Review Article

Anna-Lena Rau,* Manuel W. Bickel, Stefan Hilser, Shona Jenkins, Gavin McCrory, Nicole Pfefferle, Julius Rathgens, Dennis Roitsch, Thilo N. Schroth, Sanna Stålhammar, Danna Villada, Annika Weiser, Christine Wamsler, Torsten Krause, Henrik von Wehrden

Linking concepts of change and ecosystem services research: A systematic review

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Abstract: Transformation, transition and regime shift are increasingly applied concepts in the academic literature to describe changes in society and the environment. Ecosystem services represent one framework that includes the implicit aim of supporting transformation towards a more sustainable system. Nevertheless, knowledge and systematic reviews on the use of these concepts within ecosystem services research are so far lacking. Therefore, we present a systematic literature review to analyse the interlinkages between these concepts and ecosystem services. Using a search string we identified 258 papers that we analysed based on 40 review criteria. Our results show that transformation was mentioned most often (197 articles), followed by transition (183 articles) and regime shifts (43 articles). Moreover, there is no consolidation of these concepts. Only 13% of all articles gave definitions for the three concepts. These definitions strongly overlapped in their use. Moreover, most papers described changes that happened in the past (73%). We conclude that research would benefit from being directed towards the future rather than evaluating what has happened in the past. Based on our results, we present: i) clear definitions for the three concepts; and ii) a framework highlighting the interlinkages between the ecosystem services cascade and the concepts of change.

***Corresponding author: Anna-Lena Rau,** Faculty of Sustainability, Leuphana University Lüneburg, Universitätsallee 1, 21335 Lüneburg, Germany, Email: annrau@leuphana.de
Manuel W. Bickel, Julius Rathgens, Thilo N. Schroth, Annika Weiser, Faculty of Sustainability, Leuphana University Lüneburg, Universitätsallee 1, 21335 Lüneburg, Germany
Stefan Hilser, Shona Jenkins, Gavin McCrory, Nicole Pfefferle, Dennis Roitsch, Sanna Stålhammar, Danna Villada, Christine Wamsler, Torsten Krause, Lund University Centre for Sustainability Studies (LUCSUS), P.O. Box 170, SE-221 00 Lund, Sweden
Henrik von Wehrden, Faculty of Sustainability, Leuphana University Lüneburg, Universitätsallee 1, 21335 Lüneburg, Germany, Arizona State University, Tempe, AZ 85281, United States

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1 Introduction

Since the early 2000s, the concept of transformation has become increasingly important in academic literature to describe changes in society and the environment, with the aim of informing a more sustainable future [1–3]. In parallel, other concepts have evolved to conceptualize change, namely transition and regime shifts. These three concepts partially overlap, yet also differ in terms of their particular lenses through which the world is viewed [2,4–6].

What unites all three concepts is the focus on continuous change characterising human societies and ecosystems. Early research dealing with ecosystem services already highlighted the relevance of sustaining human well-being over time, and therefore implemented an understanding of ecological change in the provision of ecosystem services into the original concept [7]. While the ecosystem service concept was initially developed to highlight the importance of nature's benefits or services for human well-being, it has increasingly evolved into an interdisciplinary framework that integrates policies and management strategies for ecosystems as well as societal change [8–10]. More recent research increasingly recognizes the capacity of the framework to aid transformation and change[11], though other approaches recognize the capacity to link ecosystem services to sustainability [12]. The ecosystem services concept could play a major role in engaging different disciplines and stakeholders from various backgrounds in shaping and achieving societal goals. It could therefore be an instrument for implementing transformative processes for creating more sustainable relations between humans and nature [11]. Moreover, transformative knowledge is

needed to shape the management of ecosystems and their services towards societal goals [11,13,14].

However, knowledge and systematic reviews on the use and conceptualization of transformation, transition and regime shift within ecosystem services research is so far lacking. Increasing such knowledge is crucial as ecosystem services and human well-being are strongly vulnerable to fundamental changes of ecosystems caused by anthropogenic interventions [8], while transformation towards sustainability is an implicit goal in terms of the concept of ecosystem services [11]. The lack of coherence in defining and applying the different concepts is also creating dissonance or even contradictions within the literature [4]. Against this backdrop, this paper investigates the interlinkages between the concepts of transformation, transition, regime shift and ecosystem services by asking the following questions:

- How are transformation, transition and regime shift conceptualized within the ecosystem services literature?;
- How do these concepts integrate temporal dimensions of change within the ecosystem services literature?; and
- How does research on ecosystem services and concepts of transformation, transition and regime shift link to real-world sustainability challenges?

We use ecosystem services as a boundary object to better understand how transformation, transition and regime shift are applied and conceptualized in the scientific literature. By restricting ourselves to the ecosystem services literature, we seek to gain a better understanding both from a conceptual as well as an applied perspective. Furthermore, we elaborate an agenda for future research and highlight ways forward toward integrating the concepts of transformation, transition and regime shift within ecosystem services research. This permits us to advance the ecosystem services concept and associated cascade model [15] by matching it with the concepts of transformation, transition and regime shift. Ultimately, this will allow us to clarify the different concepts and enhance related research.

2 Methods

This paper is based on a systematic literature review, which combines quantitative statistical analyses with qualitative content analyses. To conduct the quantitative literature review, we followed the approach for systematic student-driven literature reviews in sustainability science described by Luederitz *et al.* [16].

