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Past intensification trajectories of livestock led to mixed social and environmental services

J. P. Domingues^{1,2†} , A. H. Gameiro², T. Bonaudo¹, B. Gabrielle³ and M. Tichit¹

¹UMR SADAPT, INRA, AgroParisTech, Université Paris-Saclay, Paris 75005, France; ²Departamento de Nutrição e Produção Animal, FMVZ, Universidade de São Paulo, Pirassununga 13.635-900, Brazil; ³UMR ECOSYS, INRA, AgroParisTech, Université Paris-Saclay, Thiverval-Grignon 78850, France

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Recent studies highlighted the multiple positive and negative contributions of livestock to society. Livestock production, through its direct and indirect impacts on land use, is an important driver of services provision. Although a few studies provide an account on the multiple services in different livestock systems, there is still an important knowledge gap on the drivers that contribute to the differentiation of services provisioning across areas. We investigated the hypothesis that the current level of services has derived from past intensification trajectories of livestock. The objective of this study was to understand the influences of past changes in livestock, land-use and socio-economic variables on the current provision of social, environmental and cultural services by the livestock sector in France. We combined a long-term country-wide database on livestock intensification between 1938 and 2010 and a database on services provisioning in 2010. We used a set of multivariate methods to simultaneously analyse the changes in livestock intensification from 1938 to 2010 and the current level of services provisioning. Our analysis focused on a set of 60 French departments where livestock play a significant economic role in agricultural production. Our study revealed that the provision of services was spatially structured and based on three groups of departments, characterised by different rates of change in intensification variables. In the first group, 'Intensive livestock areas', the high level of employment in the livestock sector was mainly associated with high rates of change in monogastric stocking rates (+1045%) and milk productivity (+451%). In the second group, 'Extensive livestock areas', the high levels of environmental and cultural services were mainly associated with moderate rates of change in herbivores stocking rate (+95%) and the stability of grassland area (+13%). In the third group, 'Transition areas', the low provision of all services was associated with the decline in livestock due to crop expansion. This study provides knowledge to understand how past changes determined the current contribution of livestock areas in providing differentiated bundles of services, which might help steer the development of the current livestock sector towards more sustainable trajectories.

Keywords: livestock intensification, service provisioning, long-term trajectories, drivers of change, spatial differentiation

Implications

Understanding how past changes have shaped the current provision of livestock related services is fundamental to guarantee the continuity and improvement of service provisioning in the long term. Acting on both land-use and livestock composition can improve the provision of socio-economic and environmental services. This knowledge might also steer the decision-making process, placing the priority on desirable TRAJECTORIES of changes, namely those enabling higher and more balanced patterns of service provision.

Introduction

Recent studies highlight the positive contributions of livestock farming systems to society, often framed under the perspective of provision of services (Ryschawy *et al.*, 2017; Dumont *et al.*, 2018). Provision of services refers to the benefits people obtain from ecosystems which contribute to their well-being and are classified into four categories: provisioning, regulating, cultural and supporting (MEA, 2005; Rodríguez-Ortega *et al.*, 2014). Provisioning services are associated with the production of food, feed, fuel, fibre and wood. Regulating services refer to climate, flood and disease regulation as well as water purification. Cultural services relate to aesthetic, spiritual, educational and recreational characteristics. Supporting services

† E-mail: domi.joaopedro@gmail.com

are linked to nutrient cycling, soil formation and primary production aspects. Services and goods can occur in the form of bundles, which are sets of ecosystem services that appear together across space or time (Raudsepp-Hearne *et al.*, 2010).

Different compositions of bundles mean different levels of services provision. Several studies related to livestock farming systems and services highlight the need to reconcile agricultural production with regulating, supporting and cultural services, in view of maintaining the long-term capacity of ecosystems to provide services (Bernués *et al.*, 2011). However, not all livestock systems have the same ability to provide the same kind of services. This is a result of various possible combinations of livestock species and management types, that is, like the ability of pastoral systems in nutrient cycling, and the contribution of food provisioning in industrial pork and poultry systems (Herrero *et al.*, 2009; Leroy *et al.*, 2018). Thus, the varied composition of bundles of services in a given space emerges from the combinations of the different types of livestock farming systems, yielding varied contributions to the society.

Ryschawy *et al.* (2017) proposed a novel approach to assess the provision of services derived from livestock production. It includes indicators to assess employment in the livestock sector and cultural services in addition to the more frequently assessed services, that is, food provisioning and environmental-wise services. Although Ryschawy *et al.* (2017) identified four major types of bundles of services across France, varying from depleted bundles to multifunctional ones, the authors do not provide any views of what might have driven such spatial differentiation. It is therefore necessary to identify the main drivers of the present state of services, which we hypothesise to be a result of past changes.

In this context, the objective of this study was to understand how past intensification changes in livestock, land-use and socio-economic characteristics have influenced the current provision of social, environmental and cultural services by the livestock sector in France. We used a set of multivariate methods to simultaneously analyse changes in the production intensity from 1938 to 2010 and the current level of the provision of social, environmental and cultural services.

Material and methods

The influence of past intensification on the current provisioning of services by livestock (i.e. environmental, cultural and employment in the livestock sector) was assessed at department level. The department is a French administrative entity, equivalent to a NUTS3 unit (Nomenclature of Territorial Units for Statistics, which is the basic classification for regional data in the EU). From a total of 96 French metropolitan departments, a subset of 60 departments were selected according to the coefficient of livestock specialisation of each department (Ryschawy *et al.*, 2017). The coefficient of

Table 1 Variables considered in the analysis of change in the intensification process of the livestock sector between 1938 and 2010

Variables	Units
<i>Livestock variables</i>	
Herbivore stocking rate	LU·ha ⁻¹
Monogastric stocking rate	LU·ha ⁻¹
Herbivore ¹ meat production per area of grasslands and fodder crops	kg·ha ⁻¹
Milk ² production per area of grasslands and fodder crops	kg·ha ⁻¹
<i>Land-use variables</i>	
Share of utilised agricultural area in the department	–
Share of the area of grasslands and fodder crops in utilised agricultural area	–
<i>Socio-economic variables</i>	
Average farm size	Ha
Labour productivity (UAA:AWU)	ha·AWU ⁻¹
Dependence ratio (purchased feed/final livestock output)	–
Tractor density	tractor·ha ⁻¹

Source: Domingues *et al.* (2018).

