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Using the concepts of resilience, vulnerability and adaptability for the assessment and analysis of agricultural systems

Abstract: Resilience, vulnerability and adaptability have emerged as dominant concepts in the study of disturbance and change of social-ecological systems. We analyze the conceptual, methodological and operational aspects in using these concepts for the assessment and analysis of agricultural systems and try to identify differences and possible overlaps between them. The analysis is performed considering a number of published studies on agricultural systems over a wide geographical range where these concepts have been applied. Our results show a clear conceptual overlap and often the exchangeable use of the concepts. Furthermore, the driving methodological and operational criteria for their application could not be separated unambiguously. It was, thus, difficult to identify guiding principles for the operational application of the individual concepts. We stress that the operationalization of these concepts requires consistency in the approaches and protocols to ensure their coherent use. We also argue that the conceptual and operational integration of resilience, vulnerability and adaptability would perhaps lead to a more complete portrayal of the behavior of agricultural systems in changing situations. But this requires more research including the development of operational protocols for which the premises of complexity, participation and functionality seem key.

Keywords: disruption, change, evaluation, operationalization, integration.

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1 Introduction

Resilience, vulnerability and adaptability have become dominant concepts in the assessment and analysis of social-ecological systems (SES) when disturbance and change have been identified as the principal constraints [1,2].

Although resilience, vulnerability and adaptability have emerged out of different disciplines, they are increasingly being used in the interdisciplinary scheme [3], but due either to epistemological differences or to differing evaluation procedures, their operationalization for practical applications is still carried out separately.

Agricultural systems are complex SES that are substantially affected and increasingly threatened by various hazards, e.g., climate change [4], hence are often assessed with respect to their resilience, vulnerability and/or adaptability. Nonetheless a clear understanding of the use of these concepts including possible complementarities and overlaps is lacking.

Accordingly, in this study we aim to analyze the use of these concepts for the assessment and analysis of agricultural systems. More particularly, we want to explore the conceptual, methodological and operational premises existing among resilience, vulnerability and adaptability in their application to agricultural systems.

The second section of the paper focuses on defining the three concepts of resilience, vulnerability and adaptability as used in this study based on a review of specialized literature. The third section investigates the conceptual and interrelations among these concepts. The fourth section analyses the use of these concepts for agricultural systems considering a number of published case studies. The last section draws conclusions, suggests pathways and identifies needs for further research.

2 Determining the basic concepts

Resilience, that originally alluded to the biological capacity of ecosystems to absorb shocks and recover functions [5],

has lately been extrapolated to the SES arena by including concepts such as renewal and reorganization into a broad understanding of the systems [6,7].

Resilience alliance (www.resalliance.org) has defined resilience as the ability of a system to absorb shocks, avoid crossing thresholds into an alternate and possible irreversibly new state and regenerate after disturbance. This becomes feasible through the maintenance of the system's identity, structure, functions and especially the capacity to reorganize itself while the change takes place [8].

It is acknowledged that resilience is circumstance- and time-dependent since stresses on "*(...) the capacity to recombine evolved structures and processes to renew the system and its trajectories (...)*" [9] what can happen together with adaptive processes. In other words, resilience focuses on the system performance when one or more disturbing events occur [10], and is intended to determine the desirable pathways towards a sustainable state [8,11].

Although resilience has proposed a valuable concept for analyzing SES, the bridge between its conceptual evolution and its use in assessment and analysis, has not taken place consistently. Instead, much of the contemporary discourse on resilience deals with its semiotics rather than with its practical use.

The precise meaning of vulnerability lacks a consensus and is still subject to controversy since it has been applied extensively in different contexts [12]. It is acknowledged though, that vulnerability deals generally with socio-economic criteria rather than with biophysical issues [13]. Vulnerability is roughly understood as '*The susceptibility to change of a system exposed to certain perturbation*', which implies the assumption that a system is vulnerable to certain factors but not to others [13,14]. This broad definition requires other concepts to better characterize the dimension that vulnerability aims to address, including exposure, sensitivity, adaptive capacity and cognition [12,15]. Exposure refers to the degree, duration and extent for which a system is in contact with a disturbing factor, and hence depends more on the relationship between the system and the external perturbation rather than on the intrinsic characteristic(s) of the system [13,16]; sensitivity alludes to the degree to which a system is affected by or can absorb impacts without suffering long-term harm; thus it is rather an intrinsic quality of the system [13]; adaptive capacity (capacity to adapt, capacity of response or coping capacity), refers to the ability to become adapted, to cope with the constraints that a system faces, or as in the context of climate change, it is the "*adjustment in natural or human systems to actual or expected climate stimuli and their effects*" [17]; and finally, cognition refers to the human participation via the administration of information (reception, perception, exchange, evaluation, updating, etc.) and its implementation when decision making [18] (Figure 1).

