Methodological Proposal and Results for compiling EU- level Spatial Nutrient Condition Accounts

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Introduction

Maintaining the extent and condition of ecosystems is essential to achieving the EUs ambitions for Natural Capital. Natural capital accounting is increasingly seen as providing an essential information framework that can inform integrated management and policy responses to deliver on the EUs natural capital targets. In this context, the measurement of pressures on ecosystems is acknowledged as an important component of the ecosystem assessment process (MAES, 2018). As noted in the MAES (2018) 5th Report, due to the strong causal relatinships between pressures and ecosystem condition they can be used as indicators to approximate ecosystem condition.

As a contribution to the development of an integrated natural capital system in Europe, this note summarises the European Environment Agency's European Topic Centre for Spatial Information and Analysis (EEA ETC/SIA) methodological approach to compiling Spatial Nutrient Condition Accounts and presents initial accounting results from its implementation. This note further builds on this work by exploring, the following:

- Key policy questions the nutrient accounts can address
- Options for presenting the accounts in different formats
- Discussion of key European scale accounting results
- Review of the analytical uses the flexible spatial framework underpinning the accounts provides
- A summary of recommendations for further development of the accounts.

Key policy questions

Natural Capital Accounting

The European Union (EU) has set itself ambitious targets for the preservation and better management of natural capital in the 7th Environmental Action Programme of the EU (7th EAP) and the EU Biodiversity Strategy to 2020. To build the knowledge base for achieving these objectives a shared project was set up at EU level to develop an integrated system for natural capital and ecosystem services accounting. As nutrient inputs into agriculture, grassland and forest ecosystems represent major impacts on their functioning and service provision understand where these are a critical infomration component to formulating the correct policy and management solutions to conserve and enhance Europe's Natural Capital stocks and an important accounting theme for KIP INCA. This is also reflected in the EEA (2017a) information note on EU wide ecosystem condition indicators for ecosystem accounting.

In the context of delivering on the EU 7th EAP and Biodiversity Strategy Targets for natural capital, spatial nutrient pressure condition accounts will yield essential cross-cutting indicators for informing on where to target investment in natural capital protection and track progress towards policy targets for natural capital.

Mapping and Assessment of Ecosystems and their Services (MAES)

EU Biodiversity Strategy to 2020 (target 2, Action 5) calls on Member States to map and assess the state of ecosystems and their services in their national territories and integrate their values into EU and national scale accounting and reporting systems. The MAES initiative responds to the need for a consistent analytical framework to support this action across member states. MAES (2018) identifies nutrient balance as a key pressure indicator for ecosystem assessment. Specifically, MAES (2018) identifies nitrogen balance as one of the key pressure indicators for agro-ecological systems. Nutrient loading is also identified as an indicator for a number of ecosystems, expressed via the Streamlined Environmental Biodiversity Indicator (SEBI) 009 for critical load exceedance for nitrogen (see EEA, 2017). Accordingly, spatial nutrient pressure condition accounts will yield essential cross-cutting indicators that will directly support and operationalise the ambitions of the MAES initiative.

Other relevant policy applications

Fertiliser use in basins and gross nutrient balance are also identified as important indicators for freshwater ecosystems. With respect to wider policy targets, these indicators are also highly relevant to the Water Framework Directive (and the Nitrates Directive that is now integrated into this) (EC, no date). The Spatial Nutrient Pressure Condition Accounts would provide very useful information on where to focus efforts on the use of good farming practices to protect waters against agricultural pressures. Similarly they could be used to identify where a more efficient use of nutrient and soil resources could be achieved, a key challenge identified for the implementation of the EU Soil Thematic Strategy (EC, 2012).

Key policy applications for spatially disaggregated nutrient data are identified with respect to the call for monitoring the environmental impacts of agriculture under the Common Agricultural Policy (CAP). Furthermore, environmental assessments are required at the regional level under the European Commission Rural Development Policy.

In consideration of the above, there are multiple policy entry points that Spatial Nutrient Pressure Condition Accounts ca target. They could clearly inform on progress towards these multiple policy targets but, more importantly, support a coordinated approach to tackle nutrient based pollution problems in multiple contexts.

Methodological Overview

In broad terms, the Spatial Nutrient Pressure Condition Accounts seek to quantify the difference between nutrient inputs and nutrient outputs in a spatially explicit approach. A simplified approach is adopted that considered the major inputs as: Fertiliser use; Manure application; Biological fixation; and, atmospheric deposition. The main nutrient output is represented by harvested products. By organising information on these inputs and outputs in a manner that is spatially integrable, the approach allows the nutrient surplus to be calculated in a spatially explicit fashion. This surplus is characterised as leaching / run-off or losses to atmosphere. The former impacting most on water systems and the latter on atmospheric conditions and subsequent deposition. Eight broad steps to compiling the Spatial Nutrient Pressure Condition Accounts for Europe are presented Figure 1. These steps can be broken down into three stages: 1) Getting the data together; 2) Calculating derived datasets; and, 3) Integrating data and compiling the accounts.