UAA = utilised agricultural area; AWU = annual work unit.

¹ Herbivore: cattle, sheep and goat meat.

² Milk: cow, sheep and goat milk

livestock specialisation was calculated with the following equation:

$$\text{Coefficient of specialisation} = \frac{\frac{\text{Livestock sector standard output (NUTS3)}}{\text{Agricultural standard output}}}{\frac{\text{Livestock sector standard output (FRANCE)}}{\text{Agricultural standard output}}}$$

Departments with a coefficient of livestock specialisation equal to or above 0.5 were selected. This was the minimum threshold that we suggest that livestock play a role on services provision through its link to land and resources use. Results of the coefficient of specialisation for all French departments and their distribution are presented in 'Supplementary Figure S1'.

Two datasets were used to describe intensification trajectories and services provision. The first dataset characterises changes in the process of intensification between 1938 and 2010. It includes 10 variables classed under three categories: livestock, land use and socio-economic, which are presented in Table 1, and more details are available in Domingues *et al.* (2018). To enable comparisons among different intensification variables (i.e. to detect the direction and rate of change in the intensification process), each numeric variable was divided by the national average for both years 1938 and 2010. Subsequently, we calculated the rate of change subtracting 1938 from 2010 previous calculated values. Variable values equal or close to zero meant the rate of change was similar to the average department. Negative variable values meant the rate of change was lower than observed in the average department. Positive variable values meant the rate of change was higher than observed in the average department.

Table 2 Indicators selected to characterise services provided by the livestock sector

Services	Indicator	Abbreviation
<i>Employment livestock sector</i>		
Employment on livestock farms	Workforce on livestock farms (AWU)	Emp Farm
Employment in the livestock agro-food industry	Employees in livestock agro-food industry (number of)	Emp Ind
Contribution of livestock to employment	Contribution of livestock sector to overall employment (%)	Employ
<i>Environmental</i>		
High nature value of landscape	Area classified as High Nature Value (% UAA)	HNV
Conservation of biodiversity	Proportion of grassland birds in bird community (%)	Biodiversity
Water quality	Proportion of municipalities outside nitrate-vulnerable zones (%)	Water
<i>Cultural</i>		
Heritage landscapes	Areas in heritage landscapes (%) (grassland, specific areas and trees)	Landscape
Agro-tourism	Proportion of farms practicing agro-tourism (%)	Agrotourism
Quality-label animal products	Number of quality-label animal products (%)	Product

AWU = annual work unit; UAA = utilised agricultural area.
Adapted from Ryschawy *et al.* (2017).

The second dataset that quantifies service provisioning was first presented in Ryschawy *et al.* (2017). The authors – formed by a committee of livestock and environment scientists, economists and advisers – have used their expert knowledge to select indicators to assess services derived from livestock farming across France. From Ryschawy *et al.* (2017) we select indicators of employment in the livestock sector, environmental and cultural dimensions (Table 2) and propose to identify the main determinants of their spatial variability from an intensification point of view. The employment in the livestock sector category included variables related to employment in livestock farms, in the agro-food industry and the contribution of the sector to overall department employment. The environmental category included variables related to high nature value areas (HNV), that is, areas sustaining high levels of biodiversity (EEA/UNEP, 2004), the proportion of grassland birds (Teillard *et al.*, 2015) and water quality. The environmental category provides an account of aspects related to the multifunctionality of farming systems, the maintenance of habitat diversity and wildlife and supporting services such as nutrient cycling and water purification (Andersen *et al.*, 2003; Power, 2010). The cultural category included variables related to heritage landscapes, agro-tourism and quality-label animal products. Although cultural services usually consist of immaterial benefits provided, they can be directly experienced and intuitively appreciated by people, such as aesthetic, social relations, recreational and heritage aspects (Plieninger *et al.*, 2013). The reference year for the second dataset was 2010.

Statistical analysis

The analysis of the relationship between the intensification process over time and the provision of services by the livestock sector included three major steps: principal component analysis (PCA), co-inertia analysis and hierarchical cluster analysis (HCA). The choice of a multivariate approach (i.e. co-inertia analysis) enables to build links between the two datasets in the search for relationships between them. The co-inertia analysis gives some directions to explain the present state of service provisioning as a result of past

changes in the intensification process. This is a methodological advance as we move beyond analytical frameworks that uses present characteristics to explain present states. It therefore allows to identify direct-indirect relationships between past intensification changes and the extent to which they are linked to the current service provisioning. Dray *et al.* (2003) compared the benefits of the co-inertia analysis to other multivariate methods for coupling two tables, namely redundancy analysis and canonical correspondence analysis. They reported that co-inertia analysis is more flexible and allows numerous possibilities for coupling tables, in addition to its suitability for quantitative, qualitative or fuzzy environmental variables. Tichit *et al.* (2005) provide a practical application of the co-inertia analysis for studying the role of grazing intensity in creating suitable sward structures for breeding birds in grasslands.

The three major steps (PCA, co-inertia analysis and HCA) are preceded by the study of the correlation coefficients between variables of first and second datasets for the identification of interactions between the two datasets. The three major steps are explained below.

First, a PCA was performed on the first and second datasets to reduce the number of variables while keeping the largest possible variance. The PCA performed on the first dataset retained four components which explained 72% of the total variance (eigenvalue >1). The PCA performed on the second dataset retained three components which explained 80% of the total variance (eigenvalue >1). The two PCAs generated two tables that were used as inputs to the second step of the statistical analysis.

