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Analyzing indicators for combining natural resources management and production-oriented activities

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Abstract It is recognized today that production systems can be used for natural resources management, whereas it is difficult to implement management that integrates production and natural resources conservation. This difficulty can be explained by the complexity of interactions between production systems and biodiversity dynamics and by the lack of predictability of the impacts of techniques on ecosystems. Designing tools to effectively guide such integration in this uncertain context is therefore a top priority. In this perspective, the aim of this paper is to analyze the indicators used by managers when trying to integrate ecological systems and production-oriented activities and, consequently, to assess their relevance when faced with these new challenges. Our analysis distinguishes indicators-in-theory and indicators-in-use. We studied the first ones with an original analytic grid to decipher their cognitive and management orientation through documents and interviews with indicator designers. We studied indicators-in-use through interviews and ethnographic observations of indicator users in four situations (forestry, pastoral, wildlife and breed management) in southwestern France. Our findings reveal the distance between managed objects and measured objects, thus explaining their effectiveness in terms of management. We also show how the indicators strongly shape practices and how they are adapted by users to their situation, emphasizing the role of experiential knowledge to create situated indicators. Finally, we discuss our results regarding tool design for environmental management.

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1 Introduction

1.1 The challenges of managing the integration of ecological systems and human activities

In the last decades, the growing concern about environmental issues, biodiversity erosion, food security and climate change have made it necessary to design more sustainable development pathways in order to reconcile social, economic and environmental issues, without compromising the ability of future generations to meet their own needs (WCED 1987). Natural resources management (water, nutritive elements, genetic resources, etc.) has often been theorized as "dilemmas" between business and environmental objectives (Blackmore 2007), thus focusing on the competing claims on the use of natural resources and on the resulting conflicts. More recently, this view has been challenged by new approaches aimed at redesigning new agricultural and forest production modes that integrate the production of goods and the sustainable management of natural resources instead of opposing them. Faced with the extreme complexity of spatial and temporal interactions between production systems and ecosystem dynamics, a debate thus arises on how production and conservation objectives should be combined over the same area (Hubert and Ronzon 2010), between two contrasting options of "land sparing" and "land sharing." This latter model holds that the challenge is to overcome the difficulty of combining distinct objectives within the same area (Hubert and Ronzon 2010), thus calling for a paradigm shift on natural resources (Hubert and Ison 2011). The current dominant standpoint is anchored in a paradigm referred to as "resource sufficiency" (Thompson and Nardone 1999), which assumes that resources are a stock and that sustainability over time of declining resources requires either a decreasing rate of consumption or an increased efficiency or substitution with other resources. Such a paradigm is focused on the productive optimum, thus neglecting ecosystem functioning. On the contrary, the "functional integrity" view (Hubert and Ison 2011) emphasizes the systemic interactions between agroecosystems and resource management that is based on the ability of ecological systems to regenerate and to persist on the long term. Even though this vision is gaining interest both from scientists and practitioners, these authors suggest the need to devote more research to the functional integrity approach as a key for sustainable development pathways since it is still difficult to implement such a paradigm. More specifically, such a paradigm questions the role and nature of this knowledge in action, as well as the ability of existing tools, i.e., explicit knowledge and formal variables that guide management actions (Moisdon 1997), to support such management.

1.2 Indicators to manage the integration of ecological systems and production-oriented activities

In this paper, we focus on particular management tools—indicators—which are becoming increasingly popular among policy makers. In the scientific literature, the word "indicator" primarily refers to ecological indicators designed to understand ecological complexity, particularly those incorporating and applying thermodynamic principles to explain ecological observations (Jørgensen and Fath 2004) with a strong theoretical orientation unconnected with management needs. With an evaluation perspective, ecological indicators are more widely designed and used "to assess the condition of the environment, to provide an early warning signal of changes in the environment, or to diagnose the cause of an environmental problem" (Dale and Beyeler 2001). Most of them thus aim to retrospectively assess the impact of human activities (e.g., Croonquist and Brooks 1991; Fulton et al. 2005; Semeniuk et al. 2007; Hughes et al. 2010; Larsen et al. 2010), and especially of agriculture on the environment (e.g., Izquierdo et al. 2003; Buczko and Kuchenbuch 2010), or the recovery of ecosystems after rehabilitation projects (Weber and Peter 2011). Far from a reconciliation of production and conservation objectives, these works consider production-oriented activities as a disturbance of ecological systems. Suites of indicators are then built or selected among science-based indicators to assess ecological changes linked to disturbances, either natural or human-induced, responses and recovery of ecosystems. Recognizing that ecological indicators should explicitly consider social perspectives and value (Smyth et al. 2007), other types of indicators are developed as tools to quantify the environmental component of sustainable development, thus integrating socioeconomic and ecological criteria in a more systemic way (Zhen and Routray 2003; Levin et al. 2009; Salvati and Zitti 2009; Dymond et al. 2010). In keeping with the functional integrity approach, some authors like Babel et al. (2011) developed an indicator-based approach to assess the vulnerability of ecosystems expressed as a function of stress and adaptive capacity of the natural–physical–human–economic system. Others, like Woodwell (2002) for forests, and Ludwig et al. (2004) for rangelands, have developed indicators of functional integrity at the landscape scale. In all these works, indicators are built to develop a more functional and systemic approach, with the underlying assumption that understanding is essential for making sound management decisions. As a result, most of these indicators are theory oriented and focused on the description and assessment of the agroecosystem status, focusing on users such as policy makers or scientists (e.g., Kershner et al. 2011) and leaving local managers on their own to manage their specific situation.