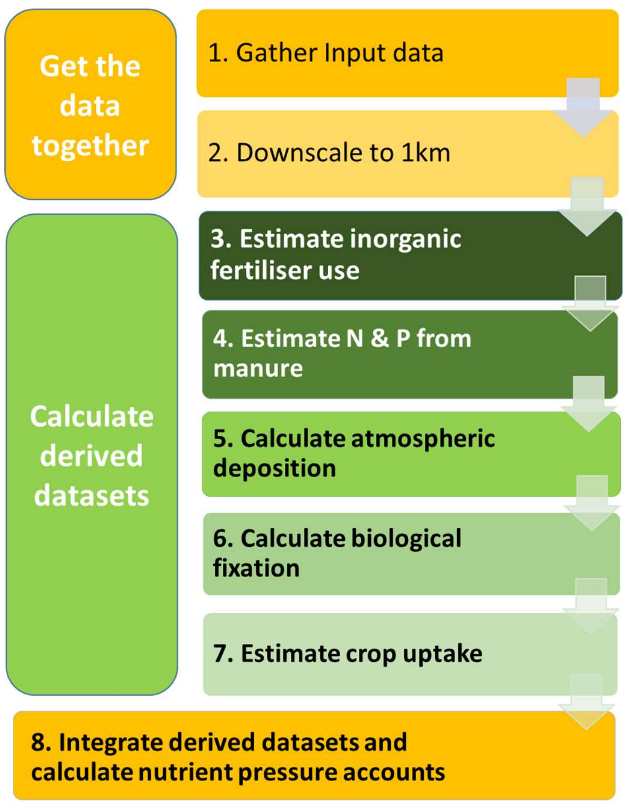

Figure 1: Stepwise approach for compiling Spatial Nutrient Pressure Condition Accounts

An expanded, detailed stepwise process to the workflow for calculating the Spatial Nutrient Condition Accounts is provided in Appendix A.

Getting the data together

The European nutrient accounts are based on the results provided by the CAPRI team of the Joint Research Commission (JRC) of the European Commission. The Common Agricultural Policy Regional Impact (CAPRI) model is a tool for ex ante impact assessment of agricultural and international trade policies with a focus on the European Union. As an economic partial comparative static equilibrium model for agriculture, its core consists of two interlinked modules: the supply module, covering about 280 regional aggregate programming models covering the EU-27, Norway and Western Balkans at the NUTS 2 level and the market module, a global spatial multi-commodity model for about 50 agricultural commodities, which together allow calculation of a wide range of economic and environmental indicators. A spatial downscaling component allows impact assessment at the FSU level for EU-27 (EU-28 minus Croatia).[1]

The CAPRI model consists of a supply and a market model and is used to estimate nitrogen balances at the level of Farm Structure Soil Units (FSU). The data used for the nitrogen balance is derived from disaggregated data from CAPRI time series. It relies on input data related to land use, manure and fertiliser input, atmospheric deposition, crop uptake etc. from different sources, but mainly based on official statistics (Eurostat) or sectoral information (e.g. fertiliser use). These data, available mainly at country level or NUTS2 level are transformed via disaggregation procedures. These are described for each input in Appendix B.

Compiling the accounts

The spatially explicit nature of the Nutrient Pressure Condition Accounts means that they are supported by geospatial data layer at a 1 x 1 km^2 resolution that can be used to generate accounts for a variety of scales. The fits with the EUs ambition for a fully spatial approach to ecosystem accounting, underpinned by a 1 km grid based spatial referencing system. As such, the data underpinning the Spatial Nutrient Pressure Condition Accounts can be integrated into a wider geospatial database of information organised by 1 km grid cells. This will allow integration of multiple datasets (e.g., nutrient pressures, land cover, vegetation indices) and facilities a wide range analytical application. Figure 2 illustrates this graphically.

[1] Further detailed information on the purpose and set-up of CAPRI is available via this Wikipedia link: https://en.wikipedia.org/wiki/CAPRI_model

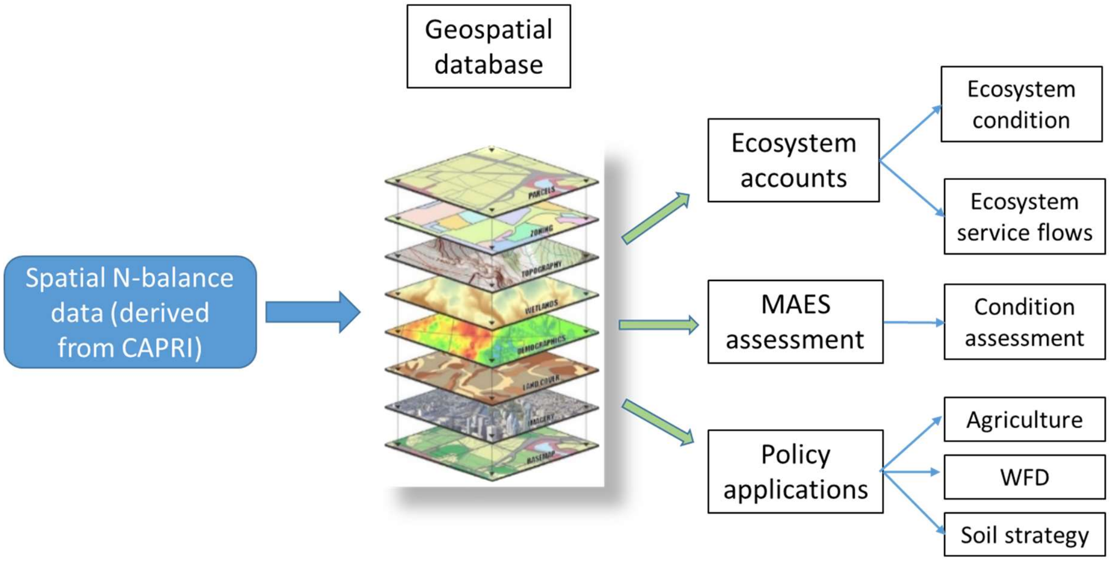

Figure 2: Applications of spatial nutrient balance data as part of a geospatial database

Whilst no hard and fast rules need to be developed on specifying Ecosystem Accounting Area (EAAs)[2] for aggregating the 1km x 1km nutrient pressure data, it is useful to reflect on what may be the most pertinent possibilities. Furthermore, as Figure 1 reveals, the process of generating the spatial nutrient balances also yields a number of derived datasets (potential accounting items) whose accounting treatment needs to be considered.

