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Article

Understanding Complexity in Freshwater Management: Practitioners' Perspectives in The Netherlands

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Abstract: Ecosystems have been stabilized by human interventions to optimize delivery of certain ecosystem services, while at the same time awareness has grown that these systems are inherently dynamic rather than steady state. Applied research fields have emerged that try to increase adaptive capacity in these ecosystems, using concepts deriving from the theory of complex adaptive systems. How are these concepts of complexity interpreted and applied by practitioners? This study applies a mixed-methods approach to analyze the case of freshwater management in The Netherlands, where a management paradigm promoting nature-fixating interventions is recently being replaced with a new paradigm of nature-based solutions. We find that practitioners have widely varying interpretations of concepts and of how the ecosystems they work in have evolved over time when described with complex system attributes. This study allows for the emergence of key complexity-related considerations among practitioners that are not often discussed in literature: (i) the need for physical and institutional space for self-organization of nature; (ii) the importance of dependency and demand management; and (iii) trade-offs between robustness and flexibility. This study, furthermore, stresses the importance of using practitioners' views to guide applied research and practice in this field.

Keywords: ecosystem management; complex adaptive systems; nature-based solutions; engineering; adaptive management

1. Introduction

We live in an anthropogenic era, where humans are interconnected with global and local ecosystem services more than ever. Ecosystems have been engineered to stabilize and optimize the delivery of those services they provide that are most directly important to humans and their economic development in the short term, traditionally in a command-and-control fashion [1]. Ever since the seminal 1987 Brundtland report [2] brought environmental sustainability into mainstream thinking, ecosystem management approaches have still most often been based on the assumption of a steady-state or stationary system [3].

Accelerated by the progress in understanding climate change, the exceptionally high rates of global environmental change [4] and the potentially long-term irreversible changes in ecosystems resulting from these [5], current day research has moved from steady-state to resilience thinking. Scholars have transitioned to understanding these systems as social-ecological systems [6], where natural and human influences need to be analyzed jointly, and as examples as of complex adaptive systems [7,8], which are characterized by the analysis of systems as composed of multiple interacting agents which mutate and evolve, and exhibiting emerging behavior that cannot be understood by perfectly understanding the behavior of each component of the system. This has subsequently led to the understanding that changes in ecosystems need to be accommodated rather than solely counteracted [9], while ensuring that critical biophysical thresholds are not crossed [10]. Furthermore, over recent years, the need for nature-based solutions, as opposed to purely artificial interventions in ecosystems, has become broadly accepted [11] and is now becoming a priority for policy makers and investment funds.

There is thus general support emerging in both policymaking and practice for a new two-sided paradigm for management of ecosystems that posits on the one hand that human-dominated ecosystems need to allow for some level of change, through an intrinsic adaptive capacity, and on the other hand need to make use of natural processes instead of engineered solutions, where possible. Applied research fields have developed, attempting to facilitate a transition towards effective implementation of this paradigm. Among these, the fields of adaptive management [12] and adaptive governance [13] focus on increasing the intrinsic adaptive capacity of ecosystems by building in feedback and learning loops. In recent years, the theme of nature-based solutions has emerged [14], which encompasses several applied research fields from engineering and ecological sciences, including ecological engineering [15,16] and ecosystem-based engineering [17]. These applied research fields share a foundation on the theory of complex adaptive systems [18].

While the thinking on ecosystem management has evolved steadily in the past decades, there is little evidence on whether this has allowed human-dominated ecosystems to effectively become more adaptive. Do the various approaches, frameworks and tools developed related to ecosystem management and engineering, and the increased awareness of the fact that ecosystems are in principle dynamic, lead to a higher adaptive capacity at the system level? Are the systems able to better deal with shocks and surprise events, resulting in less damage or quick changes in the structure of the system? Most reviews thus far (e.g., [19,20]) focus on the adoption of the adaptive approach itself, rather than the effect on the adaptive capacity of the system. While there is a rapidly increasing body of literature on ecosystem resilience and ways to measure it (e.g., [21,22]), there have been very few attempts to assess the development of resilience over time.

Water has been a primary target for human domination, with more than half of all accessible surface water being put to use by humanity ([23,24]), and water demand is predicted to increase rapidly over the coming decades [25]. With water also being a principal conduit of climate change impact, through sea level rise and changing rainfall patterns, the water management sphere has especially seen considerable activity on resilience thinking (e.g., [24,26,27]). Water has a direct linkage to human well-being, is typically situated between a high number of different users and sectors and is often subject to multiple spatial and temporal scales of management. Local human interventions in water systems, from flood protection to freshwater supply to changes in water abstraction, have complex interlinkages and causalities. Water management needs to deal with the emerging patterns from interactions between those interventions across scales, making it a good example of a complex adaptive system [28].

Complexity thinking is far from an academic exercise only. People professionally engaged in water management frequently need to use complexity aspects, thereby providing an opportunity for research into the application of complexity thinking in management of human-dominated ecosystems.

This research thus aims to understand the perspective and opinions of actors involved in human dominated ecosystems, with regards to the key features and concepts of complex adaptive systems theory, and the applied research fields building on it. It looks at ways in which actors use common system attributes in their own framing of these theories.