Second, a co-inertia analysis was performed on the two tables. Such analysis enables the simultaneous analysis of two tables and identifies the underlying data structure and the relationships between them (Dolédéc and Chessel, 1994). It finds ordinations from the two datasets by similarity via searching successive orthogonal axes from the two datasets with maximum squared co-variance. A complementary Monte Carlo permutation test follows the co-inertia analysis to verify the significance of co-structure between tables.

Table 3 Correlation coefficients between intensification and services provisioning variables from French departments

		Cultural			Environmental			Employment in the livestock sector		
		Agro-tourism	Landscape	Product	Biodiversity	HNV	Water	Employ	Emp Farm	Emp Ind
Livestock	Herbivore SR	-0.01	0.68	0.19	0.36	0.28	0.23	0.46	0.52	0.09
	Monogastric SR	-0.26	0.02	-0.42	-0.25	-0.43	-0.57	0.25	0.52	0.78
	Meat productivity	-0.26	-0.23	-0.02	-0.45	-0.59	-0.58	-0.12	0.13	0.38
	Milk productivity	-0.22	0.03	-0.41	-0.16	-0.49	-0.58	0.24	0.53	0.70
Land use	Share of UAA	-0.25	-0.02	0.11	-0.10	-0.31	-0.24	0.38	0.06	-0.09
	Area of grasslands and fodder crops: UAA	0.24	0.64	0.06	0.59	0.71	0.56	0.50	0.44	-0.04
Socioeconomic	Average farm size	-0.20	0.08	0.20	-0.00	0.02	-0.03	0.08	0.11	0.20
	Labour productivity	-0.13	0.01	0.09	0.11	0.14	0.18	0.06	-0.14	-0.14
	Dependence ratio	-0.17	0.30	-0.09	-0.19	-0.18	-0.32	0.22	0.50	0.57
	Tractor density	-0.14	0.38	-0.07	0.23	0.06	0.06	0.39	0.42	0.34

SR = stocking rate; UAA = utilised agricultural area.

Values in bold represent moderate to high correlation.

Herbivore: cattle, sheep and goat meat. Milk: cow, sheep and goat milk

Agro-tourism: Proportion of farms practicing agro-tourism; Landscape: Areas in heritage landscapes (grassland, specific areas and trees); Product: Number of quality-label animal products; Biodiversity: Proportion of grassland birds in bird community; HNV: Area classified as High Nature Value per km²; Water: Proportion of municipalities outside nitrate-vulnerable zones; Employ: Contribution of livestock sector to overall employment; Emp Farm: Workforce on livestock farms; Emp Ind: Employees in livestock agro-food industry.

Monte Carlo permutation was carried out on the two tables with 1000 permutations.

Third, an HCA was performed on the normed row scores, which is an output of co-inertia analyses. Complying with the Euclidean distance and Ward's aggregation method, the HCA generated three groups of departments. The results presented in the form of tables, graphs and maps were computed using the R software package (R Core Team, 2015). An analysis of variance (ANOVA) followed by Tukey's test was performed on results related to changes in the intensification process and provision of services.

Results

Correlations and co-inertia analysis results

Results of the coefficients of correlation between variables of intensification and variables of service provisioning are provided in Table 3. They suggest that the intensification variables related to livestock (stocking rates and productivity) and land use (area of grasslands and fodder crops) had the most moderate to strong correlations with service provisioning. On the other hand, results show socio-economic changes had only two moderate correlations with service provisioning. It suggests thus, that the socio-economic changes studied had not played a major role in service provisioning. The corresponding categories of services influenced by these variables (livestock and land use) were environmental and employment in the livestock sector. Cultural services have not had many moderate to strong correlations with the intensification variables studied. Quantitative results of the co-inertia analysis and description of correlations are provided below and are available in Table 3 and Figure 1.

According to the Kaiser criterion (eigenvalue >1), two axes of the co-inertia analysis were kept, which explained 93% of

the total variance. The Monte Carlo test revealed a high degree of co-structure between the two tables (RV coefficient = 0.57; P -value < 0.05), suggesting a relationship between intensification trajectories and services provisioning. Figure 1 shows plots derived from co-inertia analysis on the two datasets of intensification and services provisioning variables. Figure 1a shows the variables that had a higher correlation with these two axes. The first axis was positively correlated with monogastric stocking rate (Mon SR) and milk productivity (Milk prod) which are both associated to employment in the livestock agro-food industry (Emp Ind). The first axis was negatively correlated with environmental variables (water, high nature value, biodiversity). This illustrates a clear contrast between departments that had increased livestock productivity (milk productivity and monogastric stocking rate) at the cost of environmental performance (water quality, high nature value, biodiversity), and departments that had rather 'extensified' (lower livestock productivity) but sustained good environmental performance. The second axis was negatively correlated to the share of the area of grasslands and fodder crops and the herbivore stocking rate (Herb SR) as well as the provision of employment in livestock farms (Emp farm), to the contribution of livestock to overall employment (Employ) and to the provision of heritage landscapes (Landscapes).