Ecosystem Accounting Areas (EAAs)

A key driver of selecting the Ecosystem Accounting Area (EAA) for compiling the accounts will be the specific policy question to be addressed, the scale at which wider policy relevant data is organised and the scale at which management of policy decisions are implemented. This includes by ecosystem / land cover types, by ecologically relevant features such as river basins and various different statistical management units (e.g., NUTS levels).

In the context of KIP INCA, EU scale accounts will be of interested, ideally disaggregated by ecosystem type. This is readily achievable via integration of 1 km resolution data on spatial nutrient balance and Corine land cover. In the context of KIP INCA, it will be useful to identify where links can also be made between the Spatial Nutrient Pressure Condition Accounts and wider ecosystem accounts produced under this initiative. This should not just focus on exploring the trade-offs between condition and provisioning services (e.g., crops) but also provide insights into the implications for other ecosystem services. For instance, the mitigation of nutrient pressures on freshwater ecosystems is an important regulating service of ecosystems and it is important to understand where this service is being realised or where natural capital investment could improve the supply of this ecosystem service. This could

[2] The area for which an account is produced (UN *et al.*, 2018)

have important implications for range of cultural ecosystem services, the recreational potential of rivers and lakes is typically lost when eutrophication takes place (e.g., activities such as fishing, swimming and boating may no longer be undertaken at a site). Furthermore, exceeding critical loads for nutrient is known to be more widely damaging to biodiversity (as discussed in the next sub section with respect to SEBU 009, EEA, 2017b). This will also affect the recreational amenity enjoyed by visitors to natural and semi-natural ecosystems (e.g., reduced opportunities to observe wildlife, pollinators and wild flowers).

Where the Common Agricultural Policy represents an entry point for spatial data, Farm Structure Soil Units (FSU) have been developed. These are determined on the basis of being approximately homogenous in terms of Corine Land Cover, Soil and Slope characteristics. The FSUs may be discontinuous and consist of one or multiple 1km grid cells. They are confined on the basis of the administrative (NUTS 3) areas in which they occur. It will be useful to organise nutrient pressure data in a manner that is consistent with these units as it opens up pathways for multiple analysis. However, this use of discontinuous units is not consistent with the concept of ecosystem assets proposed in the SEEA EEA (UN *et al.*, 2014, 2018). As such, FSUs may not be easy to readily integrate with wider ecosystem accounts, such as those compiled under KIP INCA.

The objectives of the WFD are to be achieved via the implementation of river basins management plans. These are produced for geographically defined river basin districts, comprised of single or multiple, adjoined river basins. River basins are defined as "The area of land from which all surface run-off flows through a sequence of streams, rivers and, possibly, lakes into the sea at a single river mouth, estuary or delta" (see EU Water Directors, 2016). These would appear to be highly useful Ecosystem Accounting Areas (EAAs) for which to compile spatial nutrient pressure condition accounts.

Accounting items and structure

Specifying accounting items and structures requires consideration in both ecological, measurement and policy relevance terms. A key decision is whether to focus purely on the balances (the net values) or also compile data on the gross addition of nutrient and the reduction of nutrient via biological fixation and crop uptake. The latter is the more conventional accounting approach and this would derive a rich set of data that could support more analytical uses. For example, nutrient loading is identified as an indicator for a number of ecosystems in MAES (2018).

However, whilst information on nutrient load is important input data on the overall nutrient pressures the condition of ecosystems face, they are measured in units per unit time, rather than point measurements (MAES, 2018). As such, they do not lend themselves to recording in accounting structures with distinct opening and closing measures. Consequently, understanding the temporal trends in nutrient balances over accounting periods is considered a key concern. Essentially, this comprises of recording the net balance of additions (e.g., these fertiliser application, manure and atmospheric deposition) and reductions (e.g., crop uptake) over the accounting period for different ecosystems in a spatially explicit fashion. This would also facilitate combined presentations with other accounts, for instance ecosystem extent accounts grounded in the Corinne land cover editions. A possible example of such a 'Nutrient Pressure Condition Account' is presented in Table 1. The columns in Table 1 present the average nutrient balance for different ecosystem types within the Ecosystem Accounting Area (EAA). The final column of Table 1 provides an ecosystem area weighted average for aggregate ecosystem nutrient balances per hectare per year. As apparent from the structure of Table 1, this will only reflect the ecosystems for which nutrient balance is available.

Table 1 Proposed Nutrient Pressure Condition Account (2000 to 2018)

Nutrient Balance by MAES Types >>	Cropland (kg/ha /year)	Grassland (kg/ha /year)	Forest & Woodland (kg/ha /year)	Area weighted average (kg/ha /year)
2000	50	30	10	**39**
2006	55	30	12	**42**
2012	53	25	8	**39**
2018	67	23	8	**47**

Notwithstanding the above discussion, information on the areas impacted by nutrient overloading is a key environmental policy concern. For instance, the SEBI 009 indicator is related to exceeding for critical loads for nitrogen deposition in (semi)-natural ecosystems (EEA, 2017). This is used to inform on the potential for eutrophication and associated biodiversity impacts in Europe. As such, it would be useful to set critical thresholds for nutrient balances or loading (application + deposition) using data organised via the spatial nutrient accounts and account for the areas of different ecosystems affected over accounting periods. Particularly, given the ability to generate this data for a 1km grid (SEBI 009 is presented using a 50 km grid).