Smit and Wandel [9] affirm that adaptation (Latin: adaptō = fit, matching) "(...) *refers to a process, action or outcome in a system in order to better cope with, manage, or adjust to some changing condition, hazard, risk or opportunity.*"

Like resilience, the concept of adaptation originates in biology, dealing with a species' genetic and behavioral supportive characteristics for survival and reproduction [19]. Used in the social sciences, adaptation has been oriented to the analysis of individuals, groups and institutions and their capability of adapting to changing situations [20], e.g., the importance of cultural background in driving decisions to cope with changing environments, or the relevance of the manager's profile on his/her responses [21,22,23, 24].

Here it is important to distinguish adaptive capacity from adaptation. While adaptive capacity refers to (an) intrinsic characteristic(s) of a system that impels it to remain in a certain configuration when a specific disturbing

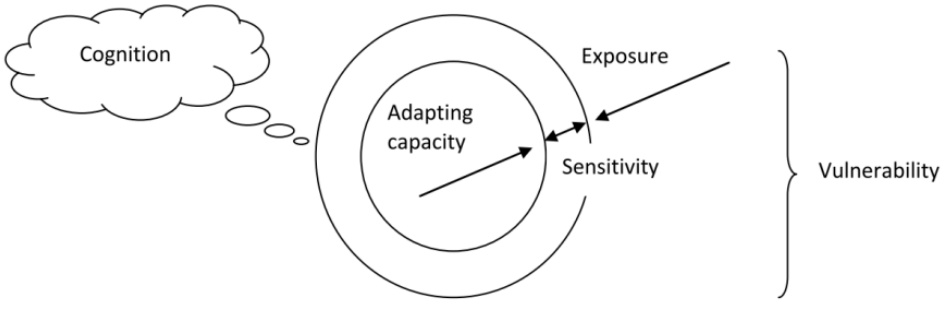

Figure 1: Ontology representing the interaction among the components of vulnerability: exposure is an external factor, adaptive capacity (feedback by manager's cognition) is an internal one, and sensitivity is the result of their interaction.

event takes place, adaptation alludes to a quality, attributable to any system that allows it to become fitted to its environment [25]. Adaptive capacity then is specific and focuses on identifying and implementing concrete means of adaptation to deal with particular disturbances.

One step further is the notion of adaptability[1], which refers to one's ability to cope with occurring changes, and involves modifications in the system along a timeline. In other words, a successive series of adaptive changes resulting from the interaction between the system and its environment.

Various other terms have attempted to embody the means of adaptation, such as 'adaptive (ecosystem) management' to determine, based on recursive observations, the most appropriate management policies in response to changing conditions [26,27]; and 'adaptive governance' which focuses on adding the adaptation basis to policy making and institutional processes [28].

However, in this paper we suggest the use of adaptability, since it emphasizes time and relies on specific adaptations as principal criteria.

3 Interrelations between resilience, vulnerability and adaptability

The above review suggests fuzzy boundaries between concepts, which is confirmed by their joint usage in scientific literature. For instance, among the key components of the 'resilience approach' [29] is the system's capacity to learn and re-adapt; the Resilience Alliance states that adaptive capacity in SES refers to the "*capacity of humans to manage resilience*"; [30] considers that the concepts resilience, robustness, and vulnerability can only be understood in relation to one another; furthermore [31] points out that phenomena with implications for resilience, vulnerability and adaptability converge during their development and finally unfold altogether; and [32] stresses that the integration of vulnerability, adaptive capacity, resilience (and transformability) should occur during the construction of sustainability science.

In October 2005, the International Human Dimensions Program (IHDP) presented a study to determine the 'state of the art' and linkages among the concepts of resilience, vulnerability and adaptation, with particular emphasis on global environmental change [3,33]. From a broad-based analysis of scientific publications between 1977 and 2005,[3] found that use of the terms shifted from disciplinary to multidisciplinary. Until 1990 most publications mentioned resilience in relation to ecological models; vulnerability was mainly applied to natural hazards and environmental change, and adaptation was used almost exclusively in reference to anthropology-related issues. The authors also observed a rapid increase in the number of publications that used these terms as driving concepts, from an annual average of 20 in 1993 to about 100 ten years later. The mingled usage of terms arose as well, especially in the case of adaptation and vulnerability together, and increased until reaching almost one fifth of all analyzed publications between 2000 and 2005. Other combinations (resilience and vulnerability, resilience and adaptation, and all three together) occurred less frequently, in up to 5% of the publications published from 1979 onwards [3].

This analysis suggests that scholars might have been using terms which were thematically overlapping but not conceptually distinguished, suggesting the need for a semantic in-depth analysis.

