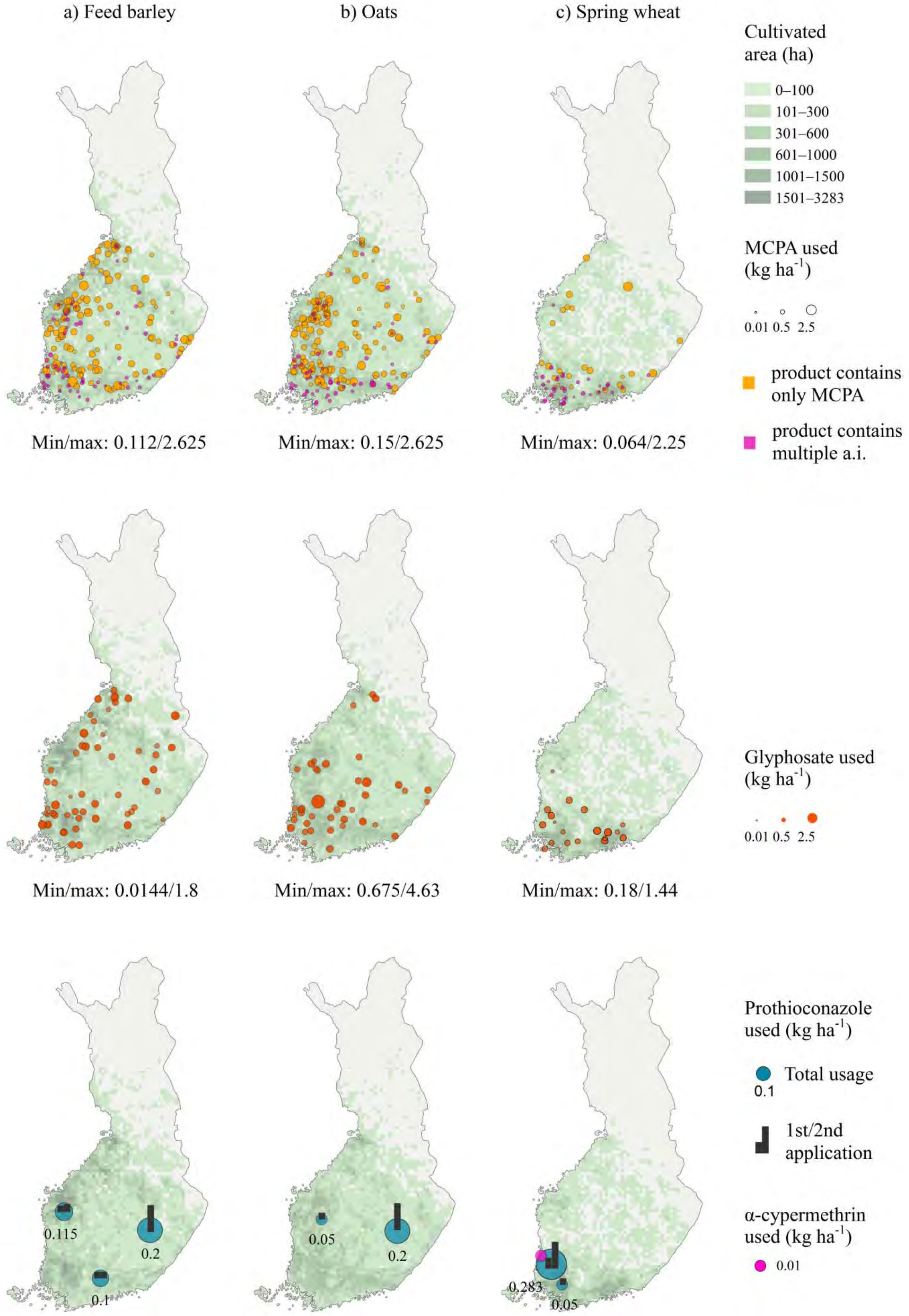


Figure 14. Amount of glyphosate, MCPA, prothioconazole and α-cypermethrin used (kg ha^{-1}) in parcels cultivating a) feed barley, b) oats and c) spring wheat. MCPA products might also contain other active ingredients, which are marked separately. The black columns in mapped prothioconazole use describe the proportion between two applications. One black column means the parcel has been treated only once.

4.2 Second step: impact and risk assessment calculations on a countrywide scale

The following value sources were used for countrywide demonstrations. In impact calculations, PPP sales data and PPP usage from the case data both in 2007 in Finland were used. In risk calculations, maximum values acquired from PPP labels, called recommended use, and PPP usage from the case data both in 2007 in Finland were used.

Four model substances (MCPA, glyphosate, prothioconazole and α-cypermethrin) were used in the countrywide calculations. Used values for calculations are shown in Table 4.

Table 4. Used values for calculating ecotoxic impacts and HAIR risk values of MCPA, glyphosate, prothioconazole and α-cypermethrin in countrywide scale in Finland based on recommended usage and also usage data from the case study.

	MCPA (pure substance/ mixture)	**Glyphosate (spring use/ autumn use)**	**Prothioconazole (one/two applications)**	**α-cypermethrin**
Application rate (kg ha^{-1})				
Recommended usage	1.5/0.5	1.08/1.08	0.2/0.2	0.02
Usage data surveyed, median	0.6	0.884/1.125	0.125/0.056	0.01
Date of application, median	11 Jun	16 May/ 19 Sep	30 Jun/ 1 Jul **	5 Jul
Treated area (crops*)				
% of total cultivated area	29/16 (in all 45)	4.3/8.6 (in all 13)	0.48/0.41 (in all 0.89)	0.15
area (1000 ha)	412	39/79	4.4/3.8	1.4
Calculated total amount of a.i. (kg)	247 200	34 480/ 88 880	550/213	14

*feed barley, oats and spring wheat
**application date of the first application, the time interval between applications was set to 20 days

MCPA products may also contain other active ingredients according to the surveyed use. When calculating impacts and risks, this was taken into account based on the use acquired from label recommendations, as it was difficult to define one single recommended amount for both situations. In calculations based on surveyed use, the median value of application rate was used. The application rate is directly proportional to risk indicator values and therefore the division between pure active ingredient and mixture was unnecessary.

Glyphosate applications generally take place in spring or autumn before the emergence of the crop or after crop harvesting. Therefore, the application rate and weather conditions can differ a lot. Thus, the risk calculations were done in sum as in other PPP model cases but also for both time periods. The application was considered spring use if it was done before 15 July; otherwise it was considered autumn use.

Prothioconazole application was done either once (four parcels) or twice (three parcels) during the growing season, according to the usage survey. As HAIR2010 takes into account the number of applications and the application date, prothioconazole applications were divided into two different cases. If prothioconazole was applied twice on the parcel, the time interval between the two applications was set to 20 days. The time interval was a median value of the time intervals found in the case data. Total risk was calculated by summing up the results of both cases.

α-cypermethrin was used only on one parcel in our case data. There its amount was half of the recommended usage. Its sale amount was 0.01% of the total active ingredient sales, and in our case it was used on model cereals in only 0.002% of the total mass of used substances.

Recommended use values of the product-specific instructions were used when we calculated the maximum risks of the usage. However, we were able to find out that in our data, the recommended use values were generally higher than those obtained in the usage case data.

In the ecotoxicity impact assessment, Comparative Toxic Unit (CTU) was used as a unit of ecotoxic impact. In risk calculations, Exposure Toxicity Ratio (ETR) was used as a unit of risk.

In HAIR2010, risk values were first calculated for 10 x 10 km grid cells. Medians of application rate and application dates were used as input parameters except for risk calculations based on recommended use, where the application rate was acquired from PPP labels. After this the risk results were weighted by the treated area and all the grid cells were finally added together to get one aggregated risk value. The treated area was calculated as a percentage of the total field area (%) of model cereals and the calculated percentage was then assumed to represent the usage of all these model cereals in the whole of Finland. In other words, usage data was generalised to cover the usage of these substances on model cereals in Finland in 2007 and also describes the risks in these models.

4.3 Third step: impact and risk assessment calculations on a regional scale

Finland is divided into 15 areas according to the Centres for Economic Development, Transport and the Environment (ELY-centres). Thus, the regional division was done using 15 ELY-centres as described in section 4 and shown in Figure 15.

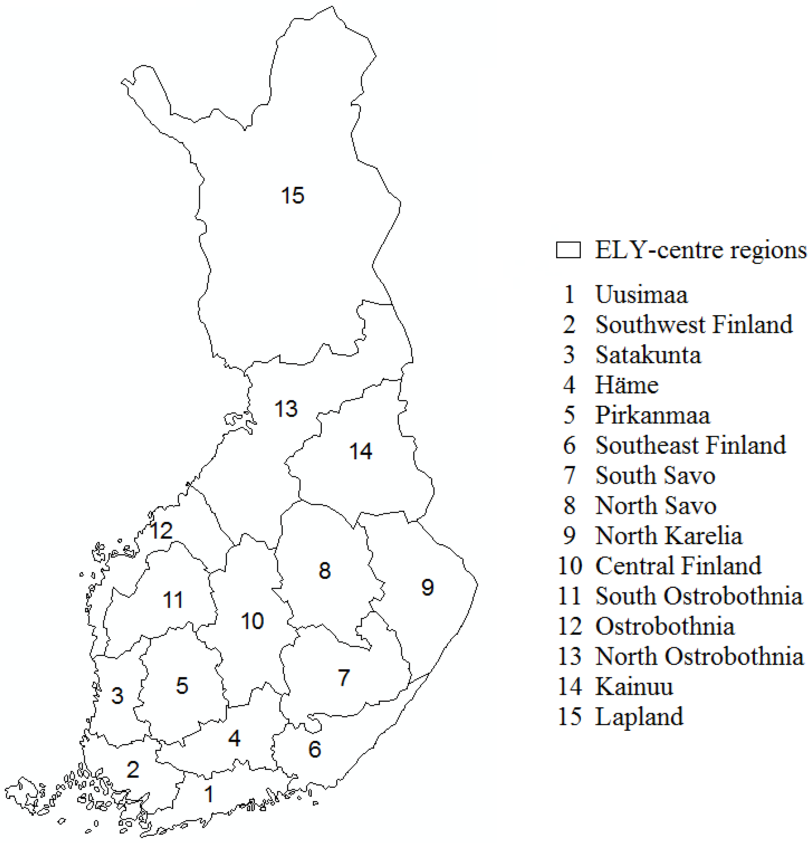


Figure 15. ELY-centre regions in Finland.

Only PPP usage data from the case study was used to calculate impacts and risk values on a regional scale, instead of additional recommended usage or sales based on data. Usage data values were generalised for the regional scale in Finland (medians of application rate, treated area % of total cultivated area) as described in section 4.2.

In addition, due to the limited number of observations on prothioconazole and α-cypermethrin uses, only MCPA and glyphosate were used in regional scale calculations. Values of MCPA and glyphosate uses for calculations have been shown in Tables 5 and 6, respectively. Substances for regional area demonstrations were chosen because of broad usage in Finland. MCPA and glyphosate were not used in Lapland in our case, probably because of low-level cropping there. Thus, Lapland was not taken into the impact and risk calculations.

Table 5. Used values for calculating ecotoxic impacts and HAIR risk values of MCPA in Finnish ELY-areas based on usage data from the case study. Lapland was not taken into the calculations because there was no usage of the model substances.

	Application rate (kg ha^{-1})	Date of application	Treated area (% of total)	Treated area (1,000 ha)	Calculated total of a.i. (tonnes)
Uusimaa	0.38	Jun 11	50	39.6	15.2
Southwest Finland	0.32	Jun 7	56	66.3	21.4
Satakunta	0.60	Jun 8	60	44.9	26.9
Häme	0.54	Jun 8	35	26.3	14.2
Pirkanmaa	0.77	Jun 11	47	35.8	27.7
Southeast Finland	0.46	Jun 14	52	30.0	13.8
South Savo	0.70	Jun 18	34	7.21	5.07
North Savo	0.70	Jun 22	32	13.8	9.66
North Karelia	0.62	Jun 24	36	8.13	5.04
Central Finland	0.66	Jun 16	37	12.2	8.10
South Ostrobothnia	0.72	Jun 13	55	67.8	49.1
Ostrobothnia	0.71	Jun 20	30	26.1	18.5
North Ostrobothnia	0.59	Jun 25	51	46.2	27.5
Kainuu	0.47	Jun 30	5.7	0.242	0.114

Table 6. Used values for calculating ecotoxic impacts and HAIR risk values of glyphosate in Finnish ELY-areas based on usage data from the case study. Lapland was not taken into the calculations because there was no usage of the model substances.

	Application rate (kg ha^{-1}, spring application/ autumn application)	Date of application	Treated area (% of total)	Treated area (1,000 ha)	Total amount of a.i. used (tonnes)
Uusimaa	0.68/1.21	2 May/29 Sep	6.6/7.6	5.27/6.10	3.56/7.36
Southwest Finland	0.97/1.19	12 May/17 Sep	3.8/6.6	4.50/7.83	4.38/9.33
Satakunta	0.83/1.20	9 May/16 Sep	7.7/18	5.82/13.8	4.81/16.6
Häme	1.01/1.26	27 Apr/8 Sep	2.1/12	1.62/8.96	1.64/11.3
Pirkanmaa	1.08/1.11	14 Jul/22 Sep	2.7/16	2.08/12.7	2.25/14.1
Southeast Finland	0.17/1.02	10 May/22 Sep	7.9/7. 9	4.60/4.58	0.802/4.68
South Savo	1.01/1.44	26 May/25 Sep	13/3.3	2.70/0.693	2.72/0.998
North Savo	-/0.98	-/5 Sep	0/7.8	0/3.31	0/3.24
North Karelia	-/1.31	-/23 Sep	0/4.1	0/0.926	0/1.21
Central Finland	1.10/1.63	15 May/21 Sep	9.9/10	3.24/3.28	3.57/5.34
South Ostrobothnia	0.96/1.07	29 May/16 Sep	1.9/4. 9	2.303/5.95	2.20/6.35
Ostrobothnia	0/1.34	-/16 Sep	0/4.9	0/4.24	0/5.66
North Ostrobothnia	0.66/1.21	31 May/26 Sep	7.7/12	6.94/11.1	4.61/13.4
Kainuu	-/1.80	-/28 Sep	0/5.2	0/0.221	0/0.398

5 Environmental vertical impacts of plant protection products

5.1 The primary steps of Life Cycle Assessment (LCA)

Life cycle assessment (LCA) is a tool for identifying and evaluating the potential environmental impacts vertically throughout the whole life cycle of products and services. The result is calculated per a functional unit. That means the ecotoxic impact per kilogram of final product or impacts per unit of services, etc.