The focus of this paper is on The Netherlands, selected as a case study area because of its leading status in the field of water management, and the influence of the Dutch water management model on the global water management dialogue. The Netherlands ecosystem has gone through a long transition from nature dominated to human dominated which culminated in the 20th century [29], while currently being dominated by a policy context of reintroducing natural variability, albeit partially.

The objective of this research is to analyze how complex adaptive system aspects in ecosystem management, such as water management under changing climatic conditions, are understood by their managers in practice. This case study looks at freshwater management provision in The Netherlands as an example of a complex adaptive system and the efforts made to make this system (more) adaptive to meet unknown and unpredictable water resources changes.

The approach of this study is to use the perspectives of people professionally engaged in ecosystem management as a basis to understand the complex adaptive system aspects of the case study at the system level. This study, therefore, uses a multi-phased approach. In phase 1, it analyses the way in which the actors use concepts (such as adaptive management, ecosystem-based engineering) and attributes (such as resilience, flexibility, robustness, adaptive capacity) linked to complex adaptive systems theory. In phase 2, an analysis of these results leads to emerging patterns and hypotheses held by ecosystem managers. These are further analyzed in phase 3, using existing biophysical and socio-economic data to, where possible given data availability, validate those hypotheses.

While some of the concepts in this study are relatively recent, this study purposefully applies a lens of modern concepts to not only analyze the present and the future, but also the past. While most resilience and climate change studies are forward looking, evaluations of how systems have developed in the past using modern-day theory are scarce. Such historic evaluations can, however, provide a grounding or calibration opportunity for assessments of expected future developments.

2. Materials and Methods

A mixed-methods approach has been applied using the logic of an exploratory sequential mixed-methods design [30]. Mixed-methods research gained traction in the 1980s [31] as a way to combine the qualitative approach of exploring and understanding viewpoints of individuals and groups [32], while letting information emerge from the research, with a quantitative approach that is principally aimed at testing hypotheses through variables that can be measured. Integrating these two methods, through mixed-methods research, is a way to provide a more complete understanding of a problem under study and is, therefore, particularly suitable for studying complex adaptive systems. Exploratory sequential mixed-methods research starts with an investigative, qualitative phase. The analysis of the results of the first phase is then used to guide the second, quantitative phase.

This study begins with a literature review (qualitative) followed by semi-structured interviews with key actors who are part of the complex adaptive system to gain an understanding of their individual perspective (qualitative). From the interviews and exercises carried out during these interviews, patterns are identified and analyzed in the different viewpoints of actors. The emerging viewpoints are then triangulated with independent data where possible (quantitative), which was collected from existing literature and data sources.

The population group of interest to this research comprises actors who are professionally engaged in the governance and management of freshwater in The Netherlands as well as representatives of water users. The study sample participants were identified based on a mapping of relevant actors and institutes, using published reports and participants lists from stakeholder meetings held on the subject. This was followed by a criteria-based sampling strategy, identifying potential candidates based on the type of organization they belong to and their primary area of interest as defined by their mandate in their respective organization (see Table 1). A total of 17 participants were interviewed during March–April 2017, in their respective offices. The interviews were undertaken in Dutch and participants were informed about anonymized use of the data collected, prior to their consent to start the interview. Interviews were audio-recorded and transcribed, after which they were analyzed using qualitative data analysis software (Nvivo) for word frequency analysis and source clustering.

At the start of the semi-structured interview, participants were provided with a graph showing a horizontal timeline axis (from 1900 to 2080) and a vertical index scale (from 0 to 200, with a 100 mark at the year 2017). As an experimental qualitative-quantitative method, the participants were asked to sketch the development of two complex adaptive system attributes, 'robustness' and 'flexibility' of freshwater provision in The Netherlands, over time. Participants had not been informed in advance of this exercise.

The two attributes, robustness and flexibility, were chosen because of their frequent use in most of policy and strategic documents on freshwater provision in The Netherlands as identified in the literature review, as well as in international literature (e.g., [33]). Among others, a reference document for the Delta Programme 2017 [34] states that "solidarity, flexibility and sustainability are the basic values" ([35]) to achieve sustainable and robust water security and freshwater provision. This common use of 'robustness' and 'flexibility' in documents, suggests a certain familiarity with and shared understanding of the attributes, which was considered preferred as compared to using system attributes or terms that are less frequently used and/or with which participants are likely to be less familiar (such as resilience and adaptive capacity). 'Robustness' and 'flexibility' can, furthermore, from a theoretical point of view, be regarded as attributes with considerable distance between them in terms of common interpretation—while the former is more often linked to reliability and continued functioning of a system, even under stress, 'flexibility' is more often linked to capacity to adapt to changes.

During the interview, participants were not provided with any definition or explanation of these attributes, but instead asked to use their own definitions of the two attributes, to obtain their personal perspective and individual framing instead of imposing a particular definition. This qualitative, constructivist method is most fit to establish the meaning of a phenomenon from the view of the participant.

After sketching the historic trend in the two system attributes *robustness* and *flexibility*, using the year 2017 as an index benchmark (2017 = 100), participants were asked to explain the trend they observed. From there, participants were requested to sketch their expectation in terms of future trends for both attributes, while indicating the events or trends they consider as influencing the two attributes. The graphs drawn by participants were later analyzed using Microsoft Excel, combined with analysis of narratives, aiming to determine patterns in the responses, both with and without taking into account the categorization of participants in terms of organization and primary area of interest. The remainder of the semi-structured interview was carried out using an interview guide, with the drawn graphs used as a reference point.

