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European Environment Agency
European Topic Centre on Inland, Coastal and Marine Waters

Composite pressures on water from agriculture

Defining Broad European Agricultural Regions with relevance for water management

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Contents

1. Abstract

Overview

EEA's report "Water and agriculture: towards sustainable solutions" (EEA 2020a) provides a thematic assessment of agricultural practices in Europe and their implications for water resources. Central to this assessment was the description of four key pressures on water originating from agricultural activities: Pollution from nutrients; pollution from pesticides; water abstraction for irrigation; agricultural land use in the floodplain.

This paper describes the data, methodology and results of an analysis that shows variation of farming-related pressures exerted on freshwaters depending on agricultural landscape types. Adopting the present-day farming landscape typology of Levers et al. (2018) (who delineated different types of agricultural land use intensities), it derives 15 broad European agricultural regions (BEAR), specifies their pressure-profiles, and derives the composite multi-pressure index. The index includes the four aforementioned pressures, using datasets available with European coverage aggregated at the level of more than 30 000 river catchment units. Further analysis on linking agricultural production to the pressure index is given in the annex.

Key results

In total, 15 different BEARs were defined, which show different combinations and intensities of pressures on water from agriculture. The most abundant BEARs were 'Extensive grassland and fallow farmland' (covering 25 % of catchments) and 'Western intensive cropland' (covering 17 % of catchments).

The most intense composite multi-pressures were identified for the 'Mediterranean intensive cropland' located in parts of Spain, Italy and Greece (Figure 1). In this BEAR, most pressures, including pollution from pesticides, water abstraction for irrigation and agricultural land use in the floodplain are particularly high, whereas nitrogen surplus is lower. The regions with the lowest composite multi-pressures were 'Northern and Highland livestock farming' and 'Extensive grassland area and fallow farmland'.

Consultation questions

1. Do you think it is useful to establish a composite multi-pressure index of agriculture on water at pan-European scale?

2. Do you think the methodology used is appropriate for this type of analysis (regarding BEAR delineation and definition of the composite multi-pressure index)?

3. Can you agree with the results of the multiple pressure analysis in your country (in general, and in detail regarding specific areas)?

4. How could such an analysis be subject to regular updates, and at which frequency?

5. What further information could be included to support or improve the analysis?

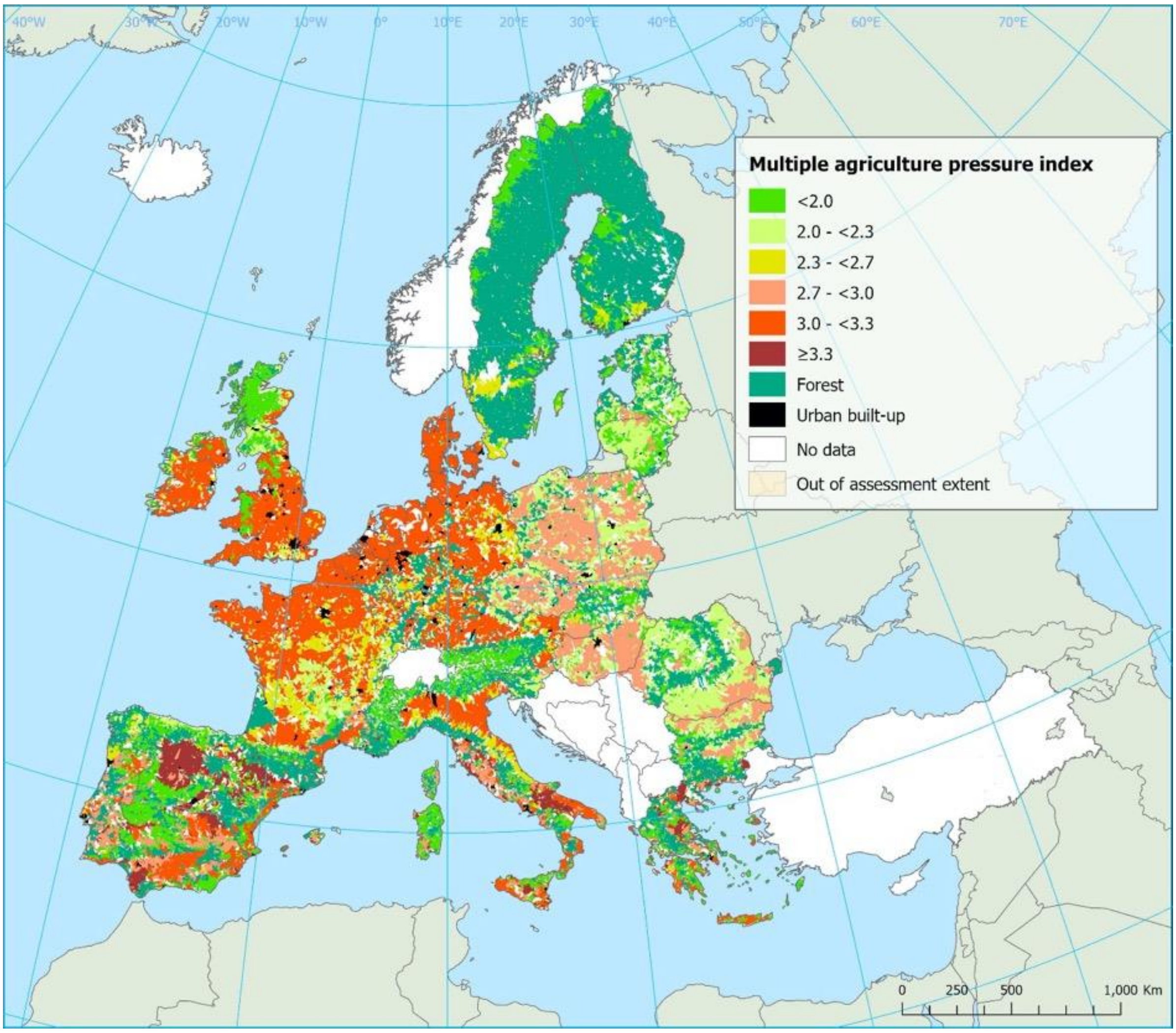

Figure 1: Composite agricultural pressure index classifying the average intensity of multiple pressures from agriculture on water bodies in a catchment

2. Data basis

2.1. Spatial reference units

The study was built on the ‘European catchments and rivers network system’ (Ecrins), i.e. a geographical information system of the European hydrographical sub-catchments organised from a layer of 104,684 so-called ‘Functional Elementary Catchments’ (FECs) with an average size of about 60 km2 (EEA, 2012). The FEC-level represents the spatial unit at which all data used in this study were processed. All data referring to different spatial units (e.g. NUTS or E-HYPE sub-basins) were transferred into FEC-level (see Globevnik et al., 2017).

2.2. Existing landscape classifications

Two existing landscape classifications were influential to this study: (1) Six different agricultural land systems (derived from the “Land-system Archetypes” of Levers et al., 2018) and (2) four major European agricultural regions (derived from the biogeographical regions of the Habitats Directive of the European Community; Roekaerts, 2002).

The “Land-system Archetypes” developed by Levers et al. (2018) were defined at the pan-European scale (covering EU-28, except Croatia) on the basis of selected land-use indicators (e.g. various agricultural or forestry land cover, fallow farmland, nitrogen input, livestock density) representing the conditions in the year 2006. These archetypes describe landscapes featuring similar patterns of land cover and management intensities related to farming and forestry. Management intensity is classified by indicators of input-intensity (nitrogen application rates, livestock stocking densities) and output-intensity (amount of harvested biomass). The “Land-system Archetypes” were aggregated into six agricultural land systems characterised by type of land cover and management intensity: intensive and extensive cropland, intensive and extensive livestock, extensive grassland and fallow farmland. Management intensity classifies the material and labour input and harvest yield output, generally separating between intensive and extensive agricultural land systems.

Four major European agricultural regions were delineated to be used in all subsequent analysis: Western, Eastern, Mediterranean, and a combination of Northern and Highlands. This classification is framed by the biogeographical regions in Europe (Roekaerts, 2002) grouped into four major regions matching the geographical intercalibration groups relevant in ecological freshwater status assessment (Poikane et al., 2014). It considers the coarse climatic and socio-economic differences between the areas, which influence the agricultural land systems: The Western area generally exhibits favourable climatic and economic conditions for productive agriculture, while the Eastern area is still characterised by less-favourable conditions for historically and socio-economic reasons. Climate-induced water scarcity is the decisive factor in the Mediterranean, and the Northern and Highland areas are largely less-favourable areas for agricultural production due to wet and cold climatic conditions (Metzger et al., 2005; Kuemmerle et al., 2008).

Figure 2 shows the distribution of different agricultural land systems across Europe, for which the management intensity was quantified combining nitrogen input, livestock density and harvested output (Levers et al., 2018), together with the major agricultural regions of Europe.