Figure 1b illustrates the results of the HCA which revealed three groups of French departments: 'Intensive livestock areas', 'Extensive livestock areas' and 'Transition areas'. The positive and negative spaces along the first axis illustrate the opposition between 'Intensive' and 'Extensive' livestock areas, with 'Transition areas' in-between. This opposition is mainly evidenced by the maintenance of the area of grasslands and fodder crops along with moderate herbivore stocking rates in the 'Extensive livestock areas', in contrast to increased monogastric

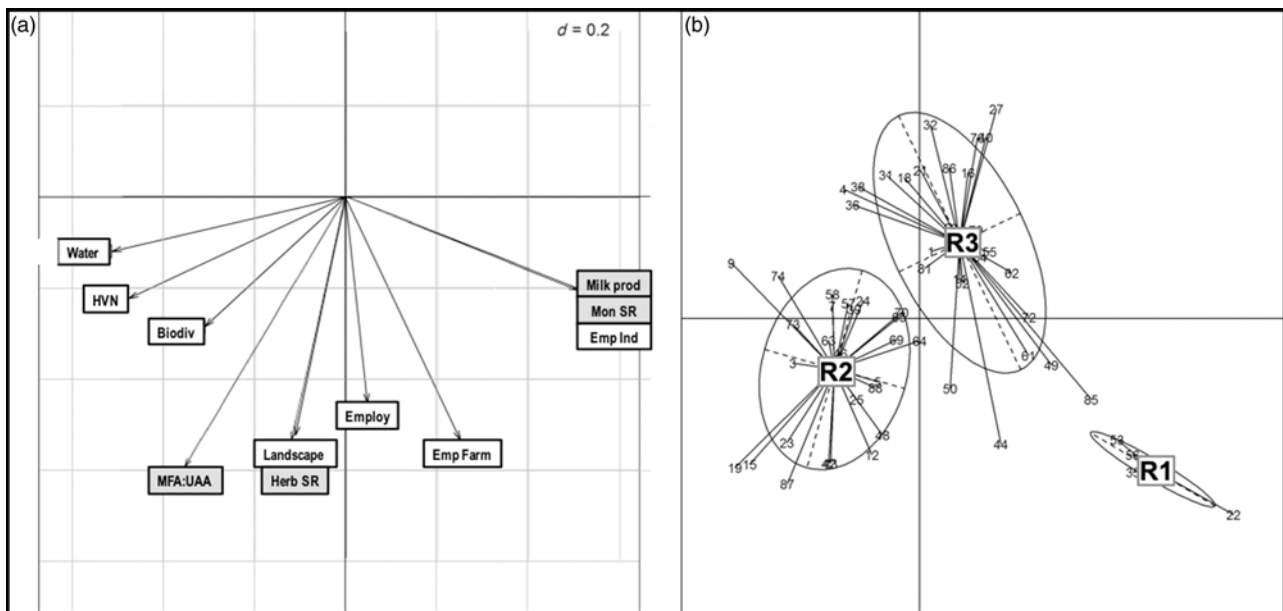


Figure 1 Co-inertia analysis results followed by classification. (a) Projection of intensification and services provisioning variables most correlated with axis 1 and axis 2 of the co-inertia analysis. (b) Projection of the three groups of French departments on the first and second axes of the co-inertia analysis after hierarchical cluster analysis. R1, R2 and R3 correspond to 'Intensive livestock areas', 'Extensive livestock areas' and 'Transition areas', respectively. See Table 2 for the abbreviation description. MFA = area of grasslands and fodder crops; UAA = utilised agricultural area; Herb SR = herbivore stocking rate; Mon SR = monogastric stocking rate; Milk prod = milk productivity.

stocking rates (+1045%) and milk productivity (+451%) in the 'Intensive livestock areas'.

The high degree of co-structure (RV coefficient = 0.57; P -value < 0.05) resulted from a number of correlations between intensification and service provisioning variables in the two tables (Table 3). Moderate to strong correlations occurred 17 times out of 90 correlations (10 variables in Table 1 times 9 variables in Table 2).

Ten correlations referred to livestock-related variables:

- Herbivore stocking rate was positively correlated with the provision of heritage landscapes (Landscape) and employment on livestock farms (Emp Farm).
- Monogastric stocking rate and milk productivity were positively correlated to provision of employment at both farm and agro-food industry (Emp Farm; Emp Ind). However, there were negative correlations between monogastric stocking rate and milk productivity and water quality (water).
- Herbivore meat productivity was negatively correlated with the provision of HNV and water quality (water).

Five correlations referred to land-use-related variables:

- The share of the area of grasslands and fodder crops was positively correlated to the provision of heritage landscapes, the conservation of biodiversity, water quality and the contribution of livestock to employment (Employ). It also showed a strong correlation with HNV.

Two correlations referred to socio-economic-related variables:

- The dependence ratio (i.e. inverse of self-sufficiency) was positively correlated to the provision of employment in livestock farms and in the agro-food industry.

Three trajectories of intensification and corresponding bundles of services

Three bundles of services emerged as a consequence of three contrasted trajectories of intensification. The intensifications trajectories were mainly characterised by varied rates of change in livestock productivity and stocking rates, and the share of the area of grasslands and fodder crops. These diverse levels of intensification over the period of 1938 and 2010 contributed to the emergence of three distinct bundles of services, each one linked to a specific combination of past changes that shaped a unique trajectory intrinsically linked to a unique bundle of services.

Figure 2 allows to visually distinguish the location of the departments in each of the three trajectories identified (Intensive, Extensive and Transition), as well as varied rates of change in the intensification variables and diverse composition of bundles of services. Figure 2a shows the spatial grouping of departments representing the influence of past intensification trajectories over the current provisioning of services. Figure 2b shows bar charts illustrating the rate of change for intensification variables per group, and Figure 2c shows polar charts with corresponding bundles of services provided in each group.

