Embracing complexity in landscape management: Learning and impacts of a participatory resilience assessment

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ABSTRACT
Landscapes and their management are at the center of many of the sustainability challenges that we face. Landscapes can be described as social-ecological systems shaped by a myriad of human activities and biophysical processes, interacting across space and time. Managing them sustainably requires considering this complexity. Resilience thinking offers ways to address complexity in decision-making. In this paper, we analyse the learning and impact on a diverse group of local actors from participating in a participatory resilience assessment.

Introduction
Production landscapes, and how we manage them, are at the center of many sustainability challenges (Nyström et al. 2019). Agriculture, forestry and other land uses accounted for 23% of anthropogenic greenhouse gas emissions during the last decade (IPCC 2019) and land use pressures have reduced biodiversity intactness beyond safe limits on almost 60% of the world’s land surface (Newbold et al. 2016). How we manage these landscapes will arguably define whether or not we succeed in serving humanity’s needs within the means of the planet. Landscapes are culturally defined areas whose specific character is shaped by interactions between biophysical processes and human actions (Plieninger et al. 2015). In other words, landscapes are physical representations of intertwined social-ecological systems (Folke et al. 2010). Landscape management, therefore, is a complex endeavour that needs to address different, and sometimes competing, land use needs, in face of continuous biophysical as well as social changes, stemming from smaller as well as larger scales (Walker et al. 2002). However, management has historically often been based on a reductionistic understanding and linear models of the world (Holling and Meffe 1996). While some reduction of complexity is necessary for decision-making, management based on assumptions that are too simplistic often leads to negative unintended consequences (Levin et al. 2013; Schultz et al. 2015).

An approach to address some of these complexities in decision-making is resilience thinking (Figure 1). This approach assumes that humans are part of intertwined social-ecological systems (Folke et al. 2010). A core tenet of resilience thinking is the recognition that these social-ecological systems are complex and adaptive, including features such as non-linear feedbacks, cross-scale interactions, self-organization and inherent uncertainty (Levin 1998; Preiser et al. 2018). This means that social-ecological systems are dynamic, with the possibility of changing along multiple alternative pathways, depending on both internal and external factors (Lade et al. 2020). Resilience thinking provides theoretical frameworks to understand and analyze these complex interactions and changes over time. One such framework presents the seven resilience principles: maintaining diversity and redundancy, managing connectivity, slow variables and feedbacks, encouraging learning, broadening participation, promoting polycentric governance.
systems, and fostering complex adaptive systems thinking (Biggs et al. 2012). Acknowledging and managing for these principles can enhance the agency of actors within the system to influence change in a desirable direction, while still maintaining flexibility to handle emergent behaviours and surprise (Elmqvist et al. 2019). Fostering an understanding for the non-linear and emergent behaviour of complex adaptive systems (henceforth called ‘complexity thinking’) is a fundamental principle, as it allows social actors in the system to better apply the other resilience principles in decision-making (Bohensky et al. 2015).

The application of resilience thinking in practical decision-making is called resilience practice (Walker and Salt 2012; Sellberg et al. 2018). Resilience practice encompasses various resilience assessment guides and other tools that enable social actors to situate the theoretical understandings from resilience thinking in real-world places and situations. Some applications use an analytical framework to assess the resilience of various systems, focusing on measurement (Salomon et al. 2019; Rocha et al. 2022). Others, such as the Wayfinder (Enfors-Kautsky et al. 2021), are designed to provide exercises to increase social actors’ understanding for the system as complex and adaptive, and through that enhance their capacity to enact management that increases the likelihood of the system evolving along a desirable and sustainable pathway (Lade et al. 2020). It is this later, action-oriented version of resilience assessments that we have applied in the current study.

A tool that is often included in resilience assessments is the ecosystem service concept, as it is argued to translate complex social-ecological interactions into usable knowledge for landscape management (Daily et al. 2009; Reyers et al. 2013). Its increasing use by local, national and international policy-makers (Díaz et al. 2015; Hansen et al. 2015; Bouwma et al. 2018) means that various actors are both aware of and motivated to explore how it can be used, making it a favourable concept to craft usable knowledge around (Clark et al. 2016). More research is needed, however, to understand whether and how the ecosystem service concept indeed can support decision-making that incorporates considerations for system interdependencies and complexity (Beery et al. 2016; Bouwma et al. 2018; Schubert et al. 2018), that is, support the application of resilience thinking.

Lastly, resilience practice is often conducted in participatory multi-actor processes (Sellberg et al. 2018). In complex endeavors such as landscape management, different actors have diverse interests in and knowledge of the processes and values that are shaping the landscape (García-Nieto et al. 2015). They are also affected by management decisions in diverse ways (Daw et al. 2015). Therefore, it is important to involve a diversity of knowledge-holders in the research process, both due to the complementarity of local and scientific knowledge (Tengö et al. 2017), and to ensure the saliency and legitimacy of the produced knowledge outputs (Marre and Billé 2019). Thus, the participation of diverse actors in processes such as resilience assessments enables credible, salient and legitimate co-production of

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Figure 1. Conceptual framework showing how resilience thinking, resilience practice and resilience assessments are connected to theories about complex adaptive systems and complexity thinking.
knowledge (Folke et al. 2010; Clark et al. 2016; Norström et al. 2020). In addition, involving diverse actors in a participatory resilience assessment has the potential to generate social learning (Sellberg et al. 2018). As social-ecological systems constantly change and evolve, maintaining capacity to adapt requires continuous learning among actors in the landscape (Schultz and Lundholm 2010; Berkes 2017). Bringing such actors together in facilitated processes can enable them to learn from each other and help them to link and situate their knowledge in relation to other knowledge-holders (Reed et al. 2010; Brown and Lambert 2013; Ashwood et al. 2014; García-Nieto et al. 2019). How and through what means such learning occurs in participatory research processes, however, still requires further study.