The steps of an LCA calculation are presented in Figure 16.

They are:

1. Assembly inputs and outputs of product life cycle (=inventory analysis, LCI)
2. Environmental impact assessment linked to inputs and outputs (=impact assessment, LCIA)
3. Interpretation of the results of inventory and impact assessment as for the aims

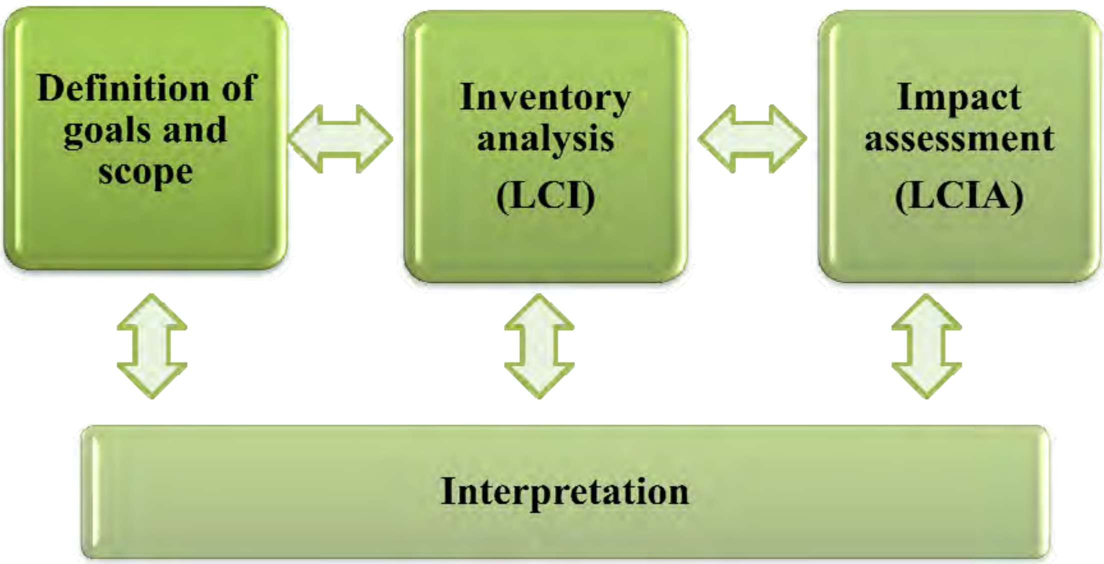


Figure 16. Steps of LCA. LCI = life cycle inventory analysis, LCIA = life cycle impact assessment.

5.2 Ecotoxicity impact in LCA through the product chain

LCA is normally expressed for different points of the life cycle of a product. By combining the points for each category of environmental impacts, for instance ecotoxicity, we can see a profile of impacts for this impact category through the particular food chain. From such a profile of a schedule of life cycle points, we can identify the most hazardous key impacts.

Different chemicals are used in different steps of the food chain, for example plant protection products in the crop production or industrial chemicals in the production of food packing materials. The final quantitative result of the whole product life cycle is a potential ecotoxicity impact that describes all ecotoxicity effects induced by measured chemicals used throughout the particular production chain per functional unit of the final product. In the colloquial, the ecotoxic impact assessment can also be called the ecotoxicity footprint. Other environmental impacts of a product chain, e.g. climate change, eutrophication, acidification, etc. could also be measured with LCA (Figure 17).

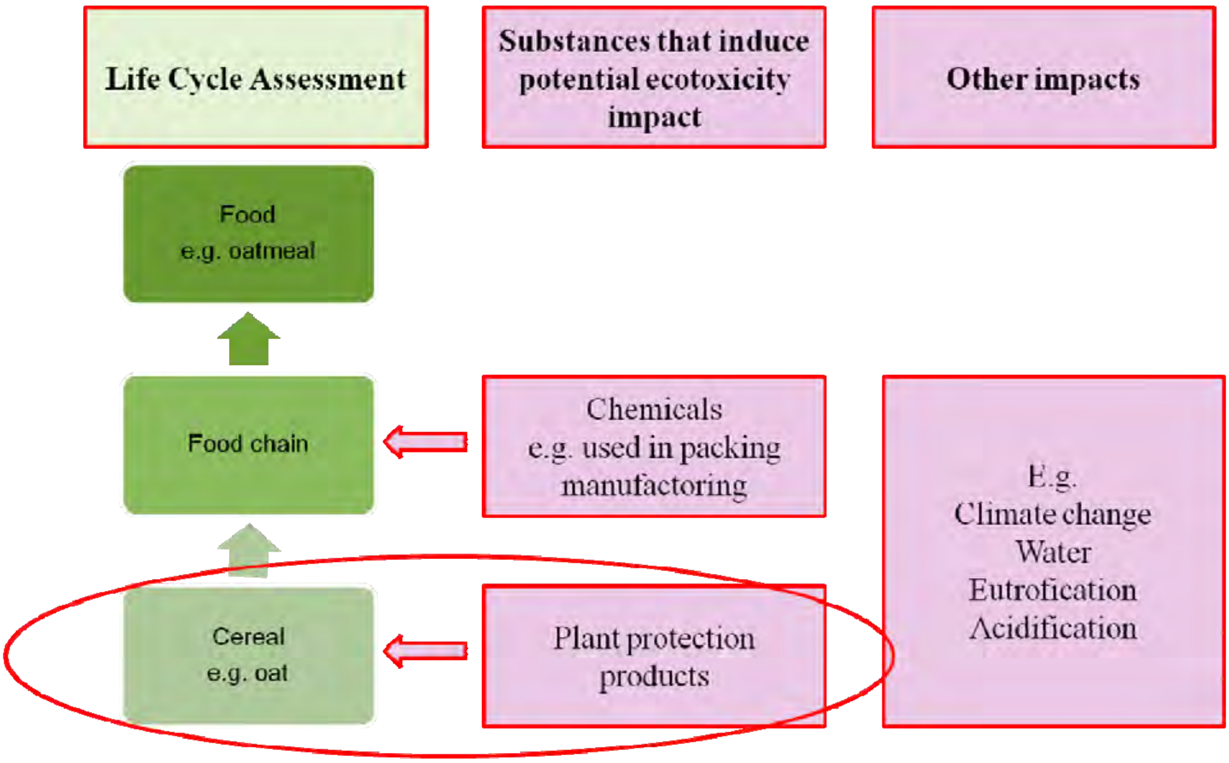


Figure 17. Forming of potential ecotoxicity in life cycle assessment. Circle illustrates the substance of our study.

Ecotoxicity impact assessments have been processed in recent years (EC 2006, UNEP 2010, Recipe 2012, USEtox™ 2013). In Finland, only a few studies have been done on ecotoxicity impact assessment in LCA, such as PPP field usage emissions in chicken production (Katajajuuri et al. 2006), or on the food plate model (FoodWeb project 2011-2013). Ecotoxicity impact has been considered also as a part of other environmental impacts in Finnish economy (Seppälä et al. 2009). In addition, Mattila (2009) has written a Finnish literary review of this. The benefits of LCA are diverse. It is improving the understanding of the environment expressed against a certain quantity or value of final products or service units.

5.3 Models for counting ecotoxic impacts

The ecotoxic impact includes the fate of the emitted hazardous substance on different environmental compartments (air, water, soil), and the exposure and effect on organisms in a defined area. The effects can be modelled with particular models built into LCA.

In a life cycle impact assessment (LCIA) for ecotoxic impact assessment, the characterisation factors are calculated for each substance (= chemical). The most developed LCIA model is called the SETAC consensus model USEtox™ (Rosenbaum et al. 2008, USEtox™ 2013). However, at this moment it includes effects only on aquatic organisms as a developing model. In USEtox™, the substance-specific characterisation factor (CF) represents the substance's potency to induce potential ecotoxic damages for aquatic organisms. They are quantified via an impact assessment of the fate to the environment (air, soil, water), exposure and effect on the organisms of used substances (=chemical) in a defined area.

The characterisation factor is added to the emission that is an emitted substance amount. In this step, the emission fate on different environmental compartments (water, soil, air) can be additionally modelled. PPP emissions can be modelled with PestLCI 2.0 (Dijkman et al. 2012).

Final quantitative ecotoxic results include a potential ecotoxic pressure (= impact score) per substance. In USEtox™, it describes the potentially affected fraction (PAF) of species in the environment that is induced by the use of the particular substance. Impacts of different substances are summarised as Comparative Toxic Unit (CTU) to stress the comparative nature of the characterisation factors. Formula A illustrates ecotoxic impact calculations when PestLCI 2.0 and USEtox™ (version 1.01) are used.

Formula A. The potential ecotoxicity in life cycle assessment is calculated using the following formula:

$IS = \sum\sum CF * M = EF*XF*FF*M$
where:

IS = impact score (= potential ecotoxicity, CTU)
CTU = Comparative Toxic Unit
CF = ecotoxicological characterisation factor (PAF m3 * day/ $kg_{emission}$)
M = substance emission (kg)
EF = effect factor (= toxicity)
XF = exposure factor (=bioavailability factor)
FF = fate factor (=substance emission into environment parts)

5.4 USEtox™ application

In our food chain-oriented study, the potential ecotoxicity impact in a life cycle assessment (LCA) was used to extend the PPP impact assessment view into the vertical food chain. In this study, impacts were studied only at the field scale induced by the usage of plant protection products. In the step of life cycle inventory assessment (LCIA) characterisation factors were calculated with the SETAC consensus LCIA model for ecotoxic impacts USEtox™ (version 1.01) (USEtox™ 2013). This is the most developed model for calculating ecotoxic effects in LCIA, although at this moment it only includes effects on aquatic organisms. PPP emissions from field application to the different environmental parts in average Finnish field conditions were modelled with PestLCI 2.0 (Dijkman et al. 2012). Throughout the whole process, we cooperated with the Finnish Environment Institute (SYKE).

In this study, ecotoxic impacts were calculated based on the PPP sale and usage data (total mass of active ingredient kg = emission/substance) of the model compounds: MCPA, glyphosate and α-cypermethrin. The Comparative Toxic Unit (CTU) was used as the unit of ecotoxic impact. There was no data of prothioconazole in USEtox™ (version 1.01), so its impact could not be calculated. Parameters were generalised to countrywide and regional ELY-centre scale from the PPP case data presented in section 4. Impact scores for each PPP were calculated in our manuscript (Räsänen et al. 2013). In addition, the method is described in detail in the manuscript. As far as we know, the present paper is the first to study the PPP impacts on such a large scale in Finland. This data from our manuscript can be used for other similar studies in the future, as far as the models will be reformed.

5.5 Environmental vertical impacts on cereals induced by plant protection products

5.5.1 Impacts on countrywide scale

Impacts on country wide scale were assessed using the same usage values per substance for the whole of Finland. In addition, sales data was used. The starting parameters are shown in Table 4 in section 4.2. The ecotoxic impact (CTUs) of MCPA, glyphosate and α-cypermethrin are presented in Table 7. There was no data on prothioconazole in USEtox™ (version 1.01), so its impact could not be calculated. PPP impact values of the model compounds on a countrywide scale were summarised to give the main results of the use of this procedure. There are more details available in section 7.1. See also the sales data of model substances in Figure 10 in section 3.2.

Table 7. Ecotoxic impact (CTUs*) of MCPA, glyphosate and α-cypermethrin based on their usage or sales data in 2007 on countrywide scale in Finland. The total is the sum of all PPP impact values.

	MCPA	**glyphosate**	**α-cypermethrin**	**Total**
Based on usage data	347,287	29,118	779	377,184
Based on sale data	446,261	131,577	9,010	586,848
				964,032

*CTU = Comparative Toxic Unit

MCPA induced the highest impacts from these three model substances and both data sources. One clear reason is due to the highest used amount; the glyphosate impact (29,118 CTU) was 8% of that of MCPA (347,287 CTU), even though its usage was about half of MCPA one. MCPA was applied the most (247,200 kg) on cereals, glyphosate was the second (123,360 kg) and use of α-cypermethrin was almost null (14 kg). Even though, there were less sales of MCPA (318,000 kg) than that of glyphosate (557,000 kg), its sale data impacts (446,261 CTU) were three times higher than that of glyphosate (131,577 CTU). The other reason is also MCPA's toxicity properties compared to glyphosate; MCPA is known to be more lethal to aquatic organisms than glyphosate (EC 2008 MCPA, EC 2002 glyphosate).

However, α-cypermethrin impacts were relatively high, even though it was used and sold the least. Its usage base impact (779 CTU) was 0.2% of that of MCPA (347,287 CTU) and 2.7% of that of glyphosate (29,118 CTU), even though its treated amount was only 0.006% of MCPA and 0.01% of glyphosate. α-cypermethrin sales (200 kg) were only 0.03% of glyphosate and 0.05% of MCPA sales in 2007, but its sales-based impacts (9010 CTU) were 7% and 2% of glyphosate and MCPA, respectively. This is reasonable, given that α-cypermethrin is known to be toxic to aquatic organisms even in low concentrations (EC 2004 alpha-cypermethrin).

