Environmental and Health Impacts of Pesticides and Fertilizers and Ways of Minimizing Them: Envisioning a chemical-safe world

Annexes to Chapter 4.3 – Adverse environmental effects of pesticide use

Contents

Annex 4.3-1 Recent reviews of pesticide concentrations in surface water bodies and their risks to aquatic life

Included are reviews published between 2010 and 2020

Region (coverage)	**Monitoring (or publication) period**	**Extent of review**	**Pesticides**	**Outcomes**	**Reference**
Global					
Global	2012 – 2019 (publication)	Not specified	No specified	– Most detected herbicides in surface water were atrazine and its metabolites, metolachlor – Most detected insecticide was chlorpyrifos – Mist detected fungicides were carbendazim, tebuconazole	De Souza *et al.* 2020
Global (73 countries)	1960 – 2011	838 studies with 11,300 measured concentrations	28 insecticides	– in 97% of the cases, no insecticides were measured in the samples – 52% of measured insecticide concentrations exceeded regulatory thresholds from the USA and/or the EU, and on 69% of the sampled sites – Median concentrations of neonicotinoids exceeded those of organochlorines and organophosphates by a factor of about 3, and of pyrethroids by a factor 10 – Most insecticide concentration monitoring data for surface waters were available from North America, Asia and Europe – No monitoring of surface water exposure by insecticides exist for about 90% of high-intensity agricultural areas of the world – Highest insecticide concentrations were detected in Africa, Asia and South America	Stehle & Schulz 2015 Stehle *et al.* 2018
Global (11 countries)	2010 – 2016 (publication)	31 studies	Neonicotinoids	– Geometric mean for average concentrations = 0.13 µg/L – Geometric mean for peak concentrations = 0.63 µg/L – 74% of measured average concentrations exceeded ecological thresholds – 81% of measured peak concentrations exceeded ecological thresholds – Average neonicotinoid residues in surface waters increased over past 15 years	Morrissey *et al.* (2015) Sánchez-Bayo *et al.* (2016)
Global (15 countries)	1986 – 2017 (publication)	176 papers	Pyrethroids	– Pyrethroid concentrations in surface water worldwide ranged from not detected to 13,000 µg/L – High concentrations of pyrethroids are found across all global regions; no geographical hot spots – No risk assessment conducted	Tang *et al.* 2018

Region (coverage)	Monitoring (or publication) period	Extent of review	Pesticides	Outcomes	Reference
Regional					
Europe (34 countries)	2007 – 2017	Monitoring data from the Waterbase – Water Quality Database	180 pesticides	– Assessed were the exceedance rates of European aquatic environmental quality standards – 5–15% of European surface water monitoring stations showed exceedances by herbicides; 3–8 % of stations by insecticides; exceedances of fungicides were less prevalent	Mohaupt *et al.* 2020
Africa	2000–2018 (publication)	Not reported	Organochlorines Current use pesticides	– Concentrations of pesticides reported in African surface waters range from 0.06 ng/L to 69 µg/L (insecticides), 0.2 ng/L to 14 µg/L (herbicides), and 0.1 ng/L to 9 µg/L (fungicides) – Highest concentrations reported for chlorpyrifos, chlorpyrifos-ethyl, malathion, diazinon, endosulfan, DDT and spiroxamine	K'oroje *et al.* 2020
Africa	2000 – 2018 (publication)	22 studies from 7 African countries	Organochlorines	– Average values in surface waters: Σ-DDT = 1271 ± 1721 µg/L; dieldrin = 793 ± 1760 µg/L; aldrin = 384 ± 1043 µg/L; Σ-HCH = 159 ± 368 µg/L; HBC = 77± 104 µg/L; methoxychlor = 49 ± 85 µg/L – OCP concentration were many times higher than levels in other parts of the world where OCPs were still used during the same period (e.g. Japan, China, Iran, India and Mexico)	Taiwo 2019
Caribbean and Pacific	1997 – 2001	33 samples from marine surface slicks	Organochlorine pesticides (OCPs)	– OCPs detected in 31 out of 33 samples – Concentrations observed were below commonly accepted toxic levels to animals and humans – Traces of OCPs were observed in areas far away from human habitation	Menzies *et al.* 2013
Europe (91 river basins across the continent)	2006 – 2010	4,001 monitoring sites	223 organic chemicals, including 98 pesticides	– 14% of the monitoring sites were likely to be acutely affected by organic chemicals and 42% likely to be chronically affected – Pesticides were responsible for 81%, 97% and 96% of the observed exceedances of acute risk thresholds for fish, invertebrates and algae respectively	Malaj *et al.* 2014
South Asia	1988 – 2011	13 studies from 3 countries	Organochlorine pesticides (OCPs)	– All studies reported 1 or more OCPs in surface water at concentrations above detection levels – Ranges of concentrations detected : Σ-DDT = non detectable (ND) – 400 µg/L; Σ-HCH = ND – 75 µg/L; endosulfan = ND – 66 µg/L	Ali *et al.* 2014

Region (coverage)	Monitoring (or publication) period	Extent of review	Pesticides	Outcomes	Reference
National (selected country-wide or review studies)					
Brazil	Up to December 2015 (publication)	17 studies	43 current use pesticides	– Pesticides were detected in 14% of the samples in concentrations above the LOQ of the analytical method used – From the 43 pesticides investigated, 34 were quantified at least once – Freshwater water quality criteria (WQC) for the protection aquatic life were compiled from the literature for 31 of the 34 pesticides – A potential risk to aquatic life was identified for 59% of the pesticides with the occurrence data in Brazil – This review only encompasses 43 compounds, which are 11% of the pesticides approved in Brazil for agricultural use	Albuquerque *et al.* 2016
China	1995 – 2013 (publication)	National review: 30 studies for surface water 51 studies for sediment	Mainly organochlorine pesticides (OCPs); some current use pesticides	– Risk assessments only conducted for Σ-DDT and lindane, based on Norwegian quality criteria for sediment and surface water – Quality criteria for Σ-DDT in surface water: 13% of all cases = good, 22% = bad, 4% = very bad – Quality criteria for Σ-DDT in sediment: 58% of all cases = good, 3% = bad, 3% = very bad – Quality criteria for lindane in surface water: 73% of all cases = good, 16% = bad, 5% = very bad – Quality criteria for lindane in sediment: 54% of all cases = good, 10% = bad, 10% = very bad	Grung *et al*. 2015
China	2013	26 surface water and sediment sampling locations in the Yellow River estuary	Organochlorine pesticides (OCPs)	– Σ-HCH was detected in all surface water and sediment samples; and Σ-DDT in all surface water and 96% of sediment samples – Mean concentration of Σ-HCH in surface water = 19 µg/L and in sediment = 20 µg/L; Σ-DDT in surface water = 10 µg/L and in sediment = 7 µg/L – No environmental risk assessment	Li *et al.* 2015
China	2016	96 samples from 16 rivers in eastern China	9 neonicotinoid insecticides	– Average concentrations of the 9 neonicotinoids combined were 343 ng/L during the dry season, and 174 ng/L during the wet season – 27% of river water samples exceeded the thresholds for acute ecological risks – 84% of river water samples exceeded the thresholds for chronic ecological risks – Contamination levels were higher than those found in the USA and Japan	Chen *et al.* 2019

Region (coverage)	**Monitoring (or publication) period**	**Extent of review**	**Pesticides**	**Outcomes**	**Reference**
Egypt	2013	60 samples from 20 sampling sites along the River Nile	Organochlorine pesticides (OCPs) & organophosphate (OP) pesticides	– Organochlorine pesticides detected were dieldrin, endrin, p,p'-DDE, p,p'- DDD and p,p'-DDT – organophosphorus pesticides detected were triazophos, ethoprophos, quinalphos, chlorpyrifos, fenitrothion, ethion, fenamiphos and pirimiphos-methyl – dieldrin and p,p'-DDT residues in some sampling sites exceeded drinking water guidelines of WHO	Dashan *et al.* 2016
Ethiopia	2015	46 sediment samples from 1 river basin	16 organochlorine pesticides (OCPs)	– All samples contained measured concentrations of at least 1 OCP – Total concentrations of OCPs, ranged from 6.63 to 206.13 ng/g dry weight (dw) – Heptachlor, heptachlor epoxide, p,p'-DDT and β-HCH) had highest concentrations – Adverse ecological effects were expected to occur mainly due to p,p'-DDT and γ-HCH	Dirbaba *et al*. 2018
Ghana	2001 – 2016 (publication)	8 studies	Organochlorine pesticides (OCPs)	– Range of OCP concentrations in surface water = from below limit of detection – 6350 ng/L – Concentrations in surface water of Σ-DDT and Σ-endosulfan showed significant increase from 2004 – 2012; concentrations of Σ-HCH did not – No aquatic risk assessment conducted	Bruce-Vanderpuije *et al.* 2019
Hungary	1990 – 2015	National monitoring programme	49 pesticides and degradation products	– Pesticide residues detected in 32 – 61% of samples – Main surface water contaminants were triazines (atrazine, propisochlor), chloroacetamides (acetochlor, metolachlor), and phenoxycarboxylic acids (2,4-D, MCPA) during the late 90s, followed by triazines (atrazine, prometryn, and diazinon) and chloroacetamides (acetochlor) after the turn of the millennium, while glyphosate and neonicotinoids were more frequently detected in latter years of the programme	Székács *et al.* 2015
India	1990 – 2014	14 studies	organochlorine pesticides (OCPs)	– Surface water bodies throughout India – Σ-DDT = not detected (ND) – 6121 ng/L; Σ-HCH = ND – 4911; endosulfan = ND – 130 ng/L	Yadav *et al.* 2015
Italy	1997 – 2013 (publication)	10 studies	137 pesticides	– 54.3% of reported maximum pesticides concentrations in surface water were above the environmental quality standards – Pesticides considered to represent the most severe threat for the Italian water resources were AMPA (glyphosate metabolite), terbuthylazine, diuron, 2,4-DB, 2,4-D, terbutryne, malathion, metolachlor, pendimethalin and linuron.	Meffe & de Bustamente 2014

Region (coverage)	**Monitoring (or publication) period**	**Extent of review**	**Pesticides**	**Outcomes**	**Reference**
Japan	1987 – 2016	34 samples from 11 rivers	9 organophosporous pesticides	– High risks for aquatic organisms = 56% of cases – Low risk for aquatic organisms = 18% of cases – Diazinon and fenitrothion pose highest risks to aquatic environments	Derbalah *et al.* 2019
The Netherlands	2013 – 2018	96 sampling locations	Plant protection products	– Exceedance of national surface water quality criteria (chronic exposure) declined between 2013 to 2015 with 15% for chronic exposure and with 30% for acute exposure – Number of sampling locations with exceedances by at least one pesticide did not significantly decline	PBL 2019
Romania	2016	19 streams	244 pesticides and metabolites	– Up to 50 pesticides were detected simultaneously, resulting in sum concentrations between 0.02 and 37 µg/L – Streams in low intensity agriculture, despite a minor reported use of agrochemicals, exhibited similar levels of pesticide pollution as in regions of high intensity agriculture – The sum concentration as well as the toxicities were in a similar range as in high intensity agricultural streams of Western Europe	Schreiner *et al.* 2021
South Africa	1977 – 2011	41 studies	OCPs and current use pesticides	– Even more recent studies focus primarily on OCPs – Widespread occurrences of OCPs with some banned organochlorine residues still present in the aquatic environment – Atrazine frequently detected in surface waters	Ansara-Ross *et al.* 2012
Sudan	2004 – 2005	27 samples from 3 locations	22 pesticides	– Organochlorines detected in 70% of samples, pyrethroids in in 15% of samples, herbicides in 4% of samples, organophosphates not detected – Highest pesticide concentrations ranges for: Σ-heptachlor = non-detected (ND) – 1123 ng/L; Σ-DDT = ND – 427 ng/L; cypermethrin = ND – 630 ng/L; fenvalerate = ND – 600 ng/L; pendimethalin = ND – 1060 ng/L – Pesticide concentration appear to be lower and less frequently detected than in earlier studies in the Nile	Nesser *et al.* 2016
Switzerland	2005 – 2012	345,000 samples	60 pesticides	– 27% of evaluated pesticides showed exceedance of national regulatory acceptable concentrations (RACs) at 1 or more sampling sites – 95% of measured concentrations (including non-detections) of all pesticides were below their respective RACs – Exceedance of RACs occurred in small to medium surface waters, surrounded by vineyards – Mainly herbicides and fungicides exceeded RACs	Knauer 2016

Region (coverage)	**Monitoring (or publication) period**	**Extent of review**	**Pesticides**	**Outcomes**	**Reference**
Tanzania	2003 – 2014 (publication)	5 studies	Mainly organochlorine pesticides (OCPs)	– Up to 7 OCPs measured in surface waters above detection levels in individual studies – No risk assessment	Elibariki *et al*. 2017
USA	1962 – 2017	259 studies with 5817 measured concentration covering 644 sampling sites	32 insecticides and 6 degradation products	– 49% of measured pesticide concentrations exceeded US regulatory threshold levels – 70% of sampling sites experienced at least one exceedance of a US regulatory threshold level – Exceedance rate of pyrethroids = 81%; organophosphates & carbamates = 42%, organochlorines = 33%; neonicotinoids = 22%; phenylpyrazoles = 25% – Overall exceedance rate 1960–2001 = 49%; 2002–2015 = 49%	Wolfram *et al.* 2018

USA	1992 – 2011	USGS – National Water Quality Assessment database, covering 182 sites (1992–2001) and 96 sites (2002–2011)	47 pesticides (1992–2001)
			123 pesticides (USA2002–2011)
				– Exceedance rates of US chronic aquatic-life benchmark levels (2002–2011)
				  – Agricultural streams/rivers: 69%
				  – Urban streams/rivers: 90%
				  – Mixed streams/rivers: 46%
				– Exceedance rates did not significantly change from 1992–2001 to 2002–2011 for agricultural and mixed streams; they increased considerably for urban streams
				– Upward and downward trends in pesticide concentrations to large extent reflect changes in their use patterns
					Stone *et al.* 2014

USA	2012 – 2014	38 streams in 24 US states; 149 samples	6 neonicotinoids insecticides	– At least 1 neonicotinoid detected in 53% of the sampled sites – 2 or more neonicotinoids in 26% of samples – 8% of samples with detectable concentrations were >100 ng/L – No risk assessment conducted	Hladik & Kolpin 2016

Annex 4.3-2 Recent reviews and studies of pesticide concentrations in ambient air.