'Intensive livestock areas' (R1; $n = 5$) included Western French departments and were characterised by the highest rates of change. Compared to an average department, departments in 'Intensive livestock areas' had slightly higher rates of change in herbivore stocking rate (89%), share of area of grasslands and fodder crops (0%) and average farm size (315%). Nevertheless, these rates of change were minor compared to the marked increased rates of change in monogastric stocking rate (1045%), meat productivity (171%), milk

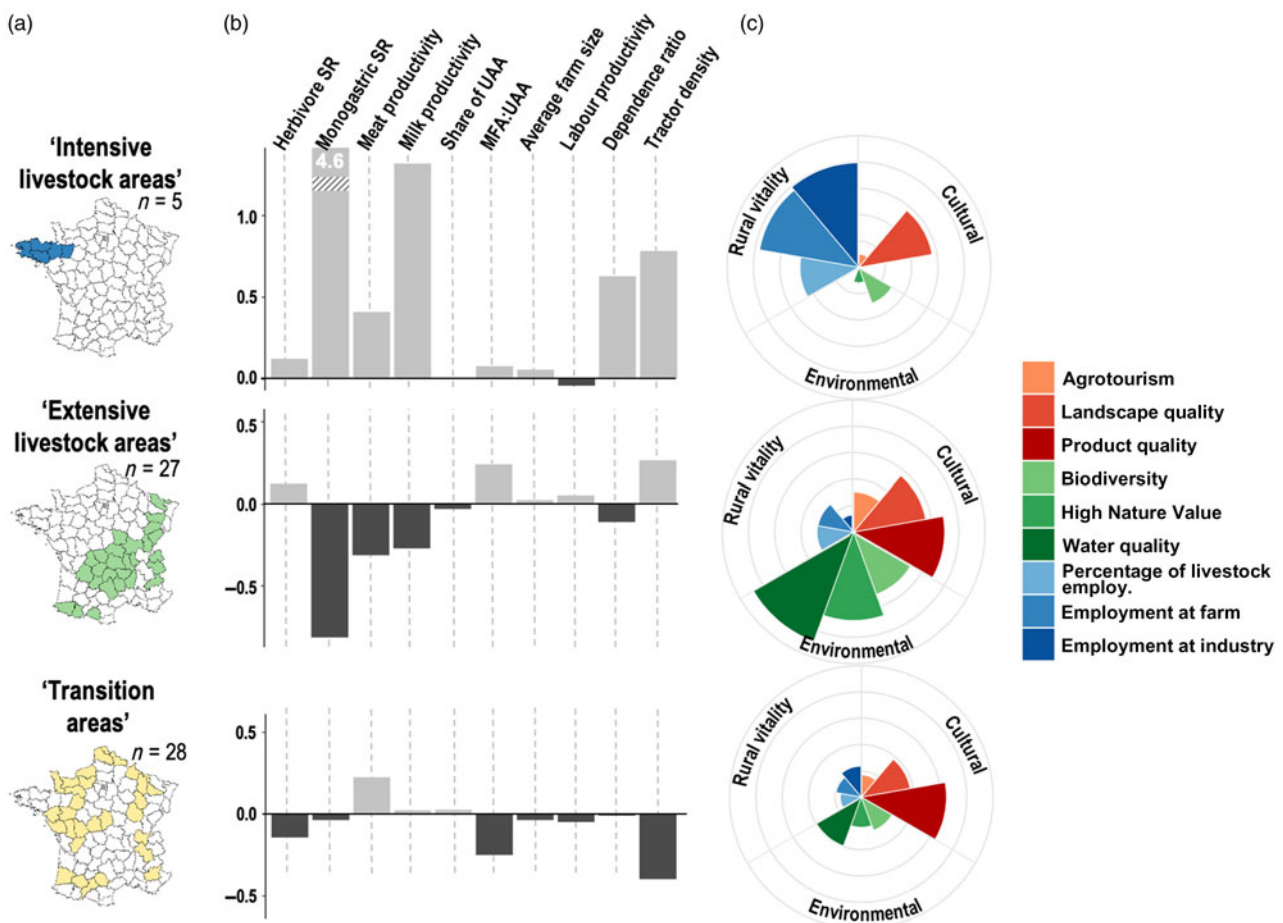


Figure 2 (colour online) Spatial trends of change in intensification variables and current provisioning of services. (a) Location of the three groups of French departments, 'Intensive livestock areas', 'Extensive livestock areas' and 'Transition areas'. (b) Average rate of change of intensification variables in three groups of French departments (bars > 0 indicate the rate of change was higher than in an average department and bars < 0 indicate the rate of change was lower than in an average department). (c) Average provision of services per group of French departments. SR = stocking rate; UAA = utilised agricultural area; MFA = area of grasslands and fodder crops.

productivity (451%), dependence ratio (199%) and mechanisation (1881%). In this group, all livestock-related variables had higher rates of change compared to an average department. The 'Intensive livestock areas' had a similar rate of change of an average department in the share of the agricultural area (-14%) and labour productivity (341%). The provision of services was mainly characterised by high levels in the vitality services (related to employment) and, to a lesser extent, to the provision of heritage landscapes. Environmental and remaining cultural services showed extremely low levels, notably for the provision of water quality and quality-label animal products. The higher rates of change in the intensification process, specifically monogastric stocking rate and milk productivity, allowed the development of the livestock sector in these departments, contributing to large employment opportunities. However, the concentration of highly intensive production systems, at high stocking rates, and the increased dependence ratio (purchased feed) lead to manure management issues, overall resulting in a decreased environmental quality.

'Extensive livestock areas' (R2; n = 27) mainly included departments located in the French Massif Central and in

the East, characterised by contrasted rates of change. Compared to an average department, departments in 'Extensive livestock areas' had lower rates of change for meat productivity (36%), milk productivity (86%) and the dependence ratio (65%). The decreased monogastric stocking rate (-28%) was markedly opposed to the average increase rate observed in all departments. The 'Extensive livestock areas' had a similar rate of change compared to an average department for the share of utilised agricultural area (-17%), average farm size (295%) and labour productivity (396%). 'Extensive livestock areas' presented rates of change considerably higher compared to an average department for herbivore stocking rate (95%), the area of grasslands and fodder crops (13%) and mechanisation (784%). The provision of services showed the most balanced pattern compared to other groups. Although low levels of vitality services were observed, cultural and environmental services were provided at the highest levels. Increased rates of changes favouring herbivores over monogastrics, along with an increased share of the area of grasslands and fodder crops, significantly impacted environmental services. Although R2 had lower levels of meat and milk productivity compared to other

Table 4 Trends of change in the French departments per group: 'Intensive livestock areas', 'Extensive livestock areas' and 'Transition areas'