5.5.2 Impacts on the regional scale

Impacts on the regional scale were assessed using ELY-centre regions. The ranges of starting parameters are shown in tables 5 and 6 in section 4.3. The ecotoxic impact (CTUs) of MCPA and glyphosate are presented in Figure 18.

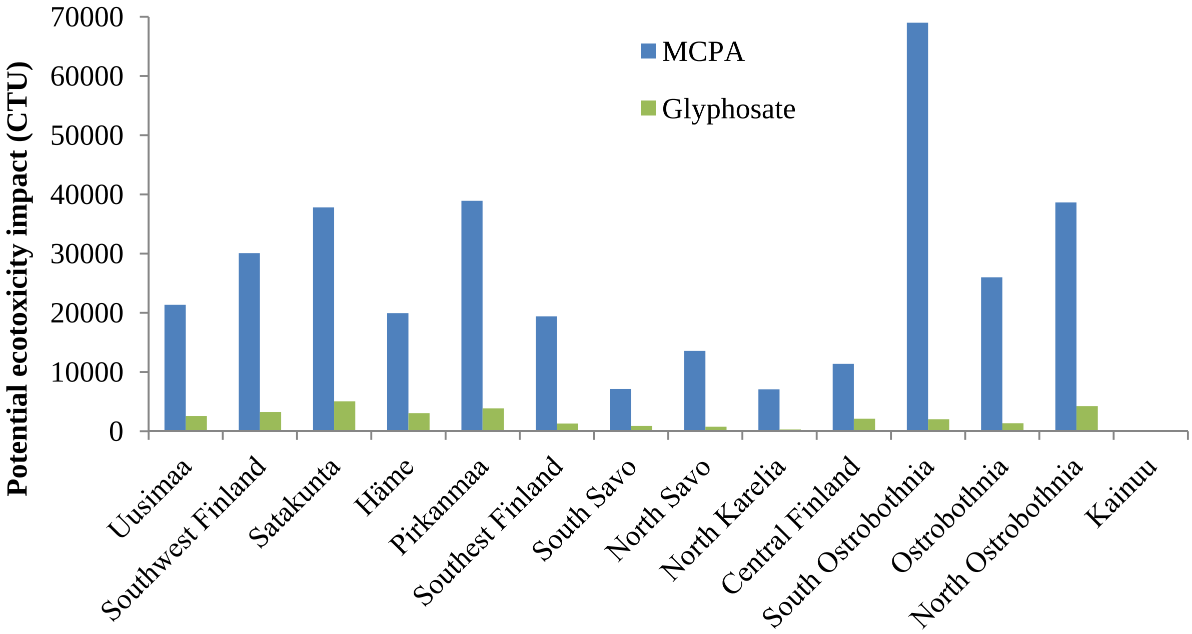


Figure 18. Ecotoxic impact (CTUs*) of MCPA and glyphosate based on their usage data in 2007 at regional scale divided into the 15 ELY-centre areas in Finland. Lapland was not taken into the calculations because there was no usage of the model substances reported in the case data.
*CTU = Comparative Toxic Unit

As the use of MCPA was used more and also its toxicity to aquatic organisms is higher than that of glyphosate (EC 2008 MCPA, EC 2002 glyphosate), the ecotoxic impact shows higher values of MCPA in all regions. The more used a compound was, the more ecotoxic impact there was in the ELY-region approach.

6 Environmental horizontal risks of plant protection products

6.1 HAIR2010 risk indicators of aquatic organisms

For comparison with the LCA investigation, HAIR risk indicators were used to demonstrate the risks to aquatic organisms. More details about HAIR are described in section 1.3.4. Similarly to the ecotoxicity impact assessment, HAIR calculations include a modelling of PPP drift into different environmental compartments (water, soil, air) and exposure of relevant organisms there. The final quantitative HAIR risk value describes the risk to the organism in question, e.g. fish, in the relevant environment that is exposed by the use of plant protection product. The risk indicator describes a relative risk value per substance. HAIR expressed the risk as exposure toxicity ratio (ETR), where the ETR value of 0 is a minimum value, meaning no risk is posed and the maximum value can be infinite. Risk values can be compared e.g. between different substances or time periods. Different risk indicators describe different things and are not comparable to the each other.

6.2 HAIR2010 application

The HAIR2010 software (Version 1.2.4, 10-01-2012) was used to investigate the risks of PPP use on aquatic organisms and groundwater in different spatial scales. The aquatic risk indicator species were fish, daphnia and algae, and groundwater risk was also investigated. HAIR input parameters were generalised to countrywide and regional scales from the PPP case data, as presented in more detail in section 4.

HAIR2010 uses NUTS2-level division for regional division and Finland has four regions in the software. The regions have changed after the HAIR2010 software was published. However, the original regional division of those NUTS2-regions was found to be unsuitable for describing regional pesticide use as the regions cover very large areas. Instead of using NUTS2-level regions, regional analysis was carried out using smaller 15 ELY-centres than originally intended in the HAIR2010 software, as described in section 4.3. ELY-centre and NUTS2-level regions are presented in Figure 19.

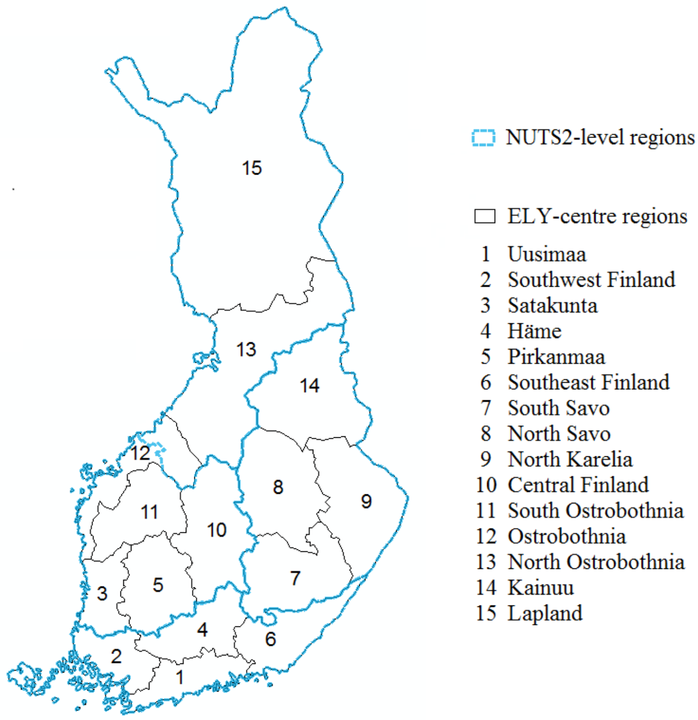


Figure 19. NUTS2-level regions used by HAIR2010 by default and ELY-centre regions, which were used instead of NUTS2-level regions.

The risk indicators were first calculated using the same input parameters for the whole of Finland. After that regional demonstrations were performed. HAIR2010 software calculates the risk indicators for 10 x 10 km grid cells, which were added together to get one aggregated risk value representing the whole of Finland. This way it is possible to compare the risk values over the years to investigate the influence of risk reduction actions. In HAIR2010, soil parameters are also defined as a 10 x 10 km grid but climate areas are defined as a coarser 50 x 50 km grid. HAIR2010 calculates risk indicator values as risk per unit area treated (henceforth referred to as the non-weighted result) and the user has the possibility to weight the results with the treated area by multiplying the non-weighted result by the area treated (weighted result).

Default values of field margin width of 6 m and a buffer strip width of 1 m were used in all HAIR2010 applications. It should be taken into account, however, that in the HAIR2010 calculations the buffer zones required for mitigating the aquatic risks in the actual uses of plant protection products were not considered.

A sensitivity analysis was performed to identify the influence of different input parameters for the output ETR values. It was found that the differences in results between cereals were negligible concerning aquatic risk indicators. Therefore, the risk indicators were calculated for spring barley cultivation but the results were considered representative of all model cereals. Details about the sensitivity analysis are presented in the internal working instructions for running the HAIR2010 software that we made in Finnish (Nousiainen and Räsänen 2013). The instructions will be published as an Appendix in our report on task 3 of COMPLY 4 project (to be published in November 2013).

The HAIR2010 software package includes a visualisation tool called HAIR Studio. Instead of using HAIR Studio for visualising the results, a GIS software was used as it was more flexible and better suited for visualising a large amount of data.

6.3 Environmental horizontal risks on cereals induced by plant protection products

6.3.1 Risks on countrywide scale

Risks on countrywide scale were assessed using the same usage values per substance for the whole of Finland. The starting parameters are shown in Table 4 in section 4.2.

Spatial variation of risk was first examined with results that were not weighted by the treated area. Risk was thus expressed as the risk per unit area treated. Non-weighted results for all the model substances are presented in Appendix A in figures A1 to A4. All the aquatic indicators behaved in the same way because the calculation procedure is similar for all. In the other words, the same parameters affect the risks in all aquatic risk indicators on our used model substances except in the following situation: for MCPA and glyphosate flowing water conditions, 10 x 10 km soil areas are visible, whereas for standing water conditions, the risk seems to be mainly influenced by 50 x 50 km climate areas. For α-cypermethrin and prothioconazole, all the risk indicators with the exception of the chronic risk in flowing water condition for algae were mainly dependent on those 50 x 50 km climate areas. Acute risk did not vary spatially, except for the risk in standing water conditions for prothioconazole - this application was performed twice during the growing season.

In the weighing operation the risk was determined by the treated area. Because the same percentage describing the treated area was applied to the whole of Finland, the areas with intense cultivation also had a higher risk than those areas with less cultivation. The difference between various risk indicators was only in order of magnitude. The exception was groundwater risk posed by MCPA use, which was not dependent on the treated area. The area weighted results for all the model substances are presented in Figures B1 to B4 in the Appendix B.

All the 10 x 10 km grid cells of each substance were added together to get one aggregated risk value representing the whole of Finland. The HAIR results of the calculations based on recommended usage and based on usage data are presented in Tables 8 and 9, respectively. Aggregated risk values of the model compounds on the countrywide scale were summarised to give the main results of using this procedure. More details are presented in section 7.1. See also sales data of model substances in Figure 10 in section 3.2.

Table 8. Aggregated risk values (ETR*) of MCPA, glyphosate, prothioconazole and α-cypermethrin use in cereal fields in 2007 in Finland. Risk values have been calculated with HAIR2010 using recommended application rates acquired from PPP labels. Median values of all the grid cells are presented in parenthesis.

	MCPA	**Glyphosate**	**Prothioconazole**	**α-cypermethrin**
Algae				
Acute, flowing	16 (0.0015)	550 (0.071)	2.06 (2.84 x 10^{-4})	0.63 (1.7 x 10^{-4})
Acute, standing			2.09 (2.88 x 10^{-4})	
Chronic, flowing	2.8 (2.6 x 10^{-4})	2.0 (2.5 x 10^{-4})	3.0 (4.2 x 10^{-4})	0.29 (7.9 x 10^{-5})
Chronic, standing	10 (9.6 x 10^{-4})	7.5 (9.6 x 10^{-4})	8.9 (0.0012)	1.1 (3.0 x 10^{-4})
Daphnia				
Acute, flowing	6.8 (6.3 x 10^{-4})	8.4 (0.0011)	3.46 (4.76 x 10^{-4})	270 (0.074)
Acute, standing			3.50 (4.83 x 10^{-4})	
Chronic, flowing	0.13 (1.2 x 10^{-5})	0.16 (2.1 x 10^{-5})	0.079 (1.1 x 10^{-5})	2.7 (7.5 x 10^{-4})
Chronic, standing	9.4 (8.7 x 10^{-4})	13 (0.0017)	2.1 (3.0 x 10^{-4})	220 (0.061)
Fish				
Acute, flowing	26 (0.0024)	0.2 (2.5 x 10^{-5})	2.46 (3.38 x 10^{-4})	82 (0.022)
Acute, standing			2.49 (3.43 x 10^{-4})	
Chronic, flowing	0.36 (3.3 x 10^{-5})	0.11 (1.4 x 10^{-5})	0.16 (2.1 x 10^{-5})	19 (0.0053)
Chronic, standing	31 (0.0029)	11 (0.0014)	3.8 (5.1 x 10^{-4})	2000 (0.54)
Groundwater	4400 (4.2x10^{-5})**	0	0	0

*ETR = Exposure Toxicity Ratio
**distribution was highly distorted

Table 9. Aggregated risk values (ETR*) of MCPA, glyphosate, prothioconazole and α-cypermethrin use in cereal fields in 2007 in Finland. Risk values have been calculated with HAIR2010 using data from the case study. The total is a sum of all PPP risk values. The medians of risk values have been left out as the distribution of the risk values is identical to Table 8 and only the order of magnitude of the risk is different.

	MCPA	Glyphosate	Prothioconazole	α-cypermethrin	Total
Algae					
Acute, flowing	8.32	532	0.907	0.316	542
Acute, standing	8.32	532	0.917	0.316	542
Chronic, flowing	1.45	1.89	1.33	0.144	4.81
Chronic, standing	5.45	7.26	3.78	0.553	17.0
Daphnia					
Acute, flowing	3.58	8.13	1.52	134	147
Acute, standing	3.58	8.13	1.54	134	147
Chronic, flowing	0.0690	0.160	0.0347	1.37	1.63
Chronic, standing	4.94	12.8	0.899	110	129
Fish					
Acute, flowing	13.6	0.189	1.08	40.8	55.7
Acute, standing	13.6	0.189	1.09	40.8	55.7
Chronic, flowing	0.191	0.104	0.0782	9.64	10.0
Chronic, standing	16.5	10.5	1.77	975	1000
Groundwater	2320	0	0	0	2320
					4970

*ETR = Exposure Toxicity Ratio

Risk values were higher with recommended use than usage data due to higher application rate values used as input parameters. The dynamics of different indicator values are identical in both approaches, as only the application rate was changed and the effect of the application rate to the risk value is linear.