Included are reviews published between 2010 and 2020

Region (coverage)	**Monitoring (or publication) period**	**Extent of review/study**	**Pesticides**	**Outcomes**	**Reference**
Global					
Global	2000 – 2015	Baseline data and time trends for 5 regions of the world.	12 organochlorine pesticides and their metabolites	– Long time series monitoring data of legacy POPs in air are available from Asia, Central and Eastern Europe and Western Europe and Others Group, while information on changes in concentrations over time is very limited in Africa, the Pacific and in Latin American and Caribbean Group – Information on changes over time in concentrations of the newly listed POPs is still limited – Overall, concentrations of POPs measured in air have largely decreased. The steep decrease in air concentrations of legacy POPs such as organochlorine pesticide) seems to have followed their early regulation in the 1980s – By 2000, the majority of primary sources had been controlled and the relatively low levels that are currently measured do not show significant changes and are driven by secondary sources and, for some compounds, emissions from stockpiles/waste management practices	UNEP 2017
Global (9 countries)	2011 – 2014	34 studies covering 475 cases (=pesticide-study combinations)	150 pesticide active ingredients and metabolites	– Most studies conducted on herbicides and insecticides, in Canada, USA, France, Spain and China; no studies conducted in low or lower-middle income countries – Organochlorine pesticides and metabolites represented 27% of cases – The more frequently detected CUPs worldwide are the fungicides chlorothalonil and folpet, and the insecticides chlorpyrifos, dimethoate, malathion and phosmet, with average concentrations ranging from 0.01 to 11.6 ng/m^3 – Inhalation exposure of CUPs in the general population does not represent a significant concern, except in some cases for chlorpyrifos. The combined risk resulting from exposure to OP, pyrethroid and carbamate pesticides was also considered to be acceptable	Coscollà & Yusà 2016

Region (coverage)	**Monitoring (or publication) period**	**Extent of review/study**	**Pesticides**	**Outcomes**	**Reference**
Global	1988 – 2008	16 studies on air concentrations in developing and developed countries	DDTs	– Most data from the 1990s – DDTs in ambient air is compiled from Congo, Malawi and Zimbabwe in Africa; southern Mexico, the Brazilian mountains and Costa Rica in Latin America; and India, Vietnam, Thailand and the Solomon Islands in S-SE Asia. – Concentrations of DDTs a factor 10-100 higher in tropical (generally developing) than in temperate (generally industrialised) countries – Most of the developing countries described in this review are located in the tropical regions where climatic conditions favour dissipation of DDT and other chlorinated pesticides – Continuing use of DDT in indoor residual spraying programs in some parts of the region and emissions from old pesticide storage areas may be attributed to the higher DDTs levels in the developing regions	Mochungong & Zhu 2015
Global	2005 - 2008	34 – 46 sampling sites on all continents	OCPs: HCHs, HCB, chlordanes, heptachlor, aldrin, dieldrin, endrin, DDTs, and metabolites CUPs: endosulfans, trifluralin, chlorothalonil, dacthal, pendimethalin	– Organochlorine pesticides such as a- and g-hexachlorocyclohexane, endosulfans, DDT and its metabolites, and chlordane-related compounds tend to be more prevalent in developing countries, especially in Asia – Current use pesticides such as trifluralin and chlorothalonil showed higher levels in Europe and North America – Levels of hexachlorobenzene, hexachlorocyclohexanes and chlordanes decline in most world regions; levels of organochlorine pesticides in India, however, remained exceptionally high – The CUPs, including endosulfans, did not display clear trends over the four years of sampling, except that the levels of α-endosulfan and chlorothalonil were decreasing in the European atmosphere	Shunthirasingham *et al.* 2010
Regional					
East Asia to the High Arctic Ocean	2010	17 air samples on a latitudinal transect from the East China Sea to the high Arctic (33.23–84.5° N).	6 current-use pesticides (CUPs): trifluralin, endosulfan, chlorothalonil, chlorpyrifos, dacthal (DCPA) and dicofol.	– In all oceanic air samples, the six CUPs were detected, showing highest level (>100 pg/m3) in the Sea of Japan – Gaseous CUPs decreased from East Asia (between 36.6 and 45.1° N) toward Bering and Chukchi Seas	Zhong *et al.* 2012

Region (coverage)	**Monitoring (or publication) period**	**Extent of review/study**	**Pesticides**	**Outcomes**	**Reference**
Arctic, Antarctica, Tibetan Plateau	1990 – 2014 (review)	66 reviews for the Arctic, 2 reviews for the Antarctic, 1 review Tibetan Plateau	Organochlorine pesticides (OCPs)	– Concentrations of chemicals in the Antarctic are generally lower than those of the Arctic; similar concentration ranges of HCB, α-HCH, γ-HCH and α-endosulfan are apparent between the Arctic and Tibetan Plateau; – Atmospheric concentrations of most OCPs in the Arctic, Antarctic and Tibetan Plateau do not show consistent downward trends over the review period (Tables S1, S2 & S3 of the supplementary materials)	Wang *et al.* 2019
Alps	2005 – 2013	3 high Alpine stations in Austria, Germany & Switzerland	Organochlorine pesticides (OCPs)	– OCP concentrations were significantly lower than those in regions adjacent to greater emission sources in other continents (e.g., China, South America) but higher than those in the Arctic – Temporal trend of the single compounds was evaluated: The majority of OCPs did not increase during 2005–2013, but a statistically significant decline was detected during 2006–2013 only for endosulfan and α-HCH	Kirchner *et al.* 2016
West Africa (Togo, Benin, Nigeria, and Cameroon)	2012	25 OCPs 7 sampling sites	Organochlorine pesticides (OCPs)	– High atmospheric concentrations of HCHs and DDTs were found, at average concentrations of 441 pg m^{-3} (range 23–2718) and 403 pg m^{-3} (range 91–1880), respectively – Mirex had the lowest concentrations, ranging between 0.1 and 3.3 pg m^{-3} – There was significant evidence, based on chemical signatures of the contamination that DDT, aldrin, chlordane and endosulfan were recently applied at certain sites	Isogai *et al.* 2016
South Asia	(1987 – 2013; review)	7 research papers	Organochlorine pesticides (OCPs)	– Ambient air concentrations of HCHs ranged from 0.3 to 1690 pg m^{-3}, and from 0.3 – 2900 pg m^{-3} for DDTs – Highly populated and agricultural areas along the India coast were found contaminated with higher levels of OCPs, possibly originating from fresh use of DDT for vector control and agricultural purposes – Elevated concentrations of γ-HCH and HCB also indicated recent use of these pesticides	Ali *et al.* 2014

Region (coverage)	**Monitoring (or publication) period**	**Extent of review/study**	**Pesticides**	**Outcomes**	**Reference**
Arctic	(2008 – 2013; review)	Air and ice cores	Current-use pesticides (CUPs) Organochlorine pesticides (OCPs)	– Ambient air concentrations compiled from reviewed studies: o Dacthal: 0.02 – 0.1 pg/m^3 o Trifluralin: < LOD – 1.95 pg/m^3 o Chlorothalonil: 0.1 – 2.1 pg/m^3 o Chlorpyrifos: 0.5 – 2.0 pg/m^3 o Endosulfan: α-endosulfan = 0.4 - 130 pg/m^3 ; β-endosulfan: < LOD o Methoxychlor: < 0.003 pg/m3 o Dicofol: 0.9 – 2.5 pg/m3 – The time trends derived from ice cores show increasing concentrations for chlorpyrifos, endosulfan and trifluralin	Vorkamp & Rigét 2014
Latin America and Caribbean	2014 – 2015 for emerging POPs 2005 – 2015 for other OCPs	9 sampling sites in 7 countries	27 OCPs, including emerging POPs: pentachloroanisole (PCA) and dicofol	– PCA had elevated concentrations at an urban site in Chile (49-222 pg/m^3) and concentrations ranging <1-8.5 pg/m^3 at the other sites in this study – Dicofol indicators were detected at the agricultural site of Sonora (Mexico) at concentrations ranging 30-117 pg/m^3 – Atmospheric concentrations of ɣ-HCH and the endosulfans significantly decreased in this region from 2005 to 2015 – Concentrations of the chlordanes, DDT and PCBs remained similar from 2005 to 2015, suggesting implemented restrictions have not yet led to decreases in atmospheric levels in this region after	Rauert *et al.* 2018
National (selected studies)					
West Antarctica	2010 – 2018	Seven sampling sites in one location	25 organochlorine pesticides (OCPs), congeners and metabolites	– HCB, HCHs, DDTs and endosulfans were detected in most air samples, while chlordane (cis- and trans-), nonachlor (cis- and trans-), oxychlordane, heptachlor, heptachlor epoxide (cis- and trans-), aldrin, dieldrin, endrin, and mirex were not detectable in over 90% atmospheric samples in this study – Relatively low concentrations organochlorine pesticides (OCPs) (Σ13OCPs: 101-278 pg/m3) were found in the atmosphere of West Antarctica – The concentrations of HCHs, DDTs and endosulfans were found to show decreasing temporal trends over the period 2011 – 2017; HCB concentrations remained stable – The atmospheric half-life values for HCHs, DDTs and endosulfans in Antarctic air were estimated as 2.0, 2.4 and 1.2 years, respectively – Long-range atmospheric transport was considered to be the main contributing factor to the atmospheric levels of the POPs in West Antarctica	Hao *et al.* 2019

Region (coverage)	**Monitoring (or publication) period**	**Extent of review/study**	**Pesticides**	**Outcomes**	**Reference**
Brazil	2013-2015 (and comparison with 2008 data)	Two Conservation Unit sites in the Rio de Janeiro state	Current use pesticides (CUPs) and Organochlorine pesticides (OCPs)	– Atmospheric concentrations of legacy OCPs showed background air levels – Endosulfan concentrations decreased between 2008 and 2015 (max concentrations 5500 pg m^{-3} and 2000 pg m^{-3} respectively) – Chlorpyrifos concentrations increased over the same period (max concentrations 40 and 165 pg m^{-3},respectively)	Guida *et al.* 2018

Annex 4.3-3 Recent reviews of pesticide concentrations in soils and their risks to soil organisms

Included are reviews published between 2010 and 2021

Region (coverage)	**Monitoring (or publication) period**	**Extent of review**	**Pesticides**	**Outcomes**	**Reference**
Global					
Global	1993 – 2012 (publication)	73 journal publications, globally	p,p’-DDT, p,p’-DDE, HCB, α-, β-, and γ-HCH	– OCP concentrations from agricultural and background land were evaluated – For the period 2003 – 2012 and for all chemicals, the mean concentration in agricultural soil is significantly higher than the concentration in background soil – A decrease in the global mean concentration is discernible for p,p’-DDT and p,p’-DDE from the first to the second decade, but it is statistically significant only for p,p’-DDT in agricultural soil – The mean concentration of HCB in agricultural soil and in background soil does not significantly decrease from the first to the second decade – The 3 HCH isomers decrease in background soils, but not in agricultural soils, from decade 1 to decade 2 – The expected decrease in concentrations of p,p’-DDT and a-HCH in both agricultural and background soil, based on emission modelling, is not supported by measurements. The possibility of new and/or illegal emissions must be kept in mind	Camenzuli *et al.* 2016
Global	2013 – 2017 (publication)	7 studies in 4 countries	Neonicotinoid insecticides	– The current body of evidence shows that detectable levels of neonicotinoids are found in agricultural soils over a year after treated seeds were planted – Neonicotinoids known not to have been recently used can still be present in soils several years after the last application date – Neonicotinoids do not continue to accumulate indefinitely but instead plateau after 2–6 years of repeated application – The studies show that overall, annual sowing of neonicotinoid-treated seed results in chronic levels of soil contamination in the range of 3.5–13.3 ng/g for clothianidin and 0.4–4.0 ng/g for thiamethoxam. This which will act as a constant source of exposure for soil-dwelling organisms, and for neonicotinoid transport into the wider environment	Wood & Goulson 2017

Region (coverage)	**Monitoring (or publication) period**	**Extent of review**	**Pesticides**	**Outcomes**	**Reference**
Global	n.a.	Global review	Fungicides in vineyard soils	– Copper originating from the intensive application of Cu-based fungicides belongs to the most important contaminants of vineyard soils – Concentrations exceed European legislative limits in the majority of the studied vineyards – The intensive application of synthetic organic fungicides has led to increased concentrations of these chemicals in vineyard soils	Komárek *et al.* 2010
Polar regions	1998 – 2015	Review of publications about the Arctic, Antarctic, Tibetan Plateau	DDTs, HCHs, HCB	– Recent ΣHCH concentrations range from n.d. to 5700 pg/g – Recent ΣDDT concentrations range from 20 to 1200 pg/g – Recent HCB concentrations range from 20 – 1500 pg/g – Soil in cold regions are considered as sinks of POPs	Wang *et al*. 2019
Regional					
Europe	2015	317 agricultural topsoil samples from 11 EU Member States and 6 main cropping systems	76 pesticides	– Pesticide residues were present in 83% of the tested soils and 58% of the soils contained multiple residues – Glyphosate and its metabolite AMPA, DDTs and the broad-spectrum fungicides boscalid, epoxiconazole and tebuconazole were most frequently found and the at the highest concentrations – Maximum individual pesticide content was 2.05 mg/kg while maximum total pesticide content was 2.87 mg/kg – Risks to standard soil organisms did generally not exceed acceptable levels. – The presence of mixtures of pesticide residues in soils are the rule rather than the exception	Silva *et al.* 2019
National (selected studies)					
China	Review of papers published since 2000	agricultural soils	OCPs	– OCPs have been widely detected in agricultural soils throughout China – Total concentrations of OCPs ranged from <LOD (limit of detection) to 3520 ng/g, with a mean of 59±53 ng/g – p,p’-DDE exhibited the highest concentration (mean of 15 ± 21 ng/g, n = 66), followed by p,p’-DDT (mean: 13 ± 16 ng/g, n = 66) and chlordane (mean: 8.4 ± 27 ng/g, n = 15). – Most of the concentrations were considered safe under Chinese environmental legislation, though some exceeded acceptable levels – Concentrations of OCPs in almost all recent studies are lower than those that were identified decades ago, indicating that the residues of OCPs have decreased significantly after they were banned for agricultural uses	Sun *et al.* 2018