It is with this in mind that we developed and led a participatory resilience assessment focused on sustainable landscape management in the Helge å river catchment in southern Sweden. Using tools and exercises from resilience practice, including the ecosystem service concept, we strived to generate social learning and to develop usable knowledge to support decision-making. An understanding of complex adaptive systems is fundamental for applying other aspects of resilience thinking. We therefore focus on complexity thinking when analysing learning and impact of our participatory resilience assessment. We describe the design and content of the process, and present results from follow-up interviews with the participants. Our aim is to answer the questions: How did components of the resilience assessment support the participants’ learning process? Which exercises and outputs from the process emerged as useful for articulating complexity thinking for the participants? and How have the assessment outputs been useful for the participants in their professional practices? Finally, we discuss how the process could be further developed to advance both understanding and action in the complex endeavor of sustainable landscape management.

**Materials and methods**

**Context of the research and case study area**

The research in this paper focused on the Helge å river catchment area in southern Sweden (Figure 2). It was funded by the Swedish Environmental Protection Agency as part of an initiative to develop methods to operationalize the ecosystem service concept for a Swedish decision-making context. The case was selected both because of the existing collaborations between members of the research team and the Kristianstad Vattenrikte Biosphere Office, a bridging organization in the study area with a long track-record of adaptive co-management (Olsson et al. 2007), and because of the wide range of land uses that the region offers. Consequently, the participatory resilience assessment was designed with a three-fold goal: First, to generate usable knowledge and tangible outputs, such as strong visuals, about the state of ecosystem service provision in the Helge å catchment.

![Figure 2](image-url)
(per the interest of the funder). Second, to explore methods of collaboration to address sustainability challenges in the study area (the project partner’s motivation). Third, to stimulate a complexity-based resilience perspective among the participants in their everyday landscape management practice (focus of the research team). Thus, all three goals target aspects of method development and learning, rather than explicitly generating change. These goals guided selection of participants and process design.

The Helge å river is 190 kilometers long and its catchment covers 4775 km² (NE 2019), overlapping with 13 municipalities in three counties. The Helge å catchment is a cultural landscape with a long history of human management, however, there has been a gradual change in agricultural practices over the last 150 years. This has shifted the landscape composition from a mosaic of fields, grazed meadows and patches of mixed forest, to become more specialized with mainly intensely managed agricultural fields in the south, a belt of mixed agriculture, animal husbandry and forest patches in the center, and coniferous production forests in the north (Tuvedal and Elmqvist 2011). As a consequence of these land use changes in combination with climate change, the Helge å river is affected by brownification, a process of increased dissolved organic carbon in the water which reduces water quality (Kritzberg et al. 2020). The catchment area is also affected by socioeconomic trends such as urbanization, where the large towns of Hässleholm and Kristianstad are growing (SCB 2018), leading to increased pressure on land around these urban centers. Reversely, small rural municipalities are losing both inhabitants and job opportunities (SCB 2018). This combination of conditions produces a complex landscape where many different interests compete for space and natural resources. The lower part of the catchment area also contains a system of wetlands with high biodiversity values, managed by the Kristianstad Vattenrike UNESCO Biosphere Reserve (Olsson et al. 2007).

The participatory resilience assessment

Participants and scope

The participatory resilience assessment built on a series of five workshops and two rounds of interviews carried out between 2015 and 2019. The focus and initial design of the process was framed by the research team in collaboration with Kristianstad Vattenrike Biosphere Office, while the rest of the process involved a diverse group of local actors. Participants were selected to represent a wide range of sectors with relevance to ecosystem service provision and use in the Helge å catchment. These included civil servants from municipalities, regional and national agencies, representatives from the business sector and civil society organizations (Table 1). The selection was guided by an initial actor scoping done in collaboration with Kristianstad Vattenrike Biosphere Office. During the course of the project, some important knowledge gaps were identified in the group. Two new participants were invited to fill these gaps, affiliated with a hunting association and a county administrative board. Not all participants were able to attend every workshop, and some dropped out during the course of the project due to change of jobs or retirement. Communication was maintained with all participants through interviews and correspondence, however, to ensure that the views of all included actors were considered in the outputs.