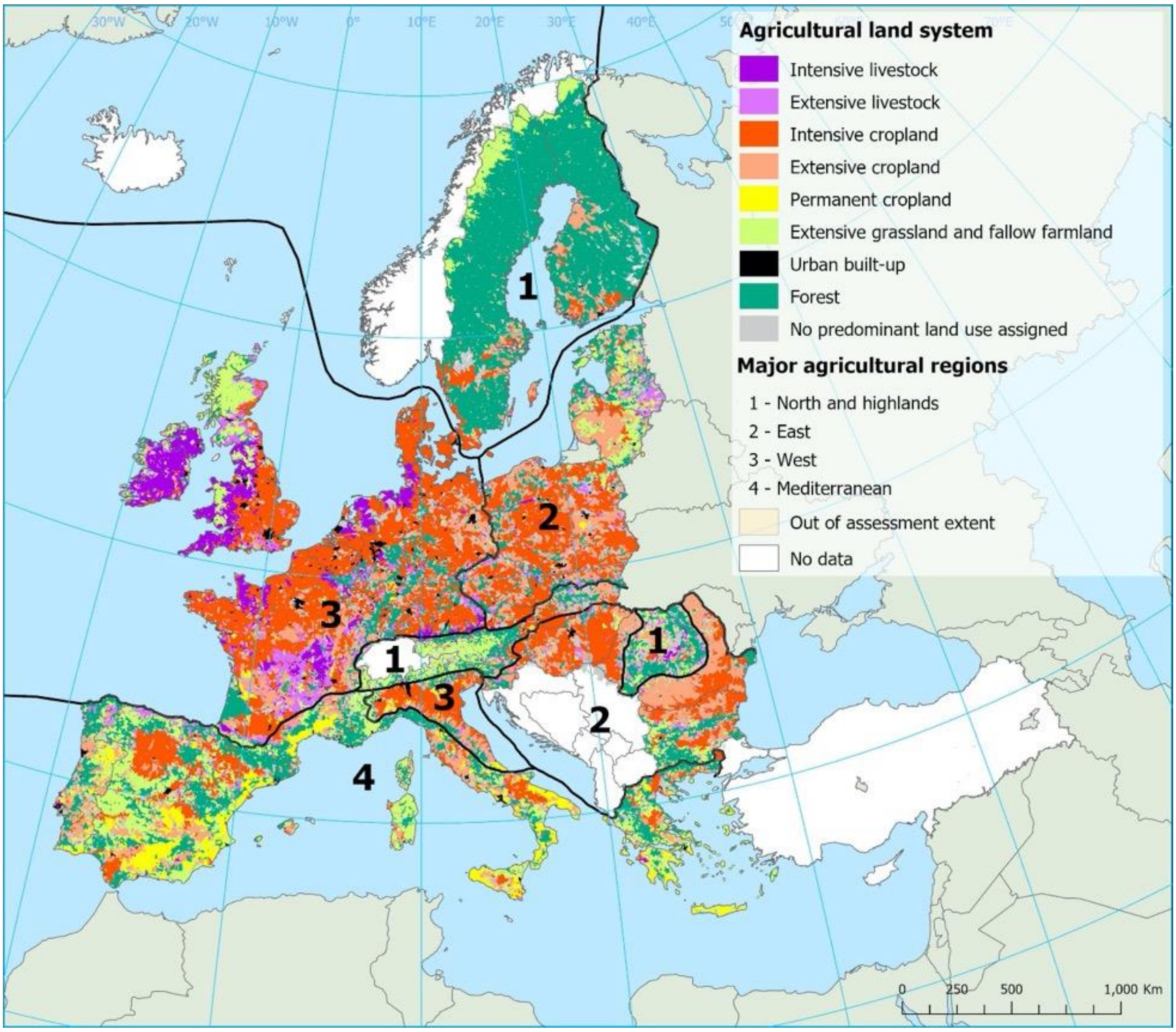

Figure 2: Agricultural land systems distributed across four major agricultural regions in Europe.
The map shows the dominant land system per FEC (see text for details).

2.3. Pressure data

Pan-European data sets on agricultural pressures were developed based on available modelled or remotely sensed datasets. These datasets include diffuse pressures (nutrients, pesticides), hydrological pressures (water abstracted for irrigation) and agricultural land use in the river floodplain (proxy-indicator for various direct agricultural pressures including morphological alteration). The available data are specified in the following sections.

Note: All pressure data used met the criteria of being available on pan-European scale at a spatial resolution corresponding to the FEC-level. Aspects of data accuracy and uncertainty have not been specified in this document, as this consultation primarily aims at learning your views on the overall approach of defining a composite multi-pressure index on water from agriculture.

Diffuse pressures: nutrients

To estimate the effects of farming-related nutrient pollution on freshwater ecosystems, the parameter nitrogen surplus, which is the difference between nitrogen input (e.g. fertilisers, feed) and output (e.g.

animal and plant products), was used. It was calculated using the CAPRI (Common Agricultural Policy Regional Impact Analysis) modelling system (Britz and Witzke, 2014), a global economic model for agriculture with a regionalised focus for Europe, which uses regional and national data inputs based on official EUROSTAT statistics. The CAPRI nitrogen balances relevant for this study were estimated for the year 2012, on the basis of four components: (1) Export of nutrients by harvested material per crop, depending on regional crop patterns and yields, (2) output of manure, depending on the animal type, (3) input of mineral fertilizers, based on national statistics at sectoral level and (4) a model for ammonia pathways. The model outputs provided indicators of regional farm, land and soil nitrogen-budgets and nitrogen-flows of the agricultural sector at the European scale (Leip et al., 2011). The indicator ‘nitrogen surplus on agricultural areas’ was selected as a proxy for nutrient pollution pressure, aggregated at FEC-level (Figure 3).

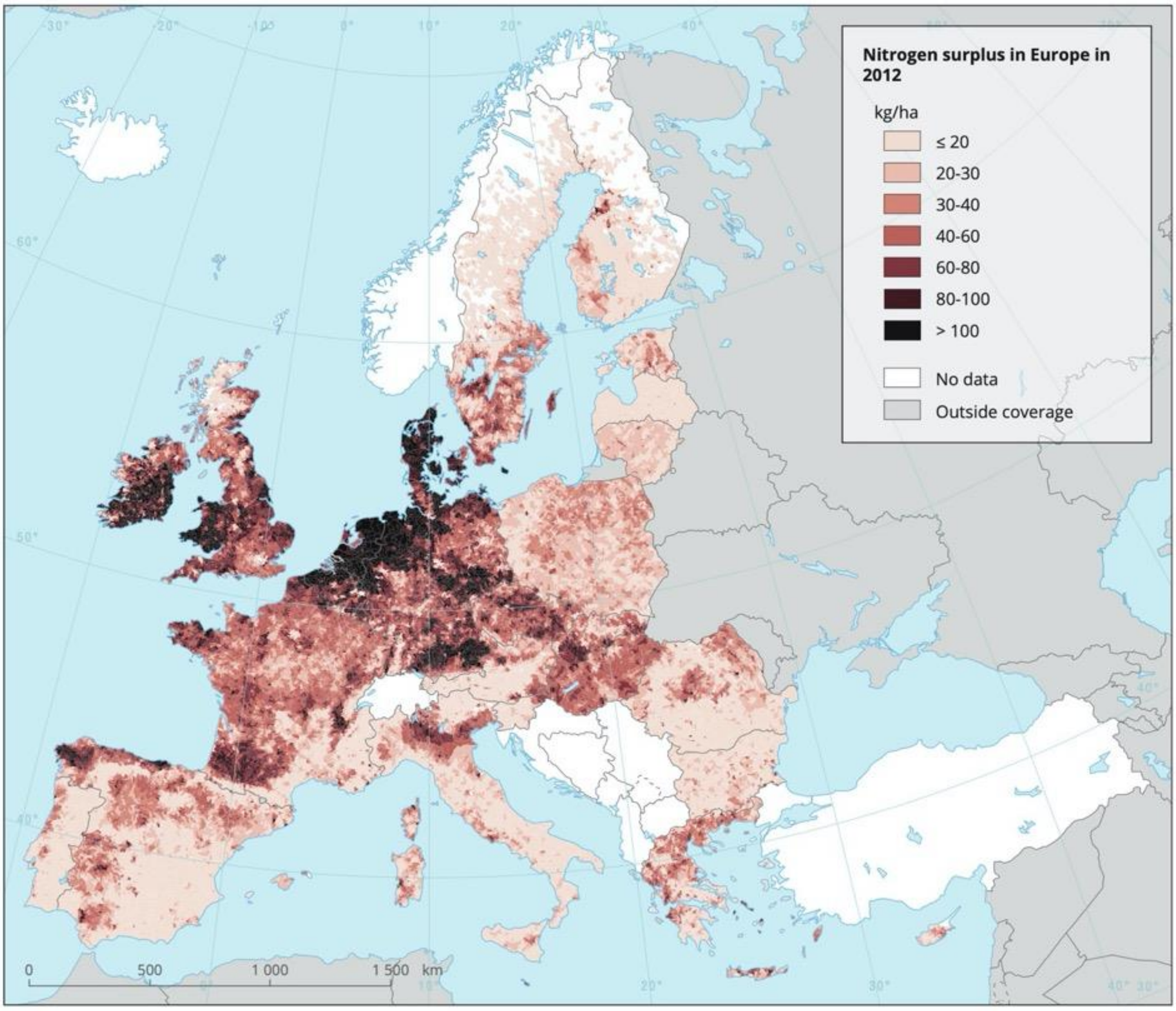

Figure 3: Geographical distribution of the nitrogen surplus on agricultural areas, calculated by FEC