From our viewpoint, the core challenge is therefore to develop more action-oriented indicators in order to overcome this division between ecosystems description and management. In management science, indicators are in fact classical management tools for planning and control and can be defined as data that can be easily and frequently measured. Indicator designers are confronted with a fundamental problem: ecosystems are complex, variable and diverse in nature. The need to reduce them to their essential features is thus generally acknowledged, whereas some authors hold that the design of indicators should raise a political debate at the interface of science and policy as to what constitutes the public interest (McCool and Stankey 2004). Yet, there are no established rules of what are acceptable levels for ecological indicators (Smyth et al. 2007) or what should be measured in order to describe the response of ecosystems to stress and their recovery (Kelly and Harwell 1990) and, even more so, to choose an action to manage them. There are still challenges in the development and use of ecological indicators with many issues hampering their use as a resource management tool (Dale and Beyeler 2001). In a broader sense, no generic guidelines exist as to what the indicators should be or how to design them. This can partially explain the profusion of indicators for sustainable development (Rey-Valette et al. 2007) and the need for guidelines for indicator selection (Kershner et al. 2011), whereas their relevance in situations where the challenge is to manage the integration of production and conservation remains under-investigated.

1.3 Focus and objectives of this paper

In the perspective of contributing to the design of tools that are more relevant to the integration of production-oriented activities and natural resources management, our aim is to identify the relevant dimensions for analyzing indicators when put into action and not to define rules on what constitutes, in theory, a "good indicator." With our conceptual perspective grounded in management science, we view indicators as the result of quantification processes that consist in making measurable what is not obviously so, i.e., to express with figures that which was previously expressed in words (Desrosières 2010). We thus consider that indicators are never obvious, fair or inevitable. On the contrary, they rely on conventions of quantification and are linked to values and social representations of what is "fair," "true" or "relevant," thus embedding a theory of action in the sense of Argyris and Schön (1974), i.e., assumptions and rules on how to act in situations. We consider that it is therefore essential to decipher the theory of action embedded in indicators to analyze their impact and relevance. This means exploring how they simplify information in variables. We also consider it crucial to examine how managers use them in their practices and, even more, how they adapt them to their specific aims and situations. On the basis of the distinction first introduced by Argyris and Schön (1974), we analyze indicators with the distinction between "indicator-in-theory" and "indicator-in-use." Central to this issue is thus the potential tension between the generic nature of indicators, generally based on scientific knowledge drawn from different areas (such as forestry, ecology, agronomy), and the contextual nature of agroecosystem management in local situations.

The objective of this paper is then to assess the gap between the theories of action embedded in indicators and the local actions that are actually carried out by indicator users. As a consequence, our paper is focused on the analysis of action-oriented indicators that are used in local situations where management aims at integrating production and conservation stakes, thus trying to assess their relevance when faced with these new challenges. From this analysis of current indicators, we draw some perspectives for tool design in environmental management.

2 Approach: method and strategy

Our research strategy is based on a cross-analysis of case studies, i.e., indicators that are used in actual and local management situations of different natural resources (local breeds, wildlife, biodiversity of rangelands and forests) embedded in livestock farming, hunting and forestry. In order to compare our analyses of each study and to extract some generic findings, we used a conceptual framework drawn from management science and adapted to our domain. Our approach thus combines case studies and generalization (David 2004), which has become a standard approach in the social sciences that proceed by a qualitative approach (Langley and Royer 2007). This work is thus the result of a multidisciplinary group that includes both researchers specialized in the domain of each case study (breeding, genetics, grazing, forestry) and researchers in management science.