Table 2 provides an structure for an account presenting this information on the areas of different ecosystems exceeding critical nutrient deposition thresholds. The account presents information on the area, in absolute terms, of each ecosystem exceeding the critical threshold within an Ecosystem Accounting Area (EAA). These ecosystem specific measures are then aggregated in the final column to show the total ecosystem area exceeding the critical threshold in the EAA. Whilst the account could also be presented in relative terms, this information on relative extent exceeding thresholds could readily be revealed by combined presentation with the ecosystem extent account for that EAA.

Table 2 Proposed Nutrient Pressure (Threshold) Condition Account

Area Exceeding Nutrient Balance by MAES Types >>	Cropland (ha /year)	Grassland (ha /year)	Forest & Woodland (ha /year)	Total (/ha /year)
2000	10,000	6,500	900	**17,400**
2006	9,800	6,450	1,050	**17,300**
2012	12,000	5,000	800	**17,800**
2018	13,500	4,700	780	**18,980**

Accounting Results

The disaggregated nitrogen data from CAPRI time series is produced for a set of 27 EU Member States (EU-28 minus Croatia). The data is available for the years 2000-2012, in 2-year-steps, which can inform the Spatial Nutrient Condition Accounts for this Ecosystem Accounting Area (EEA). The accounting items and structures presented in Table 1 and Table 2 have been calculated for each of these two year steps for each of the 27 EU Member States. These data have been aggregated in order to compile a Nutrient Pressure Condition Account for the EU 27 EAA as a whole (Table 3 and Table 4).

Table 3 presents the Nutrient Pressure Condition Account for Cropland and Grassland (the major agricultural ecosystems) for the EU-27 EAA. As Table 3 reveals, nutrient balances are positive in both cropland and grassland, implying nutrient surplus and leaching (e.g., to groundwater), run-off to other ecosystems or losses to the atmosphere from these ecosystems. Nutrient surplus is larger for grasslands, likely the result of grazing and associated animal execration. Whilst a downward trend is evident in the nutrient surplus in both these ecosystems, this is very marginal (around 3% between 2000 and 2012).

Table 4 presents the Nutrient Pressure (Threshold) Condition Account for the EU-27 EAA. This presents the extent of both croplands and grasslands where the critical thresholds for nutrient loads are exceeded. As per Table 3, Table 4 reveals decreases in the extent of both of these ecosystems exceeding critical thresholds between 2000 and 2012. The final column in Table 4 reveals the total area of these two ecosystems where critical thresholds are exceeded has decreased by nearly 10% between 2000 and 2012.

Table 4 reveals that the area of cropland exceeding critical load routinely exceeds that of grassland by a factor of two, in absolute terms. However, when evaluating this data alongside information on ecosystem extent the picture is reversed, reflecting the far greater extent of cropland in the EU-27 compared to grassland. In relative terms, approximately 24% of grassland is found to exceed the critical threshold (in 2012), whereas only approximately 14% of cropland exceeds this threshold (in 2012).

Table 3 Nutrient Pressure Condition Account for Cropland and Grasslands (EU-27 2000 to 2012)

Nutrient Balance by MAES Types >>	Cropland (kg/ha /year)	Grassland (kg/ha /year)	Forest & Woodland (kg/ha /year)	Area weighted average (kg/ha /year)
2000	64	81	ND	**68**
2002	64	81	ND	**68**
2004	64	80	ND	**68**
2006	64	80	ND	**67**
2008	63	80	ND	**67**
2010	63	79	ND	**67**
2012	62	79	ND	**66**

ND' = No data at present

Table 4 Nutrient Pressure (Threshold) Condition Account for Cropland and Grasslands (EU-28 2000 to 2012)

Area Exceeding Nutrient Balance by MAES Types >>	Cropland (10^3 ha /year)	Grassland (10^3 ha /year)	Forest & Woodland (10^3 ha /year)	Total (/ha /year)
2000	23,646	12,374	ND	**36,020**
2002	23,567	12,306	ND	**35,874**
2004	23,050	12,101	ND	**35,151**
2006	22,769	12,072	ND	**34,842**
2008	22,360	11,897	ND	**34,257**
2010	22,024	11,606	ND	**33,631**
2012	21,653	11,713	ND	**33,366**

ND' = No data at present

It is highlighted that whilst Table 3 and Table 4 present information for the EU-27, the underlying input data are derived for each Member State. Further, the flexible nature of the geospatial data underpinning the accounts also allows for accounts to be compiled for various other EAAs of policy and analytical interest. As such, Spatial Nutrient Condition Accounts will be produced for further EAAs of relevance (including member state and biogeographical regions) following consolidation of the accounting data.

Analytical uses

Spatial Nutrient Pressure Condition Accounts are likely to have a fairly wide range of uses in a number of different policy contexts, notably with respect to the WFD and CAP. Some key analytical uses to improve land and environmental management decision with respect to natural capital include:

- Identifying which ecosystems are affected in a spatially explicit approach.
- Identifying where nutrient pressure hot-spots exists.
- Identifying where nutrient pressure may be impacting on particularly sensitive ecosystems assets, for example water courses, lakes and wetlands that may suffer from eutrophication.
- Providing aggregate measures of nutrient balances by land use for macro-level planning. For example, with respect to setting fertiliser taxes / subsidy reform.
- Informing combined presentations with other ecosystem accounts to understand where nutrient pressure threatens areas of high biodiversity or ecosystem service delivery.
- Exploring the trade-offs between agricultural output and ecosystem condition in a spatially explicit manner.

The flexible nature of the data underlying the accounts can also support spatial statistical or econometric modelling to explore the relationships between nutrient pressure and other environmental and economic data of interest. Key applications in this regard would be in relation modelling at FMUs in the context of CAPRI data or aligning data on nutrient pressures with WFD data on water quality at the waterbody scale (see EU Water Directors, 2016).