Diffuse pressures: pesticides

To quantify the effects of pesticides on the freshwater ecosystems, he chronic multi-substance Potentially Affected Fraction (msPAF) was used, derived from Europe-wide integrated exposure and effect modelling for the year 2013 (van Gils et al., 2020). The msPAF specifies the potential share of the aquatic species community affected by pesticide toxicity. The model includes two components:
(1) a spatio-temporally resolved model for emissions and fate-transport of chemicals driven by a hydrological model (van Gils et al., 2020), yielding Europe-wide daily predicted environmental concentrations (freely dissolved part) of 332 pesticides in water bodies to obtain a “real-life” mixture

exposure scenario for each FEC, and

(2) species sensitivity distributions (SSD) based on effect models considering chronic non-observed-effect concentrations (NOEC) of each studied chemical as effect endpoint (Posthuma et al., 2019). Combining (1) and (2), and adding a step of mixture modelling yields the mixture toxic pressure metric, which is expressed as multi substance Potentially Affected Fraction of species (msPAF) (de Zwart & Posthuma, 2005; Posthuma et al., 2020), being an estimate of the likelihood (values between 0 and 1) of direct effects of chemical exposure to effect-endpoints of aquatic organisms such as growth and reproduction (Posthuma et al., 2019). In this study, the msPAF-NOEC based on 99th percentile predicted environmental concentrations of the daily concentration estimates was used, representing an acute toxic stress level exceeded at four days per year (Figure 4).

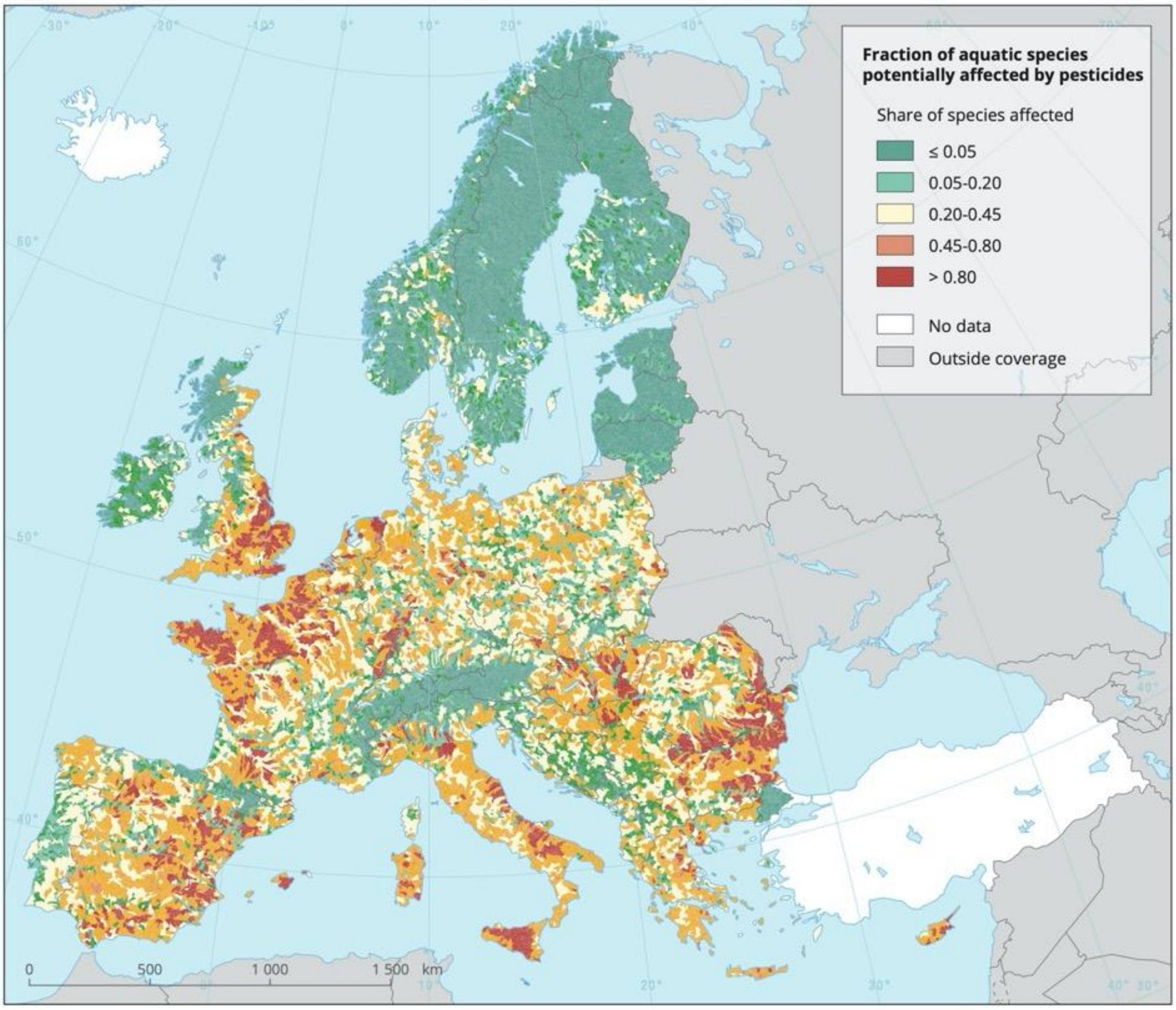

Figure 4: Geographical distribution of the fraction of aquatic species in Europe potentially affected by pesticides, calculated by FEC

Hydrological pressure: water abstracted for irrigation

To consider the effect of crop irrigation, the annual volume of water abstracted for agricultural irrigation (acquired for the year 2015) was compiled (Zal et al., 2017). Water abstraction represents the main driver of water consumption in agriculture. The data are intermediate model outputs from pan-European water quantity accounting at FEC-level with monthly resolution. The monthly values were summed up to the total annual amounts and transformed to cubic metres per hectare, dividing the annual water abstracted in each FEC by the irrigated crop area in the respective FEC (Figure 5).

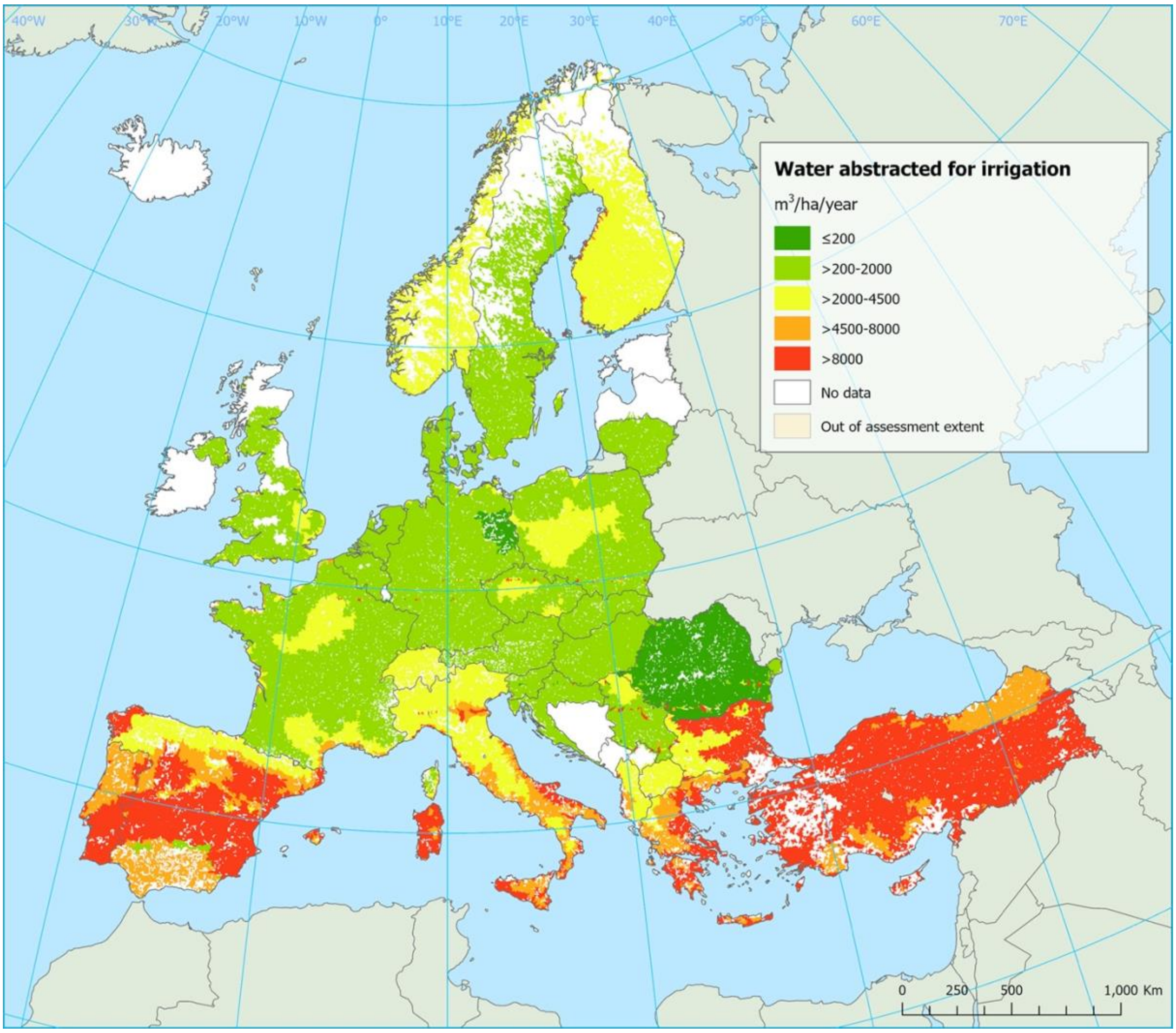

Figure 5: Geographical distribution of the annual volume of water abstracted for agricultural irrigation, calculated by FEC