Only MCPA caused a risk to groundwater, but the risk values varied a lot between all the grid cells (median value being 4.2 x 10^{-5}) and the resulting sum value (2320) is high due to a few grid cells situated in Southern Finland. The soil and climate parameters in the HAIR database were plotted against the groundwater risk values to investigate the reason for the high risk in a few grid cells. The parameters correlating with high groundwater risks were e.g. the hydrological soil group, which determines the susceptibility to soil erosion, and the soil texture class, which in the case of groundwater risk calculation determines the soil moisture content at field capacity. High groundwater risk values were correlating with hydrological soil group of 1 and soil texture class of 1 which both describe sandy soils (Figure 20). All the classes are described in detail in HAIR documentation (Kruijne et al. 2011).

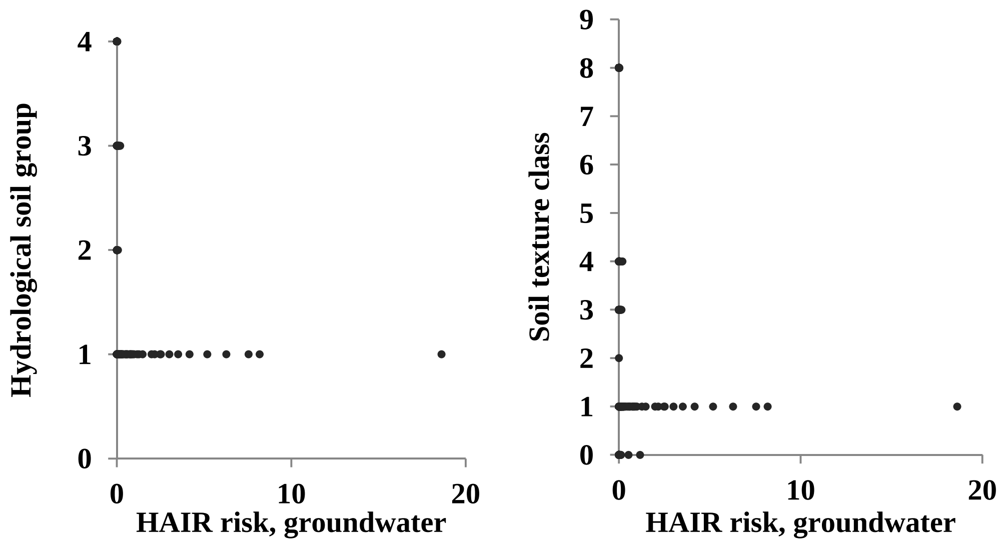


Figure 20. a) Hydrological soil group and b) soil texture class compared to groundwater risk (ETR*) posed by recommended MCPA use (pure substance only). Hydrological soil group 1 means lowest runoff potential and soil texture class 1 means coarse soil texture (more details in Kruijne et al. 2011).
*ETR = Exposure Toxicity Ratio

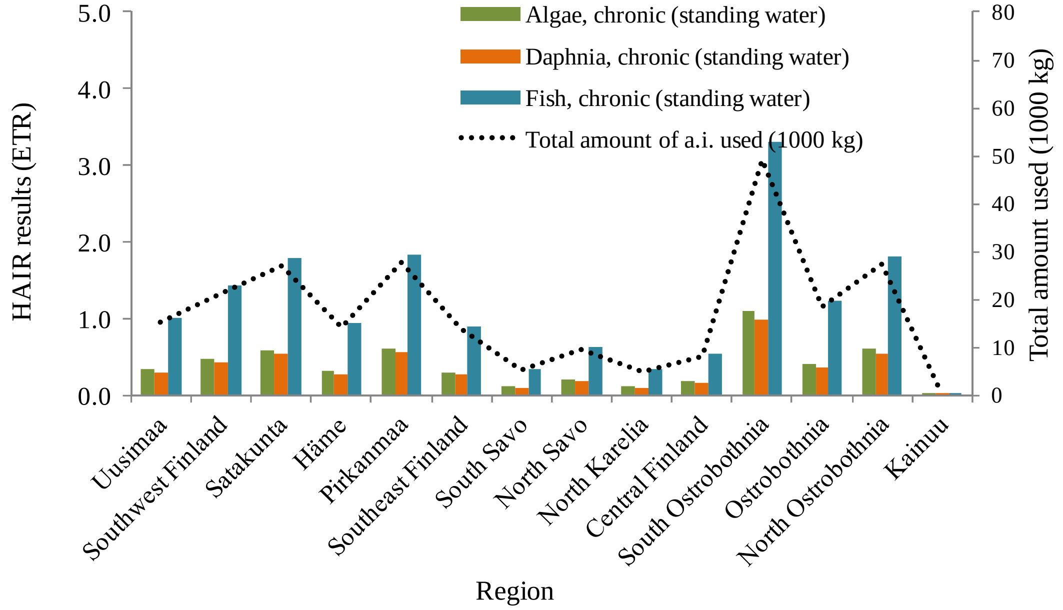
Glyphosate induced the highest risk acutely to algae, being 532 ETR with both flowing and standing indicators. Its toxicity was over 60 times higher than MCPA, even though the total amount of glyphosate applied (123,360 kg) was only about half of the amount of MCPA applied (247,200 kg). The risk value of glyphosate to algae was nearly 600 times higher than the risk value of prothioconazole (ETR about 0.9) and over 1,700 times higher than risk value of α-cypermethrin (ETR about 0.3). This result was expected as the amount of prothioconazole (763 kg) and α-cypermethrin (14 kg) usage was low.

α-cypermethrin induced the highest risks in most of the fish and daphnid indicators, and the toxicity risk was over 50-500 times higher than other model compounds, even though it was applied by only 14 kg, being 0.006% of MCPA and 0.01% of glyphosate. However, this is obvious, as the substance is commonly known to be toxic to aquatic organisms even at low concentrations in the laboratory experiments (EC 2004 alpha-cypermethrin).

6.3.2 Risks on the regional scale

Risks on the regional scale were assessed using ELY-centre regions. The ranges of starting parameters are shown in tables 5 and 6 in section 4.3. The aggregated risk results for aquatic risk indicators for MCPA and glyphosate are presented in Figures 21a and 21b, respectively. All the indicator results as a table are presented in Appendix C.

a)



b)

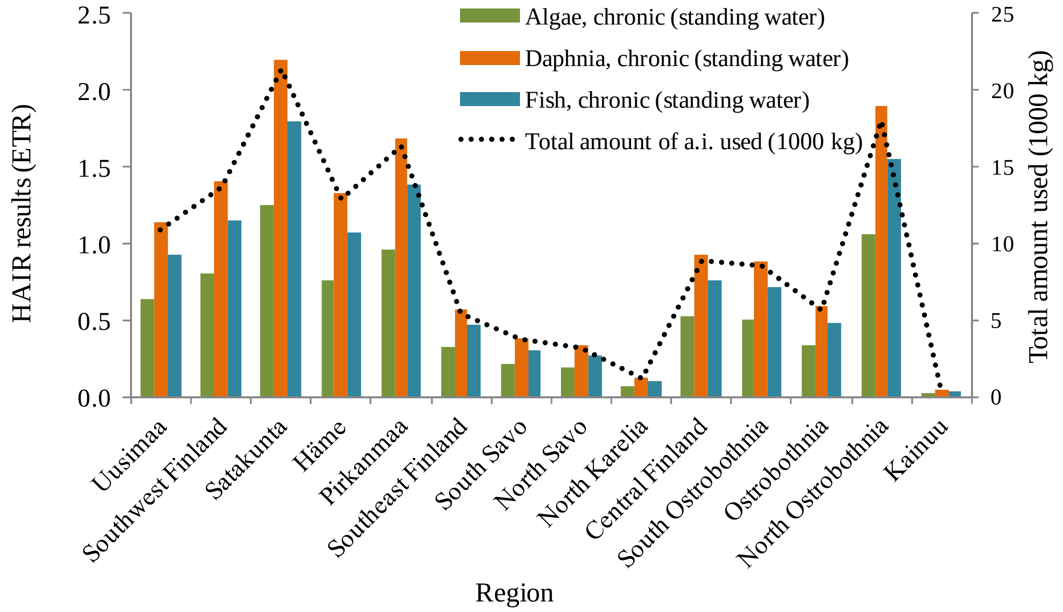


Figure 21. Aggregated risk values (ETR*) on aquatic risk indicators used induced by a) MCPA and b) glyphosate use on cereal fields in 2007 in ELY-centre regions. Risk values have been calculated with HAIR using data from the case study. The total amount of a.i. used is calculated using the median use and the treated area of the region. Lapland was not taken into the calculations because there was no usage of the model substances.
*ETR = Exposure Toxicity Ratio

The dynamics between different aquatic risk indicators were the same for all regions within both substances. Risk results for both substances were dependent on the total amount of PPP usage; the greater the used amount and more area treated, the higher the risk.

Glyphosate induced the highest risk for indicated aquatic organisms in the area of Satakunta, Pirkanmaa and North Ostrobothnia due to its high use. Correspondingly, MCPA induced the highest risk values for calculated aquatic indicators in the area of South Ostrobothnia due to its highest usage amounts.

However, groundwater risk indicator results differed from the results of the aquatic indicators. Risk was not dependent on the used amount (Figure 22). From the model substances only MCPA induced risk on groundwater.

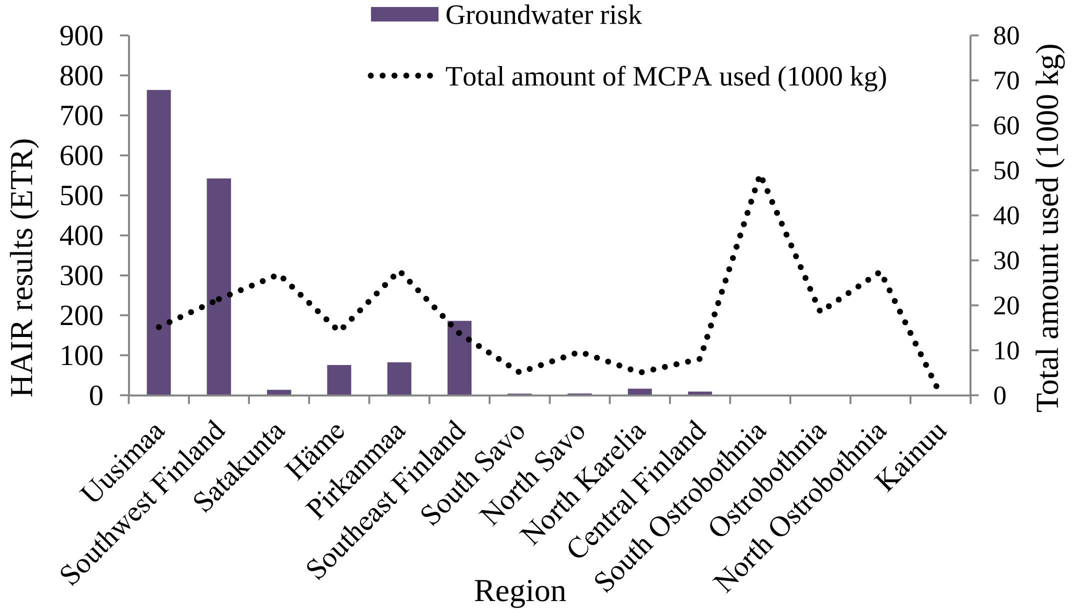


Figure 22. Groundwater risks values (ETR*) induced by MCPA use on cereal fields in 2007 in ELY-centre regions. Glyphosate posed no risk to groundwater.
*ETR = Exposure Toxicity Ratio

6.4 What problems were identified in using HAIR2010?

Some issues were found during the HAIR2010 analysis.

Some of the toxicity values for algae and daphnia of glyphosate were questionable; input values of different properties of certain active substances differed a lot between the EFSA and HAIR2010 data sources. However, the uncertainties in the compound database were clearly stated in the software documentation and the user has the possibility to make changes to the database. Toxicity data for prothioconazole was missing from the database and therefore the required parameters were added during the project. Endpoints agreed during the EFSA peer review on prothioconazole were used (EFSA 2007). The actual editing of the compound database was straightforward.

For Finland, the NUTS2-level regions used by HAIR2010 were found to be too rough for generalisation of the used data. Due to the use of different regions than that which was intended by HAIR2010, some extra effort was needed to achieve the desired result. The visualisation of the results also demanded extra effort because it was performed using GIS software instead of the visualisation software (HAIR Studio) included in the HAIR software package. The reason for using GIS software was that HAIR Studio had somewhat limited capabilities for the classification of the data. However, it was positive that using HAIR was flexible because it was possible to make all these changes and apply HAIR for our purposes.

7 Benefits and applicability of the procedure

7.1 How to measure IPM development in this procedure

In this study, the risks to the environment resulting from the changes of PPP usage habits following the implementation of IPM could be measured using this procedure (see Figure 5). With the procedure, potential environmental impacts induced by PPP usage were assessed towards the food chain using the LCA ecotoxic impact assessment, and environmental risks were evaluated using HAIR risk indicators.

The risks resulting from both dimensions can be examined in different years. The changes of the sum of total risks in different time periods illustrate the trends of risks, and thus IPM development, induced by the use of plant protection products. When this procedure was used by the authorities, the measuring IPM development can be done when risks are compared between different substances, time periods and areas. Implementing the IPM obligations will have consequences, such as further training available for the farmers, changes in the range of products available on the market and changes in their use instructions. Whether these changes are of benefit to the environment or not requires consistent measurement, and it needs to be communicated to the public. In the future, time series of the usage data of plant protection products should be available. In an ideal situation, the usage data from all the Nordic-Baltic countries could be recorded in a jointly available database.