2.1 Data collection

Using a jointly-defined search string (see Supplementary Material A), which was employed to search within the Scopus and ISI Web of Science databases in October 2015, we identified 1034 potentially relevant bibliometric entries. By following the review procedure portrayed in Figure 1, we identified 258 relevant case studies and

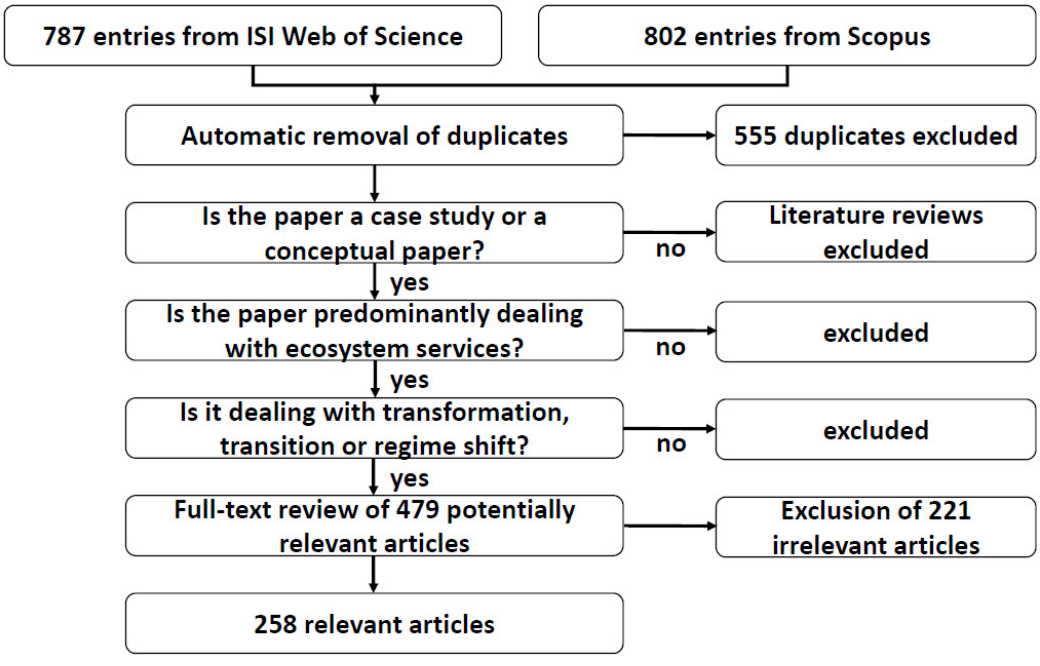

Figure 1: Review procedure

conceptual papers with the earliest publication dating back to 1993 (see Supplementary Material B for the list of articles). Those publications were analysed using 40 review criteria (Supplementary Material C).

2.2 Data analysis

We conducted a systematic qualitative and quantitative analysis of each article [17]. The resultant data were either words that were copied from the original texts, such as definitions and implications for future research, decision-makers or practitioners, or figures like how often a specific term was mentioned in the text.

To analyse and compare the results retrieved from our review categories, we clustered articles into ones that describe: i) change processes in the ecological system: ii) change processes in the social system; iii) change processes in the social-ecological system; and iv) change processes from a meta-perspective. Additionally, we noted for each paper which stages of the ecosystem services cascade (structure, function, benefit, value, management) were mentioned, and if the paper was based on data from the past or offered an outlook on the future (e.g., by simulations or modelling). Moreover, we noted if an article included system knowledge, target knowledge or transformative knowledge following the definitions presented by Brandt *et al.* (2013) [18]. System knowledge represents the analysis of a system as it is at the moment. Target knowledge describes how the system should be and transformation knowledge includes how to reach the target, e.g., by problem solving strategies [18].

Moreover, we categorized the intensity of stakeholder involvement by using the classification by Krütli et al. (2010) [19], distinguishing between information, consultation, collaboration and empowerment. Information is defined as communication from academia to stakeholders from practice. Consultation is the information flow from stakeholders to academia, e.g. in the sense of surveys and interviews. Collaboration between stakeholders and academia, however, requires a higher degree of involvement, e.g. rules for both sides. Empowerment is the highest level of involvement as the stakeholders are given decision authority [19].

All statistical analyses were performed in R (version 3.1.3; R Core Team Vienna, Austria; http://www.R-project.org/). To display our results, we used the package ggplot2 (Wickham, 2016).

Qualitative analysis of definitions for the terms transformation, transition and regime shift was conducted by collecting all definitions for these terms from our data set and systematizing them in relation to their main differences and similarities. To develop the criteria, we read through all definitions looking for items that were present in most of them and helped to characterize the most important aspects of change. This process resulted in the following criteria:

- What is driving the change?
- Which system is supposed to be changed (social, socio-ecological, ecological)?
- What is the temporal dynamic of change (incremental/abrupt)
- What is the outcome of change (e.g., more sustainable system)?
- Did the change occur intentionally or unintentionally?
- Is the change reversible?
- Are stakeholders involved?

To visualize the different literature strands of research on ecosystem services as well as transformation, transition and regime shift on a quantitative basis, we conducted a cluster analysis using the R package mclust (Scrucca *et al.*, 2017). Based on 13 of our 40 research categories that were coded using a binary classification according to the approach of Milcu *et al.* [20] we clustered all papers that gave information on these categories (N=204) into three groups. The strength of the clustering had an agglomerative coefficient of 0.97 (with 1 being the highest).