Agricultural land use in potential river floodplain

To incorporate the hydromorphological alteration caused by agriculture, the area of agricultural land located in the potentially flood-prone areas was calculated as an average of the years 2011 to 2013 (EEA, 2020; Figure 6). It was derived from two spatial layers, (1) the JRC flood hazard map for Europe 100- year return period, compiled with the flood model 'LisFlood' (Bates & De Roo, 2000; Alfieri et al., 2014) and (2) the Copernicus Potential Riparian Zone layer compiled with data from the Copernicus Land Monitoring Service (EEA, 2015; CLMS, 2019). This proxy-indicator allows for an estimate of various farming-related pressures on the freshwater ecosystems and can be interpreted as the probability of morphological alterations to surface waters due to agricultural activities, e.g. drainage of floodplain area caused by agricultural production.

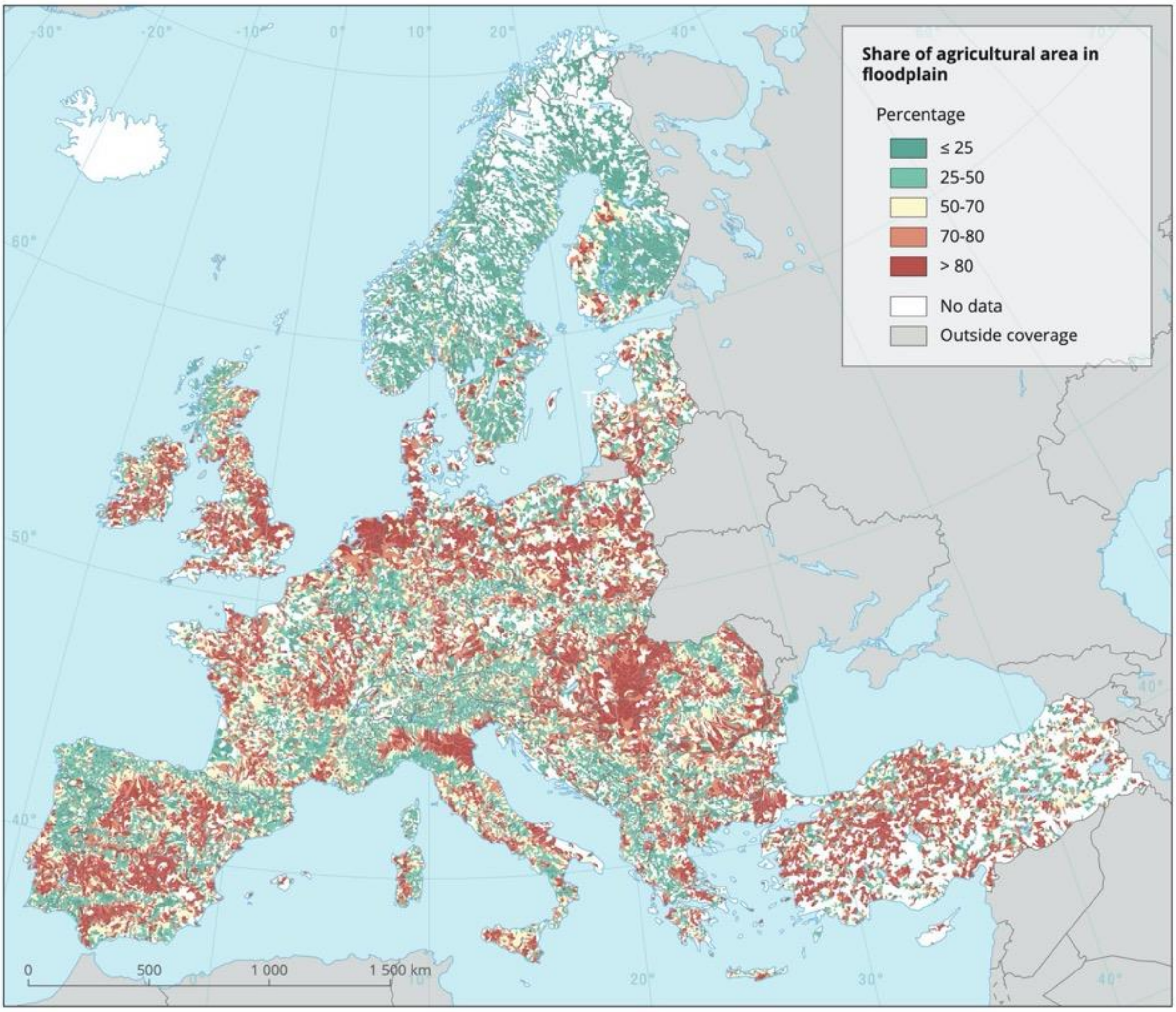

Figure 6: Geographical distribution of the share of agricultural land in floodplain areas, calculated by FEC

3. Analysis

3.1. Deriving the Broad European Agricultural Regions (BEARs)

To generate homogeneous groups of agricultural land use featuring similar farming-related freshwater pressures, existing landscape classifications were combined and associated with the pressure data as described below.

Step 1: Identifying dominant agricultural archetypes

Out of the 15 different Land-system Archetypes of Levers et al. (2018), the twelve agriculture-related archetypes were selected for further processing. Data of these were provided in 3 x 3 km raster-cells and transferred into FEC-level. A total number of 30,540 FECs were identified, for which a specific archetype was prevailing (i.e. ≥50 % FEC coverage), accounting for 32.6% of Europe's terrestrial area (European Member States in 2012). These dominant agricultural archetypes (separated into crop-related and livestock-related archetypes) formed the basis for the subsequent linkage to the freshwater pressures at FEC-level. FECs without a dominant archetype were not further analysed.

Step 2: Combining dominant agricultural archetypes and major agricultural regions

To determine the dominant agricultural archetypes per major agricultural region, these two landscape classifications were combined. This resulted in a total of 48 combined ‘regionalized archetypes’.

Step 3: Defining pressure-profiles

Using boxplots, pressure-ranges per regionalized archetype were allocated and median values were compared to identify archetypes with similar levels of pressure. These pressure levels were ranked, ranging from 1 (‘very low’) to 4 (‘high’) according to their medians (Table 1) referring to either existing classifications of pressure intensity for nitrogen surplus (Rega et al., 2019; Figure 7) and pesticides (van Gils et al., 2019; Figure 8), or expert judgement for water abstraction (Figure 9) and floodplain agricultural land use in the floodplain (Figure 10). These rankings of individual pressure-ranges established a ‘pressure-profile’ for each regionalized archetype. Note that pesticide pressure levels were not assigned to livestock archetypes and abstraction pressure levels were not assigned to low intensity grassland and fallow farmland archetypes, as these pressures were deemed irrelevant for these archetypes.

Step 4: Merging regionalized archetypes with similar pressure-profiles

To reduce the total number of types, the regional archetypes showing similar pressure-profiles were merged. In this step, the cropland-archetypes of high and medium management intensity (using the classification of Levers et al., 2018) were combined into the category of ‘intensive cropland’ featuring substantial areas with nitrogen application rates > 50 kg ha^{-1} a^{-1} and higher amounts of harvested biomass. The cropland-archetypes of low management intensity (nitrogen application rates < 50 kg ha^{-1} a^{-1}, lower amounts of harvested biomass) were categorised as ‘extensive cropland’. Pressure-profiles of intensive and extensive livestock-archetypes did not differ between regions except for the Western region, for which a distinction between ‘intensive livestock’ and ‘extensive livestock’ was made. For all other regions a single livestock category was devised. Archetypes belonging to different major agricultural regions were generally not merged except for ‘fallow farmland’ and ‘low-intensity grassland’, which were combined across all areas.

Step 5: Delineating the BEARs

The merging of regionalized archetypes done in the previous step resulted in 15 Broad European Agricultural Regions (BEARs), representing large-scale landscape units of similar agricultural land use and farming-related pressures on freshwater ecosystems.

Step 6: Calculating the pressure index

To summarize the farming-related pressures exerted on the freshwater ecosystems across Europe, a composite multi-pressure index was calculated for each BEAR by summing up the numerical values of all individual pressure levels divided by the number of pressures considered for the respective BEAR.