The procedure was demonstrated here for the first time. However, this exercise presents possibilities for evaluating the aquatic risks following the use of plant protection products in actual use in the Finland of 2007. In this study it was not possible to calculate the risk trends over different time periods due to the limited usage data available. There was only one single year of PPP usage data, even though it was a pilot study of the Finnish Information Centre of the Ministry of Agriculture and Forestry (Tike) to collect data on pesticide usage on Finnish farms in the future because of legal demands. When further data on usage become available for a longer time period, this procedure may be used for illustrating the changes in the need and use of plant protection products, thus illustrating the phase of IPM implementation over time.

In addition, to ensure that the data is sufficiently representative, more studies are needed. Because sales of most pesticides are low in Finland, the sampling methods of collecting the usage data have to be planned carefully to ensure adequate sample sizes. The mistakes in data also cause errors in risk values. In addition, due to the limited time available but also keeping the demonstration study simple, only a few model substances were studied. Thus, it is important to note that this exercise describes only the usage of the selected model substances in Finland in 2007. The risk results of this study were calculated based on the data and an assumption that model crop areas are treated with these amounts of model substances. In the future, more data from PPP usage on different crops should be collected and used for further consideration. If the procedure is to be used for measuring the effects of policy options, more detailed usage data needs to be collected with a comparable methodology over a continuous time series and by taking into account the adequate differentiation of the regions throughout the country. Also, for evaluating the policy options, cooperation is needed between the Nordic-Baltic countries and even on a larger scale.

The effects were studied only on aquatic organisms for achieving the project aim to study PPP effects on aquatic environment but also because of the lack of data in ecotoxic impact assessment (currently USEtox™ only calculates effects on aquatic organisms). So, other HAIR risk indicators should be used to achieve a more comprehensive picture of the risks. In addition, if this procedure were to be used in the future to study IPM development, it is important to compare the risks from different years with the same versions of the models. If the models were changed and developed further, it is suggested that the risks would be calculated from all years with the same model version. Only then can this procedure be used to compare risks and IPM development over different years.

The presented methodology, including the collection of PPP usage data and all risk calculations, is rather time consuming and therefore an adequate amount of human resources is needed to perform the calculations. The methodology requires quite profound knowledge of the users in data collection, risk calculations and interpretation of the results. Therefore, the procedure is not suitable for everybody – it needs a great deal of expertise and experience to be operable. Currently the calculations have been performed on a project basis, and therefore there is a risk that the experience will be lost if there is a delay in the further implementation of the methodology to a larger group of users.

In future projects for preparing the procedure, it is also recommended that risk results are related to the benefits of PPP usage, that are quantity and quality of the yield, for obtaining a more realistic picture of the action in the field. In addition, as a suggestion on an even larger scale, pesticide residue effects on humans, health problems and also health costs can be considered in order to achieve the picture of the PPP effects and IPM benefits (e.g. van Emden and Peakall 1996).

In conclusion, further work is necessary for drawing more general conclusions on the use patterns of environmental risks and IPM processing induced by plant protection products from the uses in different crops and regions in Finland. This exercise could be considered a starting point for developing means for measuring the achievements of integrated pest management in Finland and other Nordic-Baltic countries. In addition, more research is needed to develop the procedure.

7.2 What affects the risks in this procedure?

There are many aspects that affect to the demands and risks of PPP usage. PPPs have different physical and chemical properties, which affect the substance fate in the environment, bioavailability and effects on organisms. Spraying time and treated plants also have an impact on risks. Weather conditions, climate and soil quality and geographical location can affect the risks. In addition, cultivation technique can have an effect on PPP usage, e.g. herbicide demand can be increased as a result of reduced tillage (Puurunen et al. 2004.) Cultivation monoculture can increase pests (Jalli et al. 2012), which can be decreased with crop rotation.

Finland belongs to the Nordic boreal zone where are typically high annual variations in temperatures, a cold climate, low sun radiation and a short growth season. There are a lot of water systems in Finland, and groundwater systems are quite high. Finnish lakes are typically shallow and thus the amount of water is quite low, which makes them very fragile and sensitive to loads. Changes in rainfall and snow melt also affect changes in heights of water systems (Seppälä 1997). Low concentrations of active ingredients or their degraded products are found in each year in water systems, especially those that are located near agricultural areas (Mattila et al. 2007, Siimes et al. 2007, Siimes 2012). Mainly low concentrations have been found but environmental quality standards (=EQS values, 2000/60/EC, 2006/118/EC) have been crossed over within a few substances (Kontiokari and Mattsoff 2011).

Soil quality affects the behaviour of chemicals, as well as the fate of PPPs. Sprayed PPPs can drift to soil, air and water. Chemicals can bind to organic and inorganic soil compounds. PPPs are degraded by microorganisms or chemically. Typical Finnish soil quality properties are low pH and high organic material. Low pH and a cold climate can decrease chemical degradation (Seppälä 1997, Paasonen-Kivekäs 2009). Northern ecosystems have adapted to the cold climate; the biodiversity is quite low. Thus also a low number of pests are found, and less plant protection is needed than in more biodiversity areas (Seppälä 1997, Hakala et al. 2011).

In addition, climate change can bring changes to PPP usage. PPP leaching can be increased because of increased rains and floods (Hakala et al. 2011). In addition, new pests and weeds can arrive in Finland when new pest control is needed (Hakala et al. 2011, Heikkilä 2011). Can changes in cultivation methods in the future (Puustinen et al. 2005, Bechmann et al. 2009) change the usage of PPPs? At least there is an attempt to achieve this via IPM.

In this study, sensitivity analysis was performed to identify the parameters that affect the risks induced by PPP usage. In the procedure different parameters are part of the models. In ecotoxic impact assessment the parameters were the active ingredient of PPPs and its amount, sprayed crop and its growth stage, spraying time (month), field circumstances (e.g. area, cultivation technique, drainage amount, field slope, soil quality) and climate area. It calculates potential impacts only on aquatic organisms, adding PPP's fate and organism exposure and effect together. In HAIR2010, the parameters were PPP's active ingredient and its amount, crop treated, application date, soil (organic carbon, soil pH, soil texture class, soil hydrological group, slope) and climate (monthly average precipitation and temperature) which varied spatially. Within HAIR2010, the potential risks were calculated by modelling PPP's fate and effects on aquatic organisms (fish, daphnia, algae). In groundwater risk PPP's fate was modelled.

What parameters affect the risks? What could be found in this study? Because of the limited time and also the demonstration project character, only some analyses and remarks were performed. Results were linear to the used amount in both models (USEtox™ and HAIR2010) used, which means that the more PPP was used, the riskier it was. Hence, different substances can be compared to each other within the models. We could compare toxicities induced by the usage of MCPA, glyphosate, prothioconazole and α-cypermethrin. There are more details about the results in sections 5.5. and 6.3. However, it is not possible to compare different risk indicators of HAIR, they tell about the different things indicating the effects on different organisms.

In regional scale examinations, ecotoxicity impact assessment and HAIR2010 aquatic risk results were dependent on the used total amount of PPP usage; the more it was used, the riskier it was. An exception to the HAIR2010 groundwater risk indicators for MCPA was that the risk was not dependent on the used amount. MCPA induced higher risk on groundwater in the southern part of Finland than other parts (Figure 22 and Appendix Figure A1). Based on our sensitive analyses, the reason for this was in soil quality (e.g. hydrological soil group and soil texture class, Figure 20). MCPA is relatively highly used on cereals (about 45% of model cereals are treated with MCPA), thus the risk is possible in many areas in Finland. So, is there a need to set usage limits for MCPA usage in more vulnerable groundwater areas? In conclusion, geographical location had an effect to the risks. Non-weighted results of HAIR could be used to find out the geographically sensitive areas within aquatic risk indicators. Thus, should geographically sensitive areas be included and considered differently in the risk evaluations of the future?

Acute risk did not vary spatially, except for the risk in standing water conditions for prothioconazole that was used twice during the growing season. Thus, HAIR takes into account multiple applications, leading to different risk results. It is therefore important to separate all the applications performed in the field. So, when asking for usage data on the fields from farmers by authorities in the future, it is important to understand whether the compound is used multiple times or only once (including the sum of different usage days).

In conclusion, the sales data of active ingredients alone is not a sufficient parameter for describing risks that have been seen thus far. The used amount of active ingredients on a target plant in specific growth season gives a more directional picture of the risks, but neither of these is the most realistic. Thus, the substance toxicity and its behaviour but also local environment properties need to be considered in risk evaluations concerning specific growth seasons. By using the risk indicator models in addition to the risk assessment, additional information is obtained from substance differences and sensitive areas on a local level. However, in future studies more risk indicators than these used in this study are needed in order to examine and conclude this. In addtion, more studies and sensitivity analyses need to be done to find out what actually induces the risks.

7.3 Why are models needed? Developing aspects for the models

Models are needed to simplify life's complexity. Through this study, the procedure is served for this purpose (see Figure 5). The procedure presented here for first time includes the models of USEtox™ (version 1.01) and HAIR2010 risk indicators that are designed to study the effects of used PPPs on the environment.

There are differences and similarities in these procedural models. The ecotoxicity impact assessment describes the ecotoxicity impacts in the product chain, whilst in our study only looks at the effects induced by PPP usage on fields. Ecotoxicity impact assessments can be used for horizontal LCA product chain examinations and beside it other impact categories can be used, e.g. climate change, eutrophication and acidification. It adds all ecotoxicity effects together from all organisms, whereas with HAIR risk indicators the effects could be separated to individual organisms with different risk indicators. HAIR describes horizontal landscape risks. In addition, other HAIR risk indicators should be used in future studies, not only aquatic indicators, as was the case in this study. Both mathematical models give further information to the PPP risk evaluations because compounds can be compared to each other and additional geographical data can be used to examine sensitive areas. In addition, total risk changes in different years can be studied. Results from both models and this procedure can be applied for risk communication purposes. More details are presented in section 7.4.

USEtox™ and HAIR2010 were developed and are being further developed by research groups (USEtox™ 2013 and HAIR2010 2013). For developing aspects, we suggest the consideration of the following, for instance. More basic research is needed, and more details and information are required to be added to the models, for example more specific information of different landscape conditions. How would impact results be changed if effects other than simply aquatic organisms are added to USEtox™? How much soil quality information are we lacking and what are its actual effects on chemical risk forming? How much of an effect does fertilizer have on risks of chemicals and vice versa? And should these both be studied alongside each other? Is more research needed in order to study the combined effects of mixing different compounds?

7.4 How and why should we communicate about the risks?

The procedure can be used for risk communication purposes. How should we communicate about the risks? How should we apply this information so that different quarters and people who need this kind of information are reached? Who should we communicate with? When and how should we share the information? Why should the information be shared? Information about the risks are needed by scientists, politicians, advisers, farmers and consumers, among others. Information can be shared through the media, on the Internet, over chat or discussion events, etc. Different stakeholder groups may have different needs and opinions on the ways of communicating the risks (e.g. Assmuth et al. 2007), and therefore different tools for risk communication are needed.

All plant protection products are evaluated and cannot be authorised if they represent an unacceptable risk. Therefore, as a prerequisite it is not expected that they cause undesirable effects on humans or the environment. However, differences exist in their environmental properties, needs and use frequencies, which mean that some cause a lower load than others. Those loads can be compared using indicators or procedures like this. Comparisons over time can also be done on the total load of all products on the market, or trends in substituting or changing the products can be evaluated by means of this procedure.

EU Member States are obliged to identify priority items, such as active substances, crops, regions or practices that require particular attention or good practices for achieving the objectives of the directive on the sustainable use of pesticides. By means of risk indicators like this, the achievements can be demonstrated over time, e.g. if the choices made were successful in reducing the risks and impacts, encouraging the development and introduction of integrated pest management practices and reducing the dependency on the use of chemical pesticides.

The consequences of choices made locally can be illustrated to the users or the public if adequate regional data is available for calculating these indicators in the future. HAIR risk indicators provide information from the environmental landscape perspective. GIS-based graphics are illustrative for risk communication purposes, e.g. to be used in the training courses for advisers and professional users of plant protection products.

By making the changes in risks and in plant protection practices visible, the trends in environmental management and stewardship decisions can be evaluated regionally and focused on those areas where the effects are most powerful. For example, environmental monitoring resources can be targeted at areas with most intensive cultivation and the most vulnerable environmental conditions, where the loads and impacts are expected to be highest.

Considering the possible risks from the use of plant protection products, the general public should be better informed through awareness-raising campaigns and information services. For the consumer and the taxpayer, differentiation of the products based on their farming systems is difficult. Ecotoxicity impact assessments provide information on the ecotoxicity impacts in product chain. LCA information could be used in the future on product chain improvements, such as labels on product packets that companies can be used when communicate with customers, for example “carbon footprints” of Life Cycle Analysis (LCA) calculations have also be used in product documents. Even though, this can be sometimes confusing. The degree of the difficulty has been increased as the number of new labels.

This work package of the PesticideLife project is giving options for risk communication. Hopefully, the report will provide ideas for those who are working with and interested in pesticide risks arising from agriculture usage.

7.5 Environmental complexity behind IPM – future studies

In the IPM strategy, PPP usage is allowed but only when really needed. The PPP applications should be minimised because of environmental and resistance risks. In IPM farming, plant protection should be first made with pre-emptive actions, and use strictly targeted applications to the source of pest or diseases, in order to avoid PPP usage and their risks.

PPP usage increases environmental risks, for example when treatments are performed if not needed, they are done in unfavourable weather conditions, or if the crop target of the pesticide is in poor condition. In these cases, risks are higher than the benefits of the usage, i.e. increased yield quality or yield amount. When PPPs are used in a correctly timed manner, in the right amount and with the right quality of the substance, risks remain minimal: the yield quantity and quality increases, the capability of a crop to maximally use the growth resources increases, and it avoids nutrient and greenhouse gas release to the environment. Through IPM actions, attempts are made to keep environmental pressures to a minimum and still achieve the benefits of PPP usage, i.e. high quantity and quality of the yield.