3 Results

3.1 Characteristics of the analysed literature

3.1.1 Authors and Definitions

For the ecosystem services concept, three authors were mainly cited: The Millennium Ecosystem Assessment (MEA) was cited 61 times [21–23], Robert Costanza 25 times [24–27] and Gretchen Daily 22 times [28-29]. For the terms transformation, transition and regime shift, there was great diversity with regards to how these terms were presented. Within the total amount of articles analysed, transformation was the most frequently mentioned term (197 articles), followed by transition (183 articles) and regime shift (43 articles) (Figure 2). The majority of these articles did not give a clear definition of the mentioned concepts (regime shift, transition, transformation). Out of a total of 258 articles, 34 (13%) articles clearly defined transformation, transition or regime shift. None of the papers defined more than one of the terms. Within this sub-sample of 34 articles, the term regime shift was defined in

18 (53%), transformation in nine (26%) and transition in seven (21%) articles. Of the articles including a definition for one of the terms, the same term is mentioned as the research object in the title in 18 cases (53%). In detail, this is the case for 13 articles defining the term regime shift and three articles defining the term transformation. Transitions were only stated as the main research objects in the titles of two papers giving definitions for this term.

The use of specific definitions for the term regime shift began to emerge in 2004. A definition for transition appeared first in 2007 and for transformation in 2009. Definitions for all three terms were found in the papers during the years 2012 to 2014. The number of papers giving a definition for one of the terms increased from one in 2004 to six in 2014 and 2015 (Figure 3).

Interestingly, papers giving definitions for the terms were cited more often and appeared in journals with higher impact factors. Papers not defining one of the terms received up to 73 citations whereas papers giving definitions were cited up to 127 times with one outlier at 1045 times (Figure 4a). Papers defining none of the terms appeared in journals with impact factors ranging between one and two whereas papers defining one of the terms appeared in journals with impact factors of up to seven (Figure 4b).

No specific sources for the given definitions of the concepts of transformation, transition and regime shift emerged in the literature. In the nine articles defining transformation, no authors are cited with any predominance, with only Chapin [30,31] being cited more than once (four times). Three of the articles giving a definition presented transformation simply as a shift from one kind of system to another, while three other articles equated it to land-use change and the remaining three as a fundamental change in socio-ecological systems.

Within the sub-sample of eight articles defining transition, no authors were cited with any predominance - three authors were cited for more than one definition: Mather was cited by four papers [32,33] while Meyfroidt and Lambin were cited three times [34,35]. One article defined the word transition with a focus on land-use transition, five articles with a focus on forest transition and only one article with a focus on the radical, structural change of a societal (sub)system.

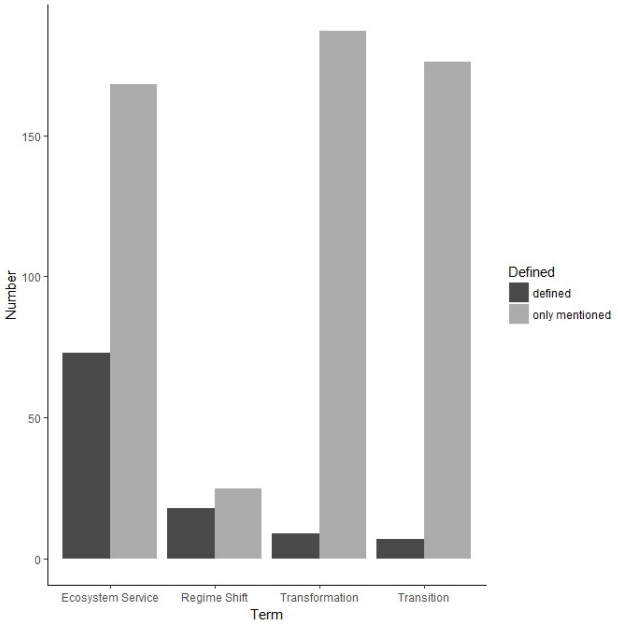

Figure 2. Number of papers defining the terms ecosystem service, regime shift, transformation and transition and those only mentioning the terms.

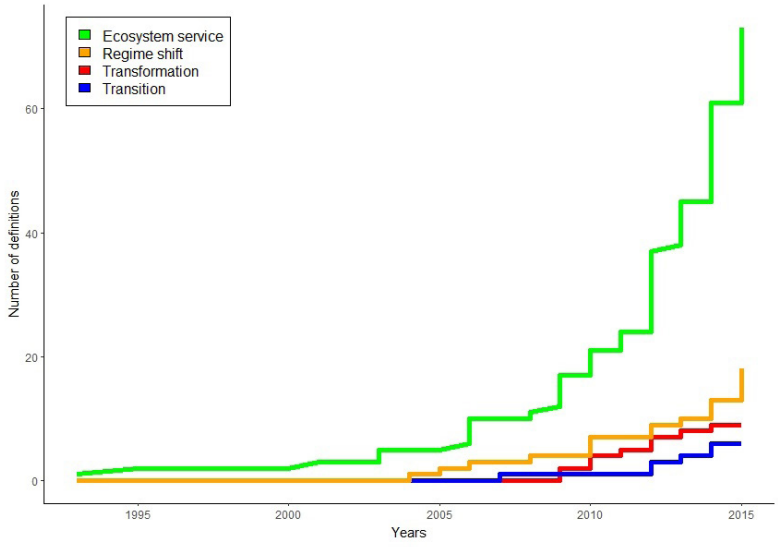

Figure 3: Number of definitions for the terms regime shift, transformation and transition over time in the articles evaluated.