| Category                              | Organization                                                                 | Workshops | Interviews, 1st round | Interviews, 2nd round |
|---------------------------------------|------------------------------------------------------------------------------|-----------|-----------------------|-----------------------|
| **Municipalities**                    | Kristianstad, including Kristianstad Biosphere Office (included 4 participants) | 1, 2, 3, 4, 5 | Yes                   | Yes (Participant D)   |
|                                       |                                                                               | 1, 2, 4, 5 | Yes                   | Yes (Participant C)   |
|                                       |                                                                               | 1         | Yes                   | -                     |
|                                       |                                                                               | 4, 5      | Yes                   | Yes (Participant B)   |
|                                       | Osby                                                                          | 1, 2, 4, 5 | Yes                   | Yes (Participant A)   |
|                                       | Östra Göinge                                                                  | 1         | -                     | -                     |
|                                       | Ålmhult                                                                       | 1         | -                     | -                     |
| **Regional and national agencies**    | Skåne Administrative County Board (included 3 participants)                   | 1, 2, 3, 4, 5 | Yes                   | Yes (Participant E)   |
|                                       |                                                                               | 1         | Yes                   | -                     |
|                                       |                                                                               | 3         | Yes                   | -                     |
|                                       | Kronoberg Administrative County Board                                         | 1, 2, 3, 5 | Yes                   | Yes (Participant F)   |
|                                       | The Swedish Forest Agency                                                      | 1         | -                     | -                     |
|                                       | Vattenmyndigheten Södra Östersjön (water agency for the southern Baltic)      | 1         | -                     | -                     |
| **Business sector representatives**   | The Federation of Swedish Farmers                                             | 1, 2      | Yes                   | -                     |
|                                       | Södra Skogsägarna (the largest forest-owner association in Sweden)            | 1, 3      | Yes                   | -                     |
|                                       | Sveaskog (state-owned forestry company)                                       | 1, 4      | Yes                   | -                     |
|                                       | Destination Småland (regional tourism interest organization)                 | 1, 2, 4, 5 | Yes                   | Yes (Participant G)   |
|                                       | The Swedish Society for Nature Conservation                                    | 1, 3, 4, 5 | Yes                   | Yes (Participant H)   |
| **Civil society organizations**       | Sportfiskarna Kronoberg (recreational fishing association)                    | 1         | -                     | -                     |
|                                       | Jägareförbundet (national hunting association)                                | 4         | Yes                   | -                     |

**Table 1.** List of participant affiliations and activities that they participated in.
Process design and components

The participatory resilience assessment was designed to support learning. Therefore, we began by collectively mapping out what the participants already knew and valued about the study area in terms of ecosystem services, to then successively add layers of complexity through introducing new concepts, models and ways of thinking. Each of the five workshops ran over a full day in the visitors’ center of Kristianstad Vattenrike, and were structured around one or two main themes. The workshops started with capacity building such as short lectures on underpinning concepts. Discussions and exercises followed, specifically designed to generate outputs for the consecutive steps in the process or to generate a final product. After every workshop, the outputs of the exercises were processed and updated by the research team based on scientific literature and information from interviews with the participants. The updated outputs, for example new visuals, were brought back to the group in the following workshop as the starting point or discussion material for the next exercise. This made the assessment process iterative, meaning that any output from the process was discussed during at least two consecutive workshops. This approach gave the participants a chance to both repeat what they had learned and to question and change the output. Three researchers were present at each workshop to facilitate exercises. One or two of these were individuals who otherwise were not involved in the research, meaning that they acted as outside facilitators with expertise in resilience thinking.

The process was divided into two phases (see timeline in Table 2). The ecosystem services assessment phase (workshops 1–3) has been described in Malmborg et al. (2021), and its main output was a collectively selected set of 15 provisioning, regulating and cultural ecosystem services (MA 2005) that represent the local landscape as well as an analysis of how the supply of these services interact to form three distinct ecosystem service bundles in the study area (Raudsepp-Hearne et al. 2010; Queiroz et al. 2015; Malmborg et al. 2021). The main outputs from the strategic planning phase (workshops 3–5) were: (1) collectively built conceptual system models describing system dynamics that underlie the distribution of ecosystem service bundles; (2) a shared future vision for the landscape; and (3) a strategic action plan to reach this vision (Enfors-Kautsky et al. 2018). This plan focused on three key challenges by addressing leverage points for change (Meadows 1997; Abson et al. 2017), identified through the conceptual system models. Figure 3 shows a schematic of the process components and how they fed into each other. For a more detailed description of process design, see Appendix 1. The resulting outputs are described in Appendix 2.

Follow-up interviews

Two rounds of semi-structured interviews with the participants complemented the information collected during the workshops. Each interview lasted for one hour on average (interview guides in Appendix 3 and 4). The first round was held after the second workshop with every participant except three (who had retired or changed jobs), while the second round only included those who had taken part in the final workshop (see list of respondents in Table 1). The first round of interviews was mainly used to triangulate results of the ecosystem service assessment (Malmborg et al. 2021) and to complement workshop outputs on system dynamics and key challenges.

The second round of interviews contributed to the main findings of this paper. They focused on individual reflections on the assessment process and potential impacts that exercises and outputs had had on participants’ current or potential future professional practices. These interviews were transcribed and coded for emergent themes using evaluation coding (Saldaña 2012) in three steps. First, we coded for statements that suggested a specific exercise, concept or output had supported the participants in their learning process. Second, we coded for statements that captured an articulation of complexity thinking in relation to a specific exercise or output. To structure our analysis of complexity thinking, we based our codes on six features of complex adaptive systems, or organizing principles, as defined by Preiser et al. (2018). They pose that complex adaptive systems are constituted relationally (relational), have adaptive capacities (adaptive), are radically open (open), contextually determined (contextual), their behavior is generated by dynamic processes (dynamic), and novel qualities that cannot be understood solely based on their individual parts can emerge (emergent) (Preiser et al. 2018). These are further described in Table 3.