Region (coverage)	**Monitoring (or publication) period**	**Extent of review**	**Pesticides**	**Outcomes**	**Reference**
China	n.a.	241 agricultural soil sites, across the Yangtze River Delta	9 organo-phosphates	– OPs were present in 93% of samples – Total concentrations of the 9 OPs ranged from <3.0 to 521 ng/g dry weight, with a mean of 64.7 ng/g dry weight – Dimethoate was most detected, followed by methyl-parathion and parathion – There was no significant difference in microbial communities among the sample sites, indicating that OPPs in these soils do not cause significant effects on microbiota	Pan *et al.* 2018
Czech republic	2015	75 arable soils	53 CUPs and 15 transformation products	– Arable soils were found to frequently contain multiple residues of pesticides at noticeable levels several months following the last possible application – In 99% of the soil samples, at least one pesticide was present > LOQ – In 81%, at least one pesticide was present at ≥0.01 mg/kg, the generic soil limit for individual non-chlorinated pesticides in the Czech Republic – The soils contained multiple pesticide residues frequently (51% soils with ≥5 pesticides) – Most frequent detections were of triazine herbicides (89% of soils) and conazole fungicides (73% of soils)	Hvězdová *et al.* 2018
Ghana	2014 – 2015	32 samples from cocoa farms	15 OCPs and metabolites	– 4 OCPs were detected: o Lindane in 31.3 % of the soil samples, at a mean concentration of 0.04 ± 0.01 mg/kg o beta-HCH in 26.6 % of samples, at a mean concentration of 0.03 ± 0.01 mg/kg o dieldrin in 62.5 % of samples, at a mean concentration of 0.02 ± 0.00 mg/kg o p,p′-DDT in 50 % of samples, at a mean concentration of 0.03 ± 0.01 mg/kg – Concentrations of OCPs recorded in the soil samples were generally below their respective US MRLs for agricultural soils – The authors conclude that the occurrence of OCP residues in soil may be attributed to the illegal use of the pesticides by farmers or due to their historic use, since OCPs are prohibited from agricultural use in Ghana	Fosu-Mensah *et al.* 2016

Region (coverage)	**Monitoring (or publication) period**	**Extent of review**	**Pesticides**	**Outcomes**	**Reference**
France	2016	180 soil samples from winter cereal crops, grasslands, hedgerows, some of which were untreated or under organic farming. 155 samples of earth-worms (*Allolobophora Chlorotica*) from the same locations.	31 CUPs analyzed (9 insecticides, 10 fungicides, 12 herbicides	– 27 pesticides detected – All the soils contained at least one CUP; 83% ≥ 5 CUPs; and 38% ≥ 10 – The herbicide diflufenican, the insecticide imidacloprid, and the fungicides boscalid and epoxiconazole were most frequently detected – 92% of earthworms contained at least one of the pesticides, and 34% ≥ 5 pesticides. – The long-term, plateau, predicted environmental concentrations in soils (PECs), as defined in EU risk assessment, were exceeded for 11 pesticides (in 94% of samples) – A high risk of chronic toxicity to earthworms was found in 46 % of samples, both in treated cereals and nontreated habitats considered as refuges	Pelosi *et al.* 2021
French West Indies (Guadeloupe)	2003 – 2009	Soil samples from 1045 plots from (former) banana plantations.	Chlordecone; applied between 1972 and 1993	– Chlordecone concentrations ranged from 0.011–52.1 mg/kg of dry soil – 8% of plots contained <0.1 mg chlordecone/kg soil; i.e. the threshold below which no MRL exceedance in subsequent root crops is expected – 34% of plots contained > 1.8 mg chlordecone /kg soil; i.e. the threshold above which almost all subsequent root crops are expected to exceed the MRL – High chlordecone residues in soil were thus present 10 to 35 years after its application	Levillain *et al.* 2012
India (Assam region)	2009	175 surface soil samples from agricultural fields, fallow and urban lands	14 OCPs and metabolites	– Mean concentrations of total HCHs ranged from 705 – 825 ng/g and of total DDTs from 757 – 903 ng/g – Residue levels were among the highest found so far in India; soils from paddy fields contained most HCH and DDT residues – DDT and HCH soil residues originated both from the long past as well as from recent sources (vector control and agricultural use)	Mishra *et al.* 2012
Kazakhstan, Poland	2012 - 2014	Poland (89 samples), Kazakhstan (32 samples)	OCPs	– DDT, DDE and HCHs were detected in 20 – 50% of soil samples – Average total concentrations of DDT in Polish and Kazakh soil samples were 0.104 and 0.097 mg/kg respectively – The authors conclude that, even though concentrations were relatively low, OCPs continue to be a ubiquitous contaminant in soils	Łozowicka *et al.* 2016

Region (coverage)	**Monitoring (or publication) period**	**Extent of review**	**Pesticides**	**Outcomes**	**Reference**
Nepal	2017	147 soil samples from agricultural land	12 CUPs and degradation products & 8 OCPs	– Pesticides were detected in 60% of the soil samples (25% had a single residue, 35% had multiple residues) – Overall, the concentration of pesticides ranged from 1.0 to 251 µg/kg, with a mean of 16 µg/kg – Residues of dichlorvos, dimethoate, omethoate, phorate, α-γ-HCH and α-β-endosulfan were below LOD. Chlorantraniliprole and imidacloprid residues were the most frequent; chlorpyrifos and p,p'-DDT were detected in the highest concdentrations – The ionic ratio of DDT and its degradation products suggested a continuing use of DDT in the area – Low/no pesticide concentrations were detected in soils from IPM fields	Bhandari *et al.* 2020
Switzerland	2015	702 soil in 169 cultivated fields over the entire lowland of Switzerland	5 neonicotinoid insecticides (imidacloprid, clothianidin, thiamethoxam, thiacloprid, acetamiprid)	– Neonicotinoids were detected in 93% of organic soils and more than 80% of soils in "ecological focus areas" (EFAs)—two types of arable land supposedly free of insecticides – Between 5%–9% of above-ground invertebrate species may be exposed to lethal concentrations of clothianidin, and 32%–41% to sublethal concentrations, in "integrated production" and conventional fields – Between 1%–7% of the beneficial invertebrate species may be exposed to sublethal concentrations of neonicotinoids in EFAs and organic fields – The authors conclude that that diffuse contamination by neonicotinoids may harm a significant fraction of non-target beneficial species. The use of neonicotinoids on crops may threaten biodiversity in refuge areas, while also potentially jeopardizing the practice of organic farming by impeding the biological control of pests	Humann-Guilleminot *et al.* 2019
Tanzania	no period	Literature review	Mainly OCPs	– Most studies analyzed OCPs – In virtually all samples, OCPs were detected, in spite of the fact that the use of most of these have been prohibited for a long time – Concentrations exceeding clean-up action levels occurred in former pesticide storage locations	Elibariki & Maguta 2017

Annex 4.3-4 Recent reviews of pesticide concentrations in groundwater and drinking water.

The studies were selected from a literature search conducted using Web of Science for papers from 2010 until June 2020 using the following search criteria: TS=(pesticide*) AND TS=(groundwater* OR subterranean OR drinking). The title and summary of the resulting 3095 hits were evaluated, of which 175 papers were downloaded and analysed in more detail.

Region (coverage)	**Monitoring (or publication) period**	**Extent of review** (GW = groundwater; DW = drinking water)	**Pesticides**	**Outcomes**	**Reference**
Global					
Global (21 countries)	Studies published between 2001 and 2017	73 studies (GW)	Pesticides form the 1st and 2nd EU watchlist (5 neonicotinoids; 2 other insecticides; 2 herbicides)	– Most studies from USA, followed by EU. Few data for other regions – Among the 5 neonicotinoids, imidacloprid was the most frequently studied and detected – Average imidacloprid concentrations ± 8 ng/L to 3 µg/L (10 studies) – Other neonicotinoids were only observed in 1 or 2 water resources – Only one study available for the other pesticides from the watchlists (8 µg oxadiazon/L in Italy)	Pietrzak *et al.* 2019
Global (6 countries)	2000 - 2015	13 studies (GW)	Organochlorines and organophosphates	– Most studies conducted in Asian countries – Diversity and concentrations lower than in surface waters – Concentrations of organophosphates were generally higher than organochlorines due to their widespread use	Pirsaheb *et al.* 2017
Global (not reported)	Studies published between 2004 and 2014	12 studies (GW)	Pesticide transformation products (TPs)	– Few pesticide TPs are usually included in monitoring studies – TPs of atrazine and terbutylazine are the most studied TPs – The most abundant pesticide TPs in groundwater derive from the chloroacetanilide herbicides acetochlor, alachlor and metolachlor, the s-triazine herbicides atrazine and terbutylazine, and the herbicides chloridazon and dichlobenil – TPs derived from banned pesticides have consistently been detected in groundwater due to their their long residence time in the subsurface or the slow release of their precursors from the soil – Pesticide TPs are occasionally more ubiquitous and abundant than their parent molecules – Pesticide TPs have occasionally been quantified at levels above the EU groundwater quality standard of 0.1 µg/L	Postigo & Barceló 2015

Region (coverage)	**Monitoring (or publication) period**	**Extent of review** (GW = groundwater; DW = drinking water)	**Pesticides**	**Outcomes**	**Reference**
Regional					
Africa	Studies published between 2000 and 2018	NR (130 pesticide detections in freshwater resources combined for 13 countries) (GW + DW)	Review on contaminants of emerging concern including pesticides. Data available for 11 insecticides and 8 herbicides	– Despite an increase in the last decade, information is available for only few compounds and countries – In many African countries, groundwater is mostly used for drinking without any treatment – Pesticide concentrations detected in groundwater and drinking water ranging 0.1 ng/L to 18.4 µg/L and 0.02 ng/L to 34 µg/L, respectively	K'oreje *et al.* 2020
6 countries in Europe, Africa and Oceania (Germany, Australia, France, South Africa, the Netherlands and Spain)	November 2015	One (duplicated) drinking water sample per country (DW)	11 pesticides (8 herbicides, 2 insecticides, 1 fungicide)	– None of the pesticides were detected in Germany, Australia and South Africa – Atrazine was detected in France and Spain; Simazine in the Netherlands and Spain; Diuron in Spain – The maximum pesticide concentration detected (37 ng atrazine/L in Spain) was below the EU standard	Leusch *et al.* 2018
Overseas departments of France (Guadeloupe, Martinique, Reunion, Mayotte and French Guiana)	April - June 2012 (1st campaign); September 2012 - January 2013 (2nd campaign)	80 samples during two campaigns (40 sampling points/campaign) (GW)	Review on 66 target organic micropollutants (including 1 synergist and 16 pesticides: 8 herbicides, 4 insecticides, 3 fungicides and 1 metabolite)	– 11 pesticides detected, with greatest detection frequencies for the herbicides pentachlorophenol (55%) and atrazine (38%) – Several of the pesticide concentrations exceed the EU groundwater quality standard: pentachlorophenol (9 samples; max. 418 ng/L), atrazine (3 samples; max. 420 ng/L), diuron (1 sample; 258 ng/L) and fenarimol (1 sample; 121 ng/L)	Vulliet *et al.* 2014
National (selected country-wide or review studies)					
Sweden	Winter of 2018 (Jan-Feb)	Nationwide: 90 water treatment plants geographically distributed all over Sweden (DW)	3 herbicides (bentazon, atrazine, quinmerac)	– Concentrations of atrazine and bentazon were higher than in surface water – Atrazine was detected in all samples, whereas quinmerac and bentazon were not or rarely detected, respectively	Karki *et al.* 2020

Region (coverage)	**Monitoring (or publication) period**	**Extent of review** (GW = groundwater; DW = drinking water)	**Pesticides**	**Outcomes**	**Reference**
China	June 2019	Nationwide: 789 tap water samples and 95 groundwater samples (GW + DW)	Herbicides 2,4-D and MCPA	– MCPA concentrations were generally higher than those of 2,4-D – The cumulative concentration of the 2 herbicides in tap water of China was up to 125 ng/L (median: 1.38 ng/L) – Higher concentrations were found in surface water derived tap water than in groundwater – The median cumulative concentration in groundwater was approximately five times lower than that in tap water. – The highest concentrations were observed in July, and the lowest in October (related with pesticide applications) – The highest concentrations were found in Northeast China and were related with intensive herbicide use	Sun *et al.* 2020
China	June 2019	Nationwide: 789 tap water and 95 groundwater samples (GW + DW)	Atrazine and its metabolites (ATZs)	– At least one of the analytes was found in all the water samples – The median sum concentrations of ATZs (sATZs) was 21.0 ng/L (range: 0.02 ng/L - 3.04 mg/L) – The level of ATZs in groundwater from rural area of China was about 1/3 of that found in tap water	Wang *et al.* 2020
Saudi Arabia	NR	Nationwide: 993 well water samples from all 13 administrative regions (GW)	22 organochlorine insecticides	– Pesticides were not detected in any of the well water samples – However, previous studies reported pesticide residues in groundwater of the country	Alquwaizany *et al.* 2019
Martinique	2009–2014	Nationwide: 282 samples from 21 sites (twice a year at 18 sites; monthly in some years at 3 sites) (GW)	Chlordecone and its metabolite chlordecone-5b-hydro (5bCLD)	– Chlordecone decreased or remained stable during the time period – 5bCLD showed an increasing, although rather erratic, evolution, probably due to the greater influence of hydrological conditions – Most concentrations were < 0.1 µg/L with higher concentrations in banana cropping areas	Cattan *et al.* 2019
Bangladesh	not limited	National review: 3 studies (GW)	7 insecticides (organochlorines and organophosphates)	– DDT (and metabolites) encountered in concentrations up to 1.2 mg/L – High DDT concentrations encountered years after ban, which may also be partly due to an apparent illegal use – Little information available, but groundwater pollution is likely since groundwater levels in Bangladesh are high, and soil is mainly coarse	Hasan *et al.* 2019