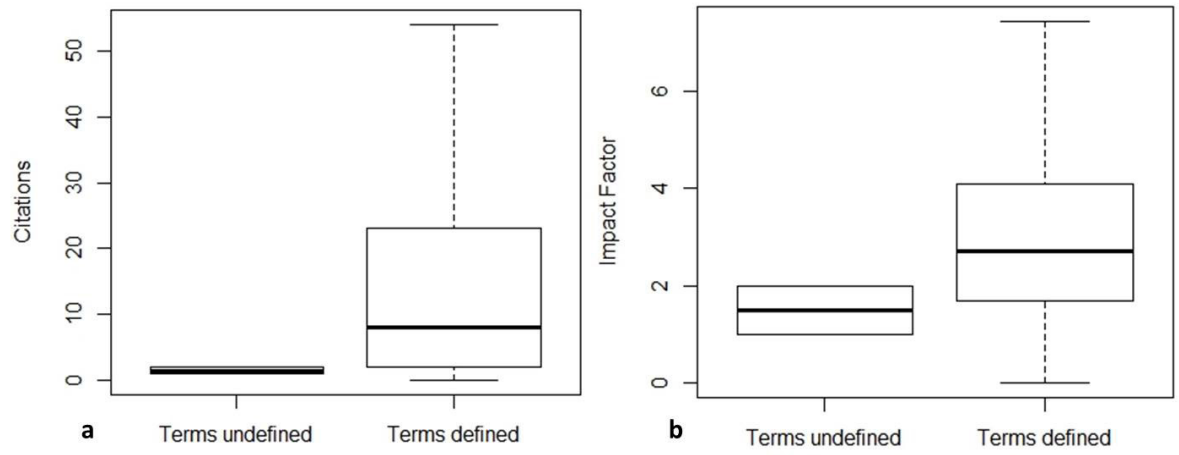

Figure 4: a) Citations for papers defining one of the terms vs. papers not giving definitions (one outlier at 1045 for terms defined). b) Impact factors in 2014 for papers defining one of the terms vs. papers not giving definitions.

Of the 18 articles defining regime shift, the authors Scheffer (12 citations) and Carpenter (7 citations) were cited most often [36–41]. Folke was cited by four articles [8] and Hughes by three articles [42,43].

While many articles do not clearly define the term they use for describing change, some articles still referred to certain literature sources. Yet, no clear baseline articles were evident from our analysis. In total, the analysed articles referred to 213 authors (first author only) when using the term transformation, transition or regime shift. Out of these, six authors were referred to at least five times: Scheffer (N=17), Carpenter (N=10), Lambin (N=8), Folke (N=9), Walker (N=9) and Mather (N=5).

Table 1 depicts the results of the qualitative analysis of the 34 definitions for transformation, transition and regime shift we found in the literature. It shows the similarities and differences of the three concepts as they are used within the ecosystem services literature.

As illustrated in Table 1, most of the reviewed articles describe a human-induced change that influenced a natural or socio-ecological system. Examples are land-use transformations that are human-induced and forest transitions that are driven by reforestation and afforestation [44]. Regime shifts are also described as the outcomes of human activity, but often in a more indirect sense, e.g., regime shifts caused by climate change or ocean acidification (e.g., Beaugrand 2015; Conversi *et al.* 2014) [45,46]. The systems that are being changed are social or socio-ecological systems in those articles dealing with transformation, social or ecological systems in articles dealing with transition, and ecosystems such as lakes [36,39], coastal [47,48] and marine ecosystems [49–51] as well as forests [52] in articles focusing on regime shifts. The speed of change is mainly stated as gradual or incremental for transformations and transitions whereas regime shifts are clearly described as abrupt changes in a system (e.g., Satake & Rudel, 2007; Zhang, 2015; Crepin *et al.*, 2012; Guttal & Jayaprakash, 2008) [48,53–55].

Table 1: Key elements and differences of the concepts of transformation, transition and regime shift in the ecosystem services literature.

	Transformation	**Transition**	**Regime shift**
Driver of change	Human-induced	Human-induced	Loss of ecological resilience (often human-induced)
Changed/targeted system	Social/socio-ecological, economic, political/institutional	Social/ecological	Ecological system
Speed of change	Gradual	Incremental or gradual (?)	Abrupt
Outcome	More beneficial system (e.g., more sustainable)	Depending on the system, e.g., forest cover gain for forest transition	Less desired ecological state
Solution-oriented/ problem-oriented	Solution-oriented	Problem-oriented	Problem-oriented
Reversibility	Hardly possible (?)	Possible (?)	Not or hardly reversible
Stakeholder involvement	Yes	Yes	No