Table 1: Pressure indicators and levels ranked into four classes of pressure intensity

Pressure indicator[1]	Unit	Very low (1)	Low (2)	Medium (3)	High (4)
Nitrogen surplus	kg/ha/year	≤ 20	> 20 - 30	> 30 - 40	> 40
Potentially Affected Fraction of species by pesticides	--	≤ 0.20	> 0.20 -0.35	> 0.35 - 0.50	> 0.50
Water abstracted for irrigation	m^3/ha/year	≤ 2,000	> 2,000 – 4,500	> 4,500 – 8,000	> 8,000
Agricultural land use in the floodplain	%	≤ 50	> 50 -65	> 65 - 80	> 80

[1] All values relate to entire FEC area (including ≥50% agricultural area). It is not based on utilised agricultural area.

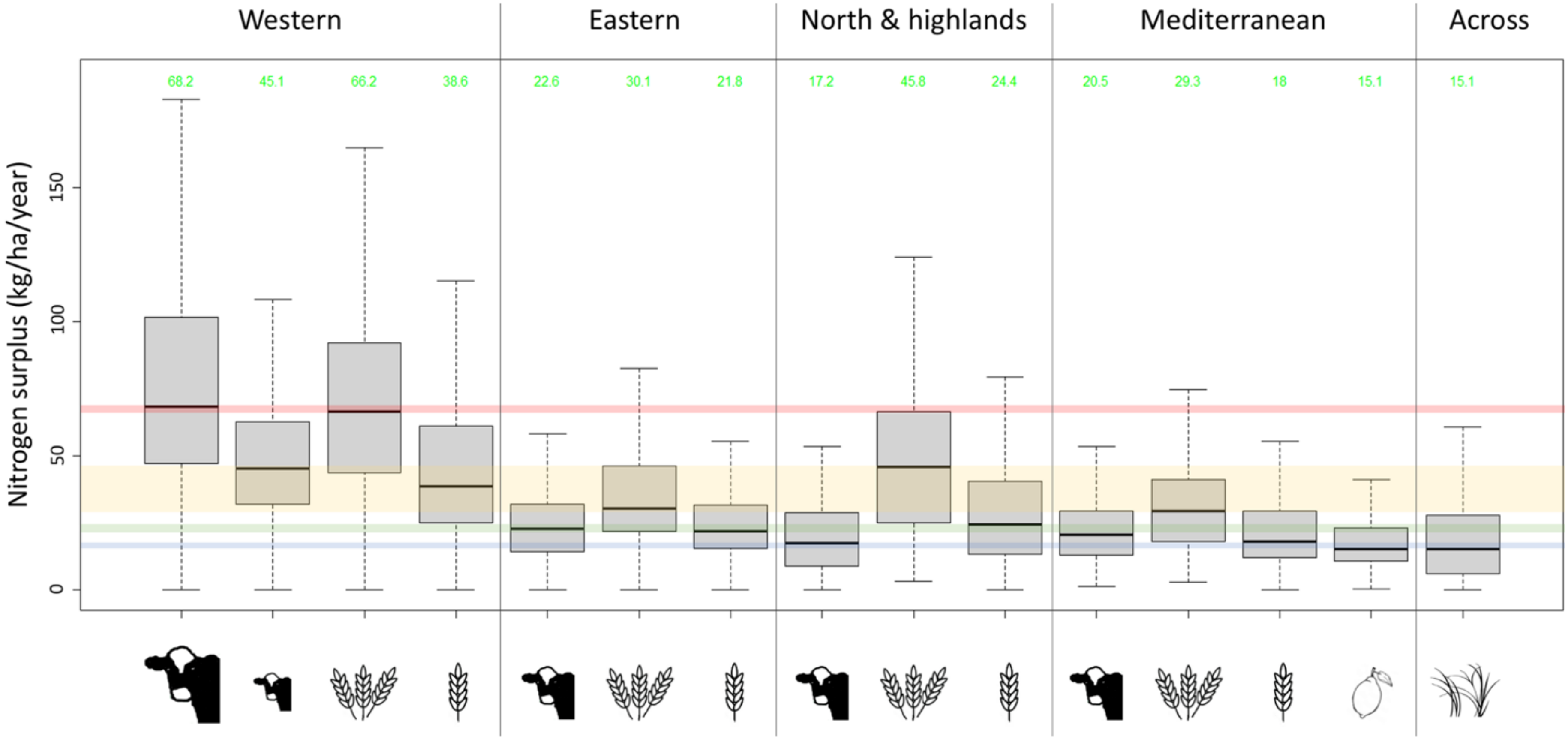

Figure 7: Nitrogen surplus ranges identified for the different Broad European Agricultural regions (BEARs)

Large cow = Intensive livestock farming; Small cow = Extensive livestock farming; Medium-sized cow = Livestock farming (incl. intensive and extensive); Three ears = Intensive cropland; One ear = Extensive cropland; Lemon = Large-scale permanent cropland, Grass = Extensive grassland and fallow farmland; Across = Defined across all major agricultural regions.

Pressure ranking: Red band = High; Yellow band = Medium; Green band = Low; Blue band = Very low.

Median values for each BEAR are given in green numbers above each plot. Extreme values (=outliers) are not plotted.

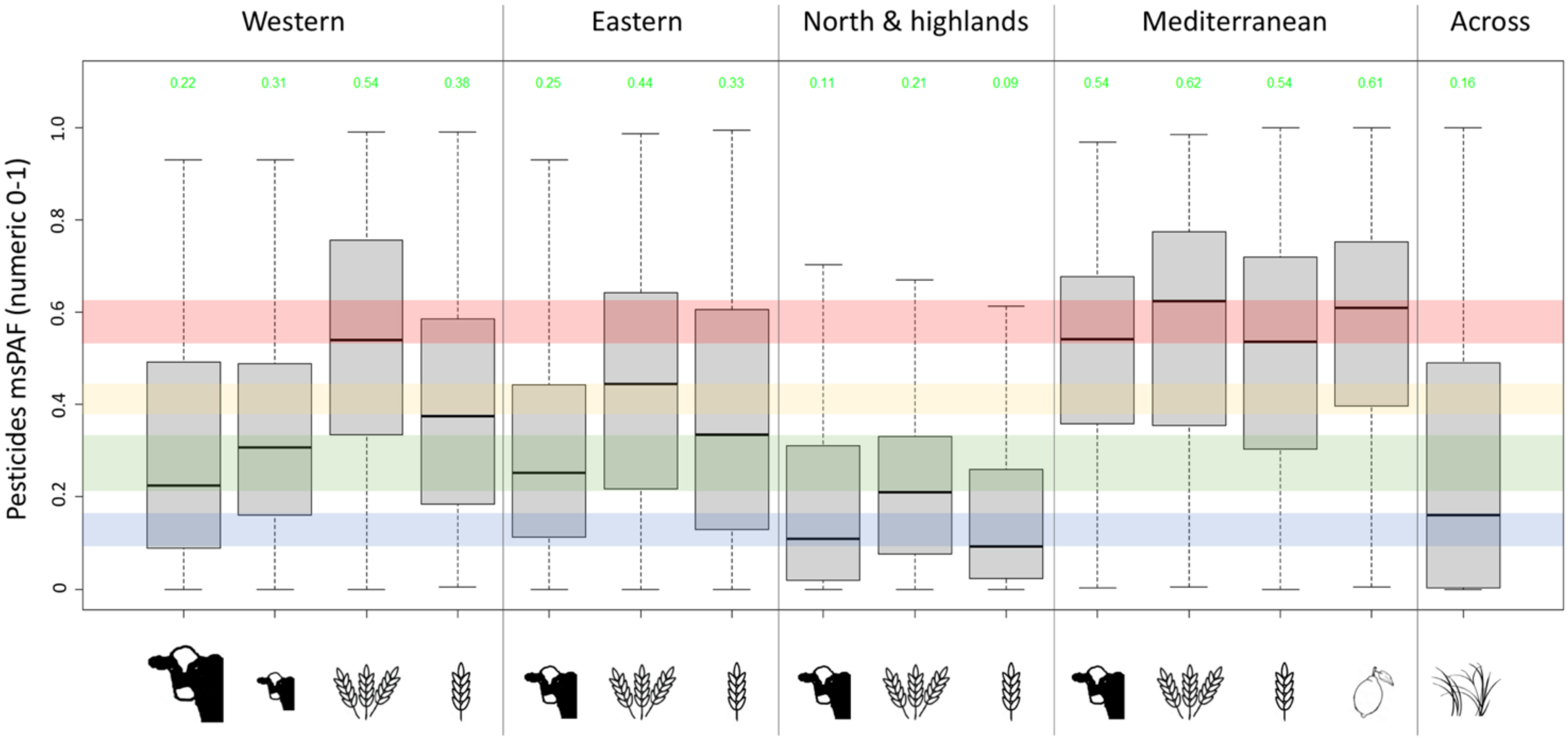

Figure 8: Pesticides msPAF ranges identified for the different Broad European Agricultural regions (BEARs).
See Figure 7 for details.