2.1 Case studies

We chose four situations in southwestern France (Table 1), in which managers use indicators to guide their management of communities or populations:

Table 1 Characteristics of the four situations studied

	Management of hunted wildlife in southern Aquitaine	Management of shrubby rangelands in pastoral areas of the Central Pyrenees	Management of the pine forest in southwestern France	Management of local sheep breeds in the Western Pyrenees
Production	Game and avoided agricultural damage	Cattle or sheep meat	Timber	Milk and cheese
Stakeholders	Hunters, farmers	Farmers, pastoral technicians, natural area managers	Forest owners, forest technicians	Farmers, selection scheme technicians, geneticists
Potential actions	Hunting, scattering of grain, planting game crops, crop protection by fencing	Grazing, agricultural burning, roller chopping	Cutting, planting, thinning	Mating, replacement, culling
Spatial and temporal management scale	From commune to department, annual and pluriannual	Summer mountain pasture, annual and pluriannual	Long-term	Department, annual and pluriannual

- Management of hunted wildlife in southern Aquitaine with a focus on the roe deer. Indicators studied concern the population status of a wildlife species and the damage that it causes to agricultural activities;
- The management of shrubby rangelands in pastoral areas of the Central Pyrenees. The main indicator used is known as the pastoral value (PV);
- The management of the pine forest in southwestern France hit by severe storms in 1999 and 2009 and currently subject to both PEFC[1] certification and the French Forest Law of 2001. Forest stakeholders use indicators of biodiversity for timber production and forestry practices for honey production;
- The management of local sheep breeds in the Western Pyrenees, which is based on the genetic index (an estimate of the genetic value of an animal for the selected characteristics).

We chose these situations for the diversity that they represent in terms of the type of production and the stakeholders involved, as well as the type of actions that can be carried out to manage them at various spatial and temporal management scales (Table 1). Our cases also illustrate a wide diversity in the way in which the integration between production and conservation stakes is expressed. For example, production and conservation management can be seen as being obviously convergent in the case of shrub-covered mountain management,[2] whereas it is to be negotiated in the case of hunted wildlife. Maintaining the biodiversity of production systems is the same challenge for the two other cases. For example, in the local breed case, it is important to maintain a domestic biodiversity that is adapted to the territory and to local livestock system practices. The interdependence of stakeholders may be different: strong in the case of breed management because genetic resources are "common pool resources" (Ostrom 1990), and weak in the case of forest management in which forest owners decide individually what to do.

[1] Program for the Endorsement of Forest Certification (http://www.pefc.org/).

[2] Pastoral use of shrub-covered mountains is generally seen as being beneficial to biodiversity conservation.

2.2 Conceptual framework to analyze indicators-in-theory

To carry out the analysis of the theories of action embedded in indicators used in our four case studies, we used a common analysis grid that we have already tested and formalized in the case of genetic resources (Labatut et al. 2009, 2012) and of pastoral resources (Gross et al. 2011). This analysis grid is grounded in the three dimensions of a management instrument developed by Hatchuel and Weil (1995) and thus makes it possible to cross-analyze the technical and managerial dimensions of the tool (Labatut et al. 2009).

The *technical substrate* corresponds to the material and informational dimension of the instruments (software, maps, graphs, etc.), close to the idea of the cognitive artifact of Norman (1992), i.e., "artificial device designed to maintain, display or operate upon information in order to serve a representational function." This dimension is generally well described in biotechnical analyses of tools. However, this substrate alone does not determine the management mode, and that is why Hatchuel and Weil (1995) propose to describe management tools by their *management philosophy* as well, i.e., the "system of concepts that designates objects and objectives that form the targets of a rationalization," making it possible to take the managerial nature of these tools into account. Hence, the managerial philosophy integrates the designer's intentions and desires and reflects broader rationalization projects within the technology framework. A tool therefore contains a philosophy of action and an efficiency theory (David 1998) that provide criteria for performance evaluation. The *organizational model* describes the relationships between the various stakeholders involved in the management, their role and the theoretical distribution of competences and knowledge prescribed to implement the tool.

Our grid goes a step further by delineating the three dimensions proposed by Hatchuel and Weil (1995) in various formalized criteria. The technical substrate dimension has in fact been little theorized in management science literature, whereas it is at the core of our perspective of integrating production-oriented activities and ecological dynamics. We therefore propose to describe this technical substrate by qualifying the object that is measured and the measurement and calculation procedures. In the same vein, we propose to explain the management philosophy by describing the management target and object, the conceptual basis and interpretation rules, the postulates and efficiency criteria.

2.3 Data collection and analysis

For each case study, we collected data on the origin and design of indicators by gathering documents written by designers and by carrying out interviews with them in order to decipher the theories of action that are embedded in their indicators. We then used the grid as a common analytic framework, thus allowing us to compare these indicators-in-theory.

In parallel, using an ethnographic approach, we investigated the use of these indicators in local situations through interviews with local managers who used the indicators and observations of their practices, thus collecting data on indicators-in-use. For some cases, we also observed these managers during meetings (indoor and in the field) during which they collectively discussed the tools that they use. Interviews were recorded and transcribed.