Q methodology is a method originally developed in the 1930s by William Stephenson [36]. Q methodology combines qualitative and quantitative elements to investigate the subjective views held by those people directly involved in a topic [37]. Q studies aim to identify patterns in individuals' responses to statements without imposing a priori meanings, in order to understand the range of viewpoints regarding a particular topic.

Participants are presented with a set of statements and asked to rank these from −4 (don't agree) to +4 (agree) on a pre-defined matrix (Figure 1). In order to be able to understand the viewpoints of participants, it is important that the set of statements reflects the full range of sentiments likely to be held on the topic of interest. For this case study, a set of 34 statements (Figure 2) was developed from a literature review [18], but adjusted to better match the prevailing terminology and language used in the various documents pertaining to the case study. The statements have been selected to cover the most frequently cited issues with adaptive management and engineering linked to water management, as identified in the literature review.

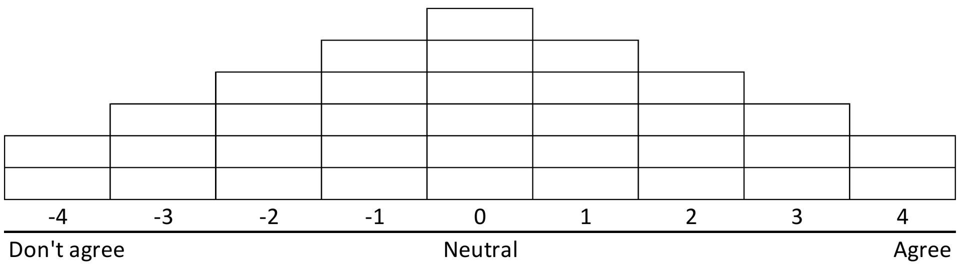

Figure 1. Ranking matrix used for Q methodology.

Q statements used

1. Adaptive management is something we were doing all along
2. Adaptive management increases readiness for surprise events
3. Scenario use is an adequate tool to deal with future uncertainty
4. Many spontaneous initiatives for adaptation are blocked by laws and regulations
5. Authorities do not want to publicly acknowledge lack of certainty on important topics
6. There is enough stakeholder participation to allow for adaptive management
7. Physical structures often have greater and longer-term impacts than what we design them for
8. Organizational structures often have greater and longer-term impacts than what we design them for
9. Current-day physical infrastructure provides the system with more flexibility than in the past
10. The concept of tipping points is useful for real-life application
11. Tipping points need to be anchored in policies and regulations
12. Failure at lower system level may be needed to increase resilience at higher level
13. Policies are systematically reviewed to check if the assumptions made were correct
14. Adaptive management increases risks
15. The costs of adaptive management are preventing its adoption
16. Legacy physical structures significantly decrease the system's adaptive capacity
17. Legacy organizational structures significantly decrease the system's adaptive capacity
18. We've found a good balance between short-term gains and long-term sustainability
19. Current practice effectively prevents lock-ins and lock-outs
20. There is too much focus on studies and plans and too little on reality
21. Our ecosystem is over-engineered
22. Our ecosystem is over-managed
23. Economic interests decrease the system's flexibility
24. Regulations are changing too fast to provide stability for economic development
25. Some adaptation measures are implemented too early, before they are absolutely necessary
26. The use of adaptation pathways increases understanding of future uncertainties
27. We need to better harness nature's self-organizing capacity
28. Increased local decision-making increases risks
29. There is too much "command and control" in our system
30. Devolved or decentralized government decision-making increases adaptive capacity
31. Self-monitoring of devolved government functions increases adaptive capacity
32. Lower-level public entities have sufficient capacity to carry out devolved functions
33. Some physical structures have been put in place mostly for prestige or interest of builders, less for their function
34. Adaptive management encourages experimentation

Figure 2. Q statements used in study.

The Q-sorting exercise was carried out after the semi-structured interview with 14 participants from the larger set of 17 interviewed. The participants were asked to think out loud while sorting the statements to enrich the information obtained from the exercise. The resulting *Q sorts* were analyzed using the PQMethod software as developed by Peter Schmolck, using centroid factor analysis and varimax rotation [38] and a significance level of $p < 0.01$. The results, represented in generalized viewpoints or factor arrays, were interpreted using the qualitative data collected from the interviews.

Table 1. Categorization of participants by organization and by primary area of interest.

Organization	Number	Primary Area of Interest	Number
Water boards and provincial government	5	Water management	9
Scientific	4	Environment and climate	3
Central government	3	Economy, laws and regulation	3
Water user representatives and civil society organizations	3	Agriculture	2
Independent consultant	2		
Total	**17**	**Total**	**17**

3. Results

3.1. Case study Background

The case study area in The Netherlands is a highly human-dominated river delta with a long history of water management interventions and institutions. Historically, water management interventions in The Netherlands were carried out at community or village level, and mostly focused on preventing flooding, reclaiming land, and to create military defence structures. Between 1600 and 1800, local communities created approximately 600 km^2 of polders, and by the end of the 18th century, more than a thousand different organizations were involved in the Dutch public water works [39]. In 1798, a national public works agency was created, Rijkswaterstaat, which would, however, take until 1850 to take a leading role in addressing flooding problems. They embarked on a large project of "river improvement", reshaping hundreds of kilometers of river to efficiently and more rapidly channel water to the sea and reduce flood risks, thereby completely changing the Dutch landscape.