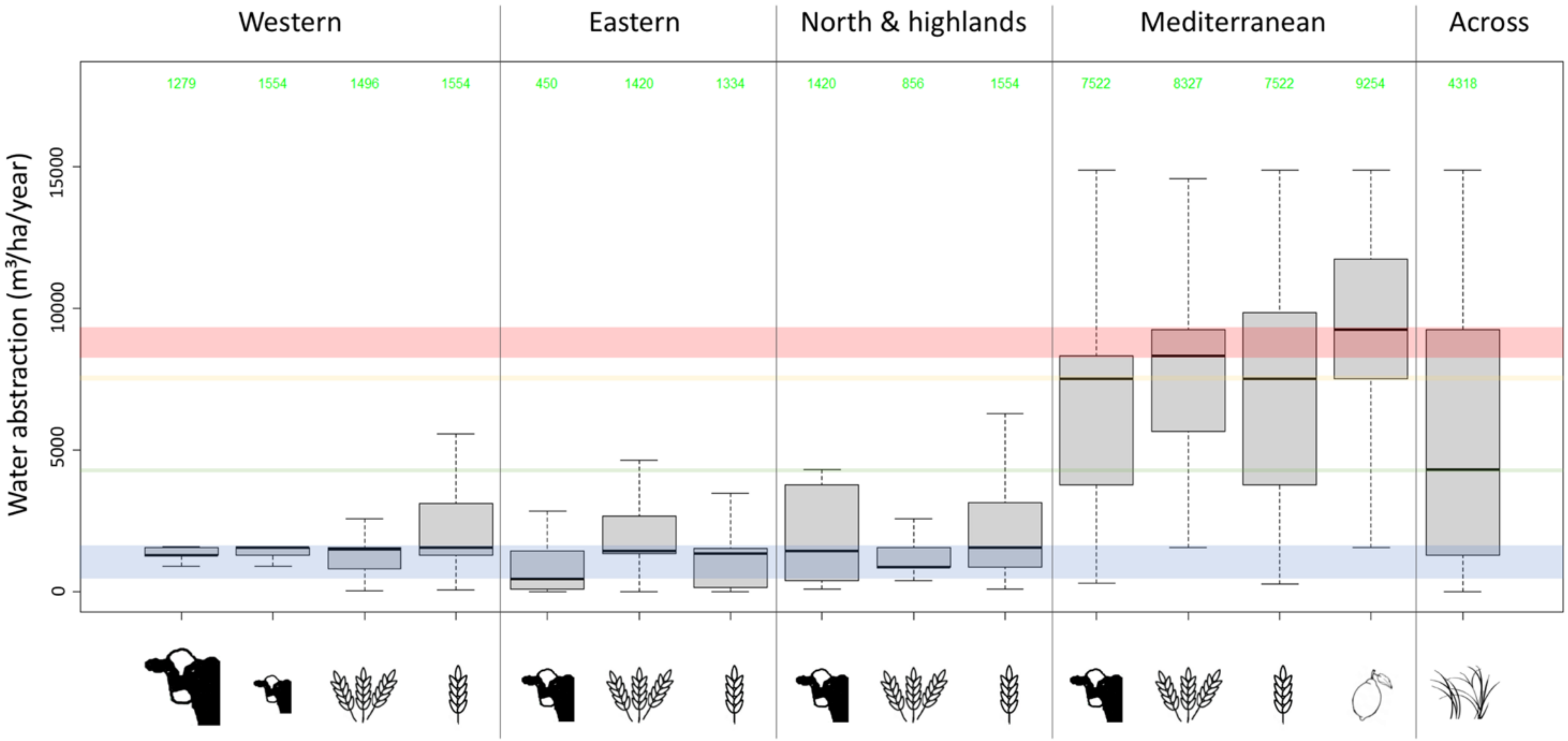

Figure 9: Water abstraction ranges identified for the different Broad European Agricultural regions (BEARs). See Figure 7 for details.

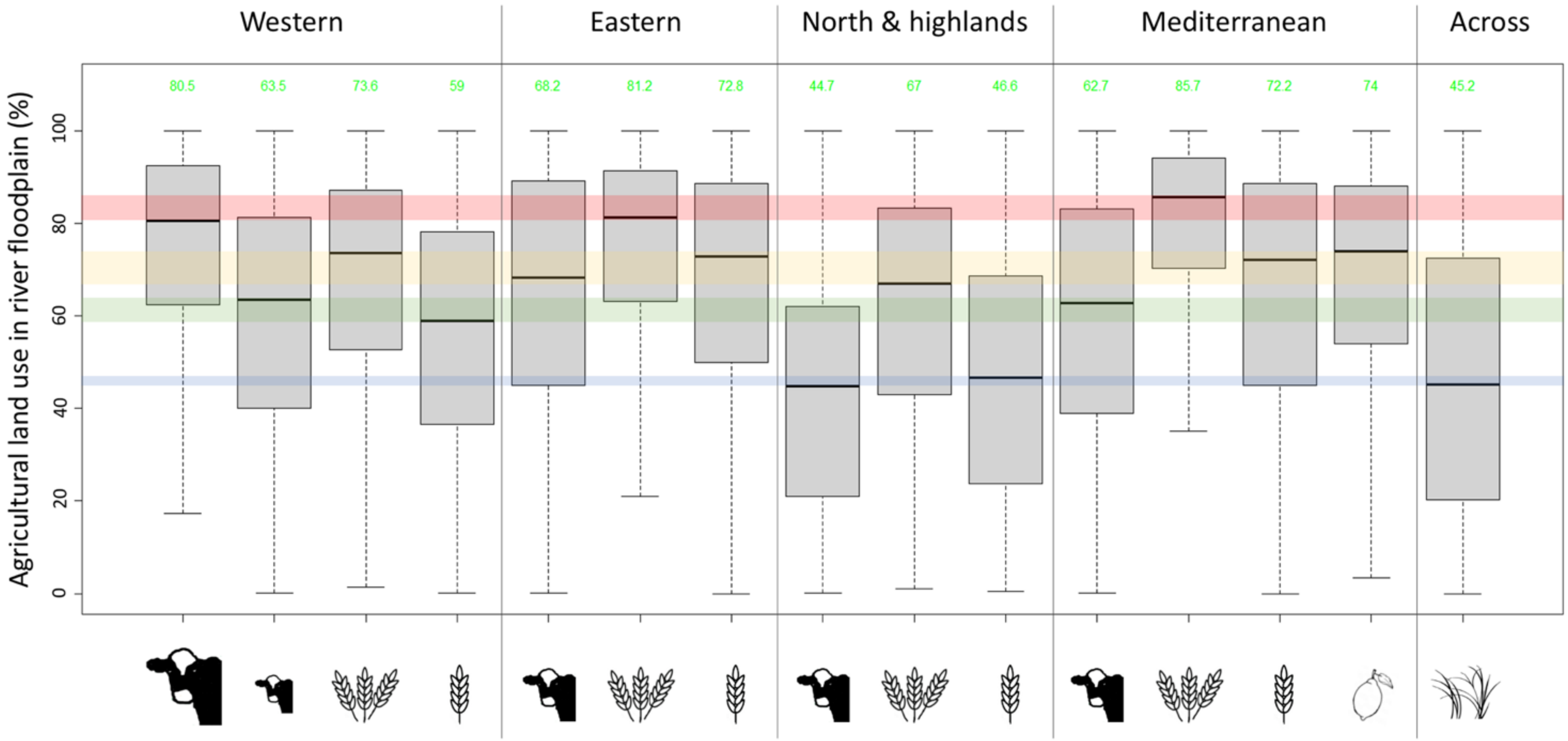

Figure 10: Agricultural land use in the floodplain ranges identified for the different Broad European Agricultural regions (BEARs)
See Figure 7 for details.

4. Results

4.1. Delineation of Broad European Agricultural Regions (BEARs)

The delineated 15 BEARs portray the diversity of agricultural land systems in Europe. While Northern Europe is mostly covered by forests, the other areas are mainly covered by BEARs of different size and character. Overall, the most abundant BEARs are ‘Low-intensity grassland and fallow farmland‘ (share: 25.3 % of FECs) and ‘Western intensive cropland‘ (17.1 %). Accordingly, ‘Northern and Highland livestock farming’ (1.0 %) and ‘Mediterranean livestock farming’ (0.8 %) are least represented (Table 2).

4.2. Pressure-profiles

A broad range of pressure levels across the BEARs can be observed, with the ‘Mediterranean intensive cropland’ featuring overall highest pressure levels (Table 2). The BEARs in Western Europe show the highest levels of nutrient pressure, whereas the BEARs in the Mediterranean show the highest levels of pesticide and water abstraction pressure, with the latter being very low for all other BEARs. The composite multi-pressure index shows highest values for the ‘Mediterranean intensive cropland’, located in specific regions of Greece, Italy and Spain (Figure 11). The intensively farmed regions of Western Europe, including France, Germany Denmark and UK, also feature high values of the pressure index. Agricultural areas with low pressure index values are located in the Eastern as well as the Northern and Highland regions.