The capacity of ecosystems to mediate nutrient pollution could be related to their location with respect to Nitrate Vulnerable Zones. These are areas of land which drain into polluted waters or waters at risk of pollution and which contribute to nitrate pollution (EC, no date). Integration of spatial nutrient balance data with data on the location of Nitrate Vulnerable Zones can inform on where to target action to ameliorate wide spread nitrate impacts. However, designation of NVZ is not consistent across countries, some countries assess their entire territory as an NVZ (e.g., Germany, Romania and Sweden) (see JRC, no date).

Other data may provide more widespread insight into the capacity of ecosystems to mediate nutrient leaching and run-off, for instance soil structure, groundwater condition, slope and net primary production could all be key in determining this and should have spatial data that are readily available (e.g., the input data for defining FMUs). It is noted the primary production is closely related to the uptake of nutrients by crops, so there may be some circularity associated with including this as an indicator of such capacity. Nonetheless, this approach potentially offers a pathway to calculating ecosystem service accounts related to "Regulation of the chemical condition of freshwaters by living processes" (Haines-Young and Potschin, 2018). Understanding rates of application and location of freshwaters allows a level of demand for this service to be established. There will also be a wider ecosystem services where the links to these can be made (e.g., the cultural ecosystem services discussed in the preceding section).

Nutrient balances may also be useful for exploring where nutrient mining may be occurring, the converse to the issue of excessive nutrient loading. Given soil nutrients represent a significant natural capital asset with substantial socio-economic benefits identifying the scale and location of this problem is a key conceptual concern. However, it is not necessarily the case that this would be a significant issue for the European landscape.

Summary

The rich spatial data and spatial infrastructure underpinning the Nutrient Pressure Condition Accounts is very flexible and multiple analysis of the data is possible. However, given these manifold applications, some methodological recommendations for testing the compilation and use of the Spatial Nutrient Pressure Condition Accounts in the context of policy priorities are required. Key recommendations in this regard comprise the following:

- In order to support KIP INCA and MAES an EU scale account by MAES ecosystem type would be a key contribution and should be progressed. This should include on building on deposition data for ecosystems outside crop- and grassland ecosystem types. This would allow communication of macro level trends. Linking this approach to spatial data on the distribution of particularly sensitive ecosystems to nutrient pressure would be very relevant for directing sustainable management of ecosystems and natural capital.
- The stepwise approach summarised in Figure 1 reveals that multiple datasets are derived on the nature of nutrient inputs and outputs in a spatially explicit manner. As such, an accounting structure that can capture this rich set of information in a comprehensive manner could be developed.
- Ecosystems usually do not react immediately to changes in pressures and there may be significant time lags in their response time. As such pressure and environmental state indicators are both important measures and policy relevant. It would be useful to explore the potential for integration or combined presentation of Spatial Nutrient Pressure Condition Accounts and other ecosystem condition accounts being progressed by the EEA (e.g., biodiversity or water quality).
- It would be useful to explore combined presentations with other ecosystem accounts or spatially referenced data to understand links or correlations with

ecosystem services. This could include providing information on "Regulation of the chemical condition of freshwaters by living processes", links to cultural ecosystems services based on the direct interaction with nature and trade-offs with respect to agricultural production.

- As part of a geospatial database the data underpinning the spatial nutrient pressure condition accounts is very flexible and can support many analytical applications of policy interest. Key possibilities for statistical spatial analysis of the relationships between nutrient pressures and other environmental concerns could be explored using by aligning nutrient data to water bodies (the spatial statistical unit for WFD reporting) or the FSU used by CAPRI.

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Appendix A: Spatial nutrient accounts data processing work flow

This workflow consists of 12 steps in total, several of which are broken down into sub-steps. They describe the data processing steps required for producing interim data layers and the final spatial nutrient accounts.

	Step	Input datasets	Processing	Result
1)	**Create a spatial layer of cropland and grassland farming across Europe**	• 1a) Crop area predictions from the LAPM (Land Area Prediction Model) at HSU (Homogeneous Spatial Unit) level. • 1b) Farm Structure Survey crop area at 10 x 10 km grid, gap-filled, for the year 2010 (other years not (yet?) available) • 1c) CAPRI crop area at NUTS2 level for time series 2000 – CAPRI base year; now-casting is possible for later years	Constraining 1a) results with 1b) to derive priors as input to constrain to 1c).	A) Crop and grassland area at HSU level for time series (2000 – current year-2).
2)	**Create spatial layer on mineral N fertilizer application**	• 2a) Country statistics on the use and application of mineral fertilizer by major crops for time series • 2b) Mineral fertilizer application by crop at NUTS2 level from CAPRI for time series based on 2a) • Crop and grassland area at HSU level (Result A from step 1) for time series • Crop yield at HSU level (Result H from step 8) for time series • 2c) Crop nutrient requirements based on CAPRI look-up table of crop N contents	Disaggregate 2b) to the HSU level based on crop distribution, and crop N requirements (taking into account other sources of N as e.g. manure from H).	B) Mineral N application to crops and grassland area at HSU level for time series (2000 – current year-2).