In the 1920s and 1930s, human control over the ecosystem took another significant leap with a considerable investment program on canals, river canalization and the closing of the Zuiderzee in the north, creating a large freshwater lake called Ijsselmeer (see Figure 3). These measures were primarily intended to prevent riverine and coastal flooding. The 1953 flood in the southwestern delta, which claimed 1800 lives, was the impetus for another large infrastructural work program, the Delta Works [40], guided by a special high-level Delta Commission. Implemented between 1958 and 1997, the Delta Works comprised a series of physical interventions aimed at closing off the southwestern delta and reducing the number of dikes needed inland. As the Delta Works were progressing and the global debate on environmental sustainability unfolded, criticism on the negative impacts the interventions increased. The physical barriers blocked fish migration, reduced the extent of tidal zones and imposed a sudden seawater/freshwater interface thereby removing important habitats, and created many other ecological problems. By the time the last major sea arm Oosterschelde was to be closed off and turned into a freshwater lake according to the Deltaplan, it was decided to install a barrier with large sluice gates instead, only to be closed under adverse weather conditions.

Figure 3. Layout of the water management system in The Netherlands, divided into five major areas here: the main rivers (Rhine and Meuse) and associated canals and water control structures (weirs); the Ijsselmeer area, an artificial lake created in the 1930s; the southwest Delta with fully closed, semi-closed and open river arms; the closed coastal zone along the North Sea and the tidal mudflat areas of the Wadden Sea in the north; and the "high grounds" areas with small waterways. [41].

Famed for these efforts to control the water but increasingly experiencing ecological issues as a result of the large-scale interventions, it is argued that The Netherlands has experienced a transition from technocratic water engineering to integral and participatory water management in recent decades [29], in line with the EU Water Framework Directive. This transition is illustrated by directives and large-scale programs to reduce canalization of rivers (the Room for the River programme [42]) and the emergence of policy objectives such as "living with water" and "building with nature" which are now largely becoming part of the paradigm of nature-based solutions. Pahl-Wostl et al. [43], however, state that, despite the changing policy narratives, water managers in one representative area in The Netherlands still have a mindset "very much in line with the traditional command and control approach".

The entry point for this case study is freshwater provision (Dutch: zoetwatervoorziening), a provisioning ecosystem service highly relevant for the society, economy and nature. Though freshwater provision was not the main reason for implementing the large-scale water control structures in the 20th century, it was an important co-benefit next to flood protection and transport connectivity. Following the creation of the Ijsselmeer in the north in the 1930s, the series of freshwater lakes in the Southwestern delta between 1958 and 1997 and various water control structures such dams and sluices, large parts of the country were provided with freshwater that previously only had access to saline or brackish water.

The combination of land reclamation and increased availability of freshwater enabled strong growth in the agricultural sector.

Since the start of century, and in particular following a very dry summer in 2003 and a dry spring in 2005, increased attention is being paid to freshwater shortages. The *Delta commission new style* was instituted in 2007, and in 2011 a new Delta law was approved which aims to protect the country against flooding and ensure freshwater security through yearly *Delta Programme* [44]. In case of freshwater shortage, water allocation is currently guided by a *sequence of priorities* (Figure 4), originally created after the drought of 1976, updated after the drought of 2003 and accompanied by further detailed guidance in 2019 [45]. However, this policy is not considered adequate to deal with the increasing stresses expected in the future, when climate change will reduce the inflow of freshwater through the major rivers and increase water demand, while a rising relative sea level will increase salinization through both surface waters as well as groundwater.

Sequence of priorities in allocation of freshwater (Dutch: *verdringingsreeks*)

- Category 1 (highest priority): safety and the prevention of irreversible damage
  - Stability of flood defence structures
  - Settling and subsidence of peat bogs and moorland
  - Nature, irreversible damage
- Category 2: utilities
  - Drinking water supply (only if critical supply risk exists, otherwise category 4)
  - Power supply (only if critical supply risk exists, otherwise category 4)
- Category 3: small-scale high-quality use
  - Temporary precision irrigation of capital-intensive crops
  - Process water
- Category 4 (lowest priority): other uses
  - Shipping
  - Agriculture
  - Nature, as long as no irreversible damage occurs
  - Industry
  - Water recreation
  - Lake fishing

Figure 4. Sequence of priorities in allocation of freshwater [45].

The Delta (sub)programme on freshwater availability, through the Delta decision, outlines the following strategy to secure freshwater availability [46]: (i) a coherent approach based on improvements to the water supply system, while stimulating self-sufficiency of water users, (ii) an adaptive approach, using regional adaptive pathways, (iii) regional agreements between public agencies and water users on roles and responsibilities, (iv) increasing freshwater buffer capacity, and (v) reducing water demand and vulnerability through more efficient water use. In this regard, the Delta decision also responds to an OECD study [47] on water management in The Netherlands which found that economic incentives to efficiently manage water are sometimes weak, and advocates for a more robust water allocation regime as well as a more transparent cost allocation across water users.