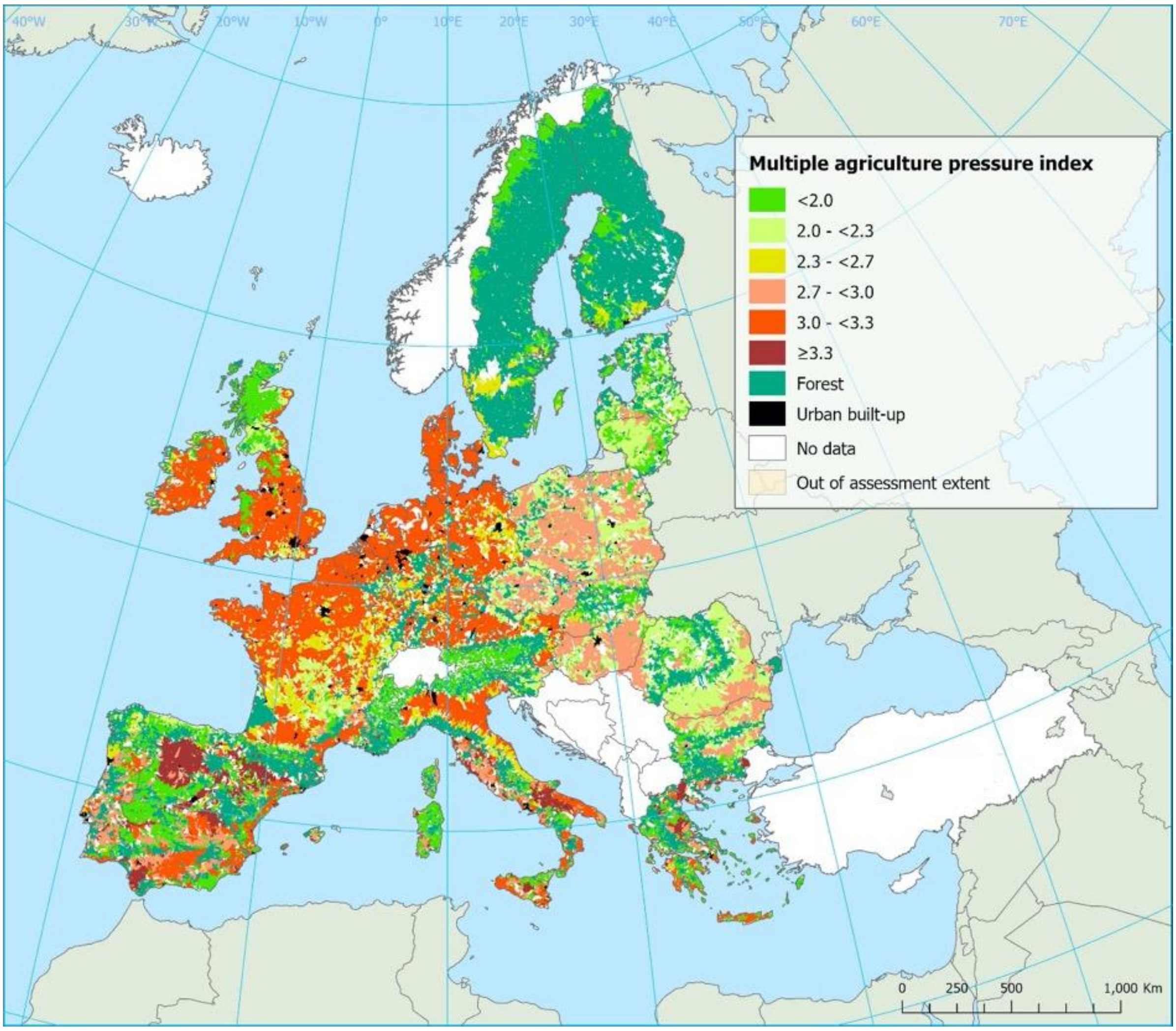

Figure 11: Composite agricultural pressure index classifying the average intensity of multiple pressures from agriculture on water bodies in a catchment

Table 2: The 15 BEARs ranked according to the composite agricultural multi-pressure index, including their pressure-profiles, total crop yield and spatial extents.

#FEC = number of FECs; %FECs = percentage of FECs; note that pesticide pressure levels were not assigned to the livestock-related BEARs and water abstraction pressure levels were not assigned to the BEAR 'Extensive grassland area and fallow farmland'.

BEAR	Pressure index	Nitrogen pressure	Pesticide pressure	Agricultural land use in floodplain	Water abstraction	Total crop yield [t km^{-2}][1]	#FECs	%FECs	Area [ha]
Mediterranean intensive cropland	3.5	*low*	*high*	*high*	*high*	60.5	1,267	4.1	8,631,175
Western intensive cropland	3.0	*high*	*high*	*medium*	*very low*	78.6	5,227	17.1	39,888,953
Mediterranean large-scale permanent cropland	3.0	*very low*	*high*	*medium*	*high*	51.9	1,958	6.4	10,299,484
Western intensive livestock farming	3.0	*high*	-	*high*	*very low*	-	2,033	6.6	12,851,906
Eastern intensive cropland	2.8	*medium*	*medium*	*high*	*very low*	61.2	2,778	9.1	26,377,358
Mediterranean extensive cropland	2.8	*very low*	*high*	*medium*	*medium*	50.8	1,463	4.8	7,176,737
Mediterranean livestock farming	2.3	*low*	-	*low*	*medium*	-	244	0.8	646,847
Western extensive cropland	2.3	*medium*	*medium*	*low*	*very low*	60.0	1,880	6.1	8,385,316
Northern and Highland intensive cropland	2.3	*medium*	*low*	*medium*	*very low*	55.0	374	1.2	2,681,189
Western extensive livestock farming	3.0	*medium*	-	*low*	*very low*	-	1,323	4.3	6,240,752
Eastern livestock farming	2.0	*low*	-	*medium*	*very low*	-	553	1.8	2,037,532
Eastern extensive cropland	2.0	*low*	*low*	*medium*	*very low*	42.2	2,618	8.6	16,590,568
Northern and Highland extensive cropland	1.3	*low*	*very low*	*very low*	*very low*	40.8	816	2.7	3,799,863
Northern and Highland livestock farming	1.0	*very low*	-	*very low*	*very low*	-	314	1	779,044
Extensive grassland area and fallow farmland	1.0	*very low*	*very low*	*very low*	-	0.2	7,689	25.1	33,737,274

[1] see Annex 1 for details on the production data and related analysis

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Annex 1 Linking composite pressures to agricultural drivers

The composite pressure index allows for analysing the interrelations of driving forces, pressures, states, impact and responses according to the DPSIR analytical framework. In this annex, we exemplarily demonstrate the assessment potential by analysing the relationship between agricultural production and the intensity of composite pressures from agriculture at the pan-European scale.

Data basis: Agricultural production

The agricultural crop yields (tons per hectare; reference years: 2016, 2017), livestock population density (heads of individual livestock types per hectare and 'Livestock Units' [LSU] as an indicator aggregating from various livestock types and ages; reference year: 2016) were mapped based on Eurostat (EUROSTAT, 2019a; 2019b; 2019c; 2019d). These agricultural production data were largely available at NUTS2-level and supplemented by data at NUTS1- and NUTS0-level, where necessary. Ten crop types (Table A.1) and the following four livestock types were delineated: Cattle, dairy cattle, pigs, poultry.

Table A.1: Crop types, crop codes and share of production area in 2015

Group	Crop type	Crop code	Production area (%)
'Ubiquitous' crops	Cereals for the production of grain (including seed)	C0000	52.4
	Plants harvested green from arable land	G0000	18.8
	Industrial crops	I0000	11.5
	Root crops	R0000	2.9
	Dry pulses and protein crops for the production of grain	P0000	2.0
	Fresh vegetables (including melons) and strawberries	V0000, S0000	2.0
Permanent crops for human consumption	Olives	O1000	4.6
	Grapes	W1000	2.9
	Fruits, berries and nuts	F0000	2.3
	Citrus fruits	T0000	0.5

Linking agricultural production to BEARs

For each of the ten crop-related BEARs (see Table 2 in the main text above), the yields of all crop types produced in a FEC (tons per hectare) were summed up and the median value of total crop yields per BEAR was calculated as a simple proxy for agricultural productivity. To characterize the main crop patterns cultivated in each BEAR, the dominant crop type shares contributing to the total crop yield were also determined. For each of the five livestock-related BEARs, the median values of LSU and the four livestock BEARs were calculated.

Relating agricultural production and pressure

To analyse the connection between agricultural production and pressure, the median values of total crop yields per BEAR and the median values of LSU, respectively, were correlated with the pressure index using Spearman Rank Correlation.

Agricultural crop production

Substantial differences in the total crop yields across BEARs can be observed (see Table 2 above), with overall highest yields for 'Western intensive cropland' and lowest yields for 'Extensive grassland and fallow farmland'. Regarding individual crop types, all BEARs feature considerable shares of root crops, with these crops being dominant in all Western, Northern and Highland BEARs and 'Eastern intensive cropland'. 'Eastern extensive cropland' shows largest shares of cereal yields, while the Mediterranean BEARs are dominated by yields of either citrus fruits or industrial crops.