3)	**Create spatial layer for livestock distribution as preparation for step 4**	• 3a) Farm Structure Survey livestock numbers at 10 x 10 km grid, gap-filled, for the year 2010 (other years not (yet?) available) • 3b) CAPRI livestock numbers at NUTS2 level for time series • 3c) E-PRTR database of large pig and poultry farms for the years 2007 – current year 2	Downscaling livestock numbers to HSU constrained by 3a) and further on by 3b). Possibly using 3c as additional information for pig and poultry.	C) Livestock numbers (distinguishing dairy cattle, other cattle, sheep + goats, pigs, poultry and other animals) at HSU level for time series (2000 – current year-2)
4)	**Calculate nutrient excretion from livestock and create spatial layer for manure application to crops**	• 4a) Dynamic excretion rates calculated as animal budget: feed intake – retention in products and animal biomass = excretion. Combined with 3b) to calculate N excretion from livestock. • 4b) Application of manure N on crops based on CAPRI fertilizer module. The module takes into account crop N requirements, N availability and crop over-fertilization factors. CAPRI data at NUTS2 level for time series	Downscaling of 4b) to the HSU level based on A) and C)	D) Manure application to crops and manure deposition by grazing animals on grassland at HSU level for time series (2000 – current year-2)
5)	**Estimate amount of N fixed in crops**	Biological N fixation (BNF) data set; BNF is estimated as fraction of crop N uptake by crop type	Calculate N fixation from BNF, crop N requirements and crop type/yield (A and G)	E) BNF at HSU level for time series (2000 – current year-2)
6)	**Estimate total N deposition levels on cropland and grassland from air**	EMEP MSC-W modelled air concentrations and depositions	Data from the EMEP model, downscaled to 1km x 1km through distribution of 50x50km data to 1km grid Note: *atmospheric deposition depends on land cover.*	F) Specify results. Two 1x1 km grids preferably annual – but may also be 2000, 2010 Resolution required: preferably HSU, but also 1

			Assumption on land cover in EMEP must be considered during disaggregation.	km is OK, also NUTS2 if assumption that spatial variation small/uncertain
7)	**Create a spatial layer of crop yields**	7) Eurostat statistics on crop production and yield at NUTS2 level for time series, checked for consistency within CAPRI Crop and grassland area at HSU level (Result A from step 1) for time series	Disaggregating crop production based on combining 7a) with A), taking additional information on irrigation, potential/rain-fed yield into account.	G) Crop yield at HSU level for time series (2000 – current year-2)
8)	**Estimate N contents in crops removed from the fields**	8a) Country-specific N contents for major crop groups / Eurostat 8b) Where data not available, CAPRI modelling *	CAPRI look-up table of crop N contents. Combine with crop yield data (G) to estimate N removal at spatial level; straw and crop residues movements considered.	H) N removal with crop and grass biomass at HSU level for time series (2000 – current year-2)
Results				
9)	**Total Nitrogen input to cropland and grassland**	Datasets resulting from steps 2, 4, 5, 6	Add up N inputs calculated in steps 2, 4, 5 and 6 at HSU level I=B+D+E+F	I) Total N input at HSU level for time series (2000 – current year-2)

				J) Total N input (K) mapped to 1x1 km raster layer
10)	**Total N output**	Dataset resulting from steps 7) + 8)	Take spatial N exports calculated in steps 8) per HSU and allocate values to each 1x1 grid cell per HSU	H) N removal with crop and grass biomass at HSU level for time series (2000 – current year-2) K) Total N output (J) mapped to 1x1 km raster layer
Accounting steps				
11)	**Produce accounting table for spatial N balance on spatial mask covered by results**	Combine 1x1 km raster layer results from steps 9) and 10)	Produce accounting tables with information at 1x1 km raster layer L=J-K	L) N surplus for crops and grassland at HSU level for time series (2000—current year-2) M) Corresponding accounting tables based on 1x1 km raster layer for agricultural land area
12)	**Relate results to MAES ecosystem types**	MAES dominant ecosystem type dataset to be produced for condition accounts	Overlay results on MAES dominant ecosystem type maps to produce information by ecosystem	N) Spatial data set on N-account at HSU level overlaid on relevant MAES ecosystem types (cropland and grassland)

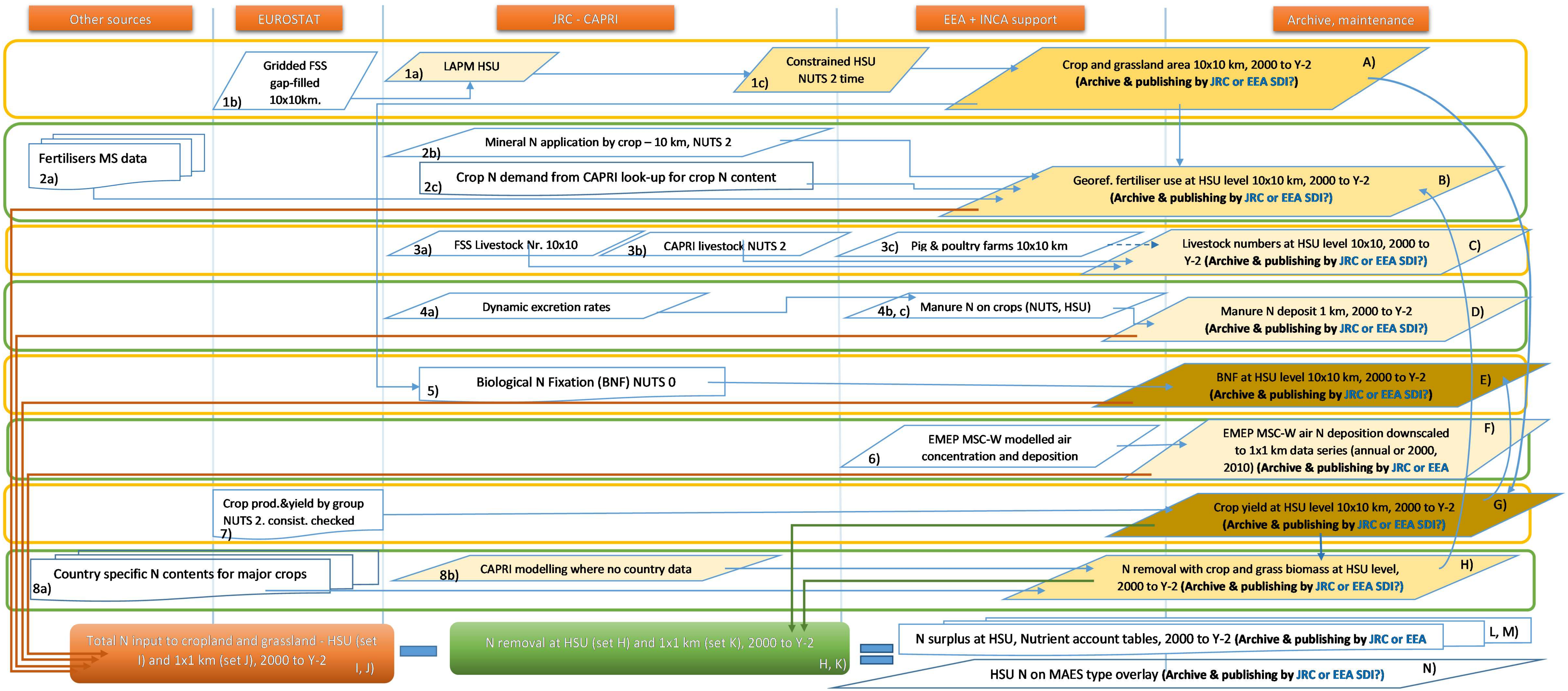
***Methodological note regarding N-removal with crops:**