The outcomes of the fundamental change in a system are strongly different for the three concepts (Table 1). For transformation, the outcome is viewed as a more beneficial system (e.g., Gelcich *et al.*, 2010) [56], whereas for regime shifts, it is a less beneficial system, like a less desired ecological state in which the ecosystem is less capable of providing ecosystem services [54]. In addition, papers dealing with transformation processes often mention that these are intentional, for instance, creating a more sustainable society (e.g., Chapin *et al.* 2012; Gelcich *et al.* 2010) [56,57]. In many articles dealing with transformations, authors do not only concentrate on a specific development, but also make qualified statements about transformation being beneficial in one way or the other. This stands in contrast to regime shifts which are described as caused by unintentional and unnoticed gradual changes in a system, leading to an abrupt change when a certain threshold is crossed (cf. Ernstson *et al.*, 2010) [58]. For transformations, there is no clear pattern as this term is used for various systems. In the case of forest transitions, the outcome is positive in the sense of net reforestation [59] whereas it can also be negative in the sense of land use transition causing lower ecosystem services values [60]. Hardly any study on transformations and transitions supplies information on the reversibility of the changes it presents. In contrast, for regime shifts, it is commonly stated that these are hardly or not reversible [54]. In Table 1, we also highlight stakeholder involvement in the articles, although only a few mention these. Stakeholders were, amongst others, tourists, residents, farmers, governmental and non-governmental organizations. However, those few studies that did mention stakeholders investigated transformations and transitions. In the evaluation of regime shifts, stakeholder involvement plays just a minor role (e.g., Burkhard & Gee, 2012; Conversi *et al.*, 2014; Troell *et al.*, 2005) [46,47,61].

3.1.2 Focus on social and ecological systems

Our results reveal the great variety of social and ecological systems in which change is described. The largest share of articles (38%, N=99) deals with change in social-ecological systems, followed by 28% (N=71) of the articles that concentrated on change in the ecological system.

Only 18% (N=47) of the articles defined change as occurring in the social system, and interestingly, those articles did not mention any explicit connection to the natural system or specific ecosystems.

An even smaller share of 13% of studies (N=33) defined transformation as a change from a system's perspective and on a "meta-level" (Table 2).

Of the 88 (34%) articles that gave a clear definition for the term ecosystem services, only a comparatively small share of 11 articles (13%) applied concepts of transformation, transition and regime shift in the context of the ecological system. Out of the 47 articles referring to change in the social system, 64% (N=30) concentrated on the "service" stage within the ecosystem services cascade.

Only a small share of papers (N=22, 8.5%) investigated all levels of the ecosystem services cascade from structures to policy interventions. Out of these, 81% (N=18) of papers evaluated all levels from structure to valuation. In contrast, with 84%, the largest number of papers (N=218) focused on a set of stages of the cascade, partially with gaps in between.

3.2 Conceptualization of change within ecosystem services research

Based on the results of the cluster analysis, we divided the literature into three groups (Figure 5). Each group is characterized by at least one review category that applies to all articles within this group. From each group, we

Table 2: Perspectives of identified articles on ecosystem services, transformation, transition and regime shift.

Perspective	Focus	Absolute Number	Share of articles [%]
Socio-ecological system	Change caused by humans affecting the natural system and change in the natural system affecting humans	99	38
Ecological system	Change of land, forest, fresh water and salt water ecosystems	71	28
Social system	Change in economy, values, the legislative system and cultural transformation	47	18
System`s perspective / meta-level	Event of (substantial) change itself No specific system Articles referring to the "Great Transformation" by Haberl and colleagues [62] and transition theory according to Grin and colleagues [9]	33	13

