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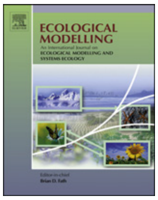

Development of a broadened cognitive mapping approach for analysing systems of practices in social–ecological systems

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ABSTRACT

This paper presents a new cognitive mapping approach for analysing systems of practices in social–ecological systems. These systems are mapped from people's views collected during open-ended interviews. Cognitive maps are made up of diverse variables (e.g., operations, drivers, constraints) linked to each other by a range of relationships: cause–effect, fluxes of matter, information flows and sequence of two operations. Individual cognitive maps heuristically model the practices and decision-making processes expressed by interviewees. The mathematical formulation of cognitive maps allows individual cognitive maps to be aggregated into a social cognitive map. The latter can be used to model the system of practices used by a particular group of people. Using this approach, we analysed the practices and decision-making processes linked to grassland management in a Belgian grassland-based livestock farming system. Our work confirmed that a social cognitive map could be drawn up for multiple locations. The results showed how this inductive cognitive mapping approach overcame two limitations frequently highlighted in previous studies: the diverse interpretations of variables and relationships; and the difficulty in revealing the rationale in cognitive maps.

1. Introduction

In social–ecological systems (Holling, 2001; Walker et al., 2004), decision-making tends to be extremely complex because of the intricacy of these systems (Ascough et al., 2008). In the agricultural context, the scientific community has developed various models of these systems and used them as simulation tools to support managers' decisions (Edwards-Jones, 2006; McCown et al., 2009). Farmers' strategies are based on the interaction of their perceptions about their ecological, economic and social environments. These strategies are translated into practices through decision-making processes. As external factors change, strategies and practices are continuously adapted. The study of managers' practices and their drivers is an important factor in modelling agricultural systems and highlights the need to model both system complexity at the farm level and system diversity at the regional level (Landais et al., 1988).

Studies of practices in agricultural systems can be grouped into two broad scientific approaches: one based on social issues (anthropological science) and the other on technical issues (engineering science). The social approaches are inductive, linked to anthropological and social sciences, and view practices as social constructs from a constructivist point of view (Darré, 1996; Darré et al., 2004). They focus on understanding managers' perceptions and representations of social–ecological systems, either as a whole or divided into sub-systems, in terms of practices, knowledge, etc. (Darré et al., 2004). The outputs of such studies provide a good understanding of the studied situations, but they are not easy to incorporate into bio-economic simulation (Mathieu, 2004; Papy, 2004). Conversely, the technical approaches involve studying complex interactions among elements of the studied systems (Janssen and van Ittersum, 2007; Darnhofer et al., 2010). They use theories from artificial intelligence or management science in order to build farming systems models and decision-support systems (Aubry et al., 1998; Girard and Hubert, 1999; Dounias et al., 2002; Keating et al., 2003; Cros et al., 2004; Louhichi et al., 2004; Merot et al., 2008; Vayssieres et al., 2009). These models can be used to simulate and evaluate scenarios in order to support managers via decision support systems (DSS). In most of these bio-economic models, the involvement of actors (managers or non-scientific experts) is

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limited to their validating, enriching or specifying the structure of a model developed by scientists (Gouttenoire et al., 2010).

Historically, models of social–ecological systems have tended to ignore the social components (Dent et al., 1995) leading to the limited impact of DSS in rural resource management. This has led various authors to highlight the need for incorporating social aspects into DSS (Edwards-Jones, 2006; Gouttenoire et al., 2011). In order to improve decision-making in social–ecological systems, greater understanding is needed of the knowledge used by managers (such as farmers) in managing their systems (Girard and Hubert, 1999). A way to address this challenge is to develop models based on farmers' perceptions that reflect the way they perceive their own agro-ecosystem in an inductive way. The structure of these models should be focused on the farmers' practices. The objective of our study was to develop a socio-technical modelling tool to inductively identify and model farmers' systems of practices.

Cristofini et al. (1978) were the first to use the term 'system of practices', referring to 'a consistent combination of practices' (Gras et al., 1989). In an organizational context, a 'system of practices' was later defined as the actions shaped by normative structures (Levitt, 1998) or as the complex network of structures, tasks and traditions that create and facilitate practice (Halverson, 2003). In our study, the definition of 'systems of practices' provided by Cristofini et al. (1978) was broadened thus: a farmers' system of practices is (i) a particular combination of elementary practices, (ii) factors influencing practices, (iii) elements affected by these practices and (iv) the way in which all of them are linked to each other.

Studying systems of practices implies a degree of complexity: systems of practices are not only constrained by their environment (e.g., market, climate, seasons, consumer choices), but are also highly influenced by human factors (actors' preferences and perceptions). The importance of these human factors underlines the need to analyse actors' local knowledge. In this context, knowledge-driven modelling techniques, such as cognitive mapping approaches, seem to be promising alternatives for implementing DSS in terms of taking account of social aspects (Fairweather, 2010).

Cognitive mapping approaches have been used to identify people's perceptions of complex social systems (Özesmi and Özesmi, 2004). In this field of study, the work of Axelrod (1976) was seminal. He was the first to use directed graphs (i.e., a network of nodes and directed edges) to show causal relationships based on actors' descriptions, and he called these representations 'cognitive maps'. Kosko (1986) applied fuzzy causal function (i.e., weighting the edges, from −1 to 1) to the relationships, creating 'Fuzzy Cognitive Maps' (FCM). Recent scientific studies have used cognitive mapping techniques in various domains, such as management studies (Pinch et al., 2010), finance (Koulouriotis et al., 2005) and medical sciences (Stylios et al., 2008; Papageorgiou, 2011). In an organizational setting, the Strategic Options Development and Analysis (SODA) technique has been developed by Colin Eden and Fran Ackermann (Ackermann and Eden, 2010). This technique is used to represent problematic situations in individual or collective cognitive maps. Taking account of a complex system of goals and objectives, it allows participants to explore options and find negotiated solutions to resolve problematic situations.

In environmental sciences, cognitive mapping techniques have been used mainly in environmental conflict management (Özesmi and Özesmi, 2003; Özesmi and Özesmi, 2004) and forest management (Mendoza and Martins, 2006; Tikkanen et al., 2006; Isaac et al., 2009; Kok, 2009; Wolfslehner and Vacik, 2011). Ten studies have applied FCM to agricultural systems analysis (Table 1) in order to: (i) understand farmer perceptions about pesticides (Popper et al., 1996) on their own farms (Fairweather, 2010) or about environmental management measures (Ortolani et al., 2010); (ii) describe practices in agro-ecosystems (Isaac et al., 2009); (iii) assess the impact of agricultural systems on the environment (Özesmi and Özesmi, 2003) and crop yield (Papageorgiou et al., 2009; Papageorgiou, 2011) and the impact of policies on agricultural systems (Hukkinen, 1993; Newig et al., 2008); and (iv) evaluate the sustainability of agro-ecosystems (Rajaram and Das, 2010; Fairweather and Hunt, 2011).