Gallopín [12] tackled the issue extensively, acknowledging a messy usage and existing omissions: "*The comparative analysis (...) puts in evidence important similarities and differences, and in some case contradictions (...) as specified, or utilized, in different fields of inquiry*"; later on, he acknowledges the reiterative overlapping "*(...) there is no generally accepted meaning for these concepts (...)* (which) *becomes more visible when they are taken together*". Finally, the author himself attempts to fill this gap by building a conceptual ontology that includes the three concepts, resilience, vulnerability and adaptive capacity (not adaptability), and sensitivity, exposure, and capacity of response as components of vulnerability. It suggests a double dependence of resilience on vulnerability (through capacity of response) and on adaptive capacity. But this may change depending on the relationship between adaptive capacity and capacity of response, to turn to be more or less vulnerable. In any case, the capacity of response is taken as a performance threshold between vulnerability and resilience, and also between adaptive capacity and vulnerability (Figure 2a).

Similarly Smit and Wandel [9] analyzed adaptation, adaptive capacity and vulnerability, stressing on their practical application using climate change as case study. They proposed as a connection between adaptation and vulnerability the 'participatory vulnerability assessment', a series of bottom-up methodologies which rely on active involvement of stakeholders to determine crucial drivers. Like [12], the authors affirm the existence of interdependence among these concepts and suggest a concentric ontology that distinguishes two main levels determined by local and broad scale determinants. 'Adaptations' are located at the first level where have to

1 Adaptedness is the equivalent term for its ad-*hoc* use in ecology.

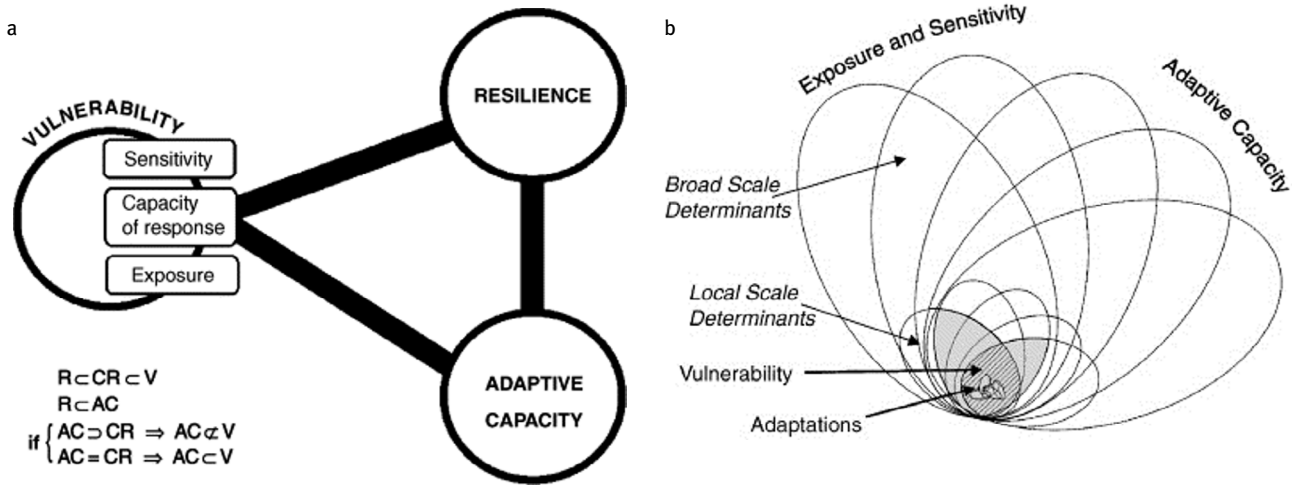

Figure 2: Representation of **a)** conceptual ontology among vulnerability, resilience and adaptive capacity [12] and **b)** nested hierarchy model of vulnerability [9].

confront specific determinants that will challenge their vulnerability; at broader scale, determinants refer to the exposure, sensitivity and adaptive capacity mainly, and are mean to play key roles on long-term adaptation processes (figure 2b) [9].

In general, these two figures (2a and 2b) do not add much to the clarification about the interaction of the three concepts, besides affirming its existence: the former appeals to other concepts to sketch subsequent dependences; and the latter uses scale (spatial or institutional) to generate niches for the terms discussed. But none offers a reasonable ontological model of interdependence.

The preeminence of one of the three concepts and a complementary role of the other two has been also proposed. [13] asserts that vulnerability should remain as the driving concept: "*vulnerability as a research tradition spans all the antecedent and successor traditions*", and the other two should circumstantially complement it: "(...) *resilience of social-ecological systems complement and can significantly add to a converging research agenda (...) given that a key element of socio-ecological resilience is the ability to adapt to new circumstances (...)*", to finally add that: *"a theory of adaptation would explicitly incorporate the formation, persistence and causes of vulnerability*" [13].