Our results are thus based on the comparison of our four case studies as well as on the analysis of the distance between the four indicators-in-theory and their use in contextual situations (indicators-in-use), thus revealing the relevant dimensions for analyzing indicators when put into action.

3 Results

3.1 Indicators-in-theory

With the help of our grid, we deciphered the theories of action that ground the indicators used in our four cases, thus offering a fruitful framework to better understand how they face the new challenges of integrating production and conservation stakes.

3.1.1 Organizational model

Most often, the indicators studied are the fruit of a research project in partnership with technical organisms in the sector. For example, pastoral diagnostic methods in the rangeland case were developed by research teams from INRA (French National Institute for Agricultural Research) and IRSTEA (French National Institute for Sciences and Technologies in Environment and Agriculture), in partnership with technicians from the French Livestock Institute and managers of natural parks. Likewise, in the domain of sylviculture, biodiversity indicators were developed through research in partnership with the ONF (French National Forestry Service) and the CRPF (French Regional Center of Forest Ownership). In the case of wildlife, indicators rely in part on scientific knowledge derived from fundamental research (studies in species biology or in ethology, for example) acquired in laboratories. In the domain of genetic resource management, the French government even entrusted public research (INRA) with the task of calculating the genetic indexes of all farm animals, within the framework of a national data system.

The organizational model generally shows three levels (national/intermediate communal or regional/local). At the latter level, stakeholders who are directly involved in the management of populations are expected to apply management plans decided by development agents (wildlife, rangeland management) or, on the contrary, are considered as autonomous agents deciding which management to implement (local breeds, forest).

3.1.2 Management philosophy

The management targets of the indicators studied are a combination of production-oriented aims and conservation, control or regeneration constraints of population dynamics. Such diversity in conservation objectives is linked to the recognition of the diversity of stakeholders' aims in the case of the forest or of local breeds. When trying to encompass the points of view of the different stakeholders, the objects managed and the management targets are difficult to define, often remain unclear, and can even find themselves at the center of heated debates. For example, the management of pastoral lands must now be in line with the challenges involved in the renewal of pastoral resources and the conservation of biodiversity in many protected areas within these zones (national and regional parks, Natura 2000 zones, etc.). In this case, the object managed, i.e., natural environments with complex plant covers, has undergone little change. The target of this management, e.g., to obtain or maintain a heath that produces pastoral resources while providing a habitat capable of maintaining a partridge population, can easily be consensual because an "open" environment is generally considered favorable by grassland specialists and managers of natural areas. This target is nevertheless the subject of a "vagueness of goals" (Voß et al. 2006) concerning the status of vegetation to be attained. This vagueness of goals has then allowed an evolution of targeted users (from technical advisors to natural areas managers; see Table 2) without questioning the initial technical substrate.

In other situations, the management object itself has evolved, like in the case of the Landes forest in southwestern France. Going from a single objective (wood production) to a sustainable objective for all of products, goods and services provided by the forest makes it necessary to go from a "tree culture" in a highly anthropized forest to the management of a complex forest ecosystem whose ecological qualities must be maintained and even increased. In this case as well, this target remains vague (what are the ecological qualities desired?).

3.1.3 Technical substrate

There is a clear homogeneity among the four cases for the measured object, which is a biological population (either animal or vegetal populations) measured by the characteristics of individuals. Additional features are considered, including the genetic link between individuals (local breeds), the damages caused by the population (wildlife) or the biodiversity status (forest). Measurements show a strong emphasis on temporal (long term for local breeds) or spatial dimensions (the three other cases), whereas all of the cases take account of the other dimension (territorial representation of measurements in genetic resource management, temporal repetition of measurements in the others).

Since indicators strongly rely on theories and hypotheses from scientific disciplines, measurements give a high weight to theories about individuals (animal physiology, species biology). All indicators then rely on the hypothesis that the individuals sampled are representative of the population and that the population is the sum of individuals, even if theories about the interactions between individuals constituting the population (phytoecology, ethology) are used.

It is necessary to take the dynamics of the managed object into account when considering the objectives of managing populations, communities and ecosystems, thus creating a gap between the managed object and the usual state indicators. Even if managers can have an idea of the evolution of the population by counting its members over time, this would be of no use for controlling population dynamics. For example, in the case of huntable wild animals, census procedures using "headlight counts" provide little information for assessing population structures according to age and sex, essential for the management of population dynamics. Another example, the degree of cover of a zone by a woody species is often measured, with a threshold above which "something must be done." However, the percentage of plant cover provides no information about the dynamics of these woody species, which may be low even if the degree of cover is high. Such indicators can thus create a gap between the diagnosis and the dynamics of the population, often leading to non-relevant management recommendations.