Region (coverage)	**Monitoring (or publication) period**	**Extent of review** (GW = groundwater; DW = drinking water)	**Pesticides**	**Outcomes**	**Reference**
Spain	Studies including monitoring data from 1993-2012	National review: 12 studies (GW)	EU Watchlist pesticides (5 neonicotinoids, 2 carbamates, 1 oxadiazole and 1 semicarbazone)	– Only imidacloprid and methiocarb were detected in the GW bodies of Spain. However, this may also be at least partly due since the other pesticides were only studies in 1 or 2 cases. – Mean imidacloprid and methiocarb concentrations generally below, and maximum concentrations above 0.1 µg/L	Jurado *et al.* 2019
India	Studies between 2001 and 2015	National review: 12 studies (GW)	10 insecticides (organochlorines and organophosphates)	– Average concentrations of almost all insecticides and in almost all studies > 0.1 µg/L – Since pesticide use is expended to increase, groundwater pollution is likely to increase even further	Malyan *et al.* 2019
India	Studies since 1995	National review (45 studies including other micropollutants) (GW)	Insecticides (organochlorines (OCP), organophosphates (OPP) and synthetic pyrethroids (SP))	– Vast majority of studies for OCP, followed by OPP. Only few studies with SP – Many (maximum) concentrations > 0.1 µg/L – Higher concentrations during/after monsoon season	Sackaria & Elango 2019
The Netherlands Part also Belgium/Flanders	Routine monitoring data: 2010 – 2014: monitoring campaign: May and June 2016	Routine monitoring data: 29,766 records from all 10 ten water companies (GW) Monitoring campaign: 90 groundwater locations used as drinking water source in The Netherlands and Flanders (GW)	408 pesticides (routine monitoring data) + 24 pesticides (monitoring campaign): 4 herbicides, 12 fungicides, 6 insecticides, 1 acaricide and 1 plant growth regulator	– 15 out of 24 recently authorized pesticides were detected, including neonicotinoids – Pesticides (and/or metabolites) were detected in the majority of drinking water sources. – In one third of the abstraction areas pesticide and/or metabolites concentrations exceeded water quality standards according to the WFD – Monitoring should focus on priority pesticides and be kept up to date with recently authorized pesticides	Sjerps *et al.* 2019
Italy	2010 - 2015	11 alluvial aquifers of central Italy (GW)	42 pesticides (16 insecticides; 18 herbicides; 8 fungicides)	– Increasing trends in pesticide concentrations over the study period were encountered for several pesticides – Some pesticides banned in 2009 showed a persistent occurrence – Mean concentrations were > 0.1 µg/L for 3 pesticides	Di Lorenzo *et al.* 2018

Region (coverage)	**Monitoring (or publication) period**	**Extent of review** (GW = groundwater; DW = drinking water)	**Pesticides**	**Outcomes**	**Reference**
Ireland	Monthly sampling between March 2010 to March 2012	Nationwide: 7 sites (GW)	10 pesticides and 6 of their metabolites	– 2 metabolites were encountered in higher concentrations than their active ingredients – Highest detections were encountered in sites with well drained soils underlain by gravel and limestone aquifers and within gravel lenses in lower permeability subsoil – Metabolites accounted for the majority of exceedances of 0.1 µg/L	McManus *et al.* 2017
England and Wales	Since 2003 with a small number of samples collected from 1992 onwards.	Nationwide: 2650 sites as part of the England and Wales Environment Agency's National Monitoring Programme (GW)	15 pesticides (including metabolites)	– Atrazine, its metabolite atrazine-desethyl and simazine in the top 5 out of > 800 organic compounds – Maximum concentrations detected for diazinon (> 150 µg/L) and chlorotoluron (> 30 µg/L)) – Although a large monitoring dataset, it did not provide sufficient data for any compound for one site to determine a trend. – However, there appeared to be a declining overall trend in both frequency and concentrations of atrazine detections from 2004 to 2009	Manamsa *et al.* 2016
France	2011: campaigns in the spring (485 sites) and fall (475 sites)	Nationwide: 494 groundwater sites (GW)	103 pesticides (48 herbicides, 29 fungicides and 26 insecticides)	– 43 pesticides were detected in at least 1 sample, with 14 and 3 (atrazine and 2 of its metabolites) of those in at least 10 and 96 samples, respectively – Detected pesticides were dominated by herbicides (68% of sites), followed by fungicides (7.5%) and insecticides (1.4%) – The ratios between the occurrence of parent molecules and metabolites varied depending on the pesticide – 32 pesticides (including metabolites) exceeded the legal standard at least once. More than half of these compounds have already been banned	Lopez *et al.* 2015
South Africa	February, April, July and October 2012 (4 seasons)	Water treatment plants in 7 major South African cities (DW)	Qualitative screening of 700 compounds (including several pesticides); quantitively screening of 2 pesticides (atrazine and terbuthylazine)	– Most frequently detected pesticides in the qualitative screening were atrazine (63%), metolachlor (75%) and terbuthylazine (100%) – The seasonal distribution of atrazine fitted with its agricultural use as herbicide for summer crops – Detected levels of atrazine and terbuthylazine were at least an order of magnitude less that the guideline values set by EPA and WHO, respectively – However, detected levels were > 0.1 µg/L in many occasions at several sampling sites	Odendaal *et al.* 2015

Region (coverage)	**Monitoring (or publication) period**	**Extent of review** (GW = groundwater; DW = drinking water)	**Pesticides**	**Outcomes**	**Reference**
Hungary	1990–2015	Nationwide: seven monitoring projects in over twenty sampling campaigns (GW)	49 pesticides (including metabolites)	– Contamination rates of 32–61% were denoted in the monitoring projects – Standards were rarely exceeded; only in the cases of point contaminations, where higher concentrations were determined for atrazine (concentrations up to 7540 ng/L)	Székács *et al.* 2015
India	NR (studies published between 2005 and 2014)	National review (10 studies) (GW)	Persistent organic pesticides (DDTs, HCHs, endosulfan)	– Concentrations up to 0.94 µg/L (DDTs), 1.1 µg/L (HCHs) and 8.9 µg/L (endosulfan) have been detected in groundwater – High concentrations of HCHs and endosulfan isomers and DDT metabolites have been detected across India	Yadav *et al.* 2015
Spain	4 consecutive years: 2007 (June–November), 2008 (June–November), 2009 (May–October) and 2010 (April–September).	265 samples from 112 wells and piezometers coming from 29 different aquifers located in 18 ground waterbodies from Catalonia (GW)	22 pesticides (18 herbicides and 4 insecticides)	– Pesticide concentrations in groundwater tend to decrease with time. – Several aquifers had pesticide concentrations that exceeded EU quality standards. – Pesticides that exceeded 0.1 µg/L more than once were atrazine, terbuthylazine and the triazine metabolites DEA and DIA	Köck-Schulmeyer *et al.* 2014
Ireland	2007 - 2008	Nationwide: 845 samples from 158 monitoring points (GW)	13 pesticides (9 herbicides, 4 insecticides)	– MCPA and mecoprop were the most frequently detected pesticides in groundwater – Mecoprop and diuron concentrations > 0.1 µg/L were noted. In addition, all detected 2,4-D and bentazone concentrations were > 0.1 µg/L	McManus *et al.* 2014
United States	1993–2011	Nationwide: 2542 samples from 1271 wells in 58 nationally distributed well networks (GW)	83 pesticides	– Pesticides were frequently detected (53% of all samples) – Concentrations seldom exceeded human-health benchmarks (1.8% of all samples) – For agricultural networks, concentrations of atrazine, metolachlor, and prometon decreased in time. – For urban networks, deethylatrazine concentrations increased and prometon concentrations decreased. – For major aquifers, concentrations of deethylatrazine and simazine increased.	Toccalino *et al.* 2014

Region (coverage)	**Monitoring (or publication) period**	**Extent of review** (GW = groundwater; DW = drinking water)	**Pesticides**	**Outcomes**	**Reference**
Lebanon	DW: December 2010 - December 2011 GW: 5 times between November 2010 and November 2011	Nationwide (GW + DW)	67 pesticides from various chemical classes	– Most frequently detected pesticides in both groundwater and drinking water samples were diazinon, DDE and DDD, hexachlorobenzene, aldrin, dieldrin and tetradifon – All were quantified at low levels (< 20 ng/L)	Kouzayha *et al.* 2013
New Zealand	September - December 2010	National review: 162 wells in 14 regions (GW)	22 organochlorines; 4 organophosphates; 23 organonitrogen herbicides; 17 acid herbicides	– Pesticides were detected in 38 wells (23%), with two or more pesticides detected in 15 wells (9%) – A total of 22 different pesticides were detected with herbicides (n = 17) as the most common pesticide group, followed by insecticides (3) and fungicides (2) – Concentrations of 9 pesticides exceeded 0.1 µg/L in 21 cases (7% of wells with pesticides detected). – Comparisons with earlier surveys (since 1990) indicate that a similar percentage of wells had pesticide detections at comparable levels and with the same types of pesticides	Close & Skinner 2012
Pakistan	1990 - 2010	Nationwide: 6 studies (GW)	Organochlorines	– HCH isomers around 0.1 µg/L (max. 16.7 µg/L) – Concentration ranges: heptachlor 0.02 – 0.17 µg/L (1 study); endrin 0.1–0.2 µg/L (1 study); dieldrin 0.06 µg/L (1 study); DDT traces – 400 µg/L (4 studies); DDT isomers traces – 0.82 µg/L (3 studies) – High DDT levels attributed to dumping, illegal use and (inappropriate) storage	Eqani *et al.* 2012

Region (coverage)	**Monitoring (or publication) period**	**Extent of review** (GW = groundwater; DW = drinking water)	**Pesticides**	**Outcomes**	**Reference**
Spain	Studies up to 2012	National review (GW)	80 pesticides (herbicides, insecticides and fungicides)	– The most studied pesticides have been triazines followed by phenyl urea herbicides), anilides and organophosphorus insecticides – Out of the 80 studied pesticides, 61 were reported in < 4 studies and 30 were not detected in any groundwater sample – Groundwater is considerably less contaminated than other water bodies – (max.) concentrations of many pesticides > 0.1 µg/L, including alachlor (9.95 µg/L) and metolachlor (5.37 µg/L), malathion (3.5 µg/L), atrazine (3.45 µg/L), chlorfenvinphos (2.5 µg/L), dimethoate (2.3 µg/L), DEA (1.98 µg/L), chlortoluron (1.7 µg/L), simazine (1.69 µg/L); parathion-methyl (1.5 µg/L), TBA (1.27 µg/L) and linuron (1.01 µg/L)	Jurado *et al.* 2012
Pakistan	Studies from 1988 to 2006	National review: 8 studies (GW)	Several (mostly insecticides)	– High variation in detection frequencies (between 0% and 100%) depending on the pesticide and area – Cotton growing areas showed higher pesticide detections and concentrations (often greater than 0.1 µg/L) – Higher pesticide groundwater concentrations probably related with the existence of ponding irrigation systems	Tariq *et al.* 2007

Annex 4.3-5 Recent reviews and large scale studies on the effects of pesticide use on vertebrate wildlife

Included are reviews and studies published between 2010 and 2020

1. Recent reviews or large scale studies on the effects of pesticide use on wild bird (and some mammal) populations.

Country	Study type	Study coverage	Organisms	Effects observed	Reference
Global					
Global	Systematic review	Scientific evidence published since 2013 about the impact of neonicotinoids on nontarget organisms	Birds	– There is considerable variation in the lethality of neonicotinoids to birds, both among bird species and individual pesticides, ranging from non-toxic to highly toxic – It is difficult to judge whether clearly demonstrated lethal and sublethal effects of seeds treated with certain neonicotinoids are manifested in wild bird populations in the field	Wood & Goulson 2017
Global	Systematic review	Direct and indirect effects of neonicotinoids and fipronil on vertebrate wildlife. Mainly laboratory-based studies available.	Mainly wild birds	– Exposure to seeds treated with certain neonicotinoids at dosages expected in the field was found to pose a risk to granivorous birds	Gibbons *et al.* 2015
		Two field studies on bird populations identified: 1 of imidacloprid and 1 of fipronil.	Insectivorous birds	– No reductions in bird abundances were observed in both studies	
		One field study of effect of fipronil use in locust control on mammals	Lesser hedgehog tenrec	– Decline in tenrec populations, likely due to depletion of termite prey	
Global	Systematic review	27 farmland bird and 22 farmland mammal species. 57 scientific publications.	Farmland birds & mammals	– Evidence for indirect effects of pesticides at the population level of 4 European farmland bird species – Studies on long-term populations effects of pesticide use in agriculture on mammals are lacking, but some studies show adverse short-term effects – Pesticides were considered to be among the major causes for population declines of farmland birds	Jahn *et al.* 2014
Global	Narrative review	65 articles addressing relationship between rice cultivation and impacts on aquatic birds, published from 1980s – 2010	Aquatic birds in rice habitats	– Direct mortality of many avian species documented as a result of rice pesticide applications – Pesticides cited were organochlorines, organophosphates and carbamates – Food resources of birds affected by pesticide applications in rice, but no resulting population effects cited	Parsons *et al.* 2010

Country	Study type	Study coverage	Organisms	Effects observed	Reference
Regional					
North America	Narrative review	Factors assessed: declines in aerial insects, contamination (incl. pesticides), breeding habitat loss, climate change, nonbreeding ground effects	Aerial insectivore birds	– While no single threat appears to be the cause of aerial insectivore declines, existing evidence suggests that several factors could be contributing to the declines – As general hypothesis, the authors propose that changes in availability of high-quality prey, due to complex interactions of multiple effects (e.g. broad application of pesticides, agricultural intensification and other land use changes, changes in climate), have variably impacted combinations of fledging success, post-fledging survival, and nonbreeding season body condition of aerial insectivores, all of which contribute to variations in population trends	Spiller & Dettmers 2019
North America	Systematic review	122 studies, covering 77 breeding bird species. Parameters assessed (among others); pesticide lethal and sublethal toxicity	Farmland birds	– Pesticides were the most predominant factor negatively affecting farmland bird populations (42% of all studies) – Aerial insectivores and shrubland species were most commonly affected by pesticides (64% of studies for aerial species, 70% for shrubland) – Pesticides affected food availability of birds (100% of studies), their survival (43% of studies) and reproduction (26% of studies)	Stanton *et al.* 2018
Estonia, France, Germany, Ireland Netherlands, Poland, Spain, Sweden	Large-scale monitoring	270 cereals farms. 13 components of agricultural intensification assessed, among which: Number of applications and total amount of a.i. applied of insecticides, herbicides, fungicides.	Breeding birds	– Application of fungicides (and correlated insecticides) was significantly and negatively associated with the total abundance of all breeding birds surveyed, as well as four individual breeding bird species. – Pesticides did not have any associations with the abundance of birds during winter, suggesting that effects of insecticides or fungicides occurred through impact on food supply during the nestling period.	Emmerson *et al.* 2016
National					
USA	Surveys & models	Population abundance of 29 species of grassland birds, 637 species of non-grassland birds, 36 species of insectivorous birds and 631 species of non-insectivorous birds. Annual mass of individual neonicotinoids applied at county-level	Birds	– The use of neonicotinoids resulted in annual decreases of 4% and 3% in population abundance of grassland birds and insectivorous birds, respectively, over the period 2008 – 2014 – When the longer-term effects of neonicotinoids on bird populations were considered, through their reduction of the number of birds left to reproduce, the average annual effect on grassland birds was 12% and on insectivorous birds 5% – The average annual reduction in non-grassland and non-insectivorous bird populations due to neonicotinoid use was about 2%	Li *et al.* 2020