Third, we identified statements suggesting the specific usefulness of individual outputs. These statements were coded to enable scoring of each output along an impact gradient following the four levels of impact developed by Wall et al. (2017). ‘Problem understanding’ suggests that producing the output had helped the participants gain a better comprehension of particular problems, while ‘Instrumental’ indicates that they gained new skills, for example how to conduct specific exercises that they believe will be useful beyond the concluded project. With ‘Personal’, the
individual participants expressed a usefulness of a specific output in their professional decision-making, while 'Explicit use' means that the output has been or is about to become explicitly used in the organization’s communication, planning or management (Wall et al. 2017). We chose to also include the participatory ecosystem services assessment as a whole and the preparatory exercises about the leverage points concept as separate components, as these emerged as useful in their own right. The number of participants expressing a specific level of impact for each of the outputs was counted and summarized in a graph. In the graph, we also include which of the features of complex adaptive systems (Preiser et al. 2018) that the participants connected to each output.

Although the main findings in this paper are based on the second round of interviews with participants, statements about exercises and process design are, when relevant, interpreted and contextualized through workshop reports. These reports are based on participant observation conducted during the workshops by the research team. Field notes were taken throughout the day by the researchers, after which the notes were discussed and synthesized into brief reports about proceedings, discussions and other reflections. These reports were only for internal use in the research team, and mainly contributed to contextualize statements of when and how different components contributed to the participants’ (social) learning.

The research in this paper was approved by the Stockholm Resilience Centre research ethics subcommittee as part of the first author’s PhD project. All participants were asked for written informed consent before being interviewed.

### Results and findings

#### Process design, tools and forms of participation that supported learning

Three themes emerged as important for the participants’ learning process. These themes, described below, focused on process design and facilitation during the workshops, the value of concepts as tools for practice, and how certain exercises supported social learning (see additional quotes in Appendix 5).

#### Process design and facilitation

The participants appreciated the general setup of the workshops, with research-based introductions, step-wise exercises and concluding discussions. Repetitions and iterations were appreciated, as they allowed the participants to become familiar with the new and sometimes complicated concepts and
models: ‘In the beginning it felt like “oh, this was new” every time. It probably took three times before I felt like this I’ve heard before. / … / From [the feeling] that this maybe felt a bit difficult to look at, these diagrams [the ecosystem service bundles], they now feel completely familiar’ (Participant D). The exercises encouraged everyone to be active, which also was supported by members of the research team being present to facilitate each group. The visualizations of results also created a feeling of progression in the process: ‘We [can] see that we’ve come up with something [during the previous workshop] when you show pretty diagrams, that you’ve developed [our material]’ (Participant H). The spread of the five workshops over three years, a relatively long time period, had positive and negative implications. Considerable time had to be spent on repeating results from previous workshops in the beginning of each day, and some participants quit the project due to changing jobs or retirement. However, the long duration of the project also supported the learning process. The workshops offered a chance for reflection and the time between workshops allowed for new knowledge to sink in.

The value of concepts as tools for practice
All participants described how producing the ecosystem service bundles had been enlightening. The process had supported their learning about the concept, indicators and data availability, but also indirectly how ecosystem services interact in the landscape. Mainly, the participants saw the ecosystem service concept as a communication tool. The interviews also suggested that the bundles analysis functioned as an anchor for consecutive steps of the process, as the participants stressed the value of iteratively returning to the bundles during the exercises that focused on conceptual system model building, future visioning and strategy development.

Additionally, the concept of leverage points made a lasting impact for several of the participants. One participant said: “For a project [to] find what it is that is the most important point [to leverage in order] to get started / … / that you do a bit of an analysis before and not just go ahead and do what you always have done” (Participant B). As this quote suggests, the leverage points concept seems to have acted as a heuristic tool, becoming the idea onto which the participants’ attached their learning about system dynamics and complexity thinking (see further elaboration in the section about complexity thinking).

Exercises supporting social learning
The participants agreed that good dialogue is essential to solve complex problems. Three exercises stood
Table 3. List of the six features (organizing principles) of complex adaptive systems, adopted from Preiser et al. (2018), including examples of aspects expressed in interviews that in the analysis were coded as articulations of each feature.

| Feature (as named in Preiser et al. 2018) | Code used in this paper | Examples of how understanding for feature was indicated in interviews (following formal definitions from Preiser et al. 2018) |
|------------------------------------------|-------------------------|--------------------------------------------------------------------------------------------------------------------------------|
| Constituted relationally                 | Relational              | Focus on relations between system elements  
|                                          |                         | Highlighting interactions between system elements  
|                                          |                         | Importance of diversity and redundancy among system elements |
| Adaptive capacities                      | Adaptive                | Awareness of the self-organizing and evolving character of the system  
|                                          |                         | Highlighting the capacity to anticipate and navigate strategically within the system structure |
| Dynamic processes                        | Dynamic                 | Awareness of fast and slow variables in the system  
|                                          |                         | Awareness of non-linear interactions between system elements  
|                                          |                         | Highlighting the importance of accounting for feedback loops in the system  
|                                          |                         | Multiple future trajectories are possible |
| Radically open                           | Open                    | System boundaries are porous, with exchange of matter and information between systems  
|                                          |                         | The system is embedded in other systems, with cross-scale interactions influencing its processes and functions |
| Contextually determined                  | Contextual              | Context matters, as the function of system elements change as the system changes |
| Novel qualities emerge through complex causality | Emergent              | Expressions of this feature was not found in the interviews. |

out as catalysts of knowledge exchange and constructive dialogue: the ecosystem service assessment, the conceptual system model building and the future vision. The ecosystem service assessment created a shared understanding of the past and current situation in the landscape. The bundles functioned as a tool to bring different participants together in dialogue, as the representation of multiple ecosystem services in the same figure meant that participants with different expertise and interests in the landscape entered into the exercise on equal grounds.