Cognitive mapping approaches are flexible tools that can model people's diverse drivers and motivations without excluding the technical dimensions linked to the studied system of practices. Özesmi and Özesmi (2004) developed a multi-step FCM approach for analysing how people perceive an ecosystem and for comparing and contrasting the perceptions of different people or stakeholder groups. The authors looked at particular examples of environmental conflicts, each one linked to one ecosystem, such as the creation of a national park or the erection of a hydroelectric dam. Fairweather (2010) has applied Özesmi and Özesmi (2004)'s approach to the study of identical ecosystems in different places. He has shown how maps from several farmers, each describing his/her own farm, can be used to build a group map that represents how a group of farmers think their farm ecosystem works. These maps created with farmers focus on the farm system as whole, overlooking details about how parts of the system work. Considering the complex nature of social–ecological systems, he suggested that further work on building causal maps for particular parts of the farm system would be needed to describe fully how the system works (Fairweather, 2010). Based on FCM, we have developed a new approach for examining a particular part of the farm system – the system of farmer practices, as defined earlier.

In this article, we initially describe a Cognitive Mapping Approach for Analysing Actors' Systems Of Practices (CMASOP) in social–ecological systems. We then apply this approach to the analysis of forage management in a grassland-based livestock farming system, as a case study. One original aspect of the CMASOP approach is its application of cognitive mapping for gaining a detailed understanding of an important part of social–ecological systems – people's practices.

2. CMASOP approach

The CMASOP approach is based on using open-ended interviews to create individual cognitive maps (ICMs). These ICMs are then used to build a social cognitive map (SCM). The four steps are illustrated in Fig. 1 and are described below.

2.1. Step 1 – data collection

The first step is to conduct a study among managers of social–ecological systems. The in-depth interview process is guided by an outline of open-ended topics that cover a broad range of themes linked to the systems being analysed: history, structure, managerial practices, and opinions and visions about the general context and local diversity of these practices. For this last topic and using snowball sampling (Pires, 1997), the names of other interesting actors are collected. The sample is therefore constituted during data collection with the aim of maximizing the diversity of structures and practices. The information collected is of both a qualitative (e.g., descriptions, perceptions) and quantitative nature (e.g., working force, exploited areas, yields). Interviews are recorded and then fully transcribed via a simple text editor.

2.2. Step 2 – coding

The transcription is coded by linking the relationships between two variables to the interview sections using computer-assisted Qualitative Data Analysis software in *family R* (*family RQDA*, Huang,

Table 1
Previous scientific work applying fuzzy cognitive mapping (FCM) approaches to agricultural systems.

Study	Subject	Place	Scale	Mappers
Hukkinen (1993)	Institutional distortion of drainage modelling	USA (Arkansas)	River Basin	Officials
Popper et al. (1996)	Knowledge and beliefs about pesticides	Guatemala	Farm	Farmers and housewives'
Özesmi and Özesmi (2003)	Lake ecosystem management plan	Turkey (Uluabat)	Ecosystems	Six groups of stakeholders
Newig et al. (2008)	EU-induced institutional change	Germany and Austria	Regional agricultural land use	Experts and stakeholders
Isaac et al. (2009)	Farm management and practices in agroforestry systems (cocoa)	Ghana	Farm	Farmers
Papageorgiou et al. (2009), Papageorgiou (2011)	Cotton yield management in precision agriculture	Greece (Central)	Field	Experts
Fairweather (2010)	Perceptions of how a dairy farm ecosystem works	New Zealand	Farm	Farmers
Ortolani et al. (2010)	Concepts of environmental management measures	Belgium	Farm	Farmers
Rajaram and Das (2010)	Sustainability components of agro-ecosystems	Southern India	Community (Case study: one village)	Farmers and villagers
Fairweather and Hunt (2011)	Sustainability of sheep/beef cattle farms	New Zealand	Farm and type of farm	Farmers

2009; R Development Core Team, 2009). One relationship can be linked to several sections (participants' quotations) and one section can be coded by several relationships.

If the interviews cover a wide topic, that topic can be divided into themes to be studied separately. In this case, optional thematic coding is required. The themes used in this sub-step are a priori based on, for instance, the topics of the interview outlines. These themes can be hierarchically structured.

Interview sections linked to the theme of interest are then coded using an inductive method. This step involves identifying the relationships among variables that participants cite to describe their systems of practices. The lists of variables and relationships are not a priori established, but are drawn up during this step. A variable is defined as an element of the system cited by the participant in order to describe his/her system. It can influence his/her practices and/or be influenced by the practices.

A relationship is a directional link between two variables cited by the participant and identified in his/her interview. In CMASOP, relationships can be grouped into six types: sequence of two operations; output of an operation; use of a product; outcome of an operation or a state; influence or condition of an operation or a product; or general statement.

As an example, the following interview section "The cut plots are often on the same fields: those that are less sloped, closer to the farm, with less damage caused by wild boar . . ." described the drivers that guide the farmers in their allocation of a plot to cutting management. This section is coded using three relationships among four variables. The variables are Cutting Plot, Topography, Plot-Farm Distance and Wild Boar. The relationship links the three influencing variables (Topography, Plot-Farm Distance and Wild Boar) to the object of the practices described (Cutting Plot). The outputs of this step are coded interviews. The RQDA package produces a complex SQLite data base, where for each interview the fields of interest are:

1. interviewed actor;
2. identified relationship among variables;
3. quotations (sections of interview) linked to each relationship.

2.3. Step 3 – individual cognitive mapping

The directional relationships identified in interviews are processed to create ICMs. In the CMASOP approach, an ICM is the graphical representation of relationships identified in a participant's interview. It takes the form of a network where the nodes are variables and edges are relationships. It illustrates how this actor perceives and expresses his/her system of practices. The graphical forms of ICM were generated using the R-package RgraphViz (Gentry et al., 2010). In these maps, the variables are arranged using a multidimensional scaling algorithm minimizing the number of edge crossings (Kamada and Kawai, 1989).