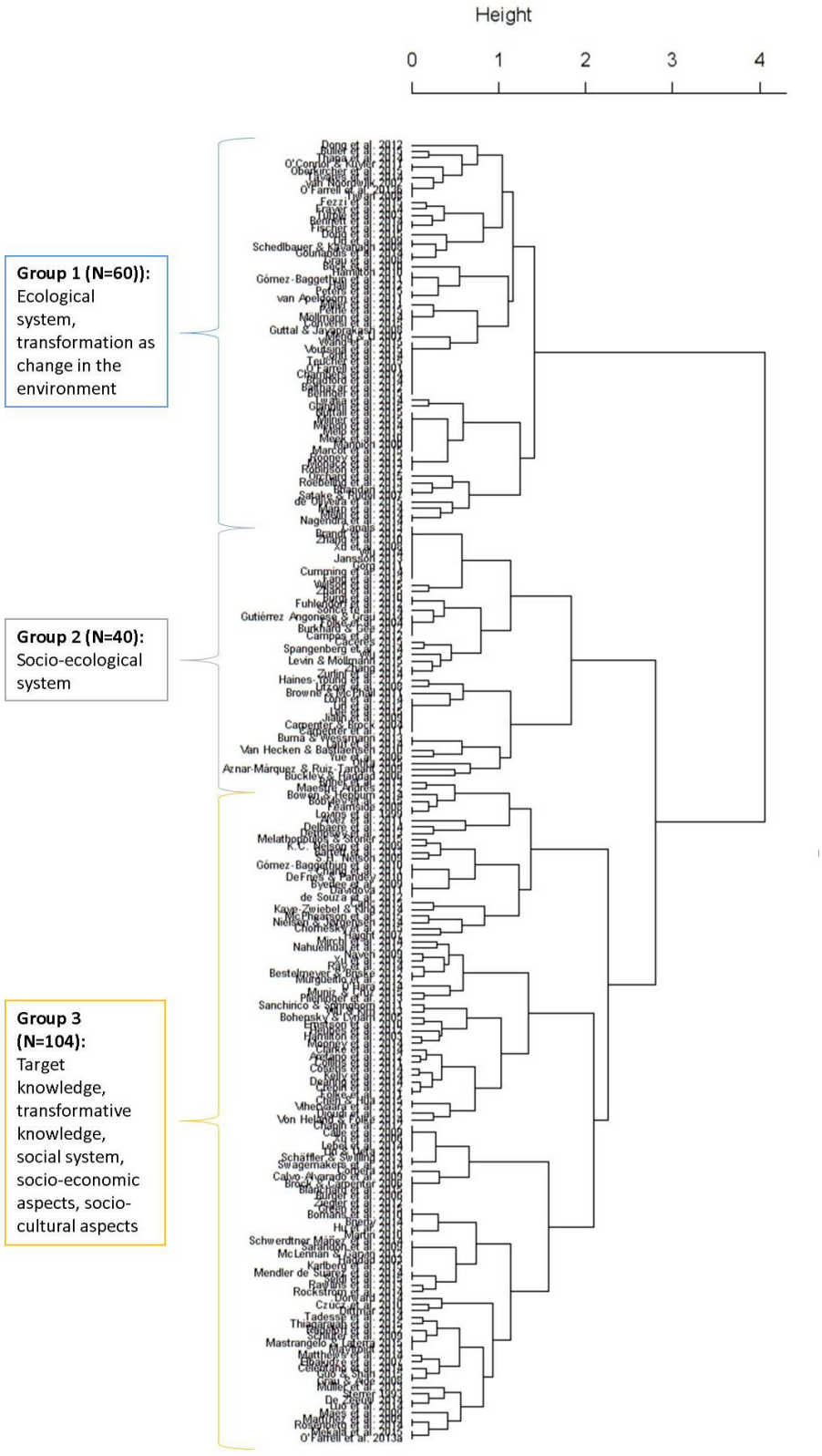

Figure 5: Dendrogram of all articles giving information on the 13 research categories that were coded using a binary classification. Articles that appear more closely to each other are more similar in the way the columns of the review categories were filled out. A list of all articles per group can be found in Supplementary material D.

chose the most-cited articles to present as examples. This helps highlight the main topics of each literature strand we identified. The first group contains 60 articles focusing on change in the ecological system. The field covers a variety of ecosystems and mostly assesses the resilience of ecosystems and regime shifts. The second group consists of 40 scientific publications. This group is characterised by a focus on socio-ecological topics with a diverse range of research with different foci. Human behaviour and its impact on ecosystems is investigated in this strand of literature. Group 3 comprises 104 papers focusing on transformation as change in the social system, socio-economic and socio-cultural changes and providing target knowledge as well as transformative knowledge.

3.3 Integration of temporal dimensions

Of the 206 papers that provided information on whether they were building upon data from the past or predicting change in the future, 177 (86%) were case studies and 18 (9%) were conceptual papers. Articles building on data from the past (N=150, 73%) were the most prevalent in our data set. Future changes were predicted in 23% of papers (N=47) whereas only nine dealt with changes both in the past and future.

Information on the velocity of change is rarely given. In total, 52 of 258 papers provided this information by characterising change as abrupt (N=24, 46%), incremental (N=18, 35%) or describing both patterns (N=10, 19%). Of the 34 papers that give definitions for one of the three terms, only those defining regime shift supplied information on the velocity of change by describing it either as abrupt or incremental. Of those eight papers, four mentioned abrupt dynamics, one incremental dynamics and three both types.

Although dealing with change, long-term research was rarely conducted in the papers we reviewed. Out of all papers, just 11% (N=28) described their data as deriving from a longer-term study. Of the 34 papers giving definitions of one of the three concepts, only in two papers did the authors state they conducted long-term research.

3.4 Consideration of real-world sustainability challenges

In the literature on ecosystem services and concepts of transformation, transition and regime shift, real-world sustainability challenges were present to different degrees and partly addressed by involving various stakeholders affected by the problem and offering recommendations or solutions to problems, e.g., in the discussion or conclusion. Stakeholder involvement and participation were only reported by a small share of articles. From a total of 258 articles, 52 (20%) mentioned some form of stakeholder involvement. About half of these articles mentioned the term participation. Out of the 52 articles involving stakeholders, 27 (51%) were related to transformation, 22 (42%) to transition and three (6%) to regime shifts. Stakeholders were informed in 10 cases, consultation was conducted in 43 cases and collaboration in 10 cases. Interviews were applied in 32 cases whereas questionnaires and workshops were each only used in 16 cases.

Of all analysed papers, 39% (N=101 of N=258) had clear recommendations for solutions, with just 27% (N=69 of N=258) offering a detailed intervention strategy transgressing the academic system. A comparable number of articles suggested a change in methods for future research or a change in academic institutions (N=51, 20%).

4 Discussion

Research on ecosystem services and transformation, transition and regime shift has strongly gained momentum over the last decades. Most of these studies were conducted on the continent of the first author`s affiliation. Both these patterns have also been observed for ecosystem services research in relation to other topics, such as urban environments and climate adaptation [63,64].

Most papers were written by first authors who are affiliated with European research institutions. This is in line with other reviews on ecosystem services that have shown that related research is primarily dominated by authors from the northern hemisphere, although this study displayed a lesser dominance of China and the United States [63]. Our study further showed that research on ecosystem services has been consolidated over the last years, indicated by the fact that a larger share of studies refers to the same three definitions for ecosystem services.