PPP usage is only one part of agricultural plant protection and also risk formation. The whole agriculture and risk formation is more complex than can be illustrated in this research. Other risk inducers can be e.g. fertilizers. Environmental risks are achieved to be reduced via IPM, the main aim in IPM actions is to achieve sustainable agriculture. One view to illustrate IPM actions in agriculture is shown in Figure 23. In the future, more research is needed to study risks in agriculture in national scale but also around the world.

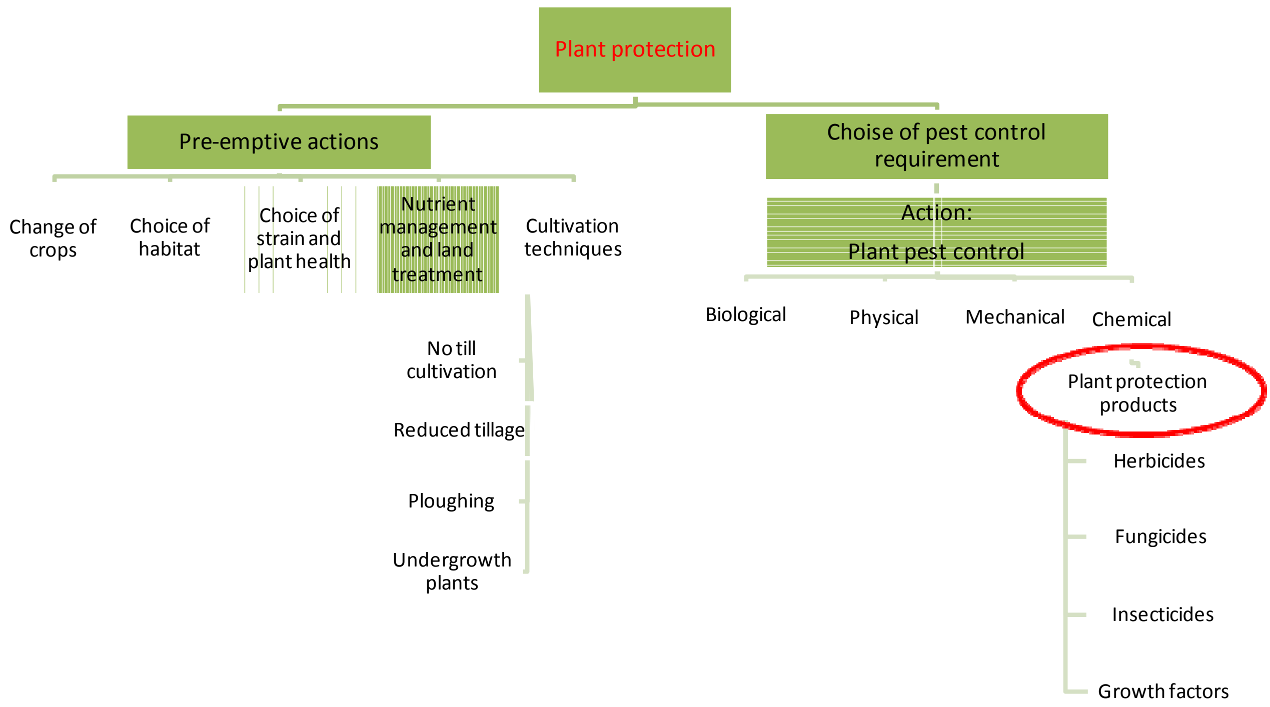


Figure 23. One view of plant protection via IPM. Environmental risks are not induced only by usage of plant protection products but the wholeness of agriculture is much more complex.

8 General conclusions

Environmental systems are complicated and the complexity of agricultural and food production systems were proven in this demonstration study. The use of models is one way to make it possible to describe systems and functions in order to realise what are the factors that effect to the studied system. In risk assessment and management, it is important to focus resources on the most relevant points and factors. In our demonstration study, we added to the challenge when two aspects (i.e. demonstration dimensions) were integrated into one procedure. It was also very important that the data (use of PPPs), originally collected for administrative purposes, was provided for the testing of the used models. We were able to combine knowledge of different kinds of experts working in different types of projects. The experts had the willingness and competence to cross borderlines of teams and projects. The borders between research teams and the authorities were blurred during the demonstration study! In the future, it will be important to expand collaboration respectively among the Nordic-Baltic countries. The storing of PPP usage data in a jointly usable database would make the risk assessment and follow-up of IPM processing more powerful. Risk communication based on hard data will be the basis of confidence. Collaboration and more similar studies are needed to be done also in the future.

Acknowledgements

This study was financed by the PesticideLife project (2010–2013) coordinated by MTT Agrifood Research Finland and co-financed by the EU LIFE+ programme. We would like to thank all project partners that offered us advice in this work. We are grateful to Irene Mustalahti, Pasi Mattila and other co-operators at the Finnish Information Centre of the Ministry of Agriculture and Forestry (Tike) for obtaining the PPP usage data, and Mervi Savela at Tukes kindly provided us with sales data. We would particularly like to thank Pentti Ruuttunen, Jarmo Ketola and Asko Hannukkala for their help and knowledge of PPP usage targets in Finland. We also kindly thank Tuomas Mattila and Petri Porvari at the Finnish Environment Institute (SYKE) for cooperating and helping with the ecotoxicity impact assessment. Thank you all also for building similar co-working in the future. We are also very pleased that other colleagues offered their time, help and valuable comments throughout this study.

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Appendices

Appendix A. Unweightened risks for the model substances.
Appendix B. Aggregated weighted risks for the model substances.
Appendix C. Aggregated risks of regional scale calculation of MCPA and glyphosate.

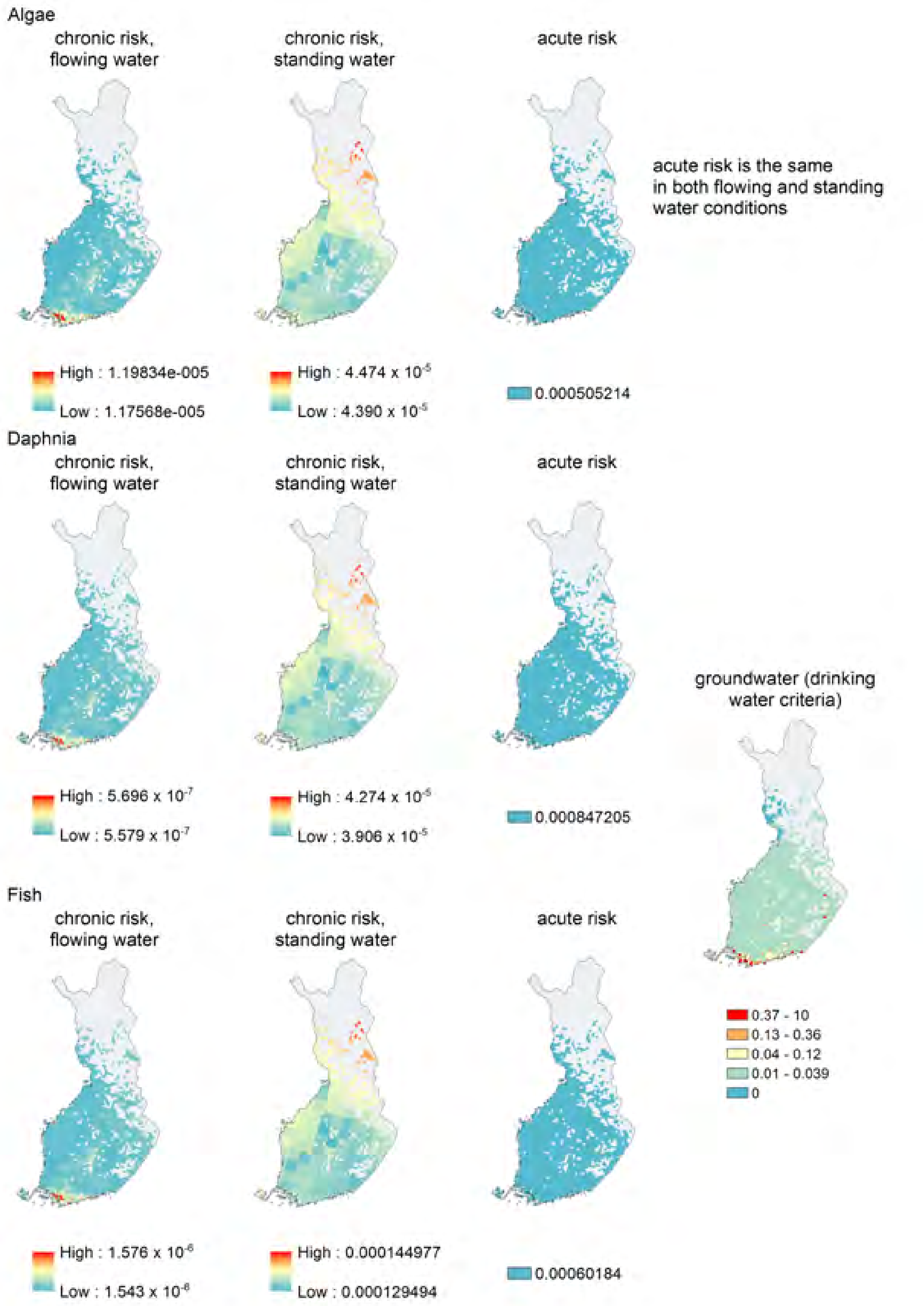

Figure A1. Unweighted risks for recommended usage of MCPA use per unit of area treated (ETR* ha^{-1}).
*ETR = Exposure Toxicity Ratio

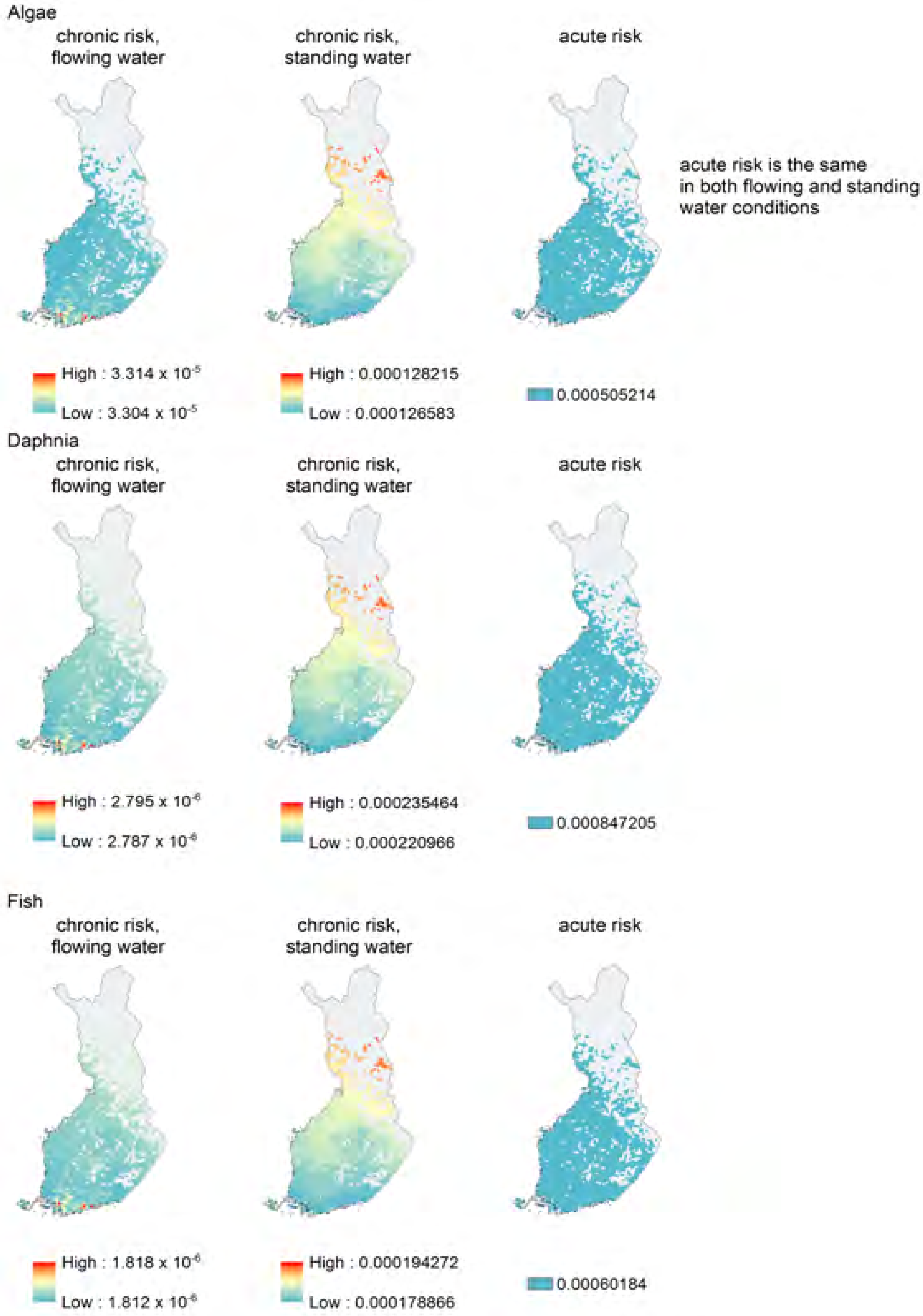

Figure A2. Unweighted risks for recommended glyphosate use per unit of area treated (ETR* ha^{-1}). Spring and autumn treatments have been calculated separately and then summed up. The risk for groundwater was 0.
*ETR = Exposure Toxicity Ratio