In mathematical terms, each map corresponds to an $N \times N$ Boolean matrix where N is the number of variables quoted by the actor. It is called an adjacency matrix (Özesmi and Özesmi,

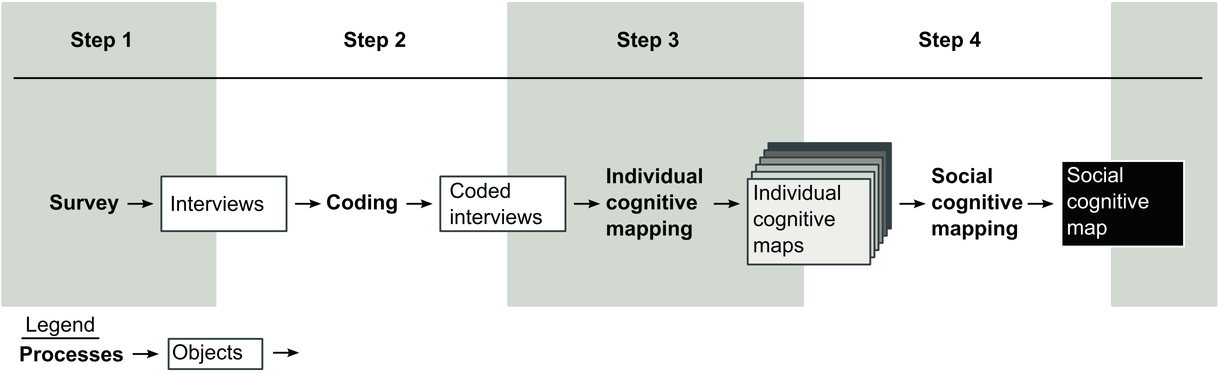

Fig. 1. The four main steps of the CMASOP approach and the objects that are used, produced or generated.

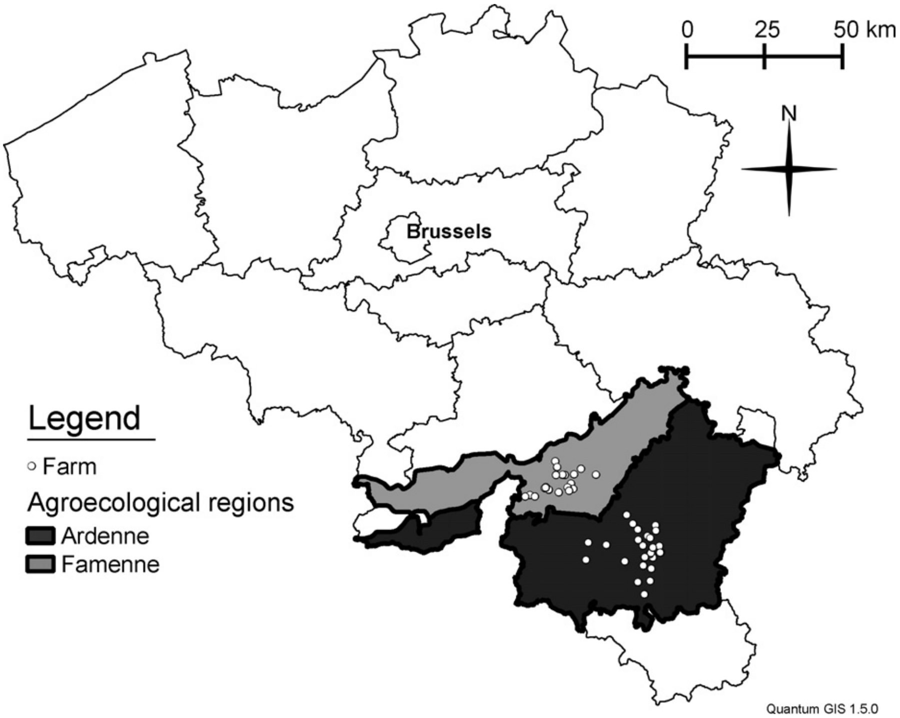

Fig. 2. Location of the two studied agroecological areas, Ardenne and Famenne, in Belgium. Location of the 49 farms in the study.

2004). For instance, if the relationship a_{ij} between variable i and variable j is identified, the value of the relation a_{ij} is 1, which corresponds to `TRUE` in Boolean language. The output of this third step is a collection of ICMs and their related adjacency matrices.

2.4. Step 4 – social cognitive mapping

An SCM is generated by aggregating the ICMs. This operation is an arithmetic addition of adjacency matrices. The result is an adjacency matrix that is processed to generate an SCM. The adjacency matrix of an SCM is ordinal: the value of the element a_{ij} (i.e., the weight of the relationship linking variable i to variable j) can be greater than 1. In our study, the weight of a relationship is the number of interviewed actors who quoted this relationship. The output of this last operation is one SCM and its related adjacency matrix.

There are three ways of analysing SCMs: (i) graphical form of the cognitive map, (ii) graph theory indicators of map, variables and relationships and (iii) farmers' quotations linked to relationships. The graphical analysis of the cognitive map aims to sketch the general structure of the map and to identify the most central variables in the system and show how they are linked to each other through important relationships. Graph theory indicators can support the graphical analysis of maps by evaluating the weight of relationships, outdegree, indegree and centrality of variables. At the variables level, the outdegree is the cumulative weight of relationships exiting this variable, the indegree is the cumulative weight of relationships entering it and the centrality of a variable is the sum of its outdegree and indegree. The farmers' quotations linked to relationships during the second step (coding) are available during all subsequent steps. The quote-retrieving module is useful for understanding the complexity and diversity that can characterize relationships in order to interpret the whole SCM.

3. Case study: grass forage management in a grassland-based livestock farming system

We used the CMASOP approach to analyse grass forage management (harvest, preservation and conditioning of grass forage) in the livestock farming systems of Ardennes and Famenne, two grassland-based systems in Belgium (Fig. 2). The study carried out among the farmers in this area is described here.

3.1. Materials: data collection (step 1)

A total of 49 farmers were interviewed over two periods: December 2008 to March 2009, and February to June 2010. We used a snowball sampling method (Pires, 1997), with farmers selected for interview being asked to name other interesting farmers who could participate in the survey. The selection criterion was aimed at maximizing the diversity of the studied farms in terms of their structure and, if possible, their functioning.

The studied farms occupied an average Utilised Agricultural Area (UAA) of 110 ± 48 ha. Grasslands occupied 85 ± 12% of the UAA and maize crop 8.2 ± 8.4% of the UAA. The average size of the herd was 220 ± 98 Livestock Unit (LU). Twenty-nine farms only had beef cattle, four only had dairy cattle and 16 had beef and dairy cattle.

3.2. Results

The results of the coding, ICM and SCM, are presented in this section. For this case study, only interview sections linked to grass forage management were analysed.

3.2.1. Coding (step 2)

Among the sections related to grass forage management, 599 farmer quotations were identified as a relationship between two variables. In each interview, averages of 11.8 ± 5.0 relationships

Table 2
Grassland management variables taken into account by farmers and their centralities.