As part of the Delta Programme and research programs on climate change adaptation, a large number of studies have been and are currently carried out to understand future freshwater demand and potential bottlenecks at national level (e.g., [48,49]) as well as regional level (e.g., [50]), under the Delta scenarios which combine climate scenarios [51] with socio-economic scenarios [52]. Furthermore, separate guidance has been developed on adaptive management in the context of water management in the Delta Programme [53].

An analysis of available quantitative data from secondary sources (Figure 5a–e) shows a complex picture in terms of freshwater availability, demand and dependency. Firstly, an analysis in terms of quantity and quality (Figure 5a) shows that though water transport has the highest water demand (driven by minimum river water levels to allow navigation) it puts no requirements on quality, whereas agriculture has the highest combined demand of quantity and quality. Similarly, in terms of the water supplied to regional networks (Figure 5b), the majority of water is needed to maintain water levels, with less than half of the water used to flush out salt water or for irrigation.

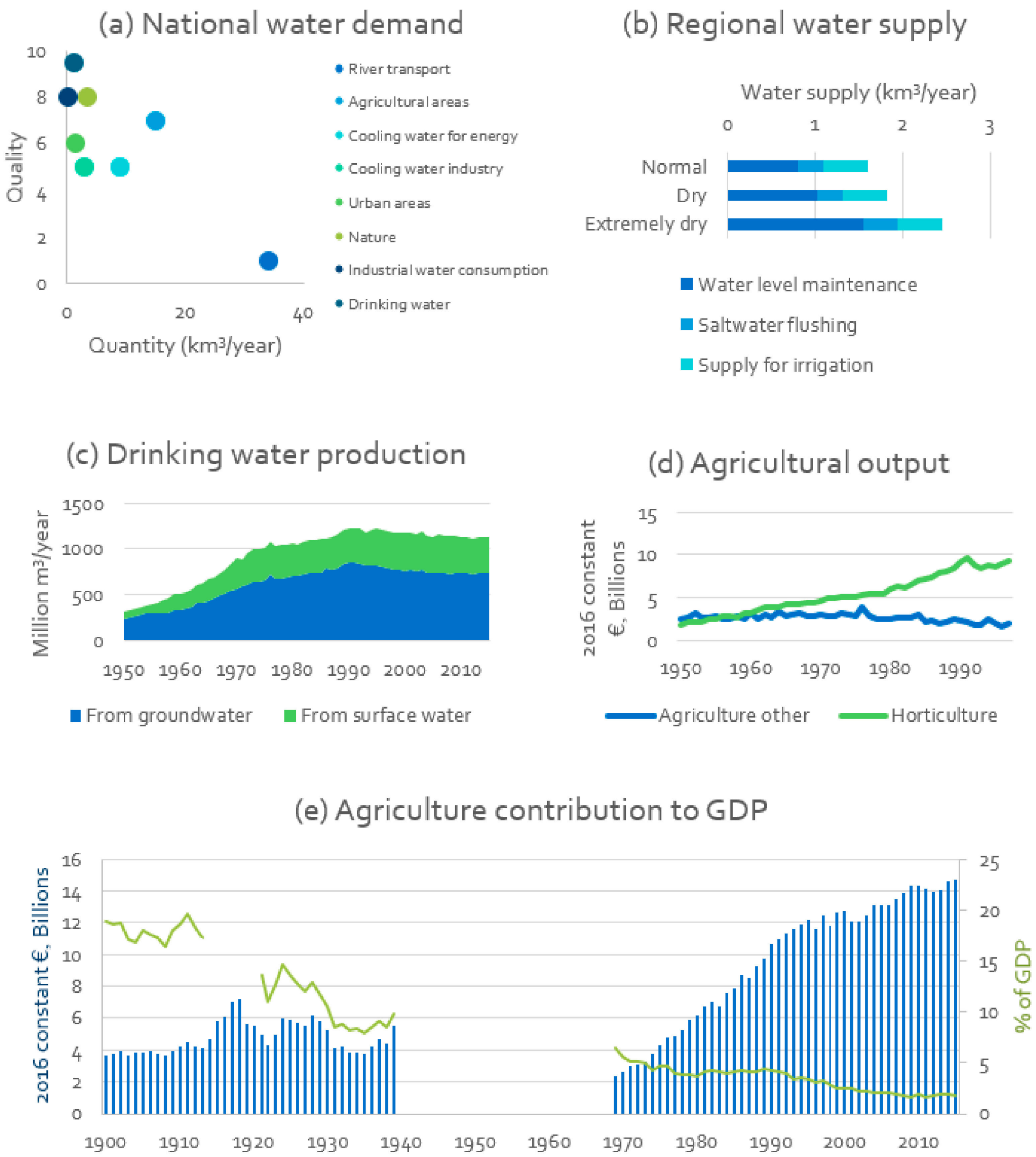

Figure 5. (**a**) National water demand by usage, with water quality (*Y*-axis) as a relative aggregate score (10 = highest) [49]; (**b**) Supply to regional water networks by purpose; (**c**) Trend in drinking water demand, [54]; (**d**) Horticultural and other agricultural (without horticulture and livestock) output [55]; (**e**) Agricultural Value Added in 2016 constant Euro (bars, left scale) and as percentage of Gross Domestic Product (GDP) (line; right scale). Agriculture includes fisheries. Data sources: 1900–1940 [55]; 1968–2016 World Bank and OECD [56]; conversion historic value in Guilder to 2016 Euro using [57].