The relevance of indicators can also come up against our (in)capacity to effectively measure the biological objects concerned, thus bringing to the forefront the relatively classic issue in biometry of the quality of the measurement and the representativeness of this measurement in relation to the target population or community. For example, three indicators are used to assess the status of a wild animal population. The first—direct—consists of an annual count (using headlights at night), making it possible to determine the number of animals observed per kilometer covered along the same routes and at the same dates. The other two indicators—more indirect—consist of deducing the status of the population from the number of animals killed the previous year, assuming a correlation between the number of animals killed and the total number of animals. Damage to crops is

Table 2 Analysis of indicators-in-theory in our four case studies

Case study	Hunted wildlife management	Rangeland management	Forest management	Local sheep breed management
Organizational model				
Designers	Monitoring methods are designed by the French National Wildlife Organization. Assessment methods are chosen locally	Research, then local adaptations of the VP indicator by development agents	Research Technical Board of National Forest Organization (ONF)	Scientists in partnership with industry, farmers and technical organisms
Targeted users, use situation	Legal and national framework, with local adaptations of hunting periods and status of species Hunting plans proposed by local group of damage victims and hunters and approved by departmental commission Hunters are expected to apply the approved hunting plans	Agricultural advisors, then natural area managers Pastoral management plan design to be implemented by farmers	Managers, forest owners Plan management design	Technicians advising farmers Breeding companies to plan mating between the best animals of the population Farmers deciding their flock renewal
Management philosophy				
Management object and target	*Object* Roe deer population *Target* Catch the largest number of animals without jeopardizing population renewal, while limiting agricultural damage	*Object* Biofacies and species *Target* to optimize the pastoral valorization of the grassland resource while maintaining the stability of the biofacies	*Object* Tree stand *Target* Harvesting biomass production Diversity of objectives depending on forest owners	*Object* the breed *Target* Increasing farmers' income in increasing milk production and individual performance of animals
Conceptual basis	Species biology (fertility rate in relation to resource variability), ethology (living areas, feeding behavior) and veterinary medicine	Phytoecology Physiological approach to animal science	Knowledge and models drawn from intensive forestry	Genetic theory (quantitative genetics), statistical models Genetic indexes = sum of measurable criteria

Table 2 continued

Case study	Hunted wildlife management	Rangeland management	Forest management	Local sheep breed management
Interpretation rules, postulates and efficiency criteria	Animals counted in the territory are representative of the population size Damage = f(population level) Changes in population result from hunting pressure and variations in resources Damage and counted animal stability = population under control	Woody species have no food value Species value can be transposed from one location to another Vegetation value = Σ species value Optimizing resource intake = consuming the maximum biomass at the full-growth phenological stage Recommended Stocking Rate = f(PV)	Species inventory is representative of the tree stand Mixed forests increase biodiversity Stand structure gives an idea of management intensity Comparing inventories to adjust real stand characteristics to the recommended norms	Performance heritability Genotype-environment interaction: considered as non-significant Index should be taken into account in the mating plan
Technical substrate				
Object measured	Population as the sum of individuals counted in the census one year and hunted in previous years Damage recorded in the last year	Biofacies as the sum of species	Stand characterized by tree species number and biodiversity, stand structure characterized by numbers of tree per diameter at one given age	Animal performances (breeding animals and their offspring)
Measurement and calculation procedure	Relationship between prescribed and real number of animals for year $n-1$ Annual count of animals in a representative sample of places Animals are counted each year at the same dates on the same circuit Estimation of population structure and age deduced from animals killed during the last year Amount of damage compensation	Zoning of the area into biofacies Botanic survey for each biofacies: specific frequency (SFi) and specific contribution of each species Calculation of the pastoral value (PV) = Forage Potential	National Forest Inventory (aerial photographs) and local inventories	Genetic indexes = estimating the animals' genetic value according to collectively defined breeding objectives Milk recording of ewe performances Artificial insemination National genetic database system

also considered as a gage of variation, in the same way as the number of animals. On the basis of these three indicators, chosen through a compromise between the reliability of the measurements and the frequency with which they can be used, managers infer the state of the population to be managed.

Attempts have been made to develop indicators that are capable of guiding the management of dynamic objects. For example, in the case of rangeland management, by studying the juveniles, the key early stage of a woody species and their proportion in the population, it is possible to estimate the shrub invasion risk, the urgency and the type of management required (Magda et al. 2005). Likewise, in the case of wildlife, biometric measurements are sometimes made on slaughtered animals. Much more time-consuming than a simple survey of the animals killed; they make it possible to monitor changes in body mass of individuals and to therefore obtain information about both their relationship to the environment (population/resource ratio) and to their reproduction potential (the fertility of females is highly dependent on their feeding conditions) and, therefore, a prediction of the dynamics. For example, the observation of low body mass in females for year n makes it possible to predict a low reproduction rate for the year $n + 1$ and, as a result, an anticipated decrease in the number of animals that can be hunted.