First cut	126	Animal health	8
Second cut	102	Topography	7
Bale wrap	95	Pregnant cows	7
Silo	82	Crop	7
Hay	80	Early topping	7
Weather	73	Autonomy	7
Cattle movement	66	Suckling herd	6
Cutting date	60	Forage maize	6
Plot-farm distance	55	Permanent grassland	5
Plot utilization	43	Calves	4
Third cut	36	Growth stage of grass	4
Forage quality	30	Wild boar	4
Forage quantity	30	Plot size	4
Yearlings	18	Turn-out	3
Supplementation	16	Dry cows	3
Meat cows	15	Utilized farm area	3
Soil type	14	Sale of forage	3
Stocking rate	14	Wet area	3
Dairy cows	11	Cows to be inseminated	2
Installations and equipment	10	Sale of cows	2
Workload	10	Off-farm work	2
Grazed area reduction	10	Working force	2
Inputs price	10	Town and Neighbours	2
Forage and Feed purchase	10	Agricultural contractor	2
Alfalfa	9	Grazing refusals	2
Temporary grassland	9	Flora	2
Natural grassland	9	Subsidies	1
Fertilizer	8	Early grazing	1

among 13.0 ± 4.5 variables were identified. In the 49 interviews, 166 relationships among 56 variables (Table 2) were identified.

To assess the diversity of studied systems of practices, we computed the accumulation curve of the total number of relationships versus the number of interviews. Özesmi and Özesmi (2004) suggested computing the number of new variables added per interview. As the CMASOP approach is more focused on relationships, we sought to evaluate the accumulation curve of relationships instead of the accumulation curve of variables. The accumulation curve was generated using Monte Carlo techniques: (i) the interviews were randomly shuffled 200 times; (ii) for each of the 200 sets, the number of new relationships linked to each interview was identified; and (iii) the median of the 200 repetitions was calculated as an indicator of the number of different relationships that could be expected after each interview. The results showed that this rate decreased as the number of interviews increased: the first interview produced eleven new relationships, the tenth produced four and the twentieth produced two. A saturation occurred after about twenty interviews: the accumulation rate reached a stable value of about two new relationships for each new interview (Fig. 3). These results confirmed those reported by Özesmi and Özesmi (2004), who recorded a saturation after about 17 interviews and the expectation of one or two new or unique variables for each new interview.

3.2.2. *Individual cognitive mapping (step 3)*

The relationships identified in each interview were used to generate 49 ICMs. The ICM of farmer #11 is shown as an example in Fig. 4 and is described detail in Table 3. In ICMs, the weights of identified relationships are fixed at 1. The quotations of farmer #11 linked to the relationships of his/her map were useful for interpreting the map and could be easily retrieved using the approach that had been developed.

An SCM can be built from individual ones in order to highlight the more important drivers and relationships for a group of farmers. The results of SCM (step 4) are presented here.

Table 3
Complete list of relationships in the individual cognitive map (ICM) of farmer #11 (Fig. 4) and their meanings, based on the farmer's quotations of the farmer linked to each relationships.

The relation from variable. . .	To variable. . .	. . . points out that . . .
First cut	Silo	The harvest of the first cut is conserved in silo
First cut	Hay	The harvest of the first cut is conserved in hay
First cut	Cattle movement	Some cut plots are reallocated to grazing after the first cut, involving a decrease of stocking rates of grazed plots
Second cut	Sale of forage	The second cut is sold if there is enough forage
Forage quantity	Sale of forage	The second cut is sold if there is enough forage
Suckling herd	Hay	To meet the needs of his/her herd breed (suckling herd), the farmer decides to harvest grass and conserve it as hay
Suckling herd	Cutting date	To meet the needs of his/her herd breed (suckling herd), the farmer decides not to harvest grass too early
Forage quality	Cutting date	The farmer tries not to harvest too early, to obtain a young and rich grass forage
Natural grassland	Cutting date	The natural grassland must not be cut before 15 June in order to meet the requirements of agri-environmental schemes
Natural grassland	Silo	The grass harvested from natural grasslands is conserved in silo where possible
Silo	Cutting date	"The silo done from natural grasslands (n.b. an agri-environmental scheme that makes rules to the cutting date, see here above) is less good. It is too dry, the conservation is less good. Maybe would have I to make hay . . ."
Plot-farm distance	Cutting plots	Cutting plots are nearer than grazed plots in order to limit forage transport
Plot-farm distance	Grazed plots	Cutting plots are nearer than grazed plots in order to limit forage transport
Plot-farm distance	Silo	Cutting plots for silage making are not far away, in order to limit transport time and the work of the agricultural contractor
Plot-farm distance	Hay	Cutting plots for hay making can be further than those for silage making because "it is lighter to carry, and we have the time to do it" (i.e., "we can stagger this work")
Plot-farm distance	Yearling	Plots grazed by yearlings (heifers, in this case) can be far away from the farm because "there is nothing to do"
Topography	Cutting plots	The sloping grasslands are not cut
Topography	Grazed plots	The sloping grasslands are not cut
Wild boar	Cutting plots	The damage they cause is greater in cutting plots, and so the more damaged grasslands are allocated to grazing

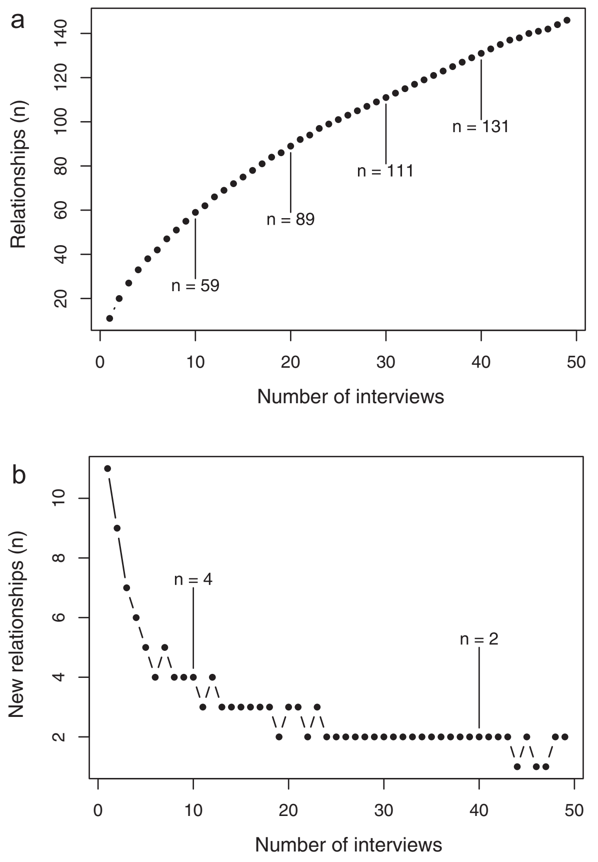

Fig. 3. Accumulation curves generated by the Monte Carlo technique in order to assess the diversity and saturation of information following the addition of any individual cognitive maps (ICMs). (a) Accumulation of relationships curve and (b) accumulation of relationships rate curve.