Building on that shared understanding, the process of collaboratively building the conceptual system model offered a platform for a more in-depth sharing of knowledge between the participants. In general, they remembered that the exercises connected to the system model building led to interesting and lively discussions. Most felt that what was visualized in the system models were conditions that they already knew, at least partially. However, ‘It can be beneficial to put it down on paper, so that you can see it’ (Participant A). Finally, the future vision exercises were valuable because they sparked discussions about the world at large and how different values translate into diverse understandings of what a desirable future would be.

### Exercises and outputs to articulate complexity thinking

Based on statements in the interviews, we found that several of the concepts, exercises and outputs from the process supported the participants in articulating complexity thinking. All key features of complex adaptive systems (Preiser et al. 2018) were identified in interview statements, except for the emergent feature. We also found that expressions of a specific feature generally were more common in connection to certain exercises or outputs, suggesting that individual process components supported different aspects of complexity thinking. Our analysis focused on how process components supported the participants in articulating aspects of complexity thinking, not the extent to which the same components had actually taught a participant about complexity. To varying degrees, most participants already seem to have had an understanding for complexity prior to joining our project. What all interviewed participants expressed, however, was that participating in the series of workshops had supported their capacity to articulate different aspects of complexity, through concepts, exercises and specific knowledge outputs. Below, we report on which components that were connected to each of the five identified features of complex adaptive systems (for additional quotes, see Appendix 6).

### Relational

Complex adaptive systems are constituted relationally (Preiser et al. 2018). This feature was mainly expressed in relation to the ecosystem service concept, bundles, and conceptual system model. Some participants expressed how the ecosystem service concept, and the bundles in particular, had made it clear for them how social-ecological processes in the landscape are connected: ‘I see it in a completely different way [now] / … / that we shouldn’t fence off [pieces of land] / … / [or] this interaction with nature / … / [Before I thought] that this area can be [used for construction], and others can be saved more spatially / … / Now I have a deeper understanding for / … / that even if we still want to develop, we can do things in this development that also benefits [the ecosystem services]’ (Participant G). This points at the insight that
the highly connected elements in the landscape makes narrowly focused management undesirable. Other participants, already well aware of this connectedness due to their areas of expertise, still appreciated the bundle as a visual output. It had supported them when communicating the importance of acknowledging system interactions in the landscape.

The conceptual system model building became an elaboration of the shared understanding gained from the ecosystem service bundles. Some participants felt that building the models was complicated, and that it required time to process. However, once it sunk in, the model was a way to articulate and visually represent interactions in the system and by having done it: "I think you get a better view of how the whole system works, so to speak. Because otherwise – normally I think about / ... / nature protection, primarily. But then, those who work in the forest or the farmers look at it from a completely different perspective. And here you have kind of molded it together / ... / you get many different aspects of the same thing" (Participant H). Many participants also expressed a frustration over what the model communicated, namely how complex the system is and that, for them, it is difficult to account for all relevant interactions in their professional practice due to how siloed Swedish public administration is.

Adaptive

Complex adaptive systems have adaptive capacities, which means that they are self-organizing and that actors or groups within them can anticipate and navigate strategically within the system structure (Preiser et al. 2018). This feature was mainly expressed in relation to the strategic action plan, especially in reflections about the leverage points concept. Listing actions together with potential allies, scales of influence and opportunity context became a way to articulate the space in which they, as agents in the system, could navigate. Few suggested actions were considered novel. However, several participants confirmed that it is important to identify key actors and organizations when planning actions. Therefore, it was beneficial to discuss strategies in this structured manner. Some participants reported that they now use this way of thinking: ‘It’s the tactics with looking for leverage points and finding / ... / the right allies – key individuals you could also call them – I think quite a lot about that before I begin now, to get sort of a self-playing piano / ... / [to] get the ball rolling / ... / so that I have the strategy ready before I begin’ (Participant B).

Dynamic

Dynamic processes in complex adaptive systems are created by non-linear interactions between fast and slow variables as well as balancing and reinforcing feedbacks. This means that multiple future trajectories are possible for the system (Preiser et al. 2018). This feature was discussed in relation to the future vision and connected exercises about barriers, opportunities and positive seeds. These visioning exercises helped to identify conditions that need to be considered in planning. The future vision as such, the mosaic landscape, was not perceived as revolutionary, but: "It is very valuable to reason around, and kind of weigh what it is one actually thinks – is it utopian, or is it realistic" (Participant C). Thinking about the future also touched upon important questions about values: ‘You can think about the meaning of protecting valuable wet meadows if you also know that in 20 or 50 years they’ll all be under water. You get into almost existential questions with what you do and the benefits of it’ (Participant E). The same participant also concluded: ‘It’s about how you move on and handle / ... / these uncertainties that exist about the future / ... / [The vision] is maybe just the first step that then needs further thinking and acting’ (Participant E). Several of the participants stressed that, for a visioning exercise such as this to instigate systemic changes, the results would need to be communicated outside the group and the exercise redone regularly within a team, as conditions change.