Other authors used a bottom-up insight to better deal with this intricacy, through underlining first the characteristics of the issues to be handled under the resilience, vulnerability and/or adaptability criteria, and then ratifying the inherent linkage among them: *"All three terms express a temporary condition of the interaction between a system and its context*", advocating an in-depth analysis of the inherent properties and dynamics of the system at different moments to determine, by comparison, the characteristics and impacts on their adaptability, resilience and vulnerability [31].

However we affirm that the overabundance of terms in the literature, either by being confined to a small aspect of the phenomena, as in the case of durability, stability, robustness, flexibility, etc. [9,12] or by overlapping their meanings without adding new insights but enlarging the number of interrelated terms, e.g. sustainagility [34], has not helped to clarify the applicability of resilience, vulnerability or adaptability either separately or jointly. This supports the main contention of this paper, i.e. that the terms' conceptualization is far easier than the identification of empirical –especially quantitative- assessment principles [30], an issue on which very little has been so far achieved [33].

In other words, what is needed is to operationalize the use of the concepts by reframing them in real situations. This means to put aside the conceptual limitations resulting from semantic discourses, and concentrate on their complementarities and value for solving concrete problems [35].

4 Analysis of agricultural systems

4.1. Conceptual aspects

We assume that through the analysis of cases where the concepts of resilience, vulnerability and adaptability were applied, common theoretical principles can be extracted.

Hence, using a scientific searching engine the scientific papers that refer to resilience and/or vulnerability and/or adaptability as main and/or secondary concept for the study of agricultural systems published during the last ten

years were identified. To capture the semantic variability, in the query were used the terms 'resil' for resilience, 'vulnera' for vulnerability and 'adapt' for adaptability.

Out of 332 papers identified, 201 (61%) applied adaptability, 77 (23%) vulnerability and 54 (16%) resilience. For the period considered (2003 to 2013), there is a frank increase in the number of papers that apply adaptability, while the other two remain somewhat stable (Figure 3).

The joint use of concepts is rather limited. When adaptability is used as main concept (n=201), vulnerability was appealed only in 6 times (3%) and resilience in two (1%); in the case of vulnerability (n=77), adaptability was also applied in 9 publications (12%) and resilience in two (3%); and for resilience (n=54), adaptability was also used in 3 papers (6%) and vulnerability in 2 (4%). The mention of the three concepts together was inexistent.

Must be noticed also, that even though all papers relate to agricultural systems, a great part of them 106 (32%) relate to climate change. It is especially higher in the case of adaptability where reaches 87 (43%), against 13 (17%) for vulnerability and 6 (11%) for resilience. All in all, adaptability is the most appealed term, probably due to its many more semantic variants, its multiple uses in various disciplines, and by the same its long-lasting presence in academia.

However, this calculation is based on the title and key words counting and not in content-wise analysis. Hence for a content-wise analysis ten publications were selected (Table 1). The first column states the title of the study and its reference; the second column specifies the research topic, and the third and fourth columns list the main (resilience, vulnerability and adaptability) and complementary (exposure, sensitivity, etc.) concepts utilized. The fifth column lists the methodological procedures used, while the sixth column shows the number of times that resilience, vulnerability and adaptability, and derivatives of them are mentioned in each paper. A final column summarizes the contents of each case study (Table 1).

It is noticeable that the papers that assume vulnerability as their main concept refer more to complementary concepts than the ones that use resilience and adaptability (ten versus two and three times respectively) including among these complementary concepts resilience and adaptability themselves. Similarly, resilience as main concept relies on vulnerability and adaptation as complementary concepts; and the analysis of adaptability, in one of the observed cases is based on the *adaptive cycle*, a heuristic model, also used as a surrogate for resilience.

Similarly, several of the complementary concepts used actually derive from the main ones, i.e., adaptive capacity and coping capacity come from adaptability; and system status and damage threshold resemble transitional stages of the adaptive cycle: exploitation-reorganization and conservation-release [6].

The complementary usage of concepts is revealed even in the titles of some of the revised publications [18,26,36,37]. For instance, in the paper *Resilience, Adaptive Capacity and the 'Lock in Trap' of the Western Australian Agricultural Region* [36] the main conceptual framework is taken from *resilience* theory, that sketches sequential phases of stability and change where a system moves across temporal and spatial scales [6] and *adaptive*