Variables	Year	Intensive livestock areas <i>n</i> = 5	Extensive livestock areas <i>n</i> = 27	Transition areas <i>n</i> = 28	Average <i>n</i> = 60
Herbivore SR	1938	0.68 ^a	0.48 ^b	0.49 ^b	0.50
	2010	1.28 ^a	0.93 ^b	0.72 ^c	0.86
	% change	89%	95%	48%	73%
Monogastric SR	1938	0.16 ^a	0.13 ^{a,b}	0.10 ^b	0.12
	2010	1.80 ^a	0.09 ^b	0.24 ^b	0.30
	% change	1 045%	−28%	149%	160%
Meat productivity	1938	74 ^a	63 ^a	64 ^a	65
	2010	201 ^a	86 ^b	158 ^a	129
	% change	171%	36%	145%	100%
Milk productivity	1938	907 ^a	628 ^a	778 ^a	721
	2010	5000 ^a	1168 ^c	2142 ^b	1942
	% change	451%	86%	175%	169%
Share of UAA	1938	73% ^a	52% ^b	65% ^a	60%
	2010	63% ^a	43% ^b	57% ^a	51%
	% change	−14%	−17%	−12%	−14%
Share of the area of grasslands and fodder crops	1938	59% ^a	68% ^a	63% ^a	65%
	2010	59% ^b	77% ^a	43% ^b	60%
	% change	0%	13%	−32%	−8%
Average farm size	1938	12 ^b	14 ^b	19 ^a	16
	2010	48 ^b	56 ^b	72 ^a	63
	% change	315%	295%	272%	284%
Labour productivity	1938	07 ^b	08 ^b	11 ^a	9
	2010	30 ^b	41 ^{a,b}	48 ^a	43
	% change	341%	396%	348%	367%
Dependence ratio	1938	0.15 ^a	0.14 ^a	0.14 ^a	0.14
	2010	0.44 ^a	0.23 ^b	0.26 ^b	0.26
	% change	199%	65%	84%	86%
Tractor density *100	1938	0.03 ^b	0.06 ^b	0.11 ^a	0.08
	2010	0.60 ^a	0.55 ^a	0.48 ^a	0.52
	% change	1881%	784%	341%	540%

SR = stocking rate; UAA = utilised agricultural area.

^{a, b}Values with different superscripts within a row differ significantly at $P < 0.05$.

groups, it had the highest level of quality-label animal products, which suggested that quality compensated for the quantity of animal products. 'Extensive livestock areas' also showed high levels of heritage landscapes and the highest level of farms practicing agro-tourism.

'Transition areas' ($R3$; $n = 28$) mainly included departments located on the surrounding area of the Paris Basin and few in the South-West and South-East of France. In the past century, these areas have undergone a transition characterised by the encroachment of crops over the area of grasslands and fodder crops. They had lower rates of change for the variables studied compared to other groups; – that is, the rates of change were close to that of an average French department (Table 4). Departments in 'Transition areas' had lower rates of change than average for herbivore stocking rate (48%) and the share of the area of grasslands and fodder crops (−32%) as well as mechanisation (341%). Also, 'Transition areas' had a similar rate of change than an average department for monogastric stocking rate (149%), milk productivity (175%), share of utilised agricultural area (−12%), average farm size (272%), labour productivity (348%) and dependence ratio (84%). The only variable that

had a considerably higher rate of change compared to an average department was herbivore meat productivity (145%). The provision of services showed low levels of all types of services, except for quality-label animal products.

Discussion

Our analysis revealed that the provision of social, cultural and environmental services was spatially structured and based on three groups, determined by different rates of change in intensification variables over time. In 'Intensive livestock areas', changes were marked by higher stocking rates and meat and milk productivity, which contributed to high levels of the provision of vitality services, such as employability in both farm and industry. In 'Extensive livestock' areas, we observed higher rates of change for variables related to specialisation on grazing (herbivores and area of grasslands and fodder crops) and lower rates of change for productivity aspects. This contributed to high levels of provision of environmental and cultural services, such as biodiversity conservation and quality-label products. In 'Transition areas', changes in the intensification process were relatively low

compared to those observed in 'Intensive' and 'Extensive' livestock areas. The geographical proximity of 'Transition areas' to crop-specialised areas in the North (Paris Basin) and to grasslands on 'Extensive livestock areas' characterises a transition frontier. Livestock lost its relative importance over the years, and grasslands were converted to cropping areas, with a loss of 32% of the initial area. The decrease in grassland areas follows a trend of agricultural specialisation and intensification as well as favourable market prices for cereals, contributing to the encroachment of cropland over grasslands (Peyraud *et al.*, 2014). Although livestock densities have increased to compensate for the reduced area, the importance of crop production still offset livestock production, the main reason for the reduced provision of services in most departments of 'Transition areas'.

How have changes in the process of intensification influenced the provisioning of services?

The process of intensification played an essential role in the differentiation of livestock areas in terms of the provision of social, environmental and cultural services. Changes in livestock productivity were the main positive determinants of employment in the livestock sector. However, these changes in livestock productivity negatively influenced the provision of environmental services. Changes in the area of grasslands and fodder crops largely influenced the provision of environmental services, and they played a positive role in the maintenance of heritage landscapes and positively contributed to overall employment. Although socio-economic changes were very high in absolute terms for all areas across France, they did not influence at department level the spatial differentiation of the provision of services (very weak correlations, Table 3), with the exception of changes in the dependence ratio (feed expenses) that went together with employment in farm and industry.

The current provision of services by the livestock sector reflects the spatially differentiated changes in the process of intensification. The three groups identified showed that varied regional rates of change in the process of intensification contributed to the formation of the distinct bundles. The nature of the relationship between the process of intensification and the provision of services was, however, not a strictly linear one: the high intensification of livestock ultimately contributed to a higher employment rate, whereas the high provision of environmental services could be conditioned to different situations, that is, non-intensification, intrinsic good environmental conditions or limitation in the availability of local resources.