Open

Complex adaptive systems are radically open, meaning that system boundaries are porous, with exchange of matter and information between systems. They are also embedded in other systems, with cross-scale interactions influencing the system’s processes and functions (Preiser et al. 2018). Expressions of this feature was spread across the visioning exercises, conceptual system model building and strategy development. For example, relating to the future vision, Participant G said: ‘And the exercises about external drivers, trends, surrounding conditions are useful. It becomes a kind of an analysis about the world around us, and that is always important to do’. It was also a feature where awareness among the participants seemed to be relatively high, but many also expressed a frustration for how difficult it is to account for in practice, considering how siloed public administration is in Sweden.

Contextual

In complex adaptive systems, context matters, as the function of system elements change when the system changes (Preiser et al. 2018). This feature was mainly expressed in relation to the ecosystem service bundles. Specifically, that the bundle was a strong visual tool and had been used by several of the participants when communicating with other actors within and outside their own organizations. The figure helped them to articulate and argue for the importance of
context, both in the way the bundle represented the landscape and because the visualization had been produced based on empirical data from the study area itself. 'The interesting thing when looking at [the bundles] is really that you can see the difference when you move across the municipalities / ... / because as soon as you move a little, you get a different baseline / ... / Looking at it like this [with the bundles], then you can see that a decision would really fall out differently depending on just this small [study area]' (Participant G).

Opportunities and impacts of process outputs

The impact levels (Wall et al. 2017) of each process component are summarized in Figure 4 (see example quotes suggesting specific impact levels for each output in Appendix 7). We also include which of the features of complex adaptive systems (Preiser et al. 2018) that the participants connected to each output.

As Figure 4 shows, the output with the highest level of impact was the ecosystem service bundles. Participants working in municipalities reported that they had already used the bundles in different ways. In two municipalities, they were explicitly using them as inspirational material when developing strategic planning documents (a green plan and a rural strategy). A participant working with environmental education also reported that their organization had developed a new educational tool for children, the 'ecosystem service flower', inspired by the bundles model, suggesting instrumental use.

Another process component that resonated strongly with some participants was the leverage points concept. As suggested by quotes in previous sections, learning this concept and participating in connected exercises had changed the way some of the participants think when, for example, planning projects. This corresponds with the personal level of impact. The future vision, conceptual system model and strategic action plan were enlightening for most participants, and several suggested that redoing the same exercises within their own teams or organizations would be both feasible and beneficial, suggesting instrumental use.

As for the process as a whole, a perceived strength was its potential to break down institutional silos: "In a project like this, to get to sit and look from all these different angles, and still find some kind of consensus in it. / ... / And [that you] can take each other’s parts into consideration" (Participant G). Several participants said that bridging organizations and initiatives are important for landscape management, but that the current structuring of Swedish public administration makes it challenging to make such organizations function properly. In general, the exercises fostered a way of thinking that has helped several of the participants in their negotiations with other actors: 'In my way of acting towards politicians and others in this municipality / ... / I have had more to put my fingers on, like “it is really important with water, we can see that here” [in the ecosystem service bundles] / ... / I knew that already, but others [at the municipality] didn’t,
and [these workshops and the exercises] have helped me in my role of explaining to them what it is all about' (Participant A).

**Discussion**

Through our five workshops with actors in the Helge å catchment, we have trialed a series of exercises meant to encourage complexity thinking, a fundamental ability for applying resilience thinking in practice. Together with a diverse group of participants, we have co-produced four concrete knowledge outputs and discussed two concepts (ecosystem services and leverage points) meant to support sustainable landscape management. Our analysis indicates that this process supported learning, but also that the outputs and concepts have been useful for the participants in their professional practices, from providing a deeper understanding to explicitly being used in strategic planning. Below, we discuss our findings in relation to learning and fostering complexity thinking, and through that, supporting resilience thinking in landscape management.

**Collaborative learning and co-production of knowledge**

Planning a participatory process requires careful selection of participants and a relevant framing of the project (Norström et al. 2020). Our collaboration with the Kristianstad Vattenrike Biosphere Office, a well-connected and respected boundary organization in the region (Hahn et al. 2006), was an asset in this regard. Our collaboration with this local organization likely increased the legitimacy of the project in the eyes of the other actors, a finding which is in line also with other participatory research (Boeraeve et al. 2018). A recent decision from the Swedish government to integrate the value of ecosystem services in decision-making (Ds 2012:23 2012) also meant that we entered into a favorable political context in which various actors were motivated to participate (Clark et al. 2016).