When the target and the managed object both change, the distance between the managed object and the measured object increases, with possible modifications of both organization levels and time steps, which may be the source of multiple tensions. For example, the management of genetic resources relies on the measurement of the individual performance of livestock within a "nucleus flock" that represents approximately 20 % of the individuals of the population. This assessment of genetic resources is only valid if this sample is representative of the dynamics of the breed and of the livestock farming systems used in the area. In France's Pyrénées-Atlantiques department, this representativeness is questioned by stakeholders outside of the nucleus flock, particularly because transhumance systems are not considered to be sufficiently represented in this sample. Some stakeholders thus consider that genetic indexes do not represent a "just" value of the potential of the animal because they are disconnected from local livestock farming systems. Changes in the target and the management object thus lead us to question the adaptability of generic indicators in relation to more situated management objectives.

3.2 Indicators-in-use

When examining the indicators-in-use, it appears that users almost always use indicators with specific practices that are partly unexpected by designers, revealing various roles of indicators in resource management.

3.2.1 Adapting indicators to action situations

Even if the indicators studied were designed using scientific theories and models whose aim was to be generic, they include a part of adaptation to the local context in their design, either by calibration on the basis of locally collected data or by directly including a "contextual factor" in the model. For example, in the case of genetic resources, an "environmental factor" is integrated into the model, making it possible to explain animal performance (Labatut et al. 2009). In the grassland sector, typologies of local biofacies exist by mountain range (e.g., Bornard and Dubost 1992), making it possible to adapt the generic calculation of a pastoral value (PV) at the regional level.

However, this adaptation is often not sufficient to take stakeholders representations into account, thus casting doubts on the relevance of these indicators in local situations. We thus observed a great deal of tension and debate surrounding the way to qualify the natural resources concerned (Lauvie et al. 2008; Saldaqui 2008), resulting in large part from the gap between the generic nature of the indicators and the local objectives. For example, genetic indexes are calculated, regardless of the breed, using a generic calculation procedure and a national information system, on the basis of a model designed through research in the Roquefort area. In France's Pyrénées-Atlantiques department, this scientific management model is then confronted with the specificities and the diversity of livestock farming systems (three local breeds, the importance of transhumance, etc.) (Labatut et al. 2009). For hunting, in the absence of a shared assessment of the number of animals and damage by available indicators, it is only when a "local expert" becomes involved, recognized by all of the stakeholders for the reliability of his diagnosis, that agreements can follow (Saldaqui 2008).

In some cases, we observed that the users themselves adapt the diagnosis using the flexibility left to the user of the tool. For example, to calculate a pastoral value (Gross et al. 2011), the method's technical substrate makes it possible for the user to qualify the values obtained on the basis of his perception of the situation that he is observing in several steps. The organizational model of the tool thus assumes that the user must "refine his degree of knowledge through experience"[3] (Designer—07/03/08). For example, the estimation of the PV is based on typologies of local biofacies that give the PV intervals per biofacies. The user must therefore choose a PV value in this interval according to his assessment of the situation. A pastoral technician thus adopted a complementary procedure by noting qualifiers in her field notebook that are not included in biofacies typologies (e.g., "luxuriant," "productive") in order to choose a value in the interval.

However, beyond the scope of what was planned by the indicator designers, it is often the users themselves that decide to correct their measurement to take the specificities of their action situation into account. In the case of huntable wildlife, if the headlight counting procedure complies with a perfectly standard protocol, reproducible in theory throughout France, those responsible for the count integrate the climatic parameters that may affect the measurement (fog that would reduce visibility or frost that would modify the night feeding sites of some species, etc.) by assigning a correction coefficient to the figures obtained. Likewise, the knowledge that hunters have of their territory leads them to make their own assessment, depending on the place and the year, and the importance attributed to different variables used for the synthetic indicator. Therefore, depending on the year, "damage" may be due to the exceptional stagnation of a corn crop at a particularly palatable maturation stage or to a change in land use by a farmer that increases the amount of damage that he is compensated for, but that has no effect on the number of animals.

In these examples, the adaptation initiated by the user is informal and remains implicit. In other situations, it can take the form of a formalization of local coefficients that may even be published by the stakeholders as a local methodological contribution. In the case of rangeland management in the Pyrenees, the stakeholders claim that the PV does not take account of the specificities of Pyrenean summer pastures. Grassland technicians therefore formalized (and published: Brau-Nogué et al. 2005) an additional coefficient that makes it possible to more thoroughly assess the resource effectively available for animals, taking into account, for example, local accessibility conditions for the herd (slopes, the presence of rocky ledges, etc.). By defining this coefficient, they adapted the technical substrate of

[3] Quotations taken from our data are referenced by the interviewee type and the date of the interview.

the tool by formalizing what farmers do implicitly in the field, thus reinforcing the safety of their estimates and minimizing the risks that they themselves take and those taken by farmers on the basis of their recommendations.