Table 4
Graph theoretical indicators calculated for the 13 variables (i.e., those with the highest centralities) of the peripheral and core hubs. Some variables have more of a transmitter character (Outdegree >Indegree); others have more of a receiver character (Indegree >Outdegree). T: transmitter, R: receiver.

	Outdegree	Indegree	Centrality	Character
Core hubs				
First cut	112	14	126	T ≫ R
Second cut	82	20	102	T > R
Third cut	26	10	36	T > R
Silo	5	77	82	R ≫ T
Bale wrap	5	90	95	R ≫ T
Hay	8	72	80	R ≫ T
Cattle movement	0	66	66	R
Peripheral hubs				
Plot utilization	5	38	43	R ≫ T
Plot-farm distance	54	1	55	T ≫ R
Forage quality	24	6	30	T > R
Forage quantity	27	3	30	T ≫ R
Cutting date	3	57	60	R ≫ T
Weather	73	0	73	T

3.2.3. Social cognitive mapping (step 4)

We generated an SCM, aggregating the 49 ICMs. This SCM would be difficult to present and interpret as a whole (Fairweather, 2010). In order to simplify it, trial-and-error tests led us to focus only on those relationships with a weight clearly greater than 1 (Fig. 5). In the SCM, the weight of a relationship is the number of farmers' interviews in which this relation had been identified. Weights are illustrated in Fig. 5 by the thickness of edges and their values besides the edges. The core of the maps is made up of variables linked to each other by highly weighted relationships: First, Second and Third Cuts, Silo, Bale Wrap, Hay and Cattle Movement (Table 4). These will be discussed later. Around this core, six variables (Plot Utilization, Plot-Farm Distance, Forage Quality, Forage Quantity, Cutting Date and Weather) are also highly connected as measured by the centrality indicators (Table 4). These 13 variables are the most central variables, their centralities all being higher than 25 (Table 4). These highly connected variables are known as 'hubs' (Barabasi and Oltvai, 2004). In this study, we distinguish between 'core hubs' and 'peripheral hubs'.

The relationships linked to the 13 hubs are shown in a simplified SCM (Fig. 6). Here, we present in detail the meaning(s) of relationships linked to some central variables. The meaning(s) of relationships were described by farmers during interviews and can be captured by the 'quote-retrieving' module. For the sake of clarity, we will focus on four variables and describe relationships with

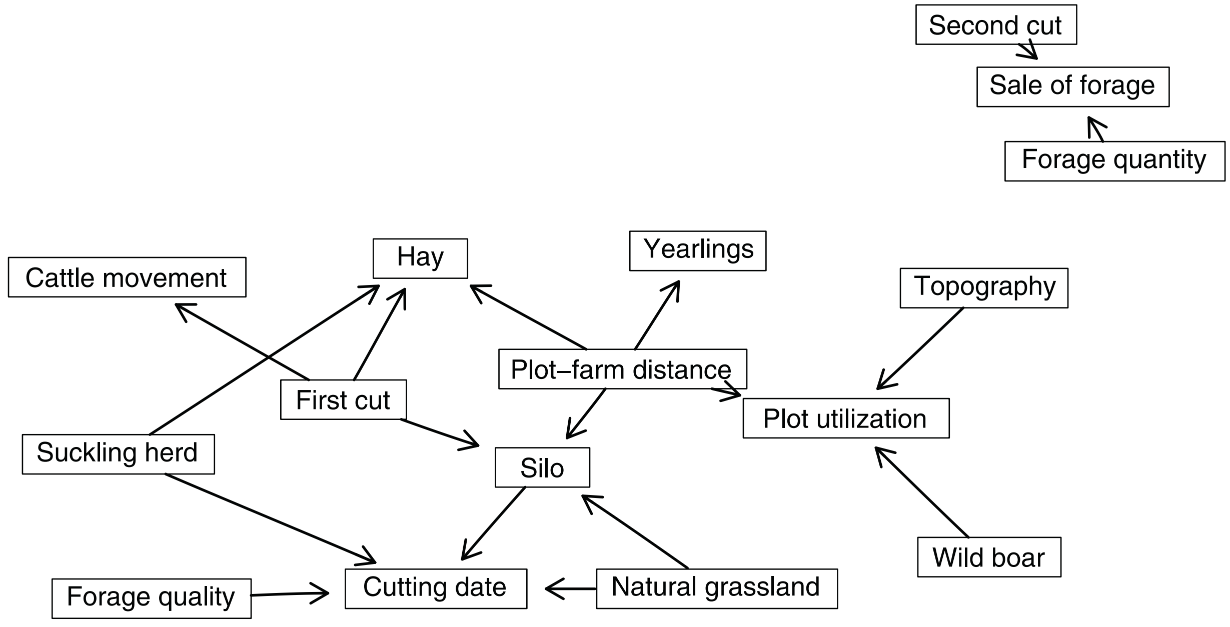

Fig. 4. Example of an individual cognitive map (ICM): farmers #11's ICM (graphical form).