On the contrary, concepts of transformation, transition and regime shift are hardly consolidated within the scientific literature on ecosystem services. The different emphases of the three groups within the cluster diagram as well as the fact that each paper only defined one of the three terms show that there are separate research communities applying these concepts in different ways. Ecological analyses featuring descriptive knowledge still comprise the largest share of the literature. Only a small proportion addresses the meaning of change in social

ecological systems. In fact, the terms transformation, transition and regime shift were employed referring to various descriptions and contexts. In addition, just a few articles included specific definitions referring to several authors/papers. Actually, a wide array of literature was cited regarding transformation, transition and regime shift, indicating that there is no standard reference for these concepts. Interestingly, those papers that provided definitions had on average more citations and were published in journals with higher impact factors.

The author that was cited most often in the reviewed papers was Scheffer, who refers to regime shifts as "sudden drastic switches to a contrasting state" caused by a loss of ecological resilience, and states that these shifts have been specifically reported for ecosystems including lakes, coral reefs, oceans and arid lands (Scheffer *et al.*, 2001: 591) [41]. The reason why the term regime shift was used relatively consistently might be based on the fact that the concept has a longer history and originated from ecology [65].

For the other two concepts (i.e., transformation and transition), several definitions were identified, of which some are more abundantly used than others. In our review, the most-cited author on transformation, Chapin, defines transformation as "a fundamental change in a social-ecological system resulting in different controls over system properties, often mediated by changes in feedbacks that govern the state of the system" (Chapin *et al.*, 2012: 3) [57]. Interestingly, this definition and approach does not consider whether the fundamental change is intentional or unintentional and does not describe the outcome of the transformation.

In contrast, outside of ecosystem services research, the transformation concept is often defined by providing specific outcomes and goals, such as the "Great Transformation" that was proclaimed by the German government in 2011 [66]. However, there are also definitions and approaches that only state the intention of change, but do not give further specifics. An example comes from Park *et al.* (2012: 5) who describe transformation as a "discrete process that fundamentally (but not necessarily irreversibly) results in change in the biophysical, social, or economic components of a system from one form, function or location (state) to another, thereby enhancing the capacity for desired values to be achieved given perceived or real changes in the present or future environment" [6]. The definitions we encountered for transition in the ecosystem services literature mostly relate to forest transition, i.e., "the transition from net forest loss to net forest gain" (Melo *et al.*, 2013: 464) [67]. On the contrary, outside of the reviewed ecosystem services literature, the term seems to be rather used in the sense of a transition towards sustainability, defined as long-term, multi-dimensional and fundamental transformation processes through which established socio-technical systems shift to more sustainable modes of production and consumption [68].

The definitions for transformation and transition differ both within the ecosystem services literature and the literature outside the field. However, our analysis confirms the statement by Hölscher and colleagues that the concepts of transition and transformation are not clearly separated from each other [4]. In summary, our results clearly indicated that a more explicit use of (differences in) concepts of transformation, transition and regime shift is crucial to fostering a more profound understanding of ecosystem services and social-ecological changes and supporting the development of further research.

Furthermore, our study has shown that the concept of regime shift was most often defined within the ecosystem services literature in relation to the concepts of transition and transformation. Regime shift is a concept that strongly focuses on avoidable negative changes in ecosystems. Consequently, the possibility of positive change of a system with a more sustainable outcome is generally neglected. Moreover, change is represented in a rather static and simplified way by the concept of regime shifts because the system is assumed to simply switch to another stable yet less desired state if resilience is reduced to a certain threshold [8].

In contrast, the concept of transformation seeks to create more sustainable systems and gives more room for dynamics and complexity inherent in social-ecological systems. A better differentiation of the use of the concepts of transformation, transition and regime shift in ecosystem services research (as proposed) could thus enhance ecosystem service research by unifying the academic discourse and improving the communication of related results. In addition, concentrating on transformation rather than on regime shifts (Table 1) would assist in fostering research and practice capable of closing the feedback loop in the ecosystem services cascade, ultimately encouraging more sustainable environmental governance that would result in the adaptive management of ecosystems in order to maintain and enhance ecosystem services provision (Figure 6).

Initially, the ecosystem services cascade was represented as starting with the stage of ecological structures (cf. Figure 6). However, as ecosystem services are the benefits that people derive from nature [7], there is an increasing consensus that people`s perceptions should be understood as the starting point of the cascade, and the benefit (ecosystem service) as well as the valuation stage