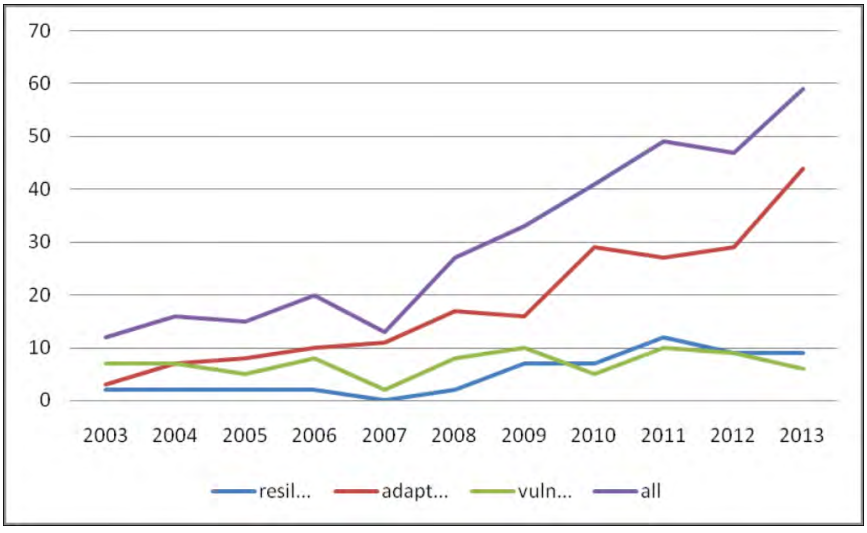

Figure 3: Trend in the use of the concepts of resilience, vulnerability and adaptability in the scientific literature related to agricultural systems during the last ten years.

Table 1: Selected studies on resilience and/or vulnerability and/or adaptability of agricultural systems

Case (title)	Main subject assessed/analyzed	Primary approach(es) (*)	Complementary approach(es) (§)	Main operational/ methodological procedures (Ψ)	Key words (times) (ξ)
Multiple exposures and dynamic vulnerability: Evidence from the grape industry in the Okanagan Valley, Canada. Belliveau *et al.* (2006) [39]	Assessment of agricultural systems vulnerability to climate change and variability	Vulnerability	- Exposure - Risk - Sensitivity - Adaptive capacity	- Impact assessment (scenario-based procedures) - Participatory procedures	Adaptability (63) Resilience (1) Vulnerability (57)
Resilience, Adaptive Capacity, and the "Lock-in Trap" of the Western Australian Agricultural Region. Allison and Hobbs (2004) [36]	Agricultural system resilience analysis	Resilience	- Adaptation analysis	- Adaptive cycle - Historical tracing	Adaptability (44) Resilience (36) Vulnerability (2)
Organic Farming and Social-Ecological Resilience: the Alpine Valleys of Sölktäler, Austria. Milestad and Hadatsch (2003) [42]	Predicting the organic farming system's resilience during policy-driven changes	Resilience	- Vulnerability	- Action research	Adaptability (10) Resilience (30) Vulnerability (4)
Unpacking "Participation" in the Adaptive Management of Social-Ecological Systems: a Critical Review. Stringer *et al.* (2006) [27]	Analysis of stakeholders' participation in adaptive management	Adaptive management (adaptability)	- Participation - Adaptive cycle (resilience)	- Sociological and ethnographic methods	Adaptability (57) Resilience (0) Vulnerability (1)
Stakeholders' views on reducing rural vulnerability to natural disasters in Southern Mexico: Hazard exposure and coping and adaptive capacity. Saldaña-Zorrilla (2008) [37]	Assessment of agricultural livelihoods' vulnerability to climate change	Vulnerability	- Coping and adapting capacity - Exposure	- Stakeholders' survey - Descriptive analysis - Qualitative interviews	Adaptability (9) Resilience (0) Vulnerability (44)
A method for quantifying vulnerability, applied to the agricultural systems of the Yaqui Valley, Mexico. Luers *et al.* (2003) [38]	Assessment of agricultural systems vulnerability	Vulnerability	- System's status - Damage threshold - Adapting capacity - Exposure	- Mathematical sensitive threshold - GIS	Adaptability (40) Resilience (8) Vulnerability (177)
Farmers' ability to cope with low flows in the lower Yellow River: A case study of temporal dimensions of vulnerability. Liu, *et al.* (2008) [41]	Analysis and prediction of farmers' capacity to cope with low water flows	Vulnerability	- Adaptability - Exposure - Resilience	- Sociological methods - Hydrological procedures	Adaptability (18) Resilience (2) Vulnerability (28)
Between structure and agency: Livelihoods and adaptation in Ghana's Central Region. Carr (2008) [44]	Livelihood adaptation strategies to economic and environmental uncertainties	Adaptation (adaptability)	- Gender	- Sociological (empirical) methods - GIS	Adaptability (93) Resilience (0) Vulnerability (2)
Saami reindeer pastoralism under climate change: Applying a generalized framework for vulnerability studies to a sub-arctic social-ecological system. Tyler *et al.* (2007) [40]	Assessing pastoral systems' vulnerability to climate change	Vulnerability	- Endogenous *(ad-hoc)* assessment - Adaptive capacity - Resilience	- Participatory procedures - Interdisciplinary and intercultural methods	Adaptability (15) Resilience (5) Vulnerability (25)

continued **Table 1:** Selected studies on resilience and/or vulnerability and/or adaptability of agricultural systems