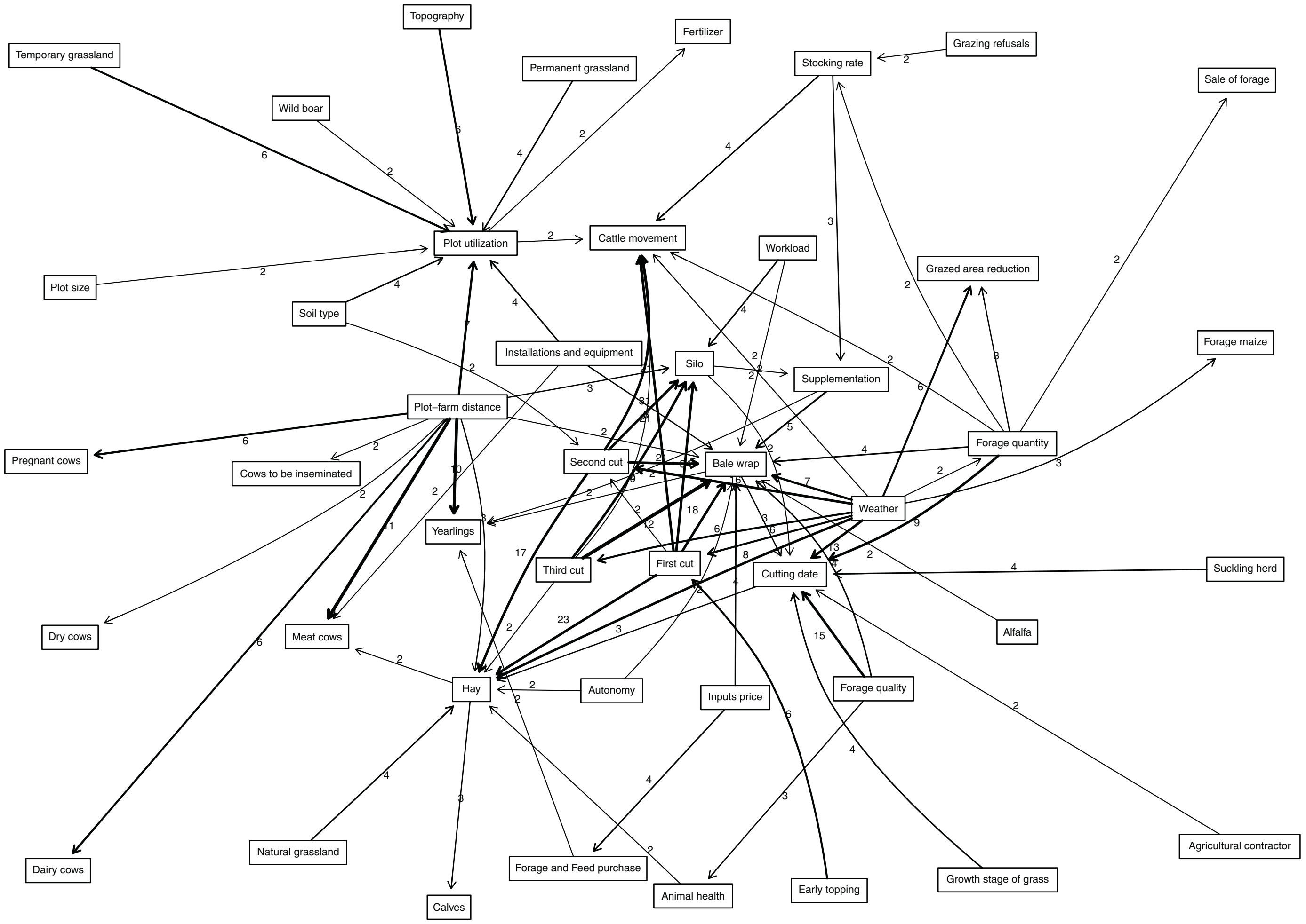

Fig. 5. Simplified social cognitive map (SCM) of the 49 interviewed farmers. Only those relationships whose weight is greater than or equal to 2 are shown.

a weight greater than or equal to 2. These variables are the two most central core hubs (First Cut and Second Cut) and the two most central peripheral hubs (Weather and Cutting Date).

3.2.3.1. *First Cut and Second Cut.*

Technical variables related to forage harvesting and conservation were the most frequently cited by farmers when speaking about their forage management. These variables describe operations (First, Second, Third Cuts and Cattle Movement) or objects (Silo, Hay and Bale Wrap). Highly weighted relationships connect them. Their centralities are therefore high and the graphical algorithm places them at the core of the map (Fig. 5).

Relationships entering or exiting the First Cut and Second Cut variables (Fig. 6) can be grouped into three types (see typology of relationships in 2.2. Coding). The first type describes the conservation mode chosen for the harvested forage (type ‘use of product’). These relationships point to other core hubs. The second type describes the succession of two operations (type ‘sequence of two operations’). The third type describes the factors influencing grass harvest (type ‘influence of an operation’). These drivers are peripheral variables. These three categories of relationships are described in the three following paragraphs.

The relationships specifying the choice of conservation mode for cut grass link one of the cutting operations (First or Second Cut) to one of the three conservation modes (Silo, Hay or Bale Wrap). Most of these six relationships are among those most often quoted (Table 4). Citing these basic technical operations is an obvious part of farmers’ descriptions of their grass forage management system. The most interesting relationships concern (i) the impact of these basic operations on other operations and (ii) the influences of other variables on these basic operations.

Four relationships indicate the sequences of two operations (Fig. 6). The relationships linking First Cut and Second Cut to Cattle Movement and linking Early Topping to First Cut reveal that some plots, after the first or second cut, are reallocated to grazing, generating cattle movement, or are grazed for a short period before the first cut. In addition, the relationship linking First Cut to Second Cut also indicates that the development of First Cut in terms of cutting date, quantity harvested or conservation mode affects the planning of the second one.

Three relationships link influencing factors with a core hub (Fig. 6). The relationships linking Weather to First Cut and Weather to Second Cut indicate that the weather affects the characteristics or existence of the cutting operations. The relationship linking Soil Type to Second Cut shows that the soil type of the cut plots can influence the second cut. The effects of potential summer drought on the second cut in terms of cutting date, forage quantity or forage quality depend on the localisation and soil type of the cutting plots (e.g., plots along rivers are less affected).

3.2.3.2. *Weather and cutting date.*

The Weather is a transmitter variable (Indegree = 0, Table 4). It is a driver that farmers link to

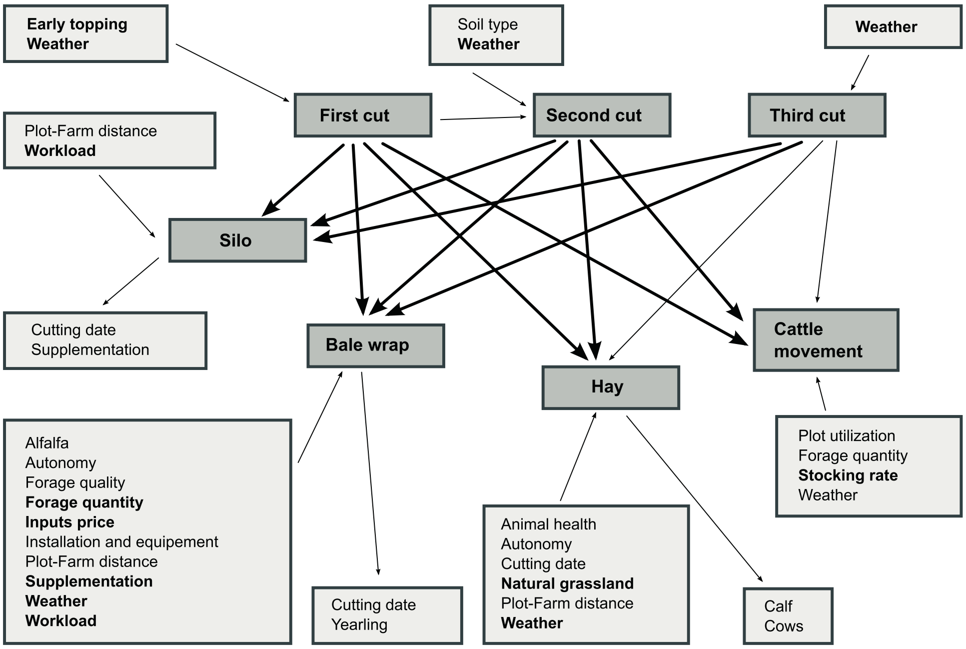

Fig. 6. Simplified representation of the social cognitive map (SCM) shown in Fig. 5. It includes relationships to variables linked to the core of the SCM (relationship weight greater than or equal to 2). Bold arrows and bold variables highlight relationships whose weights are greater than 3.

harvest operations and forage conservation modes. It can influence some cutting and grazing management operations and obviously has an impact on the First, Second and Third Cuts and, more precisely, the Cutting Date and Forage Quantity (Fig. 6). But it also affects Grazed Area reduction or Cattle Movement in that farmers will reallocate parts of the grazed area to cutting in case of good grass growth due to good weather conditions. The Weather can also affect the choice of the forage conservation mode in that Silo and Bale Wrap can tolerate wetter forage after unexpected rain, for instance, but dry weather is an absolute requisite for hay making.