When the gap between the indicator and the situation is irreducible, some users use, in addition to the "official" indicators, indicators resulting from their own experience, often tacit and individual. In particular, the gap described in Sect. 3.2.1 between the measurement of a state and the dynamics of a management object may lead users to create their own assessment of the dynamics to be managed. For example, a technician in the Pyrenees uses the "height of a tree at the center of a clump of juniper bushes" to estimate the population and community dynamics of a zone.

> I can also see that some trees have started to grow in the middle of some juniper clumps. That surely means that the trees that grow in the middle of these clumps were able to develop because they were protected from the teeth of a cow or a horse […]. You see, that gives you a little idea of […] the age of the juniper bushes. That's what I'm saying, that it's been at least 20 years since the process began and that it's not very serious. (Technician, 20/11/2009)

This indicator allows her to estimate the growth rate of the junipers and, therefore, the rate of change in the environment. If the trees at the center of the clumps are high and therefore old, that means that the juniper bushes that protect it have been there for a long time. If the zone is not completely closed, the manager then deduces that the closing dynamics are slow and/or the use of the zone makes it possible to keep it contained.

3.2.2 Connecting understanding, measuring and taking action in the design of indicators

Taken as a whole, our results illustrate the frequent disconnection between understanding, measuring and taking action, depending on the management philosophy embedded in indicators. When the aim is to decrease uncertainty and control the processes at work, understanding and taking action are seen as two separate management stages, leading to design and select indicators which make it possible to qualify resources and to predict the effects of actions. In the Pyrenees, we observed that such management mode encourages technicians to design scientifically based experiments to produce knowledge about the impact of practices on the evolution of vegetation covers, in the hopes of obtaining better control of the recommended actions. In doing so, they focus their effort on vegetation control, leaving apart livestock practices and objectives. Our analysis reveals that adopting such a predictive approach runs the risk of creating a stalemate in these situations at the crossroads between conservation and production objectives.

When dealing with indicator design at the crossroads between conservation and production objectives, understanding and taking action should be seen as being closely linked. It seems to us that the challenge of indicator design is to integrate these two phases in the same learning process within an adaptive type management system (e.g., proposal of the functional method; Guérin and Agreil 2007). In such a management mode, uncertainty is an integral part of the action within an adaptive management that makes adjustments over time.

Nevertheless, the disconnection observed in numerous situations between understanding, measuring and taking action can also be the result of organizational and administrative aspects and, in particular, the flow of collected information: Those that measure the indicator are not always those that process information or those that actually take action in relation to the resource. For example, in the case of animal genetics, information is collected on farms by a milk recording service (breeders and technicians) and is then sent for processing at the national level by INRA. It then comes back in the form of an index that will be used for the choice of rams by the technician and/or the breeder. There is therefore a distance between those who provide information and use it, and those who design the indicator and who process the information. This pyramidal structure of information management comes about as a result of the challenge of managing common pool resources (Ostrom 1990), which are local breeds in this case. The data from one herd makes no sense if it is not compared to all of the data related to the breed. It is therefore necessary to gather information in a central database so that it can be processed collectively. The link—or the disconnection—between measuring and taking action can also result from the type of land-use control, the status of resources managed and the labor available to measure and manage. In the case of wildlife, the relationship between management densities and management reactivity is close. In ordinary rural areas, where measurements are carried out locally and then sent to the departmental agency before coming back to the community, lags accumulate between the time that an indicator is measured and the time when action is taken. The relevance of the hunting plan can easily be discredited locally by casting doubts on the administrative process. In contrast, in national forests, the presence of agents from the ONF, both foresters and hunting guides at the same time, make it possible for one and the same person to assess the number of animals and the damage, and to draw up a hunting plan. Samples can then be adjusted geographically and over time to variations in numbers and/or damage. Less frequently, those who collect information are the same as those who process it to draw up recommendations. This is the case for pastoral diagnostics where pastoral technicians recommend a grazing management plan to be applied by the farmer on the basis of their analysis of the area. We have observed that they often apply a "safety margin" by underestimating, for example, their recommendations (e.g., they propose a stocking rate that is lower than the one they estimated as the potential for forage resource production) because they do not want to put the breeders in a risky situation or cast doubts on their own legitimacy as a technician (Gross et al. 2011).