Country	Study type	Study coverage	Organisms	Effects observed	Reference
USA	Narrative review	Direct and indirect effects of pesticides, and other drivers, on bird populations in the USA.	Birds	– The hypothesis that pesticides, particularly neonicotinoids, are indirectly affecting bird population status via reductions in food resources should be considered with caution and within context of other more likely causes – While it would be disingenuous to suggest that insecticides do not pose any potential risk to non-target arthropods proximal to insecticide use, and thus indirectly to avian species, it would also be misleading to suggest that these compounds are the primary driver for such indirect effects	Brain & Anderson 2019
USA	Surveys 1978 – 2012	Bobwhite abundance related to county-level total neonicotinoid use, in Texas. Other variables assessed: climate and land-use data.	Northern bobwhite (grassland bird)	– Of the six predictor variables tested in this study, the strongest negative association was between bobwhite abundance and neonicotinoid use – Neonicotinoid use was significantly negatively associated with bobwhite abundance in the time periods following neonicotinoid introduction (1994-2003) or after their widespread use (2004-2012) – Treated seeds probably present the biggest hazard to bobwhites and other granivorous species	Ertl *et al.* 2018
USA (California)	Surveys 1914 – 2013 1990 – 2013 for pesticide data	Abundance index based on 3 sets of bird survey data related to county-level total pesticides applied. Other variables assessed: land-use, harvested crop land, predator abundance, climate data.	Ring-necked pheasant	– Major changes in agricultural practices over the last three decades were associated with declines in pheasant numbers and likely reflected widespread loss of habitat – Recent negative impacts on pheasant numbers were also associated with relatively high levels of pesticide application	Coates *et al.* 2017
USA	Surveys 1980 – 2003	Number of breeding bird species; Fraction of farmland treated with herbicide or insecticide; Lethal pesticide risk	Grassland birds	– Best predictors of bird species declines were the (acute) lethal risk from insecticide use modelled from pesticide impact studies, followed by the loss of cropped pasture – A re-analysis of data by Hill *et al.* suggested that population trends of grassland birds in the U.S. were primarily associated with habitat availability, rather than insecticide use or insecticide acute toxicity	Mineau & Whiteside 2013 Hill *et al.* 2014
The Netherlands	Surveys 2003 – 2010	Imidacloprid concentrations in surface water. 15 passerine species that are common in farmlands and depend on invertebrates during the breeding season.	Farmland birds	– Higher concentrations of imidacloprid in surface water were consistently associated with lower or negative population growth rates of passerine insectivorous bird populations	Hallman *et al.* 2014

Country	Study type	Study coverage	Organisms	Effects observed	Reference
France	Large-scale monitoring	66 cereal fields located in three French departments. Bird abundance	Farmland and non-farmland birds	– Herbicide use intensity was correlated with higher total abundance of birds. – However, the abundance of herbivore specialists decreased with herbicide use intensity. This suggests that herbicides may contribute to the 'biotic homogenization' by replacing specialists with generalists.	Chiron *et al.* 2014
Canada	National estimates	Direct avian mortality from agricultural pesticides in Canada. Reproductive and indirect effects of pesticides were not included.	Breeding birds	– Pesticides were 6th source of bird mortality in Canada (out of 28 sources identified), after feral and domestic cats and collisions with power lines, houses and vehicles, resulting in 0.9 – 4.4. million casualties per year. This was 1 – 1.5 orders of magnitude lower than the first 5 sources. – Impact of this mortality on bird populations was not known, but may have significantly contributed to the decline of grassland/farmland bird species in North America (Mineau 2013).	Calvert *et al.* 2013 Mineau 2013
France	Monitoring study 2003 – 2005	Breeding bird abundance in 15 apple orchards under conventional, IPM and organic pest control, in south eastern France. Orchards were standardised for local and landscape features that might influence bird communities.	Breeding birds	– Birds were significantly more abundant in organic orchards than in IPM and conventional orchards. Bird abundance in IPM orchards was significantly higher than in conventional orchards in 2 out of 3 years. – The pest control strategy affected insectivores more than granivores.	Bouvier *et al.* 2011

2. Recent reviews of the risks and/or effects of pesticides to amphibians at environmentally relevant concentrations.

Country	Study type	Study coverage	Organisms	Effects observed	Reference
Global					
Global	Systematic review & meta-analysis	Behavioural changes induced by chemicals, including pesticides 116, mainly laboratory-based, studies	Amphibians	– Most studies focussed on insecticides – Insecticides generally invoked the strongest behavioural responses: they significantly increased rates of abnormal swimming, reduced activity and reduced the capacity to exhibit escape responses – *Note:* it was not specified whether effect concentrations were environmentally relevant	Sievers *et al.* 2019
Global *(but focus on Europe)*	Narrative review	Evidence of pesticide effects on amphibians under current conditions use	Amphibians	– The review concludes that exposure of amphibians does occur, and that this exposure may lead to decline of populations and harm individuals, which would be of high concern. Therefore, a specific environmental risk assessment scheme is needed for these groups	EFSA 2018

Country	Study type	Study coverage	Organisms	Effects observed	Reference
Global	Narrative review	Effects of endocrine disrupting chemicals (EDCs), including pesticides, in laboratory experiments and field monitoring	Amphibians, primarily frogs & toads	– Effects on reproduction (laboratory): Exposure to the herbicide atrazine in leopard frogs induce feminising effects on the male gonads (including ‘intersex’ – oocytes within testes) at concentrations measured in some aquatic environments – There is now a substantial and growing body of evidence from field studies indicating that agriculture, herbicides and/or pesticides are associated with increased intersex in anurans. Some of the strongest associations between intersex induction and EDCs come from studies that have analysed the effects of the agricultural environment or mixtures of agrochemicals, rather than those focused on single compounds – There are significant knowledge gaps on the effects of EDCs in amphibians and data are lacking for studies on wild populations. This prevents drawing definitive conclusions on the associations between endocrine disruption and wild amphibian populations	Orton & Tyler 2015
Global	Systematic review & meta-analysis	Effects of pesticides on survival and growth 66 survival studies & 45 growth studies, primarily laboratory-based	Amphibians	– At ecologically relevant concentrations: – Organophosphates, carbamates, neonicotinoids, phosphonoglycines (with POEA surfactant), triazines, adversely affected amphibian survival – Organophosphates and phosphonoglycines also adversely affected amphibian growth	Baker *et al.* 2013
Global	Systematic review & meta-analysis	Effects of pesticides on survival, mass, time to hatching, time to metamorphosis and frequency of abnormalities. 16 laboratory & mesocosm studies	Amphibians	– At ecologically relevant concentrations: ○ Pesticide exposure resulted in significant reduction of amphibian survival. ○ Effects of pesticides on body mass, developmental time and frequency of abnormalities were not statistically significant, partly due to high heterogeneity among studies.	Egea-Serrano *et al.* 2012
National					
Argentina	Field monitoring	Pesticides: cypermethrin, chlorpyrifos, endosulfan, glyphosate and 2,4-D. Enclosures in 91 ponds adjacent to agricultural field were monitored	4 amphibian species common in ponds in agricultural landscapes	– Applications to adjacent fields with the 3 insecticides reduced survival at 48h to <1 – 10%. No significant effects on acute survival observed for the most application with only herbicides – All pesticides, including herbicides, impaired the mobility of the amphibians (tadpoles)	Agostini *et al.* 2020

Country	Study type	Study coverage	Organisms	Effects observed	Reference
USA	Field monitoring	Samples of water, sediment and frog tissue from 21 sites in 7 states. Samples analyzed for >90 pesticides and metabolites, and for the amphibian chytrid fungus *Batrachochytrium dendrobatidis* (Bd)	Frogs	– Thirty-nine pesticides and pesticide degradates were detected in one or more of the samples collected during the study – Pesticide occurrence in water or sediment was not a strong predictor of occurrence in tissue, but pesticide concentrations in tissue were correlated positively to agricultural and urban land, and negatively to forested land – Frogs that tested positive for Bd were associated with sites that had higher total fungicide concentrations in water and sediment, but lower insecticide concentrations in sediments relative to frogs that were Bd negative – There were no other differences in pesticide occurrence between individual frogs that were positive or negative for Bd	Battaglin *et al.* 2016
United Kingdom	Field monitoring (1992 – 2000)	Ranavirus-consistent common frog mortality events in the UK in relation to the use of garden chemicals	Common frog (*Rana temporaria*)	– Ranavirosis occurrence (i.e. presence/absence) was not significantly associated with use of garden chemicals – Ranavirosis prevalence(i.e. proportion of the estimated total frog population killed in the mortality event) was positively associated with the use of herbicides and of slug pellets, in addition to several other abiotic and biotic variables	North *et al.* 2015

3. Recent reviews of the risks and/or effects of pesticides to reptiles at environmentally relevant concentrations.

Country	Study type	Study coverage	Organisms	Effects observed	Reference
Global					
Global	Narrative review of toxicity studies	16 articles of laboratory experiments of the toxicity of pesticides to lizards	Lizards	– Most studies assessed locomotor performance, histopathology, oxidative stress, neurotoxicology, and genetic damage – It was not clear from the review whether observed effects would occur at environmentally relevant concentrations	Freitas *et al.* 2020
Global (*but focus on Europe*)	Narrative review	Evidence of pesticide effects on reptiles under current conditions use	Reptiles	– Few laboratory and field studies of pesticide effects on reptiles are available. Some studies indicate that adverse effects on reptiles occur of pesticides at environmentally relevant pesticide concentrations, but other studies do not find such effects – However, the review concludes that exposure of reptiles does occur, and that there is evidence that active substances and authorised plant protection products in Europe do have toxic impacts on reptiles	EFSA 2018

Country	Study type	Study coverage	Organisms	Effects observed	Reference
Regional and national					
Europe	Assessment of risk of exposure, in Europe	Exposure risk is estimated based on occurrence of reptiles in agricultural areas where pesticides are used, reptile physiology and their life-history	Reptiles	– About 1/3 of all European species of reptiles exhibit a high risk of exposure to pesticides. This is especially the case in Southern Europe, with a particular focus on vineyards – Of the 21 species and 3 subspecies of reptiles with special conservation status in the EU, nearly half are at above-average risk of pesticide use	Mingo *et al.* 2016 Wagner *et al.* 2015
Germany	Field monitoring study	Fitness and enzymatic activity in lizards sampled from sites along a gradient of agricultural intensity (vineyards with mainly fungicide applications), compared to a natural, unexposed, site	Common wall lizard (*Podacris muralis*)	– Exposure to pesticides induced oxidative stress in wall lizards, which can have severe implications for individuals – Neurotoxic effects were not observed – An evident decrease in fitness of individuals was observed with increasing land use intensity (and presumed pesticide exposure)	Mingo *et al.* 2017
New Zealand	Laboratory studies	Oral acute toxicity of rodenticides (brodifacoum, coumatetralyl, pindone, diphacinone, cholecalciferol) and herbicides (glyphosate, clopyralid, triclopyr, metsulfuron-methyl, haloxyfop-methyl) Dietary risk assessment	Western fence lizard (*Sceloporus occidentalis*)	– Only pindone and triclopyr were toxic to fence lizards below 1750 µg/g (LD_{50} = 550 µg/g) – Acute dietary risk to reptiles to the tested rodenticides and or herbicides was low – Research into sub-lethal effects is also required	Weir *et al.* 2016
Portugal	Field monitoring study	4 sites under intensive agriculture compared to 2 sites under organic agriculture. Mixture of herbicide treatments in intensive agriculture sites.	Lacertid lizards	– Herbicide concentrations in soil (sum of 7 a.i.'s: mesotrione, glyphosate, bentazone, dicamba, dimethenamid-p, alachlor and terbuthylazine) ranged from 10-100 ug/kg soil in intensively cultivated sites; and from 0 -10 ug/kg soil in organic sites – No significant differences were observed between intensive and organic sites for population size and other demographic parameters – Lizards from intensively cultivated sites had a significantly lower body condition index and more blood parasites than animals from organic sites – No significant effects were observed for standard metabolic rate, locomotor performance, glutathione oxidative pathways and related enzyme activity, lipid peroxidation and liver and testis histology – Further results on thyroid and testes histology strongly suggest that exposure of lizards to the mixture of herbicides had thyroid disrupting effects that ultimately affected the male reproductive system	Amaral *et al.* 2012a, b Bicho *et al.* 2013

Annex 4.3-6 Recent large-scale studies and partial reviews of the effects of pesticide use on biodiversity

Included are studies, published between 2009 and 2020, that link pesticide use to biodiversity parameters such as number of species, taxonomic richness, etc.