Motivated participants, however, also need to be given conditions for learning. This includes sharing of time, expertise and the creation of ‘safe spaces’, which over time builds trust (Gupta and Kelly 2014; Campbell et al. 2016). Knowledge co-production benefits from transdisciplinary team-building through interactions over time (Lemos and Morehouse 2005; Angelstam et al. 2013). In our project, trust-building and a constructive learning environment was supported by facilitated discussions in small groups (Boeraeve et al. 2018) and that the same group of participants were brought together repeatedly during the four years that the process lasted. The iterations were also important for the participants’ individual learning, as it allowed them to repeat what they had learned during previous workshops. Finally, being able to situate their own expertise and connect it to the bodies of knowledge of the other participating actors is an important ability in knowledge co-production (Ashwood et al. 2014). In our process, we believe this ability was facilitated through the ecosystem service bundles and conceptual system model building. In these exercises, and in the process at large, the participants were considered knowledge-holders with valuable expertise to contribute to the shared, synthesized knowledge outputs (Tengö et al. 2017). In hindsight, however, we believe that the process and its outputs could have been stronger, had we invited relevant scientific experts. For example, our outputs regarding the key challenge brownification might have become more useful, had we invited a researcher with this expertise.

The participants were selected based on their interest and expertise in landscape management. What emerged during the process was that these participants in general had a shared vision (the mosaic landscape), but diverse expertise and main interests, which led to interesting discussions but little disagreement. This kind of constructive dialogue was beneficial for our purposes, that is, to generate learning and exploring new tools. However, as was pointed out by several of the participants, for real change towards their vision to be achieved, additional key actors would have needed to be engaged. This speaks to two of the resilience principles: encouraging learning and broadening participation (Biggs et al. 2012). Our results show that we were able to create a constructive learning environment, where the participating local actors acquired new knowledge and skills, not only from the research team but also from each other. This represents a form of social learning, in which changes of understanding occur through social interactions between actors in specific communities or social networks (Reed et al. 2010). The participatory aspect of our process also constitutes a form of broadened participation, in that a diverse group of actors with various interests and expertise were brought together to co-produce the knowledge outputs (Norström et al. 2020). However, it was done in a very specific context (a research project) with a specific group of actors (selected based on expertise, not influence). A research project cannot generate social learning that persists over time, without the targeted organizations or contexts having or creating routines that encourage continuous social learning (Johannessen and Hahn 2013; Mitchell 2013). To achieve such social learning, further institutionalization of resilience thinking within the participating organizations would be required (Sellberg et al. 2021).

Similarly, broadening participation is not only about the legitimacy and saliency of the knowledge
that actions are based on, but also encompasses participation in decision-making (Reed et al. 2018). Such participation was beyond the scope of our process, considering our focus on learning as well as practical limitations in time and resources. Including actors with influence over important decision-making processes, such as national policy-makers, would likely create a different dynamic in the group, as such actors often cover larger geographic areas within their governance mandate and therefore might have different priorities. Engaging such actors would also require longer-term and more committed engagement in the co-production process, both from researchers and participants (Wallin et al. 2016). However, our results can be used as a guide for how to create a constructive learning environment that includes a broad range of actors also in processes that target decision-making. To promote legitimacy and lasting impact for this step, however, we believe it should be led by an organization with the mandate to implement suggested changes.

Finally, another group of actors, important for broadened participation, are local citizens. For this group, a process set-up such as ours might support their learning. However, feasibly achieving sufficient representation for the diverse set of interests encompassed by local citizens would be challenging while still maintaining the small number of participants that our process was designed to include. To meaningfully achieve participation for this actor group, it might be better to elicit their views through methods that allow for larger sample sizes, such as public participation GIS (Samuelsson et al. 2018) or deliberative democracy through a deliberative mini-public (Grönlund et al. 2014).

**Contributions of the ecosystem service concept to resilience practice**

The ecosystem service concept emerged to have multiple functions in our participatory resilience assessment. In the design of the workshops, the concept proved pedagogically valuable through focusing the exercises, giving the participants a shared vocabulary and defining what was meant by multifunctionality in the landscape (Abson et al. 2014). By always returning to the ecosystem services from the initial assessment, we could add layers of complexity through the system model building and strategy development, without losing sight of what the participants recognized and valued in their landscape. As previously discussed in Malmborg et al. (2021), the ecosystem service bundles in particular also emerged as a bridging concept (Baggio et al. 2015).

Our analysis indicates that a majority of the participants used the bundles to articulate both the relational and contextual features of complex adaptive systems (Preiser et al. 2018). This confirms that concepts and specific language can contribute to sustainable landscape management (Carmen et al. 2018). In our case, the participants perceived that the bundles supported communication about social-ecological interactions to important actors in their organizations. The concept also appeared to have facilitated a structured way to simplify the complexity of a social-ecological system through terminology and an analytical framework (Preiser et al. 2018), enabling comparatively simple quantitative analyses. The resulting diagrams functioned as stronger arguments in negotiations with other actors, precisely because they were based on empirical data from the study area (McKenzie et al. 2014). The perceived effectiveness of the ecosystem service concept was most likely supported by the wide push for it in recent Swedish policy (Beery et al. 2016; Schubert et al. 2018). With their nuanced understanding of the concept combined with strong visuals, the participants have successfully been able to communicate their message within their organizations to other actors who likely knew of the concept but lacked a deeper understanding of it or of how to use it. The ecosystem service assessment was also the first suite of exercises in the process, giving the participants more time to familiarize themselves with the logic of the bundles. Combined, these aspects explain why the ecosystem service bundles scored most broadly across impact categories, compared to other outputs.