- The CAPRI team points out that N removal concerns harvested material plus crop residues removed (as feed or bioenergy or burning or other use).
- Seeds for planting are currently not considered in the CAPRI N-balance at HSU level as input. This should ideally be changed. It is not clear whether it will be possible to work on this for the 2018 product.

****Methodological note regarding denitrification:**

- Denitrification is part of the methodology proposed in the ecosystem accounting literature.
- Total soil N-surplus is differentiated into leaching and denitrification. However, the CAPRI team considers that the factual evidence that documents the denitrification process is low, data are uncertain. Therefore it is probably better to work with total surplus.

Flow diagram of contributors and processing steps for calculating spatial nutrient accounts



Appendix B: Input and derived CAPRI data used in the accounting approach

Since Eurostat has released gridded FSS data sets for Commission internal use the CAPRI team has built on this data set for producing a more accurate estimate of the spatial distribution of agricultural activity in Europe (led by staff at JRC Ispra). This builds on producing gap-filled 10 x 10 km data sets on basic agricultural statistics (crop areas, livestock numbers). EUROSTAT provided crop and livestock statistics for 3 grid levels (10x10km grid, 20x10 km grid and 60x60 km grid) and 3 administrative levels (NUTS3, NUTS2, Country). The gridded FSS data provided by EUROSTAT is subject to confidentiality rules. Values have been removed where they represented data from less than 5 holdings in each individual grid cell, or where 1 or 2 holdings explain at least 85% of the information in the spatial unit. The higher the resolution, the more data was subject to confidentiality treatment (i.e. the higher the resolution the more crop area / livestock units were missing).

The JRC Ispra CAPRI team used the information from the NUTS2/3, 60x60km and 20x20km grids to gap-fill the 10x10km grid data (for example areas of the single crops at 10km x 10km had to match the area of the crop at 20km by 20km and at 60km by 60km and at NUTS2/3 level). The disaggregated nitrogen data from CAPRI time series is then produced by JRC for EU 27 (EU28 minus Croatia). The data is available for the years 2000-2012 in 2-year-steps. It includes 12 nitrogen flows relevant for the soil surface surplus of the nitrogen balances, plus agricultural activities such as the crop yields and the area of each crop and the total Utilised Agricultural Area (UAAR) of the FSU. The input data for the CAPRI model is listed in Table 5 and the delivered parameters of the CAPRI model are as listed in Table 6.

Based on the parameters delivered in CAPRI, different aggregates can be calculated, based on accounting requirements. Some are already included as parameters in CAPRI, such as NinSoi or Sursoi, other such as the N-input from manure and mineral fertiliser or the Gross Nitrogen Budget can be calculated by using the following formula:

Total excretion of N in manure

EXCRET = NMANAP + NMANGR + MANLOSSES + MMSLOSSES

N input from manure and mineral fertilizer, with

N input = NMANAP + NMANGRA + MANLOSSES + NMINSL + MINLOSSES+ MMSLOSSES

N inputs to soil (NinSOI) refers to N that 'enters the soil' with possible fates being

uptake (NRET) and surplus (SURSOI), it represents input as the farmer applies, emissions from application have yet to occur

NinSOI = BIOFIX + NMINSL + NMANAP + NMANGR + ATMOSD + CRESID

Hence, the Total N input includes NinSOI and losses from mineral fertiliser and manure applications: NinSoi + MINLOSS+MANLOSS

Soil surface surplus all gaseous emissions from manure and mineral fertilizer as well as runoff already subtracted. It equals N-leaching and denitrification (N_2)

SURSOI = NinSOI – NRET

Gross Nitrogen Budget

GNB = SURSOI + MANLOSSES + MINLOSSES + MMSLOSSES.

The aggregates are calculated per FSU and can be mapped using the FSU reference layer.