Drinking water production (Figure 5c) has stabilized over recent decades and is not expected to grow further; yet, some of the intake points are in zones prone to salinity intrusion during very dry years. In terms of agricultural output (Figure 5d), the importance of horticultural crops, which are more sensitive to water quality, has increased significantly. The overall added value of agriculture (including fisheries) to the Gross Domestic Product (GDP) has increased (Figure 5e), but the significance for the national economy has declined from 12% of GDP in 1900 to 2% in 2016.

3.2. Mapping Practitioners' Perceptions of Robustness and Flexibility in Water Management

Figure 6 shows the results of the participants' perception of trends of robustness over time. Owing to the qualitative design of the mapping exercise, the interpretation of variables was rather diverse. In this way, the interpretation of the two system attributes as chosen by participants, and the development thereof, can be grouped as following:

1. **"Robustness is a function of water supply".** Participants who used this interpretation focused on the large infrastructural works as major increases in robustness.
2. **"Robustness is a function of water supply and demand".** Participants who used this interpretation argued that though large infrastructural works increased robustness in steps, each of these increases were followed by an increase in demand, thereby gradually reducing robustness over time.
3. **"Robustness is a function of water supply, demand, and economic and social dependency".** Participants who used this interpretation also included the social and economic dependency on freshwater into the definition. Robustness in this sense was seen as an inverse of vulnerability.

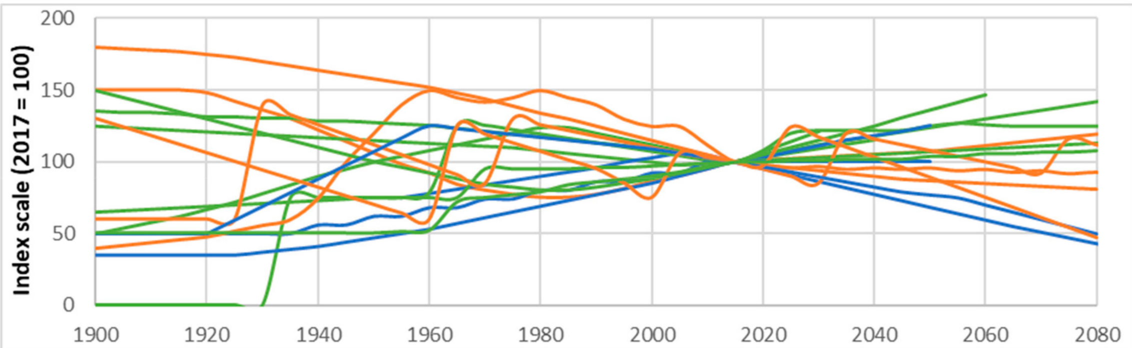

Figure 6. Trends of robustness over time, as perceived by participants, with *y*-axis as an index scale, 2017 = 100. Blue = robustness is a function of water supply, orange = robustness is a function of water supply a demand, green = robustness is a function of water supply, demand and economic and social dependency. Some lines do not cover the entire timeframe.

When looking at historic trends, the grouping of participants by definition of robustness seems to have limited significance. Instead, three general trends can be observed: (a) general negative trend; (b) general positive trend; and (c) a trend of sudden increases followed by gradual reduction.

Looking forward, the uniformly positive future development of robustness given by participants using a "supply, demand and dependency" interpretation of robustness (green lines) stands out. The analysis of narratives provided by these participants suggests that the positive development in robustness will come from reduced economic and social dependency on freshwater provided through the central water systems, rather than improvements in the supply of (quantity of) freshwater. This is a trend many participants already observed among water users with adequate resources to reduce their dependency on the water management system, notably horticulturalists investing in private water storage and treatment facilities. An increase in robustness would thus need to come from a further widespread adoption of such individual or group-based adaptive measures.

For flexibility (Figure 7), the narratives can be grouped as follows:

1. **"Flexibility is keeping options for the future open**". Participants who used this narrative interpreted flexibility as a forward-looking attribute linked to the availability of choices to deal with future changes, or the ability to adapt to future circumstances.
2. **"Flexibility is the ability to deal with extreme situations**". Participants who used this narrative focused on the current-day capacity of the system to continue functioning under extreme situations.
3. **"Flexibility is the ability to control or steer the system".** Participants who used this narrative looked at flexibility as mostly the human ability to control the system.