**Fostering complexity thinking in landscape management through concepts and tools**

To change behaviors and outcomes, new knowledge needs to be explicitly acknowledged through concrete models or language, and incorporated into already existing organizational structures (Schoon et al. 2015; Clark et al. 2016). Our analysis shows that the exercises in our participatory resilience assessment had a complementary function in supporting the participants to articulate complexity thinking. As already discussed, the ecosystem service bundles helped articulate both the relational and contextual features. The conceptual system model building further strengthened an understanding for the relational feature, while the visioning exercises opened up for acknowledging their inherent uncertainty, dynamics and radical openness. Finally, the strategy development helped in highlighting the adaptive capacity of the system, and through that provided a structured way in which the participants could explore different actors’ situated agency (Järnberg et al. 2018).

In particular, the leverage points concept seemed to become the term around which several of the participants attached a more general articulation of
their agency within the system (Westley et al. 2013; Abson et al. 2017), including an understanding for managing system feedbacks and cross-scale interactions. As a concept, it put words to an intuitive understanding that several of the participants already had. By explicitly articulating it, they claimed to have become more strategic about considering the system as a whole and where potential high-leverage entry-points could be, rather than acting according to old routines or what seemed easiest. This shows that the leverage points concept both allowed the participants to acknowledge the complex behavior of the social-ecological system in question, and to strategically navigate within this complexity (Elmqvist et al. 2019). If acted upon, this is a strategic skill that could be used, for example, to connect to informal networks of actors with shared interests. This, in turn, can become valuable in situations of rapid change, as the activation of such networks have been shown to facilitate transitions toward more sustainable management following a shock or crisis (Gunderson et al. 2017). It should be acknowledged, however, that the preceding outputs were the foundation that the leverage points and strategy development exercises built on. Therefore, the leverage points concept does not stand on its own, but synthesizes many of the aspects of complexity thinking that the participants developed throughout the course of our process.

The reported value of these tools and insights (including the ecosystem service concept) point at additional aspects of resilience thinking, namely the importance of managing connectivity, slow variables and feedbacks, and maintaining diversity (Biggs et al. 2012). However, understanding the importance of these features does not automatically mean that action will be taken to address them. Connected to this challenge is the somewhat counterintuitive finding that the more action-oriented outputs, the future vision and the strategic action plan, received lower impact scores than the ecosystem service bundles. A partial explanation for this finding might be the type of participants that were included. Their practices mostly focus on the day-to-day management of the landscape (with an emphasis on ecology), and how to generate incremental improvements within existing governance structures. The ecosystem service concept has already been shown to be useful in such settings (Wilkinson et al. 2013; McKenzie et al. 2014; Hansen et al. 2015). It is beyond most of the participants’ mandates, however, to influence the governance structures themselves – a frustration that several of the participants expressed in the interviews when, for example, reporting that cross-sect oral collaborations are hard to achieve due to administrative and budgetary restrictions. Had we included other types of participants, such as policy-makers with an influence over those governance structures, or actors who are not similarly restricted by formal governance, such as entrepreneurs and activists with pronounced interest in sustainability transformations, they might have found more direct use in articulating a future vision and strategy development. Participatory processes based on similar components of visioning and pathway development, but with an explicit focus on sustainability transformation, have successfully been trialed with such actors, for example using the Seeds of Good Anthropocenes scenario methodology for food system transformations in the Stockholm city-region (Sellberg et al. 2020).

The absence of any statements articulating an understanding for the emergent feature of complex adaptive systems is a shortcoming of our process. Arguably, this is also the feature that is most difficult to capture, and research focusing on emergence in complex adaptive systems is more recent than research on the other features (Preiser et al. 2018; Sellberg et al. 2021). To better capture emergence in future work, resilience practice could be paired with methods from fields that have started exploring this aspect of complexity, such as agent-based modelling (Schlüter and Pahl-Wostl 2007), analysing pathway diversity (Lade et al. 2020) and sustainability transformations in social-ecological research (Westley et al. 2013; Olsson et al. 2014; Lam et al. 2020).

Concluding remarks: Insights for sustainable landscape management

In this paper, we have described a participatory resilience assessment focused on sustainable landscape management. The participants were able to agree on a shared vision that incorporated their different interests, and to contribute their diverse expertise to the process and its outputs. Interviews indicate that the process and outputs supported the participants’ learning about complexity. It built their capacity to communicate and to target leverage points more strategically in order to address complexity in landscape management. The ecosystem service concept emerged to have multiple functions: a pedagogical tool, a bridging concept, and a means to communicate system interactions in the landscape. Furthermore, our results also show that the succession of exercises in the process were complementary in supporting an articulation of different aspects of complexity. This suggests that the ecosystem service concept, when combined with other tools from resilience practice, can make a valuable contribution to efforts to stimulate resilience thinking in landscape management. We believe that participatory resilience assessments, such as ours, can provide valuable sources of knowledge about the landscape. They can act as an
initial stage for strategic planning, mainly through generating learning, participation in knowledge co-production and through tools for articulating an understanding for complex adaptive systems. However, to generate more lasting impacts, especially in aspects of resilience thinking that address governance structures and decision-making, additional influential actors and social change-makers would need to be engaged in consecutive stages of the planning process.

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