The Cutting Date peripheral hub is more a receiver variable (Indegree ≫ Outdegree) than a transmitter one (Table 4). Entering relationships highlight drivers cited by farmers to explain the Cutting Date (Fig. 6): the Weather (no rain during harvesting and tedding), the Growth Stage of grass, the Forage Quantity and the Forage Quality sought for the cattle type (e.g., for a Suckling Herd: later cutting date than for dairy cattle, ear emergence stage, more dry matter but less protein) and the conservation mode (for silaging, the harvesting has not to be done too late; for bale wrapping, harvesting can be staggered and cutting date is more flexible). The only relationship exiting this variable relates to Hay and indicates that hay has to be chosen as conservation mode if the cutting date is later than expected due to poor weather conditions.

4. Discussion

Systems of practices and the way people talk about them are complex (Landais et al., 1988; Darré et al., 2004). Elements taken into account for decision-making stem from highly diverse fields – socio-economic, ecological and psychological (Cerf, 1996) – and decision-making processes are themselves affected by elements of these diverse fields. In addition, approaches used to study the practices are multidisciplinary: agronomy, mathematics, management and socio-anthropology. In this context and considering the limits of available modelling tools, we developed a semi-automated cognitive mapping approach that combined computer capability in information analysis with the richness of qualitative approaches in depicting reality.

Here we discuss (i) the properties of cognitive mapping approaches that justify their use in studying systems of practices; (ii) the originalities, strengths and weaknesses of the proposed cognitive mapping approach (CMASOP) and (iii) the potential uses of CMASOP and its future development.

4.1. Properties and limits of cognitive mapping

Cognitive mapping approaches have a twofold nature: qualitative and quantitative. The *qualitative nature* of a cognitive map stems from its graphical formulation and the nature of its basic compounds: variables and relations. This qualitative nature is useful both for elaborating models and for analysing them.

In the elaboration of cognitive maps, the qualitative nature of its basic compounds brings the flexibility required for studying highly diverse systems characterized by high internal complexity. It allows the integration of variables of a wide variety of types that can be linked together in various ways in order to model a system. The graphical formulation of cognitive maps is used by most cognitive mapping approaches for elaborating cognitive maps with actors in a participatory way. It allows actors' control of the modelling process and a detailed characterization of relationships in terms of importance, meaning, etc. However, this mapping task is not unproblematic (Fairweather, 2010) and requires from actors a deep understanding of the elements and a capacity to think of their system as a model.

In analytical steps, the graphical formulation of cognitive maps offers multiple advantages: (i) it can be used as a communication tool between people (e.g., farmers, developers, scientists) and (ii) it is a convenient way to represent the complexity of a system and capture its general structure at first glance: variables of the system, relationships among them, influencing factors, central variables, etc.

The *quantitative nature* of cognitive maps stems from their matrix formulation. The adjacency matrices are particularly useful in the analysis of cognitive maps: (i) computing graph theory indicators (e.g., centralities); and (ii) aggregating different ICMs into an SCM (Özesmi and Özesmi, 2004).

4.2. Originalities, strengths and weaknesses of CMASOP

So far as we know, the CMASOP approach is the first FCM application to systems of practices in social–ecological systems. We discuss here four methodological originalities of our approach: (i) coding-based cognitive mapping; (ii) integration of non-causal relationships in the maps, (iii) a quote-retrieving module; and (iv) a widening of diversity explored compared with traditional anthropological methods. We also highlight the strengths and weaknesses of the CMASOP approach.

4.2.1. Coding-based cognitive mapping

One methodological originality of the CMASOP approach is that cognitive maps are not elaborated with actors, but are the output of coding of open-ended qualitative interview transcriptions.

On the one hand, this process overcomes the difficulty of sharing the mapping task with actors (Fairweather, 2010). This has two implications. First, CMASOP allows qualitative data to be collected in an inductive way and to therefore include marginal and innovative systems of practices. This contrasts with other methods where actors map their systems using a predefined list of variables (Fairweather, 2010). A second positive implication is that CMASOP allows the sampling to be extended to actors who would not be able to represent their systems in models such as cognitive maps.

On the other hand, the dissociation of the mapping task from the interviews has three consequences that can be seen as limits of CMASOP. First, the cognitive maps are based on information collected during interviews. This requires from the interviewers some skills in conducting open-ended qualitative interviews (e.g., broaching themes under study without influencing interviewees, restarting the interview, Miles and Huberman, 2003; Kaufmann, 2004).

A second consequence is that the mapping task depends on the researcher's coding of interviews. This step requires an interpretation in defining or selecting variables, relationships among variables and actors' quotations linked to relationships. Actors express the same things in different ways, using different words. Part of the coding involves interpreting the interviews and aggregating in a unique relationship the quotations linked to the same reality. It is worth noting that the list of variables and relations are not a priori established, but emerge from the analysis during the coding process. It is therefore likely that variables need to be split into more detailed ones or, conversely, that some variables need to be aggregated into a more general one. CMASOP does allow these types of evolution during the coding step, but the impact of the coder's interpretation on modelling is limited because of the object under study – the practices of actors in social–ecological systems. In the present paper and because of the basic technical nature of the operation that was the subject of the case study (grass forage harvest, conservation and conditioning), the description of the farmers are also seen as technical elements, as are the elements of their cognitive maps. The relationships are essentially descriptive, but include interpretative and explanatory statements made by actors during their interviews. The coding of most technical elements do not require an interpretation from the coder. In these cases, the actors' perceptions of their practices and the diverse influencing elements (e.g., technical, social, economic) are quite simple. We recognize that the impact of the coder's interpretation could be greater when studying more complex choices that are more influenced by social and economic factors and actors' perceptions and preferences, such as choices about structural investments (e.g., new dairy, new building, new herd). In studying these types of practices, techniques used in social sciences could be used to control and limit the impact of the coder's interpretation (e.g., coding a part of interviews by two different coders and confronting their works). In addition, each relationship is linked to one or more actors' quotations. Quotations stay linked to relationships and can be retrieved at every step of the analysis. This mechanism is used as a verification tool for controlling over-interpretation.