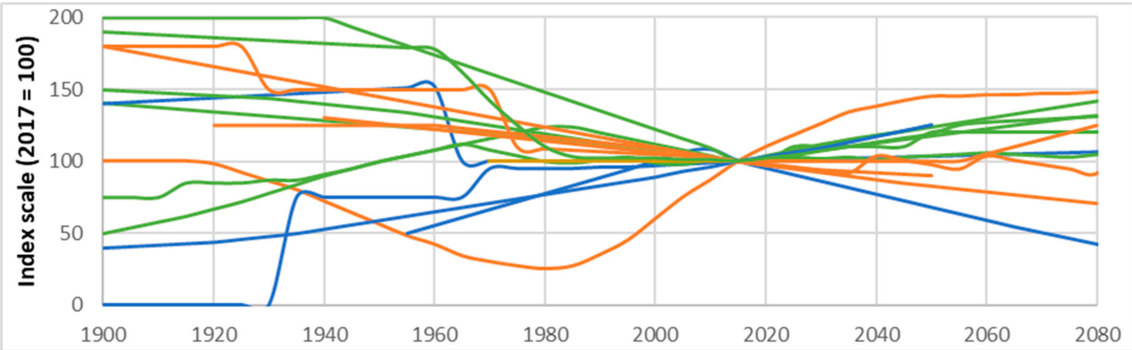

Figure 7. Sketched trends of flexibility over time, with y axis as an index scale, 2017 = 100. Blue = flexibility is the ability to control or steer the system, orange = flexibility is the ability to deal with extreme situations, green = flexibility is keeping options for the future open. Some lines do not cover the entire timeframe.

The analysis of results, whether participants are grouped by interpretation, organization or primary area of interest, shows only limited trends. Nevertheless, this experimental exercise can provide some emerging insights that could be investigated by further research.

In terms of flexibility, participants who used the interpretation "keeping options open" were similarly more positive about the future, and noted that the evolving thinking on adaptation pathways and regional studies to put this thinking to practice would contribute to the positive trend. Participants using a "ability to deal with extreme situations" interpretation showed a generally downward historical trend, but participants expressed optimism about current and near-future developments that would improve flexibility in this interpretation.

3.3. Determining Practitioners' Major Viewpoints

The analysis of Q sorts revealed two significant viewpoints, which jointly explain 46% of the variance in the Q sorts.

Distinguishing statements for viewpoint A and their scores in the representative factor array include "adaptive management was something we were doing all along" (score +4), "legacy organizational structures significantly decrease the system's adaptive capacity" (+3), "the concept of tipping points is useful for real-life application" (−3) and "current practice effectively prevents lock ins and lock outs" (−3). This viewpoint could be interpreted as in line with the "traditional command and control mindset", being skeptical of the concept of adaptive management.

For viewpoint B, distinguishing statements include "the use of adaptation pathways increases understanding of future uncertainties" (score +3), "lower-level public entities have sufficient capacity to carry out devolved functions" (+2), "devolved or decentralized decision making increases adaptive capacity" (−1) and "there is too much focus on studies and plans and too little on reality" (−4). This viewpoint supports much of the thinking of the adaptive management school. However, it disagrees on the need for decentralization.

Seven participants scored significantly on viewpoint A, five participants scored significantly on viewpoint B, one participant scored significantly on both viewpoints (confounded) and one participant did not score significantly on either.

The responses to individual statements provide additional insights, bearing in mind that the scores are relative to other statements rather than scores on their own. The selected statements in Figure 8 are those with those with a significant score in terms of the analysis of narratives.