Country	Study type	Study coverage	Elements of biodiversity studied	Effects observed	Reference
Global					
Global	Systematic review	73 peer-reviewed studies of entomofauna declines from various parts of the world, published since 1984 Insect declines are described in terms of population declines, biomass reductions as well as biodiversity losses	Insects	– Almost half of insect species are rapidly declining and a third are being threatened with extinction – The main drivers of species declines appear to be in order of importance: i) habitat loss and conversion to intensive agriculture and urbanisation (50% of reports); ii) pollution, mainly that by synthetic pesticides and fertilisers (26% of reports)	Sánchez-Bayo & Wyckhuys 2019
Global	Meta-analysis	20 studies, 49 observations comparing organic with conventional farming	Soil organisms	– Differences in soil biodiversity between organic and conventional farming practices were not detected	De Graaff *et al.* 2019
Global	Meta-analysis	94 studies, 184 observations comparing organic with conventional farming	arthropods, birds, microbes & plants	– Species richness on organic farms was on average 34% higher than on conventional farms – Plants benefited the most from organic farming; but arthropods, birds & microbes also showed a substantial positive effect – Current studies are heavily biased towards northern and western Europe and North America, while other regions with large areas of organic farming remain poorly investigated	Tuck *et al.*2015
Global	Meta-analysis	39 studies on 23 crops in 14 countries on 6 continents	Wild bees	– Organic farm management (lacking or having highly reduced use of pesticides and fertilizers) resulted in a 50% higher wild bee richness when compared to conventional farming	Kennedy *et al.* 2013
Regional and national					
Japan	Moderate-scale monitoring	21 irrigation ponds	Wide range of freshwater organisms	– A fungicide and an insecticide, alone or in combination with other stressors (invasive alien fish, concrete bank protection) had a significantly negative correlation the taxonomic richness of freshwater animals sampled in the study ponds	Ito *et al.* (2020)

Country	Study type	Study coverage	Elements of biodiversity studied	Effects observed	Reference
USA	Moderate-scale monitoring	4 sites in California, monitored between 1972 and 2012 Annual use of 5 neonicotinoid insecticides, as well as of 4 of the most widely used non-neonicotinoid insecticide classes	67 species of butterflies	– A negative association was detected butterfly diversity (Shannon index) and increasing neonicotinoid applications, while controlling for land use and other factors	Forister *et al.* 2016
USA	Moderate-scale monitoring	4 no-input, 6 organic and 15 conventional apple orchards Pesticide use was based on bee toxicity and volumes applied ("pesticide toxicity scores")	Wild bees	– Pesticide use did not adversely affect total bee species richness – Pesticide use was negatively associated with lower richness of sweat bees (*Lasioglossum* spp.); but with higher richness of mining bees (*Andrena* spp.)	Mallinger *et al* 2015
USA	moderate-scale monitoring	19 apple orchards with various pesticide use intensities	Wild bees	– Species richness of solitary wild bees decreased significantly with increasing pesticide use intensity; but richness of social wild bees did not – Fungicide sprays before and insecticide use after bloom had the strongest relationships with declines in the wild bee fauna. period. Unlike honeybees that reside in orchards during bloom only, wild bees have a greater exposure risk to pesticides as they actively forage in and around orchards weeks before and after apple bloom	Park *et al.* 2015
France	Large-scale monitoring	66 cereal fields located in three French departments	Farmland and non-farmland birds	– Herbicide dose was associated with negative effects on the Community Specialization Index. Overall, the proportion of habitat specialists, particularly of herbivorous species, decreased, and the proportion of generalists increased as herbicide doses increased. However, herbicide dose was positively correlated with bird richness and total abundance – No influence of insecticide or fungicide doses could be detected	Chiron *et al.* 2014
Germany, France, Australia (southern Victoria)	Large-scale monitoring	72 sampling sites Parameters assessed (among others): pesticide residues, macroinvertebrate abundance and taxa	Stream invertebrates	– Pesticide residues were associated with effects on both the species and family richness in both regions (statistically significant) – Decrease in taxonomic richness between the uncontaminated and highly contaminated categories ranged from 42% for the European species-level data to 27% for the Australian family-level data – Effects in Europe were detected at concentrations below environmental standards	Beketov *et al.* 2013

Country	Study type	Study coverage	Elements of biodiversity studied	Effects observed	Reference
Estonia, France, Germany, Ireland Netherlands, Poland, Spain, Sweden	Large-scale monitoring	270 cereals farms. 13 components of agricultural intensification assessed, among which: Number of applications and total amount of a.i. applied of insecticides, herbicides, fungicides	Wild plants, carabid beetles, breeding birds	– Number of wild plant species declined as the frequency of herbicide and insecticide application and the amounts of active ingredients of fungicides increased – Number of carabid species was negatively affected by the amounts of active ingredients of insecticide applied – Bird species diversity declined with increasing frequency of fungicide application (note: frequencies of fungicide and insecticide applications were closely correlated)	Geiger *et al.* 2010 Emmerson *et al.* 2016
Italy	Large-scale monitoring	Vine fields in northern Italy with or without applications of the insecticide fenitrothion	Wild bees, bumblebees, butterflies	– At field scale: Wild bee species richness declined after 2 or 3 insecticide applications, but not bumblebee or butterfly richness. – At the landscape level: richness of wild bees, bumblebees and butterflies was lower in areas with higher pesticide loads	Brittain *et al.* 2010
Canada	Retrospective review	Comparison of areas where imperilled species occur versus areas where they have been lost Pesticides variables were area treated with herbicides or with insecticides, or total area treated with pesticides (herbicide + insecticides + fungicides)	62 species of mammals, birds, amphibians, reptiles	– High losses of imperilled species were observed in regions with high proportions of agricultural land cover. However, losses of imperilled species are significantly more strongly related to the proportion of the region treated with agricultural pesticides. Species losses were more strongly related to herbicide use than to use of other pesticides	Gibbs *et al.* 2009

References

Agostini MG, Roesler I, Bonetto C, Ronco AE & Bilenca D (2020). Pesticides in the real world: The consequences of GMO-based intensive agriculture on native amphibians. *Biological Conservation* 241: 108355. https://doi.org/10.1016/j.biocon.2019.108355

Albuquerque AF, Ribeiro JS, Kummrow F, Nogueira AJA, Montagner CC & Umbuzeiro GA (2016) Pesticides in Brazilian freshwaters: A critical review. *Environmental Science: Processes and Impacts* 18(7): 779–787. https://doi.org/10.1039/c6em00268d

Ali U, Syed JH, Malik RN, Katsoyiannis A, Li J, Zhang G & Jones KC (2014) Organochlorine pesticides (OCPs) in South Asian region: A review. *Science of the Total Environment* 476–477: 705–717. https://doi.org/10.1016/j.scitotenv.2013.12.107

Alquwaizany AS, Alfadul SM, Khan MA & Alabdulaaly AI (2019). Occurrence of organic compounds in groundwater of Saudi Arabia. *Environmental Monitoring and Assessment*, 191(10). https://doi.org/10.1007/s10661-019-7723-6

Amaral MJ, Carretero MA, Bicho RC, Soares AMVM, Mann RM (2012a) The use of a lacertid lizard as a model for reptile ecotoxicology studies: Part 1 – Field demographics and morphology. *Chemosphere* 87: 757–764. doi:10.1016/j.chemosphere.2011.12.075

Amaral MJ, Bicho RC, Carretero MA, Sanchez-Hernandez JC, Faustino AMR, Soares AMVM, Mann RM (2012b) The use of a lacertid lizard as a model for reptile ecotoxicology studies: Part 2 – Biomarkers of exposure and toxicity among pesticide exposed lizards. *Chemosphere* 87: 765–774. doi:10.1016/j.chemosphere.2012.01.048

Ansara-Ross TM, Wepener V, van den Brink PJ & Ross MJ (2012) Pesticides in South African fresh waters. *African Journal of Aquatic Science* 37(1): 1–16. https://doi.org/10.2989/16085914.2012.666336

Baker NJ, Bancroft BA & Garcia TS (2013) A meta-analysis of the effects of pesticides and fertilizers on survival and growth of amphibians. *Science of the Total Environment* 449: 150–156 http://dx.doi.org/10.1016/j.scitotenv.2013.01.056

Battaglin WA, Smalling KL, Anderson C, Calhoun D, Chestnut T & Muths E (2016) Potential interactions among disease, pesticides, water quality and adjacent land cover in amphibian habitats in the United States. *Science of the Total Environment* 566–567: 320–332 http://dx.doi.org/10.1016/j.scitotenv.2016.05.062

Beketov MA, Kefford BJ, Schäfer RB & Liess M (2013) Pesticides reduce regional biodiversity of stream invertebrates. *PNAS* 110(27): 11039–11043. doi:10.1073/pnas.1305618110

Bhandari G, Atreya K, Scheepers PTJ & Geissen V (2020) Concentration and distribution of pesticide residues in soil: Non-dietary human health risk assessment. *Chemosphere* 126594. https://doi.org/10.1016/j.chemosphere.2020.126594

Bicho RC, Amaral MJ, Faustino AMR, Power DM, Rêma A, Carretero MA, Soares AMVM, Mann RM (2013) Thyroid disruption in the lizard *Podarcis bocagei* exposed to a mixture of herbicides: a field study. *Ecotoxicology* 22: 156–165. DOI 10.1007/s10646-012-1012-2

Bouvier J-C, Ricc B, Agerberg J & Lavigne C (2011) Apple orchard pest control strategies affect bird communities in southeastern France. *Environmental Toxicology and Chemistry* 30(1): 212–219. DOI: 10.1002/etc.377

Brain RA & Anderson JC (2019) The agro-enabled urban revolution, pesticides, politics, and popular culture: a case study of land use, birds, and insecticides in the USA. *Environmental Science and Pollution Research* 26: 21717-21735. https://doi.org/10.1007/s11356-019-05305-9

Brittain CA, Vighi M, Bommarco R, Settele J & Potts SG (2010). Impacts of a pesticide on pollinator species richness at different spatial scales. *Basic and Applied Ecology* 11(2): 106–115. https://doi.org/10.1016/j.baae.2009.11.007

Bruce-Vanderpuije P, Megson D, Reiner EJ, Bradley L, Adu-Kumi S & Gardella JA (2019) The state of POPs in Ghana – A review on persistent organic pollutants: Environmental and human exposure. *Environmental Pollution* 245: 331–342. https://doi.org/10.1016/j.envpol.2018.10.107

Calvert AM, Bishop CA, Elliot RD, Krebs EA, Kydd TM, Machtans CS & Robertson GJ (2013) A synthesis of human-related avian mortality in Canada. *Avian Conservation and Ecology* 8(2): 11. http://dx.doi.org/10.5751/ACE-00581-080211

Camenzuli L, Scheringer M & Hungerbühler K (2016) Local organochlorine pesticide concentrations in soil put into a global perspective. *Environmental Pollution* 217 : 11–18. https://doi.org/10.1016/j.envpol.2015.08.028

Cattan P, Charlier JB, Clostre F, Letourmy P, Arnaud L, Gresser J & Jannoyer M (2019) A conceptual model of organochlorine fate from a combined analysis of spatial and mid-to long-term trends of surface and ground water contamination in tropical areas (FWI). *Hydrology and Earth System Sciences*, 23(2), 691–709. https://doi.org/10.5194/hess-23-691-2019

Chen Y, Zang L, Liu M, Zhang C, Shen G, Du W, Sun Z, Fei J, Yang L, Wang Y, Wang X & Zhao M (2019) Ecological risk assessment of the increasing use of the neonicotinoid insecticides along the east coast of China. *Environment International* 127: 550–557. https://doi.org/10.1016/j.envint.2019.04.010

Chiron F, Chargé R, Julliard R, Jiguet F & Muratet A (2014) Pesticide doses, landscape structure and their relative effects on farmland birds. *Agriculture, Ecosystems and Environment* 185: 153– 160 http://dx.doi.org/10.1016/j.agee.2013.12.013

Close ME & Skinner A (2012) Sixth national survey of pesticides in groundwater in New Zealand. *New Zealand Journal of Marine and Freshwater Research*, 46(4): 443–457. https://doi.org/10.1080/00288330.2012.707131

Coates PS, Brussee BE, Howe KB, Fleskes JP, Dwight IA, Connelly DP, Meshriy MG, Gardner SC (2017) Long-term and widespread changes in agricultural practices influence ring-necked pheasant abundance in California. *Ecology and Evolution* 7: 2546–2559. DOI: 10.1002/ece3.2675

Coscollà C &Yusà V (2016) Pesticides and agricultural air quality. Chapter 17 ***In:*** *The Quality of Air. M de la Guardia & S Armenta (eds).* Comprehensive Analytical Chemistry, Volume 73, Elsevier, Amsterdam.

Dahshan H, Megahed AM, Abd-Elall AMM, Abd-El-Kader MAG, Nabawy E & Elbana MH (2016) Monitoring of pesticides water pollution – The Egyptian River Nile. *Journal of Environmental Health Science and Engineering* 14(1): 1–9. https://doi.org/10.1186/s40201-016-0259-6

De Graaff MA, Hornslein N, Throop HL, Kardol P & van Diepen LTA (2019) Effects of agricultural intensification on soil biodiversity and implications for ecosystem functioning: A meta-analysis. Chapter 1 (pp 1-44) *In:* Advances in Agronomy, Vol. 155 . Elsevier Inc. https://doi.org/10.1016/bs.agron.2019.01.001

De Souza RM, Seibert D, Quesada HB, de Jesus Bassetti F, Fagundes-Klen MR & Bergamasco R (2020) Occurrence, impacts and general aspects of pesticides in surface water: A review. *Process Safety and Environmental Protection* 135: 22–37. https://doi.org/10.1016/j.psep.2019.12.035

Derbalah A, Chidya R, Jadoon W & Sakugawa H (2019) Temporal trends in organophosphorus pesticides use and concentrations in river water in Japan, and risk assessment. *Journal of Environmental Sciences (China)* 79: 135–152. https://doi.org/10.1016/j.jes.2018.11.019

Di Lorenzo T, Cifoni M, Fiasca B, Di Cioccio A & Galassi DMP (2018) Ecological risk assessment of pesticide mixtures in the alluvial aquifers of central Italy: Toward more realistic scenarios for risk mitigation. *Science of the Total Environment* 644: 161–172. https://doi.org/10.1016/j.scitotenv.2018.06.345

Dirbaba NB, Li S, Wu H, Yan X & Wang J (2018) Organochlorine pesticides, polybrominated diphenyl ethers and polychlorinated biphenyls in surficial sediments of the Awash River Basin Ethiopia. *PLoS ONE* 13(10). https://doi.org/10.1371/journal.pone.0205026

EFSA (2018) Scientific Opinion on the state of the science on pesticide risk assessment for amphibians and reptiles. EFSA PPR Panel (EFSA Panel on Plant Protection Products and their Residues): Ockleford C, Adriaanse P, Berny P, Brock T, Duquesne S, Grilli S, Hernandez-Jerez AF, Bennekou SH, Klein M, Kuhl T, Laskowski R, Machera K, Pelkonen O, Pieper S, Stemmer M, Sundh I, Teodorovic I, Tiktak A, Topping CJ, Wolterink G, Aldrich A, Berg C, Ortiz-Santaliestra M, Weir S, Streissl F and Smith RH. *EFSA Journal* 16(2): 5125. https://doi.org/10.2903/j.efsa.2018.5125

Egea-Serrano A, Relyea RA, Tejedo M & Torralva M (2012) Understanding of the impact of chemicals on amphibians: a meta-analytic review. *Ecology and Evolution* 2(7): 1382–1397. doi: 10.1002/ece3.249

Elibariki R & Maguta MM (2017) Status of pesticides pollution in Tanzania – A review. *Chemosphere* 178: 154–164. https://doi.org/10.1016/j.chemosphere.2017.03.036

Emmerson M, Morales MB, Oñate JJ, Batáry P, Berendse F, Liira J, Aavik T, Guerrero I, Bommarco R, Eggers S, Pärt T, Tscharntke T, Weisser W, Clement L & Bengtsson J (2016) How agricultural intensification affects biodiversity and ecosystem services. Chapter 2 In: *Advances in Ecological Research* 55: 43-97 http://dx.doi.org/10.1016/bs.aecr.2016.08.005

Eqani AS, Malik RN, Alamdar A & Faheem H (2012) Status of organochlorine contaminants in the different environmental compartments of Pakistan: A review on occurrence and levels. *Bulletin of Environmental Contamination and Toxicology* 88(3): 303–310. https://doi.org/10.1007/s00128-011-0496-4