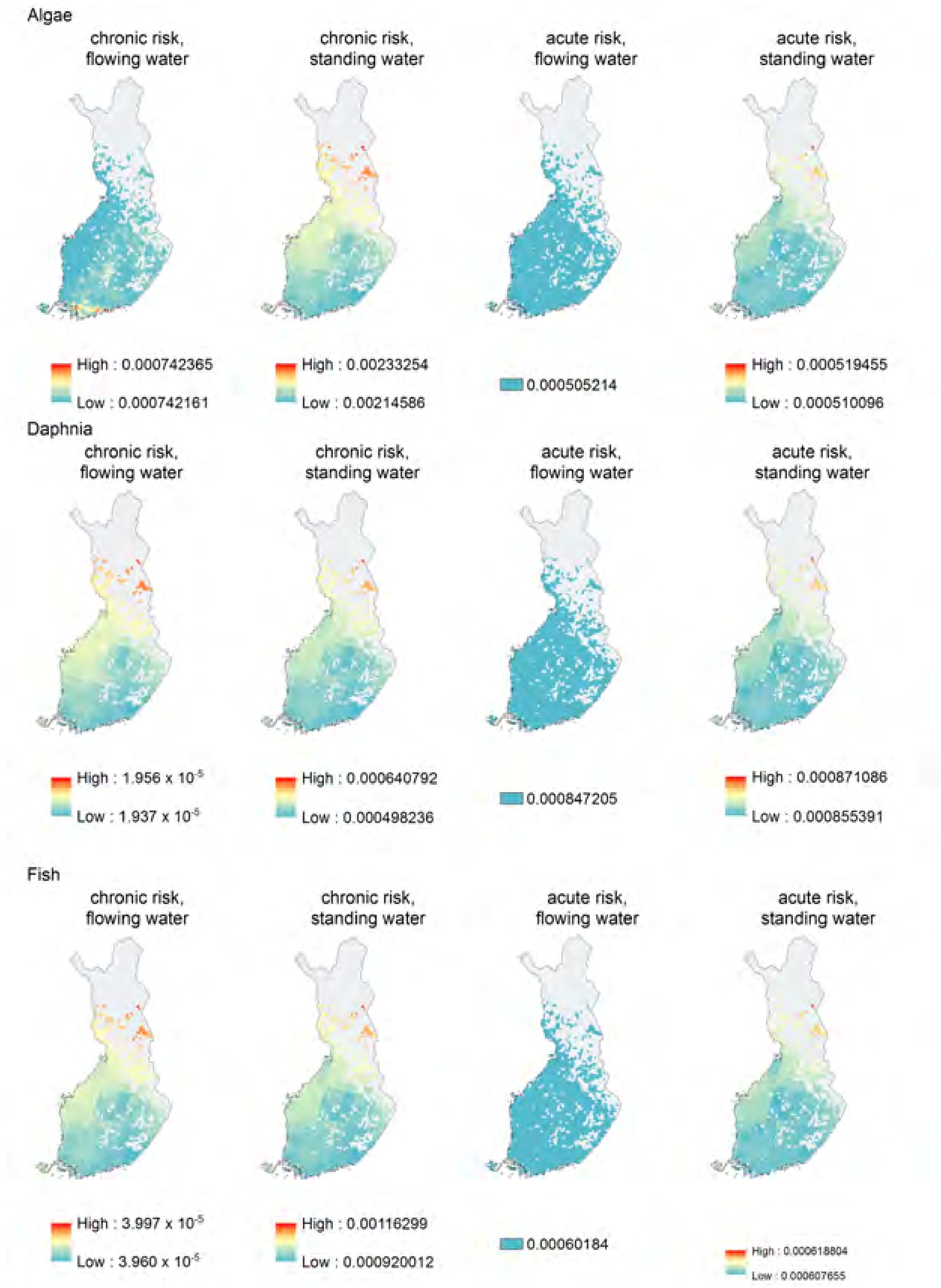

Figure A3. Unweighted risks for recommended prothioconazole use per unit of area treated (ETR* ha^{-1}). The risk for groundwater was 0.
*ETR = Exposure Toxicity Ratio

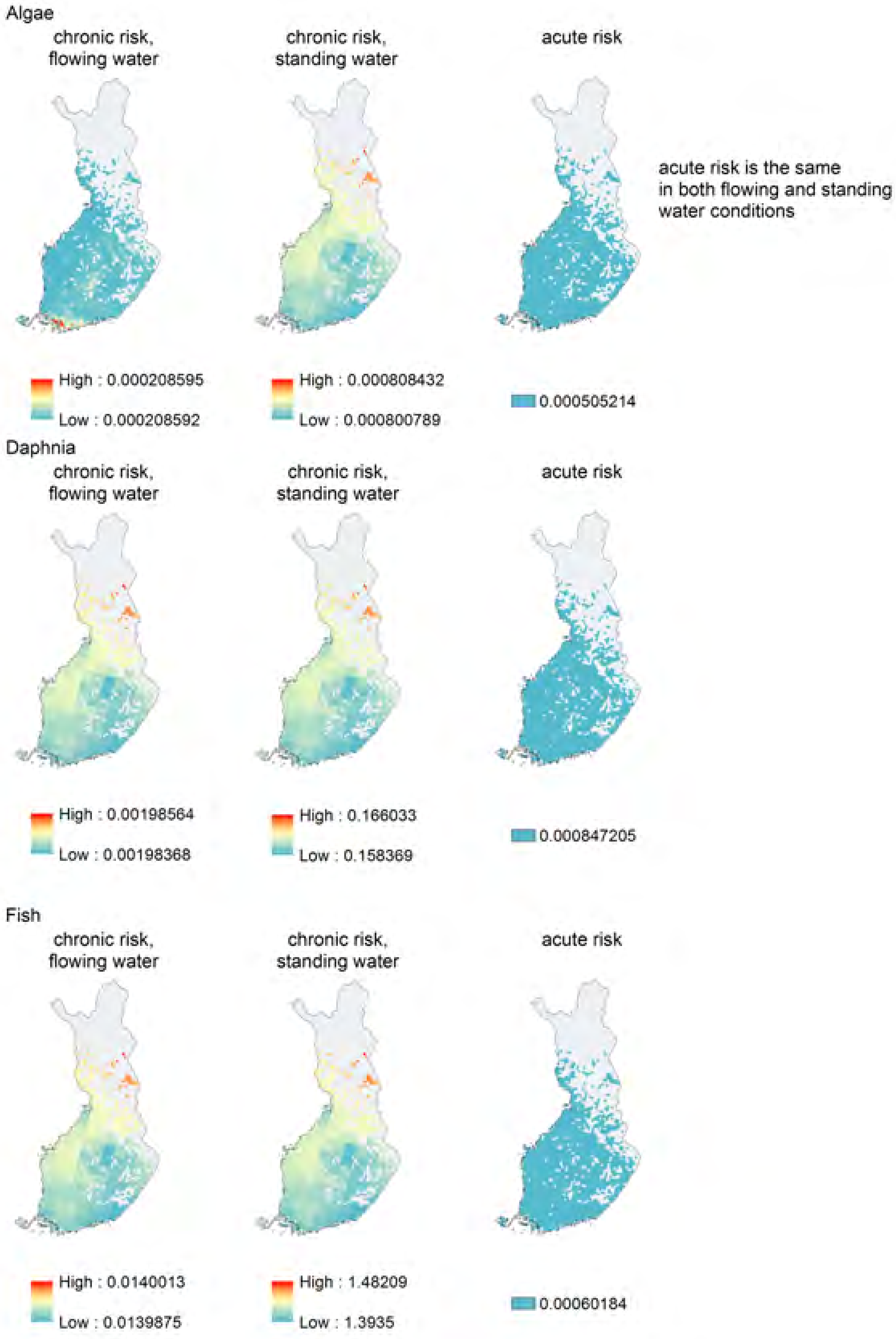

Figure A4. Unweighted risks for recommended α-cypermethrin use per unit of area treated (ETR* ha^{-1}). The risk for groundwater was 0.
*ETR = Exposure Toxicity Ratio

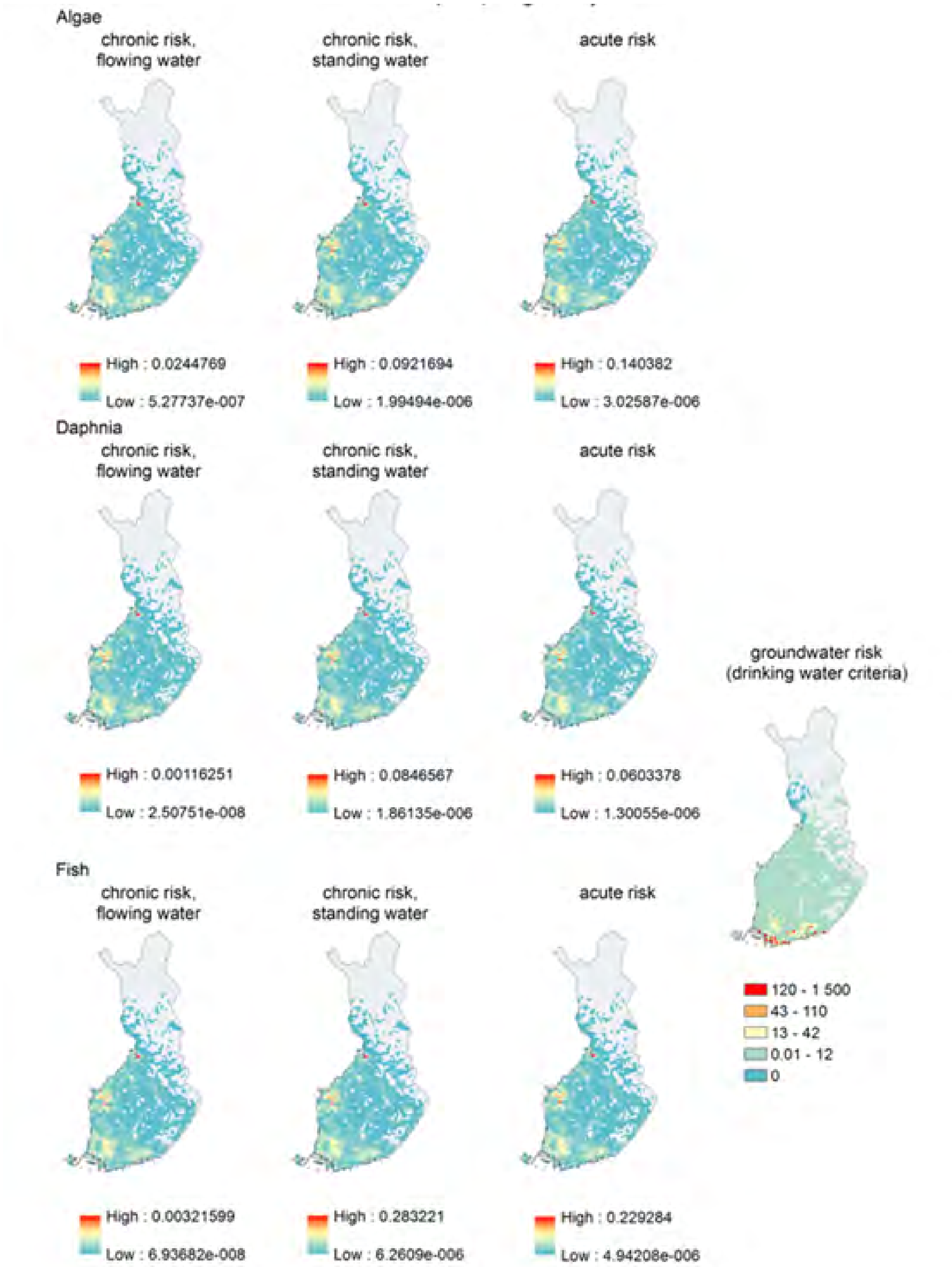

Figure B1. Risks for recommended usage of MCPA use weighted by the area treated (ETR*).
*ETR = Exposure Toxicity Ratio

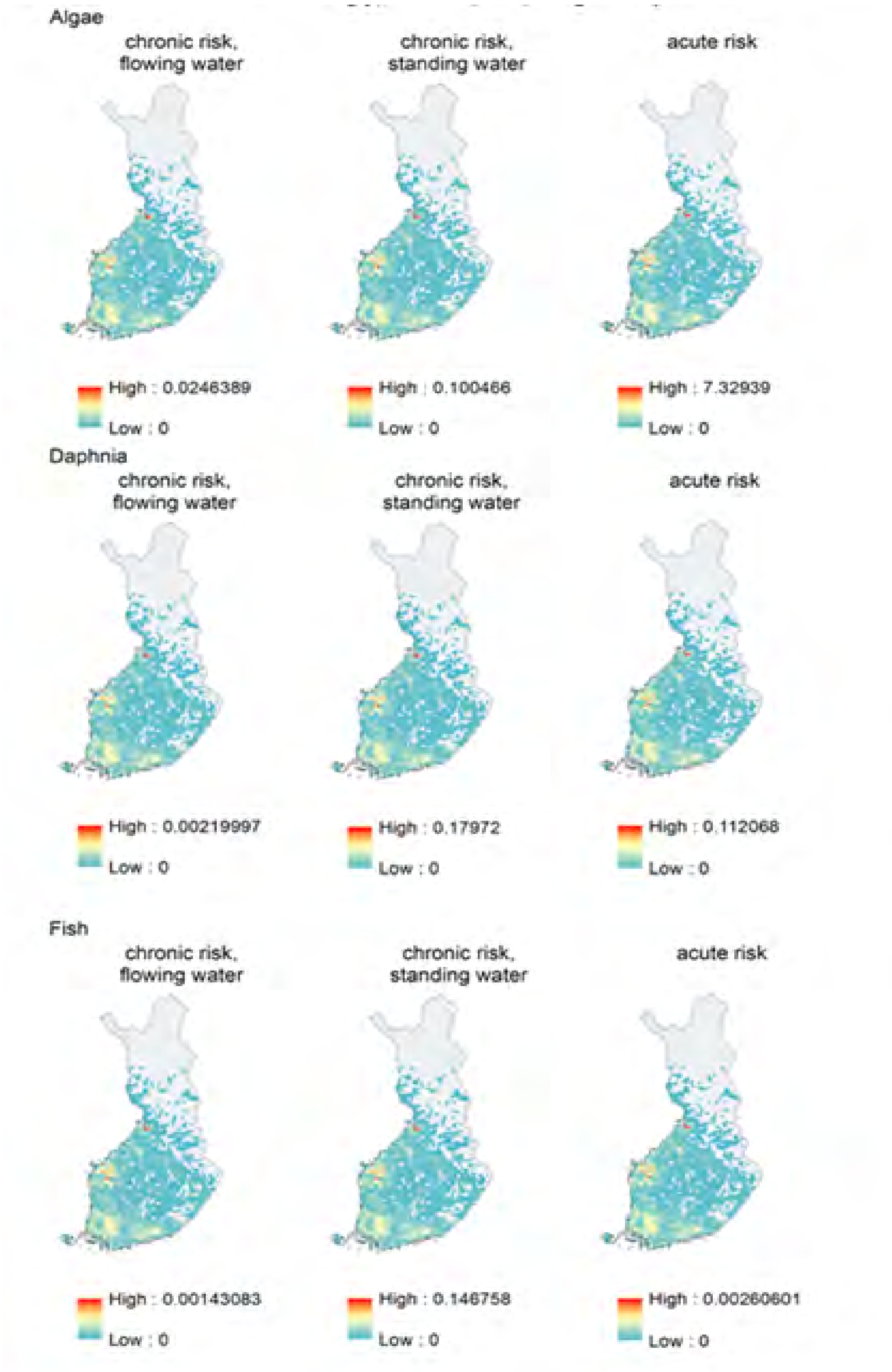

Figure B2. Risks for recommended glyphosate use weighted by the area treated (ETR*). Spring and autumn treatments have been calculated separately. The risk for groundwater was 0.
*ETR = Exposure Toxicity Ratio