Ranking drivers of changes

The specialisation in 'Intensive livestock areas' was possible thanks to initial orientation of livestock production and because of a higher share of the rural population in 1938, with a high availability of workforce (Gambino, 2015). The monogastric population surged and led to increased stocking rates, with about a 1045% change over the period, which contributed to a higher employment in the livestock sector. There was

an important movement of modernisation in these areas (Brittany) based on technological rationalism and collective development, structured around extension programmes led by the farmers' organisations. This enabled an increased productivity and was followed by the development of upstream and downstream supply chains, that is, feed and food industry, which equally benefited from short distances to ports, an essential determinant of feed imports, as well as access to markets in large consumption centres (Lang *et al.*, 2014). These changes contributed to the pronounced level of provision of employment more markedly at the farm and industry level, but also in terms of overall employment. Changes in land use, namely the focus on maize silage and temporary grasses, along with the substitution of local breeds to more productive ones, contributed to the highest levels of milk productivity. Such gains also concurred with high levels of employment in the livestock sector because of the development of down- and upstream industries associated with livestock production (i.e. feed industry, dairy processing, slaughterhouses). The large number of monogastrics, along with dairy cows kept in landless systems at high stocking rates, is certainly the main driver of increased livestock productivity. These gains were important in terms of a high provision of animal source food, but at the same time, they created issues related to manure management. Increasing quantities of manure in a limited area for spreading resulted in the over-fertilisation of agricultural areas and, consequently, high losses to water streams, thus depleting water quality.

The prominence of grazing systems in 'Extensive livestock areas' is marked by large grassland areas, moderate herbivore stocking rates and lower productivity levels. These characteristics influenced the provision of services in a more equilibrated pattern, with a high provision of environmental and cultural services, but reduced employment in the livestock sector. The relative increase of grasslands plays an essential role in the conservation of biodiversity. The maintenance of grasslands supports bird species that depend on this type of habitat to complete their life cycle, highlighting the close link between birds and grasslands (Henle *et al.*, 2008). Teillard *et al.* (2017) highlight that increased biodiversity is achieved with optimal extensification, thus corroborating our findings concerning the role of grassland habitats in maintaining diverse and adapted species. Grassland areas also influenced water quality and provide a continuous soil surface cover; when managed at low levels of inputs and stocking rates, they positively contribute to water filtering (Hooda *et al.*, 2000). If lower levels of production contrast with high levels of 'Intensive livestock areas', the strategy around a quality label in 'Extensive livestock areas' enabled a high provision of quality-label products in opposition to an industrial product base in Brittany. This is a result, for instance, of an early articulation of dairy farmers, cooperatives, cheese makers and artisans in specific parts of 'Extensive livestock areas' to produce cheese within a chain perspective of higher added-value products (Perrier-Cornet, 1986).

Biophysical drivers determined significant changes in land-use cover, characterised by the conversion of grasslands into cropland in the plains ('Transition areas'). In areas where

such change was not possible because of limited agronomic potential (marginal and mountainous areas), the alternative consisted of emphasising on grazing, as observed in the 'Extensive livestock areas' (Massif Central and Eastern France).

The link to land and resource use is different for ruminants and monogastrics. The nature of this link is more complex for monogastric production, as the sites of feed production are often physically decoupled from sites where monogastric production takes place. In the 'Intensive livestock areas' the Dependence ratio indicator reflected the need to import large quantities of feed resources to meet the feed requirement of monogastric and intensive dairy productions systems. In the long term, high import of nutrients coupled with high stocking rates resulted in large quantities of manure, which ended up in water streams and contributed to the deterioration of water quality. On the other hand, in the 'Extensive livestock areas', a larger share of livestock feed is locally sourced through grazing and manure is directly recycled back to soils. This prevented surplus nutrient in the system, and grazing at moderate stocking rates enabled maintaining grasslands habitat that hosts many bird species.

Comparison with other studies and added-value

This study presents a practical application of past studies that have identified the main changes in the process of intensification, providing a link to the consequences of such changes in terms of service provisioning (Domingues *et al.*, 2018). Our analysis was built from a long-time perspective to provide empiric evidence on the interplay between changes in the process of intensification and the provision of services. The spatial differentiation in services provision occurred because of divergent trajectories of changes in the process of intensification. Among the most influencing ones we identified changes in the area of grasslands and fodder crops, which had the largest number of correlations with service provision. It was moderately to strongly correlated with the three environmental services, with heritage landscapes and with the contribution of livestock to overall employment. Livestock-related changes (i.e. stocking rates and productivity) also played an important role, with consequences for water quality and employment on farms and in the agro-industry. If desirable patterns of service provisioning are to be attainable in the future (as a way of sustaining the long-term capacity of areas of producing food, environmental and sociocultural services), it will be fundamental to target changes in terms of land use, stocking rates and production levels.

DeFries *et al.* (2004) suggested that although land-use change can contribute to increased food production, it can also alter a range of other services, such as the provisioning of freshwater, the maintenance of soil fertility and the conservation of biological fertility. DeFries *et al.* (2004) also draw attention to the fact that land transitions (from pre-settlement through more intensive stages) come with severe implications for ecosystems functions. In our study, the water quality indicator, for example, evidenced contrasted situations between Intensive and Extensive areas, with deteriorated and high standards of water quality, respectively. The

deteriorated standard of water quality is a signal that the intensification trajectory undergone in 'Intensive livestock areas' points to an incompatibility between the farming practices adopted (e.g. high stocking rates) and the ecosystem-regulating capacity (e.g. soil filtering). This advocates urgent action to reduce water pollution by the livestock sector in 'Intensive areas' and to restabilise the capacity of these areas to provide services.