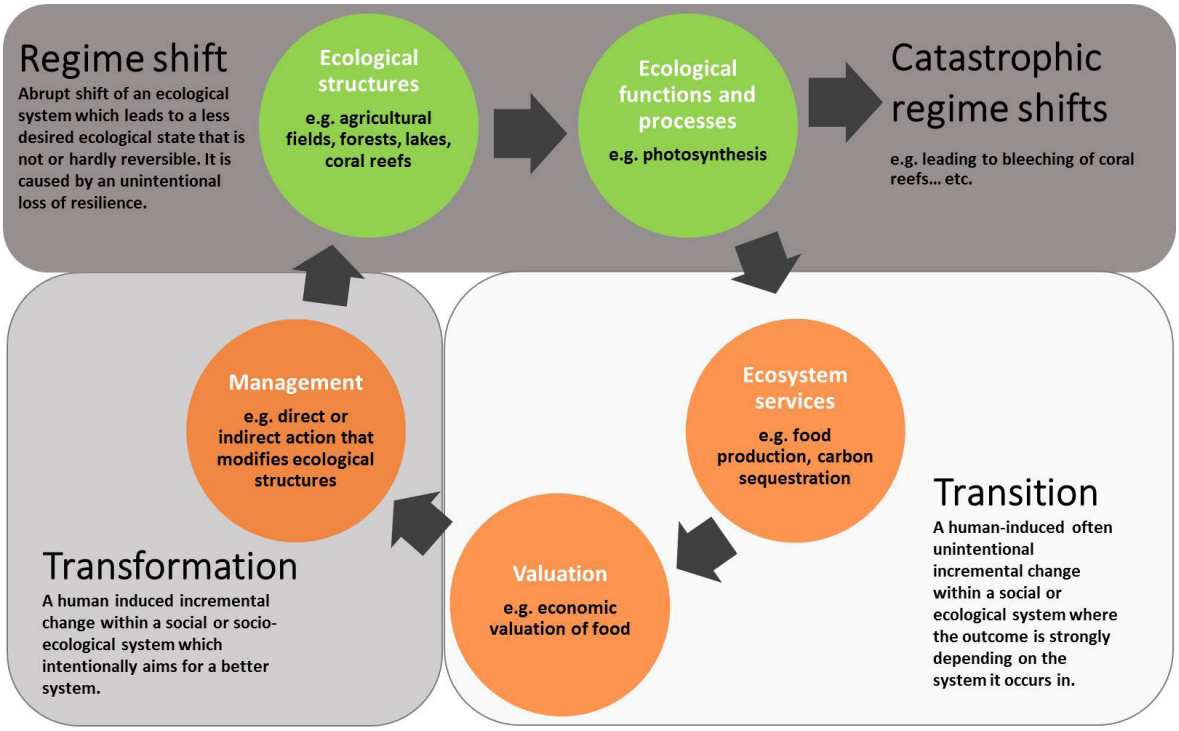

Figure 6: Ecosystem services cascade combined with the concepts of transformation, transition and regime shift (adapted from Haines-Young and Potschin, 2010; Brink et al., 2016). Biophysical stages of the cascade are indicated in green and social stages in orange.

should be provided with more attention [64,69]. This can, for instance, be facilitated by investigating how benefits and values change after the structure has been managed. Another approach would be to influence people's perceptions, e.g., by education and raising awareness surrounding ecological functions and resulting ecosystem services, allowing for an inclusive and informed discussion on environmental governance in particular contexts and of specific ecosystems.

We showed that the structure stage within the cascade is equivalent to the biophysical side of ecosystem services, which can be influenced by regime shifts (Figure 6). Ecological functions and processes are on the biophysical side as well, but are influenced by human activities, which can be unintentional, such as forest transition (in the meaning of a shift from forest decrease to forest increase), or intentional, such as the draining of wetlands. If ecological functions and processes are impacted by catastrophic regime shifts, e.g., ocean acidification leading to bleaching of coral reefs, this would define an endpoint in the ecosystem services cycle as the fundamental ecological characteristics of the ecosystem, i.e., a coral reef community is lost. Benefits derived from ecosystems and their valuation are both on the social side of ecosystem services and can be influenced by transitions, e.g., when the benefits or valuation of an ecosystem service by society change. In this case, transformation is equivalent to an intentional change in management with the goal of changing the system, e.g., the ecological structures (Figure 6).

As illustrated in Figure 6, our results indicate that transformation could be seen as a key concept for a reflected, designed, future- and solution-oriented implementation of the ecosystem services cascade. Therefore, it is vital to direct future research more towards analysing how to achieve future-oriented transformation rather than tracking what has happened in the past, which is dominating the current literature.

Accordingly, to implement the ecosystem services cascade in a future-oriented fashion, we conclude that additional research would need to have a better vision of how management and appropriation of ecosystem services should be designed in the future (target knowledge) and how to induce change to arrive at that point (transformational knowledge) [70]. Furthermore, to assure the value of ecosystem services in the long-term and not only increase it in the short-term, future-oriented policies and management are necessary. To achieve this, it is crucial to recognize the importance and inclusion of stakeholder knowledge more so than at present. Such knowledge co-production requires researchers and

stakeholders to also identify deep leverage points, i.e., points in the system which are difficult to influence but might lead to transformation if intervention succeeds [71]. To accomplish this, changing the intent (i.e., the values, goals, world views) of actors who shape the social-ecological system could enable a transformation towards a more holistic and future-oriented use of the ecosystem services concept.

5 Conclusions

We have investigated the application of the concepts transformation, transition and regime shift within the scientific discourse on ecosystem services. Therefore, we analysed the literature on ecosystem services using a systematic literature review approach. Our analysis shows that research on the concepts of transformation, transition and regime shift within the ecosystem services literature is still unconsolidated. Definitions of the terms are unclear and partly overlapping, especially for transformations and transitions. Most papers do not give definitions at all which can lead to further confusion and separation of the three different discourses.

The largest share of papers giving definitions is dealing with regime shifts in the sense of a sudden change towards a more unsustainable state that should be avoided. This ignores the possibility of positive change leading to a more sustainable outcome in the system. Moreover, most of the research is directed towards the past instead of the future and is conducted without taking stakeholders' perceptions of ecosystem service values into account.

We conclude that future research on ecosystem services and the concepts of transformation, transition and regime shift would benefit from using our definitions that clearly distinguish these concepts from each other. Moreover, a stronger orientation towards the future could be achieved by using the concept of transformations as it is directed towards positive change and involves stakeholders. This includes building visions for the future and creating strategies to reach the desired state.

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