The geo-spatial processing of the data for the purpose of this analysis consists of the following steps: [*to be completed*]

Table 5: Overview of input data for CAPRI

Data and model inputs	Data producer / main data source	Spatial Resolution / countries covered	Time series / regularity	Any future improvement envisaged	Disaggregation process or other data preparation (if required)? By whom and how ?	Data set owner (in context of producing derived data sets)
1a) Land use (EU-28, minus Croatia)	LAPM (Land area processing module)	FSU (from CAPRI approach)	2010 (based on availability of LUCAS data around FSS data set)		Multinomial log-it model using Corine and environmental drivers, calibrated at LUCAS observations https://bitbucket.org/xavi-rp/ludm_new	JRC
1b) Land use	FSS 10 km gap-filled i.e. Gridded Farm Structure Survey data (Eurostat)	10km	2010 (2000 if possible), every 10 years (envisaged)		Based on nested FSS data at 10x10 km2, 20x20 km2 and 60x60 km2, Nuts2 and Nuts3 keeping confidentiality rules. Gap-filled	Eurostat/JRC
1c) Land use	CAPRI (i) constrained at 10 km; (ii) constrained at CAPRI NUTS2	FSU (from CAPRI approach)	2000-2012 (capri baseyear) + individual points until current year - 2		Combining 1a and 1b – constraining 1a to 1b, then constraining result to CAPRI NUTS regions for base year, then to time series	JRC-CAPRI
2a) N fertilizer application	Country data on use and application of mineral fertilizer	NUTS0	Yearly			EFMA

Data and model inputs	Data producer / main data source	Spatial Resolution / countries covered	Time series / regularity	Any future improvement envisaged	Disaggregation process or other data preparation (if required)? By whom and how ?	Data set owner (in context of producing derived data sets)
2b) N fertilizer application	Mineral N application rate by crop	NUTS2	Yearly			CAPRI team
2c) N fertilizer application	Mineral N application rate by crop	FSU	Same as 1c		Disaggregated from 2b)	JRC-CAPRI
3a) Livestock numbers	Gridded Farm Structure Survey data (Eurostat) – Gap-filled	10km	2010 (2000 envisaged), every 10 years		Further processing is currently required to integrate data set into CAPRI model / for other uses	Eurostat / CAPRI team
3b) Animal livestock numbers	CAPRI livestock disaggregation	FSU	Reference year 2012		CAPRI regional data building on Eurostat statistics, distinguishing dairy cattle, other cattle, sheep + goats, pigs, poultry and other cattle; disaggregation data from 3b)	JRC-CAPRI
3c) Livestock emissions	E-PRTR database of large pig and poultry farms	Point	2007 onwards only?		To evaluate if data can be extracted and transformed to animal numbers or LU	EEA
4a) Manure	Dynamic excretion rates	NUTS0	Yearly		Calculated as animal budget Feed intake – retention in products and animal biomass = excretion	CAPRI team

Data and model inputs	Data producer / main data source	Spatial Resolution / countries covered	Time series / regularity	Any future improvement envisaged	Disaggregation process or other data preparation (if required)? By whom and how ?	Data set owner (in context of producing derived data sets)
4b) Manure	Application of manure N on crops	NUTS2	Yearly		Based on CAPRI fertilizer module, application rates depending on crop N requirements and N availability, crop over-fertilization factors. Data calculated at NUTS2 and disaggregated to FSU level	CAPRI team
4c) Manure	Application of manure N on crops	FSU	Same as 1c)		Data from 4b) disaggregated to FSU level.	JRC-CAPRI
5e) Biological N fixation (BNF) rates	Biological N fixation	NUTS0			BNF as fraction of crop N uptake by crop type	CAPRI team
6a) Total N deposition levels	EMEP MSC-W modelled air concentrations and depositions		Yearly			
7a) Crop yields	Eurostat statistics on crop production of major crop groups	NUTS2	Yearly (2000-2010)	Review needed	Eurostat statistics downscaled according to CAPRI to NUTS2 level.	CAPRI team
7a) Crop yields	Crop production of major crop groups	1km	Yearly (2000-2010)	Review needed	Disaggregation of 7a) to FSU level using additional information on irrigation (FAO and FSS) and	JRC-CAPRI

Data and model inputs	Data producer / main data source	Spatial Resolution / countries covered	Time series / regularity	Any future improvement envisaged	Disaggregation process or other data preparation (if required)? By whom and how ?	Data set owner (in context of producing derived data sets)
					potential and rain-fed yield (PESETA project).	
8) N and P contents in crops	Country-specific N and P contents for major crop groups / Eurostat	EU	Static		CAPRI look-up table of crop N contents. Calculation with crop yield data.	na

Table 6: Overview of delivered parameters of the CAPRI model

Parameters	Definition
ATMOSD	Atmospheric N deposition (kg/ha)
BIOFIX	Biological N fixation (kg/ha)
CRESID	Crop residuals (kg/ha)
MANLOSSES	Manure losses from manure after application (NH_3, N_2O, NOX, run-off) (kg/ha)
MINLOSSES	Mineral fertiliser losses (NH_3, N_2O, NOx, runoff) (kg/ha)
MMSLOSSESS	Losses from manure management systems (kg/ha)

NMANAP	Manure input net of all surface losses. Part applied intentionally to agricultural land (kg/ha)
NMANGR	Manure input net of all surface losses. Part deposited by grazing animals (kg/ha)
NMINSL	Mineral fertilizer N input net of gaseous losses and run-off (kg/ha)
NRET	N Uptake (kg/ha)
NinSOI	N input to the soil (kg/ha)
SURSOI	Surplus to soil (kg/ha)
YILD	Crop yields (kg/ha)
LEVL	Cultivation of crops [1000 ha] (1000 ha)
LEVLLIVESTOCK	Number of animals [1000 head] or [1000000 head for poultry]