The third limitation is the binary nature of the produced cognitive map. In an individual map, a relationship between two variables can only be 'present' or 'absent' and, therefore, is not quantified. When the mapping task is done directly with actors (Özesmi and Özesmi, 2004; Fairweather, 2010), relationships can be weighted in accordance with their causal influence. Weighting relationships with actors during a second round of interviews could overcome this weakness. Also, such a second round could act as a discussion-validation step of the CMASOP approach with actors.

4.2.2. More than causal relationships

Classical cognitive mapping (Axelrod, 1976), FCM (Kosko, 1986) or even causal mapping (Fairweather, 2010) approaches include only causal relationships in models. As CMASOP deals with systems of practices, it is more flexible about the nature of relationships. The systems of practices are constituted by elements of a diverse nature: technical (operation, object and person), ecological (external drivers), economic (external drivers) and social (drivers, perceptions, etc.). The relationships linking these diverse variables are therefore also of a diverse nature. They can be causality relationships (A causes B), sequences of two operations (A is followed by B) and flows of matter, information and/or energy (from A to B). A variable motivating a choice or affecting an operation is considered as a driver of this choice or operation.

4.2.3. The quote-retrieving module, a way to explore the diversity reflected by a relationship

In CMASOP, an SCM is computed in order to highlight key variables and key relationships in the systems of practices used by the sample of actors. In cognitive mapping approaches, variables and relationships can have different meanings for different actors. This heterogeneity is seen as a limit of these approaches by Fairweather and Hunt (2011). They argued that the "causal map itself does not make fully clear what the farmers took to be the meaning of each factor to be" (p. 63, Fairweather and Hunt, 2011). This assertion applies especially to cases where each ICM corresponds to a unique system, such as in a multiple locations study (e.g., in, Fairweather, 2010) or in the present study, where farmers describe their own farm systems. In these cases, merging ICMs into an SCM leads to a loss of context. If expressed by actors, the influences of the context on individual practices appear coherently in ICMs. In an SCM, actors' systems of practices implemented in different contexts are aggregated. As a result, although there is no loss of information (relationships), overall coherence could be decreased. The description and analysis of an SCM requires special attention being given to the heterogeneity of relationships and the loss of a coherent context.

In CMASOP, the quote-retrieving module was developed to address these limitations, in a posteriori analysis of the variability within variables and within relationships. This allows the diversity of actors' preferences and perceptions to be highlighted (van der Ploeg, 1994; Darré et al., 2004). For instance, the relationship linking Farm-Plot Distance and Yearling can indicate opposite practices, depending on yearlings' feeding choice. If supplemented, yearlings are located not far from the farm in order to facilitate daily feeding operations. If not supplemented, they are located on farthest plots because they need only weekly visits. The aggregation of these two meanings in the same relationships gives these relationships the categorized meaning: "the farm-plot distance is taken into account in the choice of plots allocated to yearling grazing." This step could overcome another limitation of cognitive mapping noted by Kim and Lee (1998, in Özesmi and Özesmi, 2004): "Although what-if's can be modelled in FCM, why's cannot be determined." Using the quote-retrieving module of CMASOP, the rationale of relationships can be a posteriori captured if actors expressed them.

4.2.4. The possibility of exploring a wider diversity than with traditional anthropological methods

The diversity of systems of practices has been successfully investigated using qualitative anthropological studies (Cristofini et al., 1978; Darré et al., 2004; Mathieu, 2004; Vayssieres et al., 2007; Farmar-Bowers and Lane, 2009; Madelrieux et al., 2009). These techniques have led to relevant results, but have been constrained by the time required for field work (immersion, Vayssieres et al., 2007) or for the analysis of raw data (Darré et al., 2004; Mathieu, 2004). As a result, the number of surveyed or involved farms has been limited ($n = 31$, (Cristofini et al., 1978); $n = 5$, (Mathieu, 2004); $n = 33$, (Farmar-Bowers and Lane, 2009); $n = 10$, (Madelrieux et al., 2009); $n = 6$, (Vayssieres et al., 2011)). CMASOP, based on FCM approaches, has the advantage of being less time consuming (Özesmi and Özesmi, 2004). Based on our experience in implementing the case study, the time required: (i) to organize and conduct one interview was about half a working day; (ii) to transcribe the 2-h interview was about 1 working day; and (iii) to inductively code the part of the interview linked to a specific studied theme (e.g., grass forage management in the case study) was about half a working day.

4.3. Potential uses and perspectives of CMASOP

Cognitive mapping approaches can be used in three major ways: as an end per se in order to model a system: as a communication tool or a decision-support tool for scientists, developers, actors and stakeholders; or as an intermediate object, a model preceding a simulation step in prospective or scenario evaluations (Özesmi and Özesmi, 2004; Kok, 2009).

As presented in this article, our cognitive mapping approach provides a tool that aims to describe actors' systems of practices in social–ecological systems. The map is an aim per se. In this context, CMASOP would be relevant in the study of complex and less known social–ecological systems (e.g., farming systems in developing countries).

The use of cognitive maps as decision support tools and as intermediate objects of communication or simulation will be investigated in future developments of CMASOP approach. These will include comparative analysis of systems of practices across sites. Thus, the approach could be used to characterize the diversity of practices in social–ecological systems and to identify marginal or innovative actors. Beyond this, the CMASOP approach could be used to identify types of systems of practice (or farming styles, see, van der Ploeg, 1994) using clustering methods. Another possibility is to model systems of practices in a dynamic way (Özesmi and Özesmi, 2004; Kok, 2009) in order to process simulations and test scenarios of the evolution of the environment of social–ecological systems. This could be used, for instance, to assess the resilience of systems of practices or evaluate actors' adaptability.

5. Conclusion

In this study we illustrated how cognitive mapping approaches could be used for analysing farmers' systems of practices. The twofold nature of these approaches, qualitative and quantitative, allows the studied objects to be considered in terms of their whole complexity and a model to be built based on actors' perceptions of social–ecological systems. Another key point of the analysis of systems of practices is the diversity among farms. The automation of our analysis approach takes into account a larger number of farms than is the case with traditional anthropological approaches. In addition, the social cognitive mapping step of the CMASOP approach allows a unique model of the systems of practices of various farms groups to be built. It also confirms previous works by showing that SCMs can be drawn across multiple locations, with each farmer speaking about his/her own system of practices. The approach could be applied in further work on people's perceptions of other parts of the social–ecological system (constraints, evolution, etc.) and to characterize the diversity in people's perceptions.

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