Ertl HMH, Mora MA, Brightsmith DJ, Navarro-Alberto JA (2018) Potential impact of neonicotinoid use on Northern bobwhite (*Colinus virginianus*) in Texas: A historical analysis. *PLoS ONE* 13(1): e0191100. https://doi.org/10.1371/journal.pone.0191100

Forister ML, Cousens B, Harrison JG, Anderson K, Thorne JH, Waetjen D. Nice CC, De Parsia M, Hladik ML, Meese R, Van Vliet H & Shapiro AM (2016) Increasing neonicotinoid use and the declining butterfly fauna of lowland California. *Biology Letters* 12(8). https://doi.org/10.1098/rsbl.2016.0475

Fosu-Mensah BY, Okoffo ED, Darko G & Gordon C (2016) Assessment of organochlorine pesticide residues in soils and drinking water sources from cocoa farms in Ghana. *SpringerPlus* 5 (1). https://doi.org/10.1186/s40064-016-2352-9

Freitas LM, Paranaíba JFFS, Peréz APS, Machado MRF & Lima FC (2020) Toxicity of pesticides in lizards. *Human and Experimental Toxicology* 39(5): 596-604. [OI: 10.1177/0960327119899980

Geiger F, Bengtsson J, Berendse F, Weisser WW, Emmerson M, Morales MB, Ceryngier P, Liira J, Tscharntke T, Winqvist C, Eggers S, Bommarco R, Pärt T, Bretagnolle V, Plantegenest M, Clement LW, Dennis C, Palmer C, Oñate JJ, Guerrero I, Hawro V, Aavik T, Thies C, Flohre A, Hänke S, Fischer C, Goedhart PW & Inchausti P (2010) Persistent negative effects of pesticides on biodiversity and biological control potential on European farmland. *Basic and Applied Ecology* 11: 97–105. https://doi.org/10.1016/j.baae.2009.12.001

Gibbons D, Morrissey C & Mineau P (2015) A review of the direct and indirect effects of neonicotinoids and fipronil on vertebrate wildlife. *Environmental Science and Pollution Research International* 22(1): 103-118. DOI:10.1007/s11356-014-3180-5

Gibbs KE, MacKey RL & Currie DJ (2009) Human land use, agriculture, pesticides and losses of imperiled species. *Diversity and Distributions* 15(2): 242–253. https://doi.org/10.1111/j.1472-4642.2008.00543.x

Grung M, Lin Y, Zhang H, Steen AO, Huang J, Zhang G & Larssen T (2015) Pesticide levels and environmental risk in aquatic environments in China – A review. *Environment International* 81: 87-97. https://doi.org/10.1016/j.envint.2015.04.013

Guida Y de S, Meire RO, Torres JPM & Malm O (2018) Air contamination by legacy and current-use pesticides in Brazilian mountains: An overview of national regulations by monitoring pollutant presence in pristine areas. *Environmental Pollution* 242: 19-30. https://doi.org/10.1016/j.envpol.2018.06.061

Hallmann CA, Foppen RPB, van Turnhout CAM, de Kroon H & Jongejans E (2014) Declines in insectivorous birds are associated with high neonicotinoid concentrations. *Nature* 511: 341. doi:10.1038/nature13531

Hao Y, Li Y, Ha, X, Wang T, Yang R, Wang P, Xiao K, Li W, Lu H, Fu J, Wang Y, Shi J, Zhang Q & Jiang G (2019) Air monitoring of polychlorinated biphenyls, polybrominated diphenyl ethers and organochlorine pesticides in West Antarctica during 2011–2017: Concentrations, temporal trends and potential sources. *Environmental Pollution* 249: 381–389. https://doi.org/10.1016/j.envpol.2019.03.039

Hasan MK, Shahriar A & Jim KU (2019) Water pollution in Bangladesh and its impact on public health. *Heliyon* 5(8): e02145. https://doi.org/10.1016/j.heliyon.2019.e02145

Hill JM, Egan JF, Stauffer GE, Diefenbach DR (2014) Habitat availability is a more plausible explanation than insecticide acute toxicity for U.S. grassland bird species declines. *PLoS ONE* 9(5): e98064. doi:10.1371/journal.pone.0098064

Hladik ML & Kolpin DW (2016) First national-scale reconnaissance of neonicotinoid insecticides in streams across the USA. *Environmental Chemistry* 13 (1): 12–20. https://doi.org/10.1071/EN15061

Humann-Guilleminot S, Binkowski ŁJ, Jenni L, Hilke G, Glauser G & Helfenstein F (2019) A nation-wide survey of neonicotinoid insecticides in agricultural land with implications for agri-environment schemes. *Journal of Applied Ecology* 00: 1–13. https://doi.org/10.1111/1365-2664.13392

Hvězdová M, Kosubová P, Košíková M, Scherr KE, Šimek Z, Brodský L, Šudoma M, Škulcová L, Sáňka M, Svobodová M, Krkošková L, Vašíčková J, Neuwirthová N, Bielská L & Hofman J (2018) Currently and recently used pesticides in Central European arable soils. *Science of the Total Environment* 613-614: 361-370. https://doi.org/10.1016/j.scitotenv.2017.09.049

Isogai N, Hogarh JN, Seike N, Kobara Y, Oyediran F, Wirmvem MJ, Ayonghe SN, Fobil J & Masunaga S (2018) Atmospheric monitoring of organochlorine pesticides across some West African countries. *Environmental Science and Pollution Research* 25(32): 31828-31835. https://doi.org/10.1007/s11356-016-7284-y

Ito HC, Shiraishi H, Nakagawa M & Takamura N (2020) Combined impact of pesticides and other environmental stressors on animal diversity in irrigation ponds. *PLoS One* 15. doi:10.1371/journal.pone.0229052

Jahn T, Hötker H, Oppermann R, Bleil R, Vele L (2014) Protection of biodiversity of free living birds and mammals in respect of the effects of pesticides. Report No. (UBA-FB) 001830. Federal Environment Agency, Dessau-Roßlau, Germany. https://www.umweltbundesamt.de/en/publikationen/protection-of-biodiversity-of-free-living-birds

Jurado A, Vàzquez-Suñé E, Carrera J, López de Alda M, Pujades E & Barceló D (2012) Emerging organic contaminants in groundwater in Spain: A review of sources, recent occurrence and fate in a European context. *Science of the Total Environment* 440: 82–94. https://doi.org/10.1016/j.scitotenv.2012.08.029

Jurado A, Walther M & Díaz-Cruz MS (2019) Occurrence, fate and environmental risk assessment of the organic microcontaminants included in the Watch Lists set by EU Decisions 2015/495 and 2018/840 in the groundwater of Spain. *Science of the Total Environment* 663: 285–296. https://doi.org/10.1016/j.scitotenv.2019.01.270

K'oreje KO, Okoth M, Van Langenhove H & Demeestere K (2020) Occurrence and treatment of contaminants of emerging concern in the African aquatic environment: Literature review and a look ahead. *Journal of Environmental Management* 254. https://doi.org/10.1016/j.jenvman.2019.109752

Karki AJ, Cappelli P, Dirks C, Pekar H, Hellenäs KE, Rosén J & Westerberg E (2020) New efficient methodology for screening of selected organic micropollutants in raw- and drinking water from 90 Swedish water treatment plants. *Science of the Total Environment* 724. https://doi.org/10.1016/j.scitotenv.2020.138069

Kennedy CM, Lonsdorf E, Neel MC, Williams NM, Ricketts TH, Winfree R, Bommarco R, Brittain C, Burley AL, Cariveau D, Carvalheiro LG, Chacoff NP, Cunningham SA, Danforth BN, Dudenhöffer JH, Elle E, Gaines HR, Garibaldi LA, Gratton C, Holzschuh A, Isaacs R, Javorek SK, Jha S, Klein AM, Krewenka K, Mandelik Y, Mayfield MM, Morandin L, Neame LA, Otieno M, Park M, Potts SG, Rundlöf M, Saez A, Steffan-Dewenter I, Taki H, Felipe Viana B, Westphal C, Wilson JK, Greenleaf SS & Kremen C (2013) A global quantitative synthesis of local and landscape effects on wild bee pollinators in agroecosystems. *Ecology Letters* 16(5): 584–599. https://doi.org/10.1111/ele.12082

Kirchner M, Jakobi G, Körner W, Levy W, Moche W, Niedermoser B, Schaub M, Ries L, Weiss P, Antritter F, Fischer N, Henkelmann B & Schramm KW (2016) Ambient air levels of organochlorine pesticides at three high alpine monitoring stations: Trends and dependencies on geographical origin. *Aerosol and Air Quality Research* 16(3): 738–751. https://doi.org/10.4209/aaqr.2015.04.0213

Knauer K (2016) Pesticides in surface waters: a comparison with regulatory acceptable concentrations (RACs) determined in the authorization process and consideration for regulation. *Environmental Sciences Europe* 28 (1): 0–6. https://doi.org/10.1186/s12302-016-0083-8

Köck-Schulmeyer M, Ginebreda A, Postigo C, Garrido T, Fraile J, López de Alda M & Barceló D (2014) Four-year advanced monitoring program of polar pesticides in groundwater of Catalonia (NE-Spain). *Science of the Total Environment* 470–471: 1087–1098. https://doi.org/10.1016/j.scitotenv.2013.10.079

Komárek M, Čadková E, Chrastný V, Bordas F & Bollinger JC (2010) Contamination of vineyard soils with fungicides: A review of environmental and toxicological aspects. *Environment International* 36(1): 138–151. https://doi.org/10.1016/j.envint.2009.10.005

Kouzayha A, Al Ashi A, Al Akoum R, Al Iskandarani M, Budzinski H & Jaber F (2013) Occurrence of pesticide residues in Lebanon's water resources. *Bulletin of Environmental Contamination and Toxicology* 91(5): 503–509. https://doi.org/10.1007/s00128-013-1071-y

Leusch FDL, Neale PA, Arnal C, Aneck-Hahn NH, Balaguer P, Bruchet A, Escher BI, Esperanza M, Grimaldi M, Leroy G, Scheurer M, Schlichting R, Schriks M & Hebert A (2018) Analysis of endocrine activity in drinking water, surface water and treated wastewater from six countries. *Water Research* 139: 10–18. https://doi.org/10.1016/j.watres.2018.03.056

Levillain J, Cattan P, Colin F, Voltz M & Cabidoche Y-M (2012) Analysis of environmental and farming factors of soil contamination by a persistent organic pollutant, chlordecone, in a banana production area of French West Indies. *Agriculture, Ecosystems & Environment* 159: 123-132. https://doi.org/10.1016/j.agee.2012.07.005

Li J, Li F & Liu Q (2015) Sources, concentrations and risk factors of organochlorine pesticides in soil, water and sediment in the Yellow River estuary. *Marine Pollution Bulletin* 100(1): 516–522. https://doi.org/10.1016/j.marpolbul.2015.09.003

Li Y, Miao R & Khanna M (2020) Neonicotinoids and decline in bird biodiversity in the United States. *Nature Sustainability*. https://www.nature.com/articles/s41893-020-0582-x

Lopez B, Ollivier P, Togola A, Baran N & Ghestem JP (2015) Screening of French groundwater for regulated and emerging contaminants. *Science of the Total Environment* 518–519: 562–573. https://doi.org/10.1016/j.scitotenv.2015.01.110

Łozowicka B, Kaczyński P, Wolejko E, Piekutin J, Sagitov A, Toleubayev K, Isenova G & Abzeitova E (2016) Evaluation of organochlorine pesticide residues in soil and plants from east Europe and central Asia. *Desalination and Water Treatment* 57(3): 1310–1321. https://doi.org/10.1080/19443994.2014.996008

Malaj E, von der Ohe PC, Grote M, Kühne R, Mondy CP, Usseglio-Polatera P, Brack W & Schäfer RB (2014) Organic chemicals jeopardize the health of freshwater ecosystems on the continental scale. *Proceedings of the National Academy of Sciences* 111 (26): 9549–9554. https://doi.org/10.1073/pnas.1321082111

Mallinger RE, Werts P & Gratton C (2015) Pesticide use within a pollinator-dependent crop has negative effects on the abundance and species richness of sweat bees, *Lasioglossum* spp., and on bumble bee colony growth. *Journal of Insect Conservation* 19(5): 999–1010. https://doi.org/10.1007/s10841-015-9816-z

Malyan SK, Singh R, Rawat M, Kumar M, Pugazhendhi A, Kumar A, Kumar V & Kumar SS (2019) An overview of carcinogenic pollutants in groundwater of India. *Biocatalysis and Agricultural Biotechnology* 21. https://doi.org/10.1016/j.bcab.2019.101288

Manamsa K, Crane E, Stuart M, Talbot J, Lapworth D & Hart A (2016) A national-scale assessment of micro-organic contaminants in groundwater of England and Wales. *Science of the Total Environment* 568: 712–726. https://doi.org/10.1016/j.scitotenv.2016.03.017

McManus SL, Richards KG, Grant J, Mannix A & Coxon CE (2014) Pesticide occurrence in groundwater and the physical characteristics in association with these detections in Ireland. *Environmental Monitoring and Assessment* 186(11): 7819-7836. https://doi.org/10.1007/s10661-014-3970-8

McManus SL, Coxon CE, Mellander PE, Danaher M & Richards KG (2017) Hydrogeological characteristics influencing the occurrence of pesticides and pesticide metabolites in groundwater across the Republic of Ireland. *Science of the Total Environment* 601–602: 594–602. https://doi.org/10.1016/j.scitotenv.2017.05.082

Meffe R & de Bustamante I (2014). Emerging organic contaminants in surface water and groundwater: A first overview of the situation in Italy. *Science of the Total Environment* 481 (1): 280–295. https://doi.org/10.1016/j.scitotenv.2014.02.053

Menzies R, Soares Quinete N, Gardinali P & Seba D (2013) Baseline occurrence of organochlorine pesticides and other xenobiotics in the marine environment: Caribbean and Pacific collections. *Marine Pollution Bulletin* 70 (1–2): 289–295. https://doi.org/10.1016/j.marpolbul.2013.03.003

Mineau P (2013) Avian mortality from pesticides used in agriculture in Canada. *Unpublished manuscript*, provided as Annex to Calvert *et al.* 2013.