Case (title)	Main subject assessed/analyzed	Primary approach(es) (*)	Complementary approach(es) (§)	Main operational/ methodological procedures (Ψ)	Key words (times) (Ξ)
Assessing Vulnerability of selected farming communities in the Philippines based on behavioral model of agent's adaptation to global environmental change. Acosta-Michlik and Espaldon (2008) [18]	Assessing farms' vulnerability to climate change and globalization	Vulnerability, adaptation	- Inter-vulnerability	- Agent-based modeling - Socioeconomic methods - GIS	Adaptability (48) Resilience (0) Vulnerability (53)

(*) Only the three main targeted concepts were considered: resilience, vulnerability and adaptability.
(§) Not strictly related to the three focused concepts.
(Ψ) Refer to the procedural issues only, which might or might not have been influenced by the pre-defined concept.
(Ξ) The variations of the words considered in the text included: 'adapt' for to adapt, adapted, adaptability, adaptation, adaptedness, adapting, adaptive capacity, adaptive cycle etc.; 'resil' for resilience and resilient; and 'vulnera' for vulnerability, vulnerable, vulnerably, vulnerableness, vulnerabilities, intervulnerability, etc. Excluded: title, subtitles, abstract, key words, literalcitations, graph and table headings and captions.

capacity adds the concomitant quality of the system to persist while its circumstances are changing. Without the latter condition the resilience characterization would remain static and descriptive and the possibilities of optimization prevented.

The combined application of concepts, although evident in seven of the ten cases examined, in which at least two concepts are used together, differs somewhat. For instance [38] defined an *ad-hoc* factor based on comparing a variable (e.g. yield) sensitive to a particular site characteristic (e.g. soil type) against selected stress factors (e.g. climatic records). The obtained factor then acts as a surrogate for the farmers' adaptive measures, and is suggested by the authors as an indicator of vulnerability.

Another recurrent situation, either in vulnerability or resilience analysis, is the recognition of intrinsic characteristics of the system that lead to determine their current and potential adaptabilities, i.e. a change in short-term managerial decisions, preventive adjustment to foreseen changes, etc. [18,39,40,41].

Nonetheless, the combined usage of concepts occurs mostly when authors appeal to a second term to stress a specific characteristic of the first one. This was observed in most papers, e.g., [41] affirm that short-term adjustments and long-term adaptations characterize vulnerability as an evolutionary process over time; or when [39] point out that farmers' adaptive capacity depends on resources provided by the government programs to cope with the vulnerabilities that they face; or as when [42] state that farmers' vulnerability increases when they are obliged to enlarge the scope of their managerial (adaptive) capabilities from a local to larger scales to meet EU standardization demands.

In most cases the characteristics that determine the system's adaptability acquire relevance only through the observance of the vulnerability/resilience interaction over time, rather than at a given moment. When the resilience and vulnerability concepts are applied together, an increase in the performance of one generally means the deterioration of the other's [30]. For instance, regarding socioeconomic issues [42] note that the "*Farmer vulnerability increases when the capacity of the agro-ecosystem to produce services is eroded (...) financial resources are used to enhance farmers' capacity to persist, they help build resilience*" and concerning biophysical matters that the "*system state depends on ecological services that are essential for agricultural production and tourism. The redundancy of these ecological services provides insurance against vulnerability*".

Even so, it is conceivable to have a loss of resilience and an increase in vulnerability at the same time, when a system persists to a stage where the potential to cope with disturbances decreases as well as its capacity to recover from them. Although what is more common is a *patch effect* where resilience and vulnerability have dissimilar performances simultaneously, e.g., an invigoration of the ecological resilience can be accompanied by a decline in the social resilience or an increase in the vulnerability of certain components of the system [28]. This brings us again to the need for an integrative insight, by conceiving the system as a whole and highlighting the interactions among its components [43].

Finally, the number of times that the key words (resilience, vulnerability, adaptability or derived terms) appeared in the papers was counted, assuming that the combined usage of terms must be an indication of overlap. In general there is no clear correlation between the declared 'main' driving concept and the number of times that it is mentioned. In two of the ten papers, a secondary concept is mentioned more often than the one said to be the main one, as in [38], who although targeting vulnerability as the main concept, mention variants of adaptability more often to refer to related characteristics of the systems.

The use of the three terms altogether, even though common (observed in six of the ten papers) is clearly unbalanced. Resilience is mentioned much less than vulnerability and adaptability, unless it is considered as the main concept (two cases). This is supported by the much smaller number of linguistic variations of the term in comparison with the other two, its rarer citation in scientific and lay literature, by its relative newness in academia, and the imbalanced diffusion resulting from intensive cross-citation among authorship networks. The last of these was mentioned by [3] as major cause of bias.