Other studies further corroborated the major role played by grasslands and highlighted the importance of maintaining such areas, especially in marginal regions for a better conservation of biodiversity. Werling *et al.* (2014) found that switchgrass and prairie plantings ranked higher on biodiversity metrics (methanotrophic bacterial, arthropod and bird diversity) if compared to maize cropping. Although we used only one indicator as a surrogate of biodiversity (the proportion of grasslands birds), we found a significant correlation between this indicator and the area of grasslands and fodder crops ($\text{cor} = 0.59$; $P < 0.05$). Grassland bird species well fitted the purpose of our study as they occupy a certain trophic level, which allows using them as surrogate of general biodiversity (Caro and O'Doherty, 1999). Their presence/abundance indicates a good state also in lower trophic levels, such as the presence of arthropods that they feed on. Beyond the food chain perspective, grasslands also provide the biophysical means many species depend on for nesting or carrying other vital stages of their development.

Modernel *et al.* (2016) analysed how ecosystem services provided by Pampas and Campos native grasslands were influenced by land-use changes and their drivers. With increased cropland encroaching on native grassland areas, some 22 species were considered globally threatened or near-threatened because of human-induced habitat homogenisation (Azpiroz *et al.*, 2012). As observed in our study, the trend of increased bird species proportional to grassland areas, and conversely, reflects the birds' needs of space for breeding, foraging and dispersal (Cerezo *et al.*, 2011). The intensification of livestock production targeting increased provisioning services most of the times contrasted with reduced supporting and regulating services. The question of having a balanced bundle of services is complex, as management interventions for the provision of one service often negatively affect others (Bommarco *et al.*, 2013). This highlights the importance of understanding the influences of past changes in the current provision of services.

If more balanced bundles of services are to be attainable in the future (as a way of sustaining the long-term capacity of areas of producing food, environmental and sociocultural services), it will be fundamental to target changes in terms of land use, stocking rates and production levels. Our study provides some directions in this sense and implies that achieving more balanced bundles of services is a matter of prioritising, for instance, the conservation of the area of grasslands and fodder crops or even the reconversion of cropland back to grasslands in areas where services associated to it have faced a decline. Also, stocking rates and productivity levels should comply with a given area capacity to withstand

environmental impacts and thus express its full potential in sustaining the ecosystem's ability of providing services in the long term.

Criteria selection and further implications

The coefficient of livestock specialisation, which was used to select the set of departments presented in this article, raises some points for consideration. The lower limit of the coefficient, set at 0.5, restricted the selection to 60 departments (from a total of 96), which varied from 0.5 to 2.0. This large range of variation in the coefficient reflected, to some extent, the differences observed among the three trajectories. 'Transition areas' had lower coefficients of specialisation ($\cong 1.06$), 'Extensive areas' had intermediate values ($\cong 1.49$) and 'Intensive areas' had higher values ($\cong 1.93$). The selection of departments based on a threshold of 0.5 (which means a department has at least half of the economic relevance of France's livestock as a whole) might have included departments where livestock play a marginal economic role, such as in 'Transition areas'. If the benefits brought by livestock services are considered important and their provisioning is set to continue or be enhanced in the future, the past trend observed in 'Transition areas' needs to be reverted.

The set of services selected in our study (Table 2) reflects to a certain extent the values of today's society in response to issues faced at present, for example, water quality, biodiversity, landscape and agro-tourism. These services are valued by society because they have either a direct impact on their well-being – access to water safe for drinking and to landscape with pleasing natural or human-shaped attributes, or because of the need to protect species facing decline, such as grassland-specialist birds that lost habitat over the past years because of the conversion of grasslands into croplands. Today's perceptions of services are a consequence of past changes that threaten present and future service provision and for this reason need re-thinking. This view might have not been the same in 1938, as the benefits reaped from moving towards more intensive livestock production would meet food provisioning in the short term, but ultimately harm the environment in the long term. If the present issues are dealt with accordingly, the value of the services presented in this study might no longer be of interest in the future.

In a nutshell


The process of intensification played a major role in the spatial differentiation of service provision, leading to varied composition bundles of social, environmental and cultural services. Two trajectories were principally related to livestock productions in different ways, one based on the intensification of monogastric and dairy systems, coupled to high levels of employment in the livestock sector, and another trajectory of grazing-based systems, coupled with high environmental and moderate cultural services.

Although 'Intensive livestock areas' contributed to the highest level of animal production, the unbalanced bundle of services put into question the intensification model adopted. This indirectly led, for instance, to a deteriorated

water quality and a low bird biodiversity. Such a model seems to be incompatible with the ecosystem capacity to support its natural functions, namely to cope with the overload of nutrients of livestock manure. On the other hand, the moderate levels of production and stocking rates in 'Extensive livestock areas', mainly characterised by ruminant grazing systems, contributed to the maintenance of grasslands through the direct link between animals and land. This led to a more balanced bundle of services, reflecting positive synergies of production systems that rely mainly on local resources. However, as moderate as the levels of production are, these areas found opportunities to compensate it with quality-label products. Although in this latter case, the moderate level of production was compensated with quality-label products, in the case of 'Intensive livestock areas', the weak environmental service cannot simply be compensated by another type of service, but needs a target strategy of reconciliation between provisioning and other kinds of services.

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We would like to express our deep regret as Muriel Tichit said goodbye to us so early and unexpectedly on past March. She has left not only an intellectual vacuum in the livestock farming systems community, but also a feeling of nostalgia for those who had the chance to be friends with her and share of her insatiable taste for science, readiness for hearing and helping young scientists to build a successful career. We greatly miss Muriel for her many humane qualities, and hope we can continue to follow her teachings and values.

 J. P. Domingues 0000-0003-0639-420X

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Declaration of interest

There is no conflict of interest to be declared.

Ethics statement

Not relevant.

Software and data repository resources

None of the data were deposited in an official repository.

Supplementary material

To view supplementary material for this article, please visit <https://doi.org/10.1017/S1751731119001952>

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