Mineau P & Whiteside M (2013) Pesticide acute toxicity Is a better correlate of U.S. grassland bird declines than agricultural intensification. *PLoS ONE* 8(2): e57457. doi:10.1371/journal.pone.0057457

Mingo V, Lötters S & Wagner N (2017) The impact of land use intensity and associated pesticide applications on fitness and enzymatic activity in reptiles—A field study. *Science of the Total Environment* 590–591: 114–124 http://dx.doi.org/10.1016/j.scitotenv.2017.02.178

Mingo V, Lötters S & Wagner N (2016) Risk of pesticide exposure for reptile species in the European Union. *Environmental Pollution* 215: 164e169 http://dx.doi.org/10.1016/j.envpol.2016.05.011

Mishra K, Sharma RC & Kumar S (2012) Contamination levels and spatial distribution of organochlorine pesticides in soils from India. *Ecotoxicology and Environmental Safety* 76(1): 215–225. https://doi.org/10.1016/j.ecoenv.2011.09.014

Mochungong P & Zhu J (2015) DDTs, PCBs and PBDEs contamination in Africa, Latin America and South-southeast Asia – a review. *AIMS Environmental Science* 2(2): 374–399. https://doi.org/10.3934/environsci.2015.2.374

Mohaupt V, Völker J, Altenburger R, Birk S, Kirst I, Kühnel D, Küster E, Semerádová S, Šubelj G & Whalley C (2020) Pesticides in European rivers, lakes and groundwaters – Data assessment. ETC/ICM Technical Report 1/2020. https://www.eionet.europa.eu/etcs/etc-icm/products/etc-icm-report-1-2020-pesticides-in-european-rivers-lakes-and-groundwaters-data-assessment

Morrissey CA, Mineau P, Devries JH, Sanchez-Bayo F, Liess M, Cavallaro MC & Liber K (2015) Neonicotinoid contamination of global surface waters and associated risk to aquatic invertebrates: A review. *Environment International* 74: 291–303. https://doi.org/10.1016/j.envint.2014.10.024

Nesser GAA, Abdelbagi AO, Hammad AMA, Tagelseed M & Laing MD (2016) Levels of pesticides residues in the White Nile water in the Sudan. *Environmental Monitoring and Assessment* 188 (6). https://doi.org/10.1007/s10661-016-5367-3

North AC, Hodgson DJ, Price SJ & Griffiths AGF (2015) Anthropogenic and ecological drivers of amphibian disease (Ranavirosis). *PLoS ONE* 10(6): e0127037. doi:10.1371/journal.pone.0127037

Odendaal C, Seaman MT, Kemp G, Patterton HE & Patterton HG (2015) An LC-MS/MS based survey of contaminants of emerging concern in drinking water in South Africa. *South African Journal of Science* 111(9–10). https://doi.org/10.17159/sajs.2015/20140401

Orton F & Tyler CR (2015) Do hormone-modulating chemicals impact on reproduction and development of wild amphibians? *Biological Reviews* 90: 1100–1117. doi: 10.1111/brv.12147

Pan L, Sun J, Li Z, Zhan Y, Xu S & Zhu L (2018) Organophosphate pesticide in agricultural soils from the Yangtze River Delta of China: concentration, distribution, and risk assessment. *Environmental Science and Pollution Research* 25(1): 4–11. https://doi.org/10.1007/s11356-016-7664-3

Park MG, Blitzer EJ, Gibbs J, Losey JE & Danforth BN (2015) Negative effects of pesticides on wild bee communities can be buffered by landscape context. *Proceedings of the Royal Society B* 282: 20150299. http://dx.doi.org/10.1098/rspb.2015.0299

Parsons KC, Mineau P & Renfrew RB (2010) Effects of pesticide use in rice fields on birds. *Waterbirds* 33 (Special Publication 1): 193-218. https://doi.org/10.1675/063.033.s115

PBL (2019) Geïntegreerde gewasbescherming nader beschouwd – Tussenevaluatie van de nota Gezonde Groei, Duurzame Oogst (Integrated pest management closer considered – Interim evaluation of the policy for healthy growth and sustainable yield). Netherlands Environmental Assessment Agency (PBL), The Hague, The Netherlands. (in Dutch). https://www.rivm.nl/publicaties/tussenevaluatie-van-nota-gezonde-groei-duurzame-oogst-deelproject-milieu

Pelosi C, Bertrand C, Daniele G, Coeurdassier M, Benoit P, Nélieu S, Lafay F, Bretagnolle V, Gaba S, Vulliet E & Fritsch C (2021) Residues of currently used pesticides in soils and earthworms: A silent threat? *Agriculture, Ecosystems and Environment* 305. https://doi.org/10.1016/j.agee.2020.107167

Pietrzak D, Kania J, Malina G, Kmiecik E & Wątor K (2019) Pesticides from the EU First and Second Watch Lists in the Water Environment. *Clean - Soil, Air, Water* 47(7). https://doi.org/10.1002/clen.201800376

Pirsaheb M, Hossini H, Asadi F & Janjani H (2017) A systematic review on organochlorine and organophosphorus pesticides content in water resources. *Toxin Reviews* 36(3): 210–221. https://doi.org/10.1080/15569543.2016.1269810

Postigo C & Barceló D (2015) Synthetic organic compounds and their transformation products in groundwater: Occurrence, fate and mitigation. *Science of the Total Environment* 503–504: 32–47. https://doi.org/10.1016/j.scitotenv.2014.06.019

Rauert C, Harner T, Schuster JK, Eng A, Fillmann G, Castillo LE, Fentanes O, Ibarra MV, Miglioranza KSB, Rivadeneira IM, Pozo K & Aristizábal Zuluaga BH (2018) Air monitoring of new and legacy POPs in the Group of Latin America and Caribbean (GRULAC) region. *Environmental Pollution* 243: 1252–1262. https://doi.org/10.1016/j.envpol.2018.09.048

Sackaria M & Elango L (2020). Organic micropollutants in groundwater of India—A review. *Water Environment Research* 92(4): 504–523. https://doi.org/10.1002/wer.1243

Sánchez-Bayo F and Wyckhuys KAG (2019) Worldwide decline of the entomofauna: A review of its drivers. *Biological Conservation* 232: 8–27. https://doi.org/10.1016/j.biocon.2019.01.020

Sánchez-Bayo F, Goka K & Hayasaka D (2016) Contamination of the Aquatic Environment with Neonicotinoids and its Implication for Ecosystems. *Frontiers in Environmental Science* 4. https://doi.org/10.3389/fenvs.2016.00071

Schreiner VC, Link M, Kunz S, Szöcs E, Scharmüller A, Vogler B, Beck B, Battes KP, Cimpean M, Singer HP, Hollender J & Schäfer RB (2021) Paradise lost? Pesticide pollution in a European region with considerable amount of traditional agriculture. *Water Research* 188. doi:10.1016/j.watres.2020.116528

Shunthirasingham V, Oyiliagu CE, Cao Z, Gouin T, Wania F, Lee S-C, Pozo K, Harner T & Muir DCG (2010) Spatial and temporal pattern of pesticides in the global atmosphere. *Journal of Environmental Monitoring* **12:** 1650–1657. https://doi.org/10.1039/C0EM00134A

Sievers M, Hale R, Parris KM, Melvin SD, Lanctôt CM & Swearer SE (2019) Contaminant-induced behavioural changes in amphibians: A meta-analysis. *Science of the Total Environment* 693: 133570. https://doi.org/10.1016/j.scitotenv.2019.07.376

Silva V, Mol HGJ, Zomer P, Tienstra M, Ritsema CJ & Geissen V (2019) Pesticide residues in European agricultural soils – A hidden reality unfolded. *Science of the Total Environment* 653: 1532–1545. https://doi.org/10.1016/j.scitotenv.2018.10.441

Sjerps RMA, Kooij PJF, van Loon A & Van Wezel AP (2019) Occurrence of pesticides in Dutch drinking water sources. *Chemosphere* 235: 510–518. https://doi.org/10.1016/j.chemosphere.2019.06.207

Spiller KJ & Dettmers R (2019) Evidence for multiple drivers of aerial insectivore declines in North America. *The Condor: Ornithological Applications* 121(2): 1-13. https://doi.org/10.1093/condor/duz010

Stanton RL, Morrissey CA & Clark (2018) Analysis of trends and agricultural drivers of farmland bird declines in North America: A review. *Agriculture, Ecosystems and Environment* 254: 244–254. https://doi.org/10.1016/j.agee.2017.11.028

Stehle S, Bub S & Schulz R (2018) Compilation and analysis of global surface water concentrations for individual insecticide compounds. *Science of the Total Environment* 639: 516–525. https://doi.org/10.1016/j.scitotenv.2018.05.158

Stehle S and Schulz R (2015) Agricultural insecticides threaten surface waters at the global scale. *Proceedings of the National Academy of Sciences* 112(18): 5750–5755. https://doi.org/10.1073/pnas.1500232112

Stone WW, Gilliom RJ & Ryberg KR (2014). Pesticides in U.S. streams and rivers: Occurrence and trends during 1992-2011. *Environmental Science and Technology* 48 (19): 11025–11030. https://doi.org/10.1021/es5025367

Sun J, Pan L, Tsang DCW, Zhan Y, Zhu L & Li X (2018) Organic contamination and remediation in the agricultural soils of China: A critical review. *Science of the Total Environment* 615: 724–740. https://doi.org/10.1016/j.scitotenv.2017.09.271

Sun Y, Cao M, Wan Y, Wang H, Liu J, Pan F, He W, Huang H & He Z (2020) Spatial variation of 2,4-D and MCPA in tap water and groundwater from China and their fate in source, treated, and tap water from Wuhan, Central China. *Science of the Total Environment* 727: 138691. https://doi.org/10.1016/j.scitotenv.2020.138691

Székács A, Mörtl M & Darvas B (2015) Monitoring pesticide residues in surface and ground water in Hungary: Surveys in 1990-2015. *Journal of Chemistry* 2015: Article ID 717948. https://doi.org/10.1155/2015/717948

Taiwo AM (2019) A review of environmental and health effects of organochlorine pesticide residues in Africa. *Chemosphere* 220: 1126–1140. https://doi.org/10.1016/j.chemosphere.2019.01.001

Tang W, Wang D, Wang J, Wu Z, Li L, Huang M, Xu S & Yan D (2018) Pyrethroid pesticide residues in the global environment: An overview. *Chemosphere* 191 (308): 990–1007. https://doi.org/10.1016/j.chemosphere.2017.10.115

Tariq MI, Afzal S, Hussain I & Sultana N (2007) Pesticides exposure in Pakistan: A review. *Environment International* 33(8): 1107–1122. https://doi.org/10.1016/j.envint.2007.07.012

Toccalino PL, Gilliom RJ, Lindsey BD & Rupert MG (2014) Pesticides in groundwater of the United States: decadal-scale changes, 1993-2011. *Ground Water* 52: 112–125. https://doi.org/10.1111/gwat.12176

Tuck SL, Winqvist C, Mota F, Ahnström J, Turnbull LA & Bengtsson J (2014) Land-use intensity and the effects of organic farming on biodiversity: a hierarchical meta-analysis. *Journal of Applied Ecology* 51: 746–755. doi: 10.1111/1365-2664.12219

UNEP (2017) Second global monitoring report. Global monitoring plan for persistent organic pollutants. Stockholm Convention on Persistent Organic Pollutants. Conference of Parties, 8th meeting, Geneva, 24 April 5 May 2017. Document UNEP/POPS/COP.8/INF/38. United Nations Environment Programme (UNEP), Geneva. http://www.pops.int/TheConvention/ConferenceoftheParties/Meetings/COP8/tabid/5309/Default.aspx

Vorkamp K & Rigét FF (2014) A review of new and current-use contaminants in the Arctic environment: Evidence of long-range transport and indications of bioaccumulation. *Chemosphere* 111: 379–395. https://doi.org/10.1016/j.chemosphere.2014.04.019

Vulliet E, Tournier M, Vauchez A, Wiest L, Baudot R, Lafay F, Kiss A & Cren-Olivé C (2014) Survey regarding the occurrence of selected organic micropollutants in the groundwaters of overseas departments. *Environmental Science and Pollution Research* 21(12): 7512–7521. https://doi.org/10.1007/s11356-014-2619-z

Wagner N, Mingo V, Schulte U, Lötters S (2015) Risk evaluation of pesticide use to protected European reptile species. *Biological Conservation* 191: 667–673. http://dx.doi.org/10.1016/j.biocon.2015.08.002

Wang A, Hu X, Wan Y, Mahai G, Jiang Y, Huo W, Zhao X, Liang G, He Z, Xia W & Xu S (2020) A nationwide study of the occurrence and distribution of atrazine and its degradates in tap water and groundwater in China: Assessment of human exposure potential. *Chemosphere* 252. https://doi.org/10.1016/j.chemosphere.2020.126533

Wang X, Wang C, Zhu T, Gong P, Fu J & Cong Z (2019) Persistent organic pollutants in the polar regions and the Tibetan Plateau: A review of current knowledge and future prospects. *Environmental Pollution* 248: 191–208. https://doi.org/10.1016/j.envpol.2019.01.093

Weir SM, Yu S, Knox A, Talent LG, Monks JM & Salice CJ (2016) Acute toxicity and risk to lizards of rodenticides and herbicides commonly used in New Zealand. *New Zealand Journal of Ecology* 40(3): 342-350. DOI: 10.20417/nzjecol.40.43

Wolfram J, Stehle S, Bub S, Petschick LL & Schulz R (2018) Meta-Analysis of Insecticides in United States Surface Waters: Status and Future Implications. *Environmental Science and Technology* 52 (24): 14452–14460. https://doi.org/10.1021/acs.est.8b04651

Wood TJ & Goulson D (2017) The environmental risks of neonicotinoid pesticides: a review of the evidence post 2013. *Environmental Science and Pollution Research* 24(21): 17285–17325. https://doi.org/10.1007/s11356-017-9240-x

Yadav IC, Devi NL, Syed JH, Cheng Z, Li J, Zhang G & Jones KC (2015) Current status of persistent organic pesticides residues in air, water, and soil, and their possible effect on neighboring countries: A comprehensive review of India. *Science of the Total Environment* 511: 123–137. https://doi.org/10.1016/j.scitotenv.2014.12.041

Zhong G, Xie Z, Cai M, Möller A, Sturm R, Tang J, Zhang G, He J & Ebinghaus R (2012) Distribution and air-sea exchange of current-use pesticides (CUPs) from East Asia to the high Arctic Ocean. *Environmental Science and Technology* 46(1): 259–267. https://doi.org/10.1021/es202655k

Zubrod JP, Bundschuh M, Arts G, Brühl CA, Imfeld G, Knäbel A, Payraudeau S, Rasmussen JJ, Rohr J, Scharmüller A, Smalling K, Stehle S, Schulz R & Schäfer RB (2019). Fungicides: An overlooked pesticide class? *Environmental Science and Technology* 53: 3347–3365. https://doi.org/10.1021/acs.est.8b04392