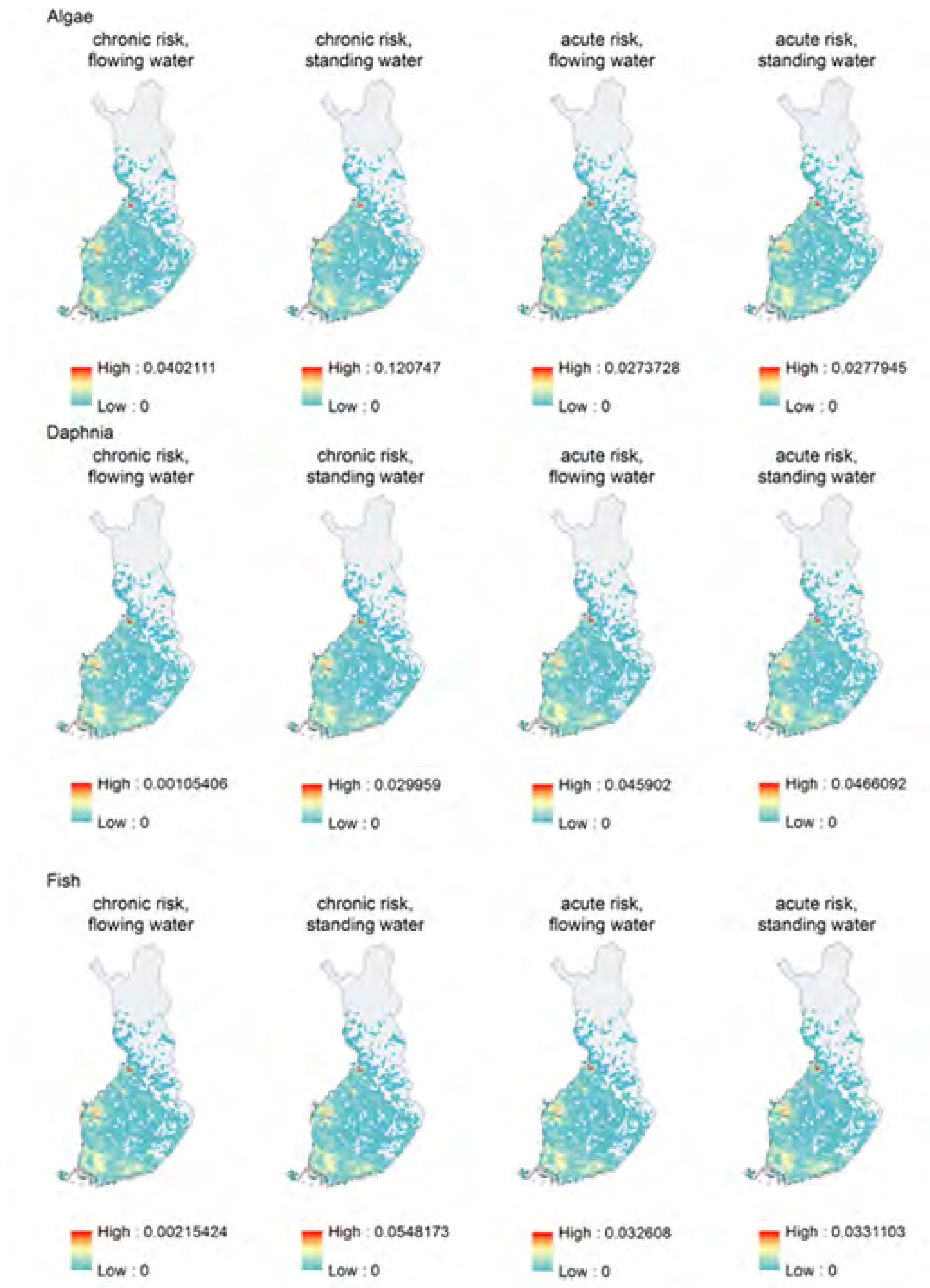

Figure B3. Risks for recommended prothioconazole use weighted by the area treated (ETR*). The risk for groundwater was 0.
*ETR = Exposure Toxicity Ratio

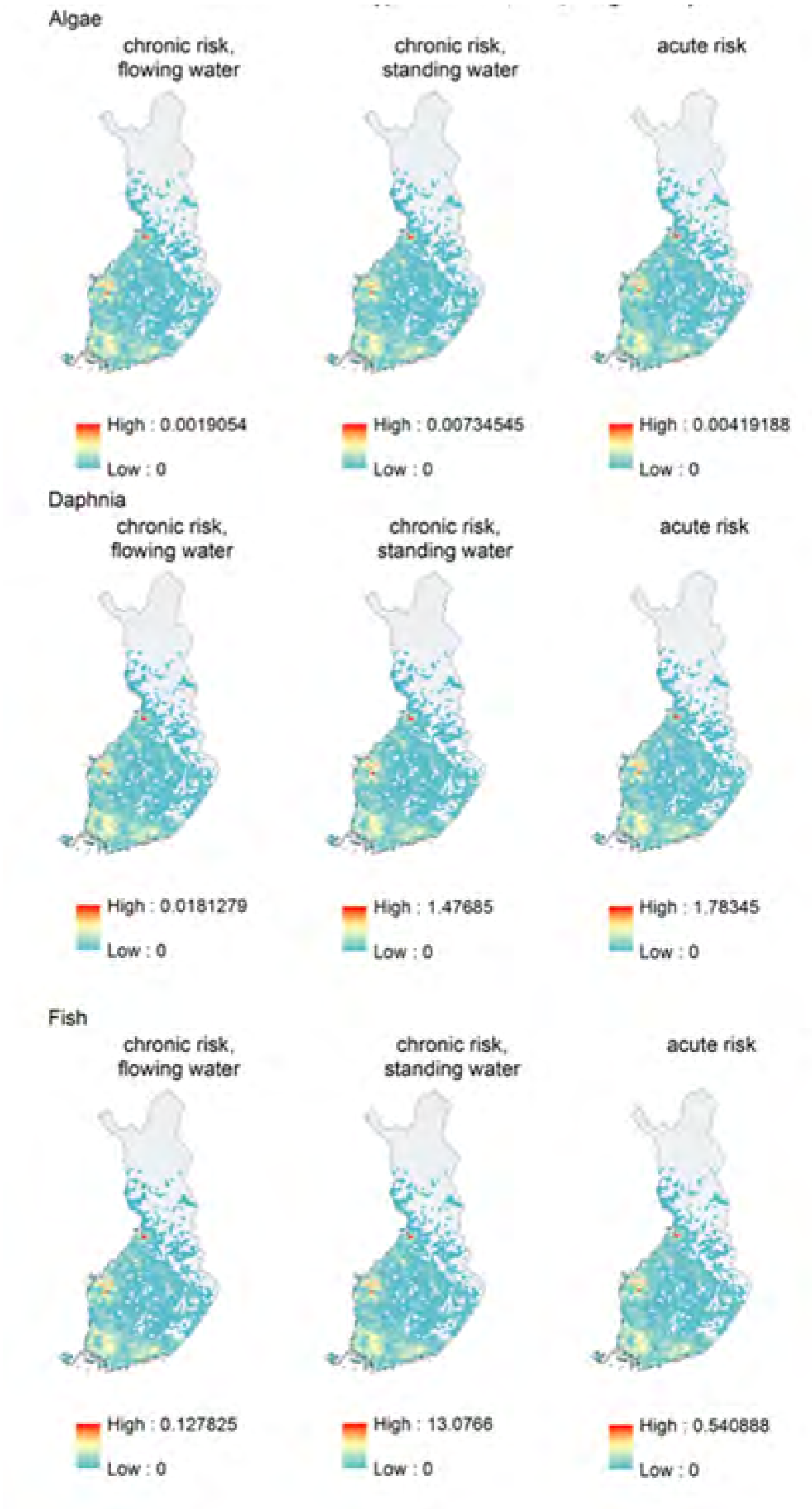

Figure B4. Risks for recommended α-cypermethrin use weighted by the area treated (ETR*). The risk for groundwater was 0.
*ETR = Exposure Toxicity Ratio

Table C1. Aggregated regional risks (ETR*) for MCPA use calculated by HAIR2010. The results are presented with two significant digits. For acute risk, the risk value in both standing and flowing conditions is the same.

	Algae			**Daphnia**			**Fish**			**Ground water**
	Acute	**Chronic**		**Acute**	**Chronic**		**Acute**	**Chronic**		
		Standing	**Flowing**		**Standing**	**Flowing**		**Standing**	**Flowing**	
Uusimaa	0.51	0.33	0.09	0.22	0.30	0.0042	0.84	1.0	0.01	760
Southwest Finland	0.72	0.47	0.13	0.31	0.43	0.0060	1.18	1.4	0.02	540
Satakunta	0.91	0.59	0.16	0.39	0.54	0.0075	1.48	1.8	0.02	14
Häme	0.48	0.31	0.08	0.21	0.28	0.0040	0.78	0.94	0.01	76
Pirkanmaa	0.93	0.61	0.16	0.40	0.55	0.0077	1.53	1.8	0.02	83
South-east Finland	0.46	0.30	0.08	0.20	0.27	0.0038	0.76	0.90	0.01	190
South Savo	0.17	0.11	0.03	0.074	0.10	0.0014	0.28	0.33	0.00	4.0
North Savo	0.33	0.21	0.06	0.14	0.19	0.0027	0.53	0.63	0.01	4.5
North Karelia	0.17	0.11	0.03	0.073	0.099	0.0014	0.28	0.33	0.00	16
Central Finland	0.27	0.18	0.05	0.12	0.16	0.0023	0.45	0.53	0.01	9.3
South Ostrobothnia	1.7	1.09	0.29	0.71	0.99	0.014	2.71	3.3	0.04	0
Ostrobothnia	0.62	0.41	0.11	0.27	0.37	0.0052	1.02	1.2	0.01	0.0000070
North Ostrobothnia	0.93	0.61	0.16	0.40	0.54	0.0077	1.51	1.8	0.02	0.20
Kainuu	0.0038	0.00	0.00	0.0017	0.0022	0.000032	0.01	0.0074	0.00	0.043
Total	8.2	5.35	1.43	3.5	4.8	0.068	13.34	16	0.19	1700

*ETR = Exposure Toxicity Ratio

Table C2. Aggregated regional risks (ETR*) for glyphosate use calculated by HAIR2010. The results are presented with two significant digits. For acute risk, the risk value in both standing and flowing conditions is the same. The risk for groundwater was 0.

	Algae			Daphnia			Fish		
	Acute	Chronic		Acute	Chronic		Acute	Chronic	
		Standing	Flowing		Standing	Flowing		Standing	Flowing
Uusimaa	47	0.64	0.17	0.72	1.1	0.014	0.017	0.93	0.0092
Southwest Finland	59	0.80	0.21	0.90	1.4	0.018	0.021	1.1	0.012
Satakunta	92	1.3	0.33	1.4	2.2	0.028	0.033	1.8	0.018
Häme	55	0.76	0.20	0.85	1.3	0.017	0.020	1.1	0.011
Pirkanmaa	70	0.96	0.25	1.1	1.7	0.021	0.025	1.4	0.014
Southeast Finland	24	0.32	0.084	0.36	0.57	0.0071	0.0084	0.47	0.0046
South Savo	16	0.22	0.057	0.24	0.38	0.0048	0.0057	0.30	0.0031
North Savo	14	0.19	0.050	0.21	0.34	0.0042	0.0050	0.27	0.0027
North Karelia	5.2	0.071	0.019	0.080	0.13	0.0016	0.0019	0.11	0.0010
Central Finland	38	0.52	0.14	0.59	0.93	0.012	0.014	0.76	0.0075
South Ostrobothnia	37	0.50	0.13	0.56	0.88	0.011	0.013	0.72	0.0072
Ostrobothnia	24	0.33	0.087	0.37	0.59	0.0073	0.0087	0.48	0.0048
North Ostrobothnia	78	1.1	0.28	1.2	1.9	0.023	0.028	1.6	0.015
Kainuu	1.7	0.024	0.0061	0.026	0.044	0.00051	0.00061	0.036	0.00033
Total	560	7.7	2.0	8.6	14	0.17	0.20	11	0.11

*ETR = Exposure Toxicity Ratio

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