Agricultural animal production

Comparing across all five livestock-related BEARs, the two Western regions show pronounced cattle densities, also reflected by the aggregated indicator 'Livestock Units' (Table A.2). 'Western intensive livestock farming' features overall highest cattle densities, including dairy cattle. The production of pigs and poultry is almost evenly distributed across the five BEARs.

Table A.2: Overview of the livestock production of the five BEARs including livestock farming (median values of Livestock Units [LSU] and heads per hectare)

BEAR	LSU[1]	Pigs	Cattle	Dairy cattle	Poultry
Western intensive livestock farming	1.21	0.43	1.53	0.15	2.55
Western extensive livestock farming	0.80	0.18	0.73	0.06	2.23
Eastern livestock farming	0.32	0.47	0.19	0.05	3.24
Northern and Highlands livestock farming	0.48	0.30	0.38	0.06	2.39
Mediterranean livestock farming	0.35	0.35	0.17	0.01	2.78

[1]The reference unit used for the calculation of livestock units (=1 LSU) is the grazing equivalent of one adult dairy cow producing 3,000 kg of milk annually.

Relating agricultural production and pressure

For the crop-related BEARs, the total crop yield and the composite multi-pressure index were significantly correlated (Spearman $R = 0.76$, $p=0.011$; Figure A.1). Root crops dominate the harvest yields of all BEARs except for the Mediterranean large-scale permanent and extensive cropland. In these two, industrial crops contribute the largest share to the total crop yield. Significant amounts of industrial crops are also harvested in the Mediterranean intensive cropland, while citrus fruits contribute a considerable share in the Mediterranean large-scale permanent cropland. Plants harvested green are harvested in almost all BEARs. It has to be noted that this weight-based characterization of crop patterns favours crops with a high specific weight (such as root crops) compared to crops with a low specific weight (such as cereals).

For the livestock-related BEARs, animal density (expressed as LSU) and pressure index showed no significant correlation, but 'Western intensive livestock' featured higher pressure levels than all other BEARs (Figure A.2).

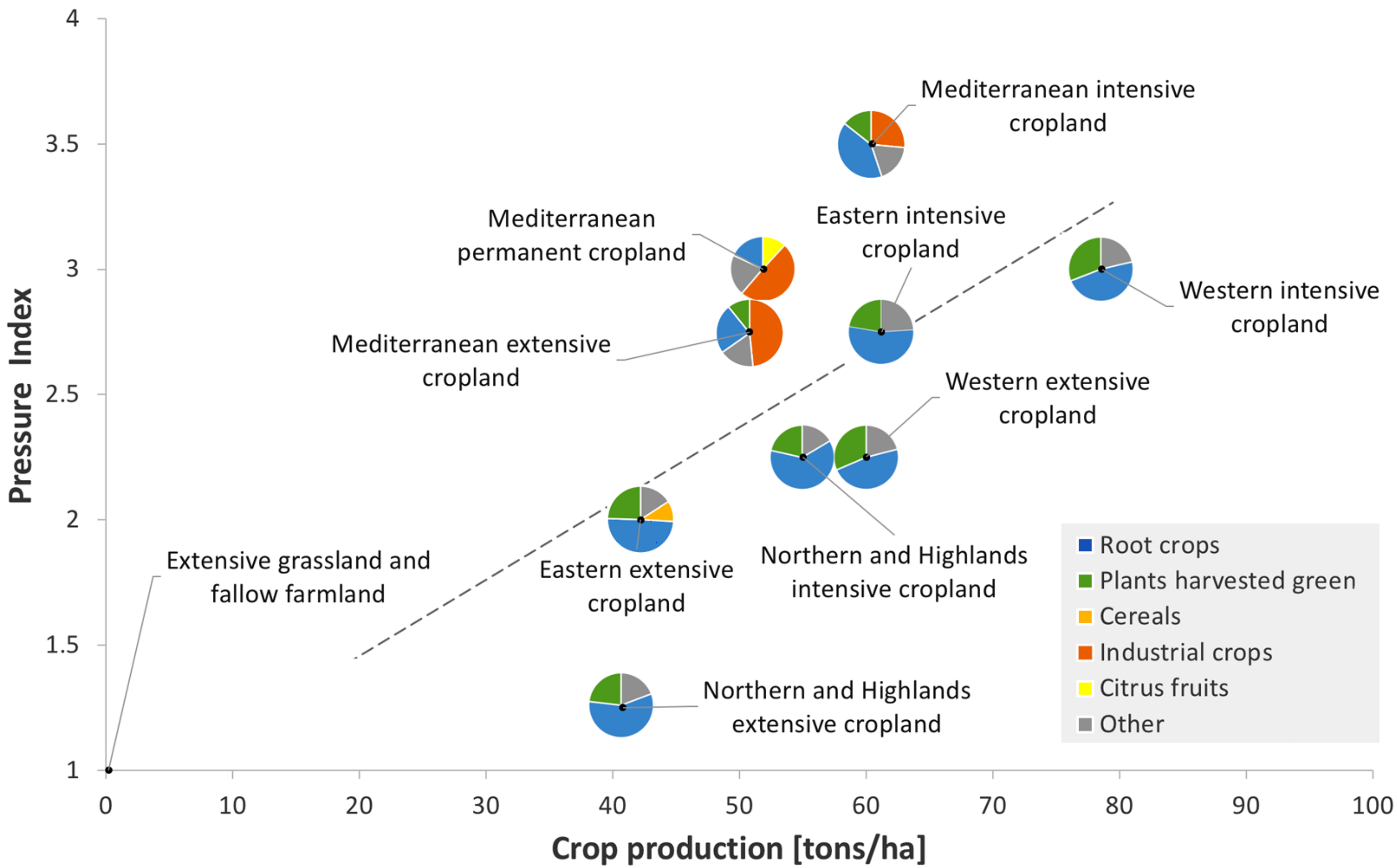

Figure A.1: Correlation of the total crop production (tons per hectare) and the composite multi-pressure index for each crop-related Broad European Agricultural Region (BEAR).
The share of crop types produced in each BEAR is shown by the pie-charts.

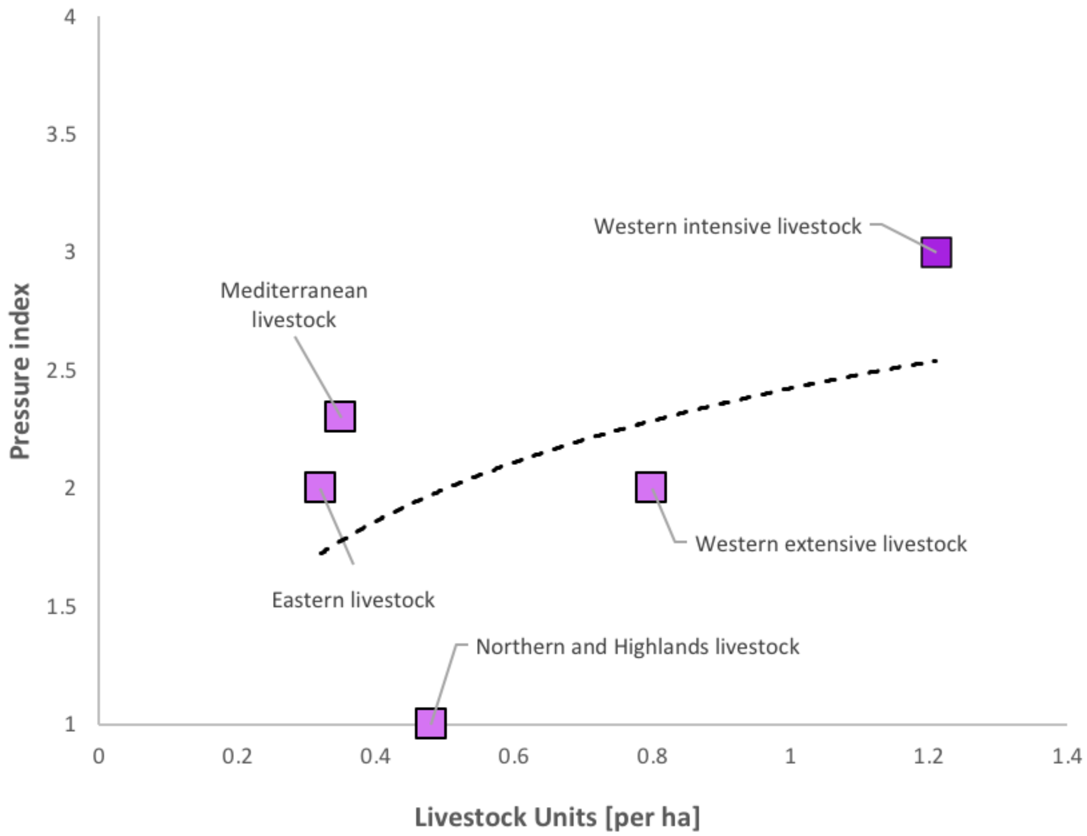

Figure A.2: Correlation of Livestock Units (per hectare) and the composite multi-pressure index for each livestock-related Broad European Agricultural Region (BEAR)