We thus argue here that the coordination and communication processes between those who use and those who process information are of utmost importance, thus enlarging the issue of indicator design to the design and management of information systems. More widely, indicators for resource management, although they are grounded on scientific knowledge, cannot be solely science based, due to their normative effects on ecosystem quality assessment. As a result, they are situated "in a fuzzy area between science and policy" (Turnhout et al. 2007) and their use—or rejection—is highly dependent on policy context, thus calling for more social sciences analysis of such indicators.

4 Discussion and conclusion

Our results highlight that indicators should be built according to the paradigm of natural resources management that is adopted. Within the framework of the "resource sufficiency" paradigm (Thompson and Nardone 1999), resources are commodified into a naturalized category whose definition, contours and metrology are not discussed. Measuring the resources available then often leads to state indicators that make it possible to reveal changes when measured regularly (Levrel 2006). In the "functional integrity" paradigm, it is primarily the process indicators that allow the stakeholder to "characterize the process by a type of evolution relevant to the action," as shown by Hoc (1989) for the operation of a blast furnace. To do this, it is not always sufficient to change the existing indicators, as illustrated by our case of genetic selection in animals. For the past 30 years, genetic indexes have evolved through the addition of supplementary selection criteria every time there is a new injunction or crisis (e.g., milk quality, resistance to scrapie), without questioning their management philosophy, whereas the objectives of the breeders and the objectives of breed management have considerably diversified (Labatut et al. 2010). We thus argue that it is absolutely essential to question both the technical substrate and the management philosophy of the tools in order to redesign indicators for natural resources management.

Moreover, our results question the management mode adopted and, more specifically, the link between diagnosis and action. Speaking about the "pathology of natural resource management," Holling and Meffe (1996) strongly criticized the command-and-control approach to natural resources management, stressing its consequences in terms of the reduction of natural levels of variation in system behavior, seen as a loss of system resilience. When viewed as co-evolving systems, agroecosystems cannot be managed by prescription and planning alone, i.e., by management that is defined ex ante and implemented to obtain the desired results, referring to the doubts raised by Mintzberg (1994) who discusses the stalemate of planned management in the form of recommendations that would be directly applicable by managers. As a consequence, much research has attempted to define alternative management modes such as "adaptive management," along the lines of Holling (1978). Nevertheless, such management is difficult to implement and there are still many conceptual and methodological issues (Allen and Gunderson 2011; Keith et al. 2011).

In particular, designing such indicators implies a transition from indicators that are taken as the objective truth (in order to plan, control and even stabilize the state of the world) to indicators that take advantage of the various sources of available knowledge (scientific as well as more empirical ones, as argued by Garcia and Lescuyer 2008). In terms of design, this incites us to go beyond the logic that consists of producing more scientific knowledge on ecological processes to reduce uncertainty and risks. Even if there have been reflections along these lines (Shennan 2008; Brugnach et al. 2011), little research has been devoted to theorizing the design of such indicators. In particular, the question arises as to the identification of the object(s) on which to focus and with which indicator to manage the functional integrity of the systems concerned: Is it the population managed, the region? Which property is able to characterize this functional integrity? For example, the hardiness of animals, the criterion put forward by breeders to choose local breeds, is a criterion whose means of objectivation are not shared, and that is very difficult to define and therefore to measure (Hubert 2011). This thus assumes the necessity of specifying the properties we are looking for, as well as taking the time to assess the relevance of such an indicator. For example, managing a forest habitat favorable to biodiversity and not a parcel of cultivated trees led scientists and development agents to build a synthetic measurement of the capacities of the ecosystem to accommodate animal and/or plant communities. This "potential biodiversity index" is therefore a new indicator whose relevance and ability for measuring a change in ecosystem status has not yet been assessed because we do not have enough experience with its use as of this time.

Our results also show that we must give thought to the design and learning system that goes with it, focusing on the role of users and use situations within a bottom-up design process. As we have shown, the generic nature of indicators designed on scientific bases comes up against local specificities, in line with Reed and Dougill (2002) who showed that indicators developed by scientists often have little significance for managers in the field who have a hard time appropriating them and Garcia and Lescuyer (2008) who claimed for a link between environmental changes and local communities' own management decisions. This is an incentive to develop bottom-up approaches based on local knowledge (Reed et al. 2006), whether it be participative co-construction (Fraser Evan et al. 2006; Levrel 2006; Reed et al. 2008), the scientific validation of local indicators (Reed and Dougill 2002; Reed et al. 2008) or, on the contrary, the local evaluation of scientific indicators (Reed et al. 2006). However, Reed et al. (2006) criticize the indicators resulting from this approach as being approximate and even unreliable and non-transposable, and thus propose to design indicators that combine scientific and empirical approaches (Reed et al. 2008), like the method and the grids proposed by the functional method (Agreil et al. 2011). This, however, leaves the question of the calibration of these indicators that are grounded in observation rather than measurement, as well as that of the right level of abstraction at which these indicators are situated.

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