4.2. Methodological and operational aspects

As shown, the overlap of resilience, vulnerability and adaptability occurs regularly in the observed examples. Now, we analyze the methodological and operational criteria that drive their application.

In methodological terms, there is no clear preeminence of any type of procedure. Sociological and ethnographic tools, such as participatory workshops, action research or historical tracing, were applied to a similar extent in each study, as were used deep-rooted biophysical protocols, like hydraulic and hydrological measures, or mathematical procedures, such as multivariate statistics, agent-based modeling or GIS-based classification.

Operationally, it is often observed that notions such as farmers' practices by their extended knowledge of their own circumstances [39], or organic agriculture by its innate nature [42] are taken as providing assertions of resilience either to climate change or EU agricultural policies in the examples. Likewise, we also find the rhetorical use of terms without their concrete practical application, as done by [44] that reviewed adaptability as a core concept, but later re-oriented the analysis towards well-known sociological approaches like power and gender-based relationships. Due to these *ex-ante* assertions, in the first case the analysis is restricted to a small number of presumptions and encourages counterbalancing statements such as 'climate change coping measures should be based on traditional and/or organic agricultural practices', which indeed occurred in the cited example; also in the second case, adaptability is used merely as a proxy for subsequent standard analyses. In both cases the initial assumptions bias the truthfulness of a legitimate analysis on disturbance and change.

Saldana Zorrilla [37] focuses on the interface between government responsibilities and the farmers' adaptive measures: how the latter are weakened by the poor support of the former; later on this simplification dilutes the *exposé* of a complex problem into a pros vs. cons argument and finally ends up in bland statements to explain the current state of the system, such as the '(...) weak governmental support' or '(...) hindered by the neoliberal system', which although perhaps correct, may be difficult to convert into pragmatic suggestions or decisions. In contrast, other investigations assume systemic principles. This is the case of [36], who target agriculture as a multi-disciplinary domain, by considering non-agricultural elements extracted from historical studies and policy analyses. Similarly the Saami peoples' pastoralism is widely evaluated by [40], including biophysical, social and political proxies, whose predictions are contrasted with projected climate change scenarios.

We argue that by underlining complexity, participation and functionality as key premises, a more accurate evaluation of disturbance and change of agricultural systems should be carried out.

By recognizing complexity as an inherent characteristic of the situation under analysis we prop the adoption of systemic approaches to handle them. Thus, we emphasize on the identification of the overall context, the delimitation of boundaries, the existence, connectedness and feedback among components, and the recognition of inflows and outflows and overall pre-established functions [45-47]. Since no assumptions are made in advance, key factors should emerge during the investigation, then prognosis based on a limited number of factors is weakened, the application of target-oriented procedures is demeaned, and the notion of central control rejected. In this concern, the adoption of social-ecological systems as a unit of analysis, widely extended in the resilience and vulnerability scientific communities is key [48,13].

Another commonly underrated aspect is participation. In most of the analyzed cases, it is treated as a procedure that requires different inputs in the form of concrete measurements [38] through the application of pre-established methodological protocols such as the adaptive cycle [36] or agent based modeling [18]; or by reducing the stakeholders' contribution to completing

encoded questionnaires [41] or responding to issues already formulated as clear hypotheses [44]. In general, the contribution of stakeholders is restricted to responding to top-down designed questions or to commenting about specific issues, excluding them from proposing their own viewpoints and interpreting the situation based on their own criteria. This is not the case in [27,39,42] for whom participation is a guiding concept and therefore soundly implemented.

Opening up research to the wide participation of stakeholders is fundamental to reveal the underlying complexity of the systems, since differences in stakeholders' expectations are the major source of reactive change; moreover, participation minimizes the bias resulting from central planning and the assumption of disciplinary viewpoints, strengthening the factual base and legitimacy of the results; finally, participation fosters social learning and hence the population's adaptive capacity itself [26,49].

Functionality is the factor least considered. Few of the reviewed investigations outline and assign a clear function to the studied systems, as for instance do [41], by pointing out that the 'farmers' responses to low stream flows' is the core research domain, and where further improvements are expected in future. Instead, most studies refer to generic responses of systems without defining specific realms. By stating goals such as 'assessing vulnerability of farming communities' [18] or evaluating the 'agricultural system -regional scale- resilience' [36], the authors gather general responses with poor thematic demarcation and hence difficult to implement.

By establishing a system's function we enlarge the analysis from describing, characterizing and understanding certain phenomena, towards the analysis of pragmatic situations where the function(s) and expected role(s) of the systems are prioritized and possibly anticipated, allowing the determination of useful policy decisions [35]. Functionality (and more recently, multifunctionality), relies on the principle that the sustainable performance of a system can be achieved only through the enhancement and intensification of the processes involved and the simultaneous generation of useful outcomes, to satisfy not only the ecological but the social and overall economic demands of land-users [50-52], what is streamlined with the strengthening of resilience, vulnerability and adaptability.

Excluding the prospect of implementation as decisions or actions would convert this emerging field into another academic domain for scholars, instead of a powerful tool for practical application to handle change and disturbance in social-ecological systems.

4.3. Towards an operative approach of resilience, vulnerability and adaptability

A precursory idea states that if resilience refers to the capacity to recover the system from changes, vulnerability alludes to the capacity to preserve the structure of the system [30]. Although this idea of symmetry is not entirely accurate because of the interplay of factors not necessarily related to resilience or vulnerability [12], it contributes to build a heuristic model based on the continuous interaction of these two elements.

Resilience and vulnerability point to the structural characteristics and settings of the systems rather than to their reactive capacity to respond to changing circumstances, where the notion of adaptability, as a chain of reacting events and processes occurring along a time line, has preeminence [31].

We suggest that joining the concepts of resilience, vulnerability and adaptability in a joint approach, which rather than identifying qualities or roles of specific events, factors or drivers, should attempt to compose an integrated view of phenomena occurring in a change- and disturbance-determined system. This would provide a better understanding, and overall to assist in the generation of decisions that prop the long-lasting (sustainable) persistence of the system.

Hence, a resilience, vulnerability and adaptability joint approach for assessing and analyzing social-ecological systems, should be grounded on the dynamic interaction between resilience and vulnerability and the resulting adaptability along a time line, following/along a change/disturbing event/process in terms of composition, structure and function (Figure 4).

5 Concluding remarks

We have tracked the epistemology of resilience, vulnerability and adaptability as driving concepts to deal with disturbance and change. A number of scientific papers where these concepts were applied in agricultural systems have been analyzed, and examined for complementarity and overlap. Our analysis shows that most authors have used the concepts resilience, vulnerability or adaptability insufficiently due to a fuzzy understanding, and beyond the standard definitions. This is due to the intrinsic theoretical linkages among the three concepts; it is not clear where one concepts ends and the another begins, leading to overlap in their use.

This conceptual overlap, rather than confusing, can help to clarify a phenomenon but requires turning this

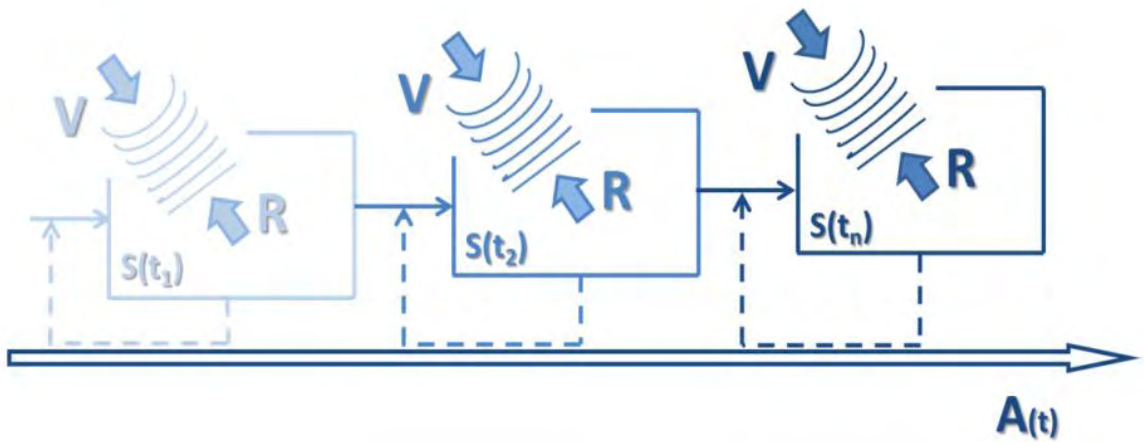

Figure 4: Ontology of an integrated application of resilience (R), vulnerability (V) and adaptability (A). Agricultural system (S) stages are function of the interaction of resilience and vulnerability across time (t), determining its overall adaptability. Feedback loops (dashed lines) contribute to improve adaptability in short-term leaps.

ambiguity into conceptual integrity by the pragmatic application of the concepts considered. Clarity about the methodological and operational implementation will be of great help in this respect. Standardized protocols designed to assess and/or analyze resilience and/or vulnerability and/or adaptability [14,29] are an important step in this direction.

Given the considerable overlap between these concepts their integrated use should provide a more complete portrayal of the behavior of agricultural systems in changing situations. This integration should go beyond the application of available methodological tools, and consider the operational premises of complexity, participation and functionality. We suggest a notion of how this approach could look like. However, more research will be needed to sharpen its conceptual scope, and most importantly, operational and methodological implementation.

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