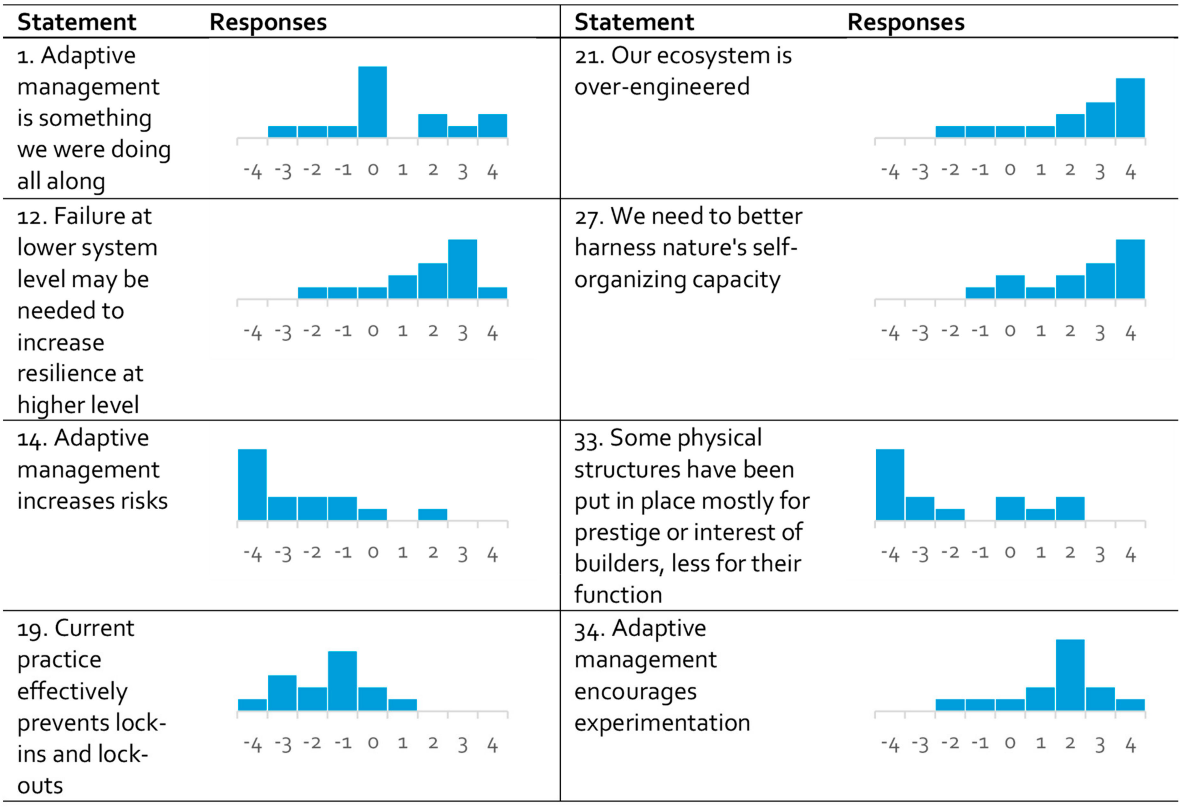

Figure 8. Responses to selected numbered Q statements.

3.4. *Emerging Themes from Results*

While the two system attributes selected for the mapping exercise are used very commonly in policies, plans and studies in the context of water management in The Netherlands, the results show great variety in interpretation and assessment of historic and future trends among participants. While some of the participants focused on specific geographic areas which can partially explain the differences, similar lines of reasoning provided widely diverging results.

Four emerging themes from the results are discussed in further detail.

3.4.1. Space for Self-Organization in Nature

Participants show high agreement in the Q sorts on the statements that the ecosystem is over-engineered (statement 21) and that there is a need to better harness nature's self-organizing capacity (statement 27). At the same time, respondents indicate that the operating space for using that self-organizing capacity is limited, because of the high pressures and demands on the system. As one participant said, "the system is becoming ever more restricted". Operating space in this matter could refer not only to physical space, but also to political, social and economic space.

3.4.2. Dependency and Demand Management

Dependency was one of the key terms most frequently mentioned in the interviews and seen as a slow variable gradually eroding robustness built up through physical interventions that increase water availability (see Figure 9). Dependency is manifested by demand of water, in terms of quantity, quality, location and timeliness, linked to the economic and social functions that would be damaged if the demand is not met.

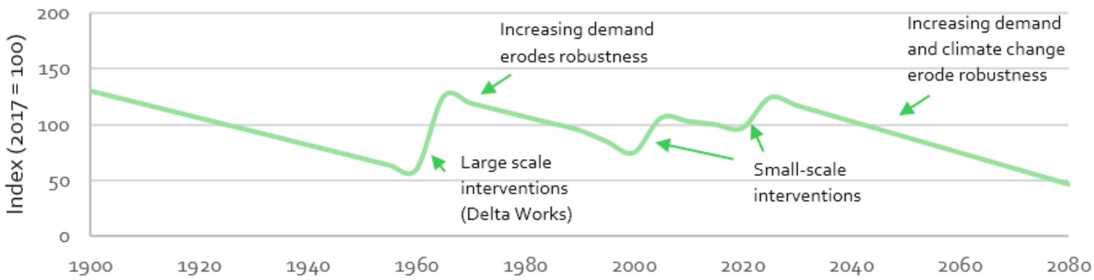

Figure 9. Representative mapping and narrative of robustness as a function of supply and demand, with interventions increasing robustness and increasing demand and climate change as slow variables. Small scale interventions can be minor canals or pumping stations. Source: author.

Participants observe that overall the dependency on freshwater has grown considerably, while some water users are taking private measures to reduce their dependency on the larger water system. The agricultural sector has intensified, and industry and drinking water companies are increasingly relying on the intake of freshwater from rivers. Farmers are demanding more and more strict water quality standards, primarily in terms of salinity level, and are less flexible in terms of timing of harvest as they increasingly produce under strict contract farming terms with large supermarket chains. Where in the past farmers could wait one or two weeks to harvest if the crop had not received enough water to grow, this flexibility is now gone. Horticulturalists in west-Netherlands are increasingly moving towards self-supply systems (groundwater, storage and desalination) as they feel that the public provision of freshwater is not reliable enough.

Comparing the results of participant interviews with quantitative data from existing sources (Section 3.1), the latter do not support the statement of increased dependency on freshwater at the macro level. Instead, the dependency of the economy on agriculture has reduced significantly, and an increasing percentage of drinking water is derived from groundwater sources.

3.4.3. Trade-Off between Robustness and Flexibility

The results suggest there exists a tight relationship and a partial trade-off between robustness at the system level (the reliability of water provision) and the flexibility, or adaptive capacity at the individual level. There are and have been efforts to actively manage demand, by encouraging individual freshwater storage through awareness raising, pilots and subsidies, but many participants argue that without freshwater scarcity, these adaptive measures will not be taken to scale. This links also the high agreement with the Q statement "Failure at lower system level may be needed to increase resilience at higher level" (statement 12). Many participants feel that a transition towards a system with lower dependency on freshwater provision from the rivers (increased resilience) will only occur after one or a series of consecutive dry summers and damage to the economy (failure at the lower system level), which would provide an impetus to the political agenda and incentivize farmers to invest in alternative technologies.

3.4.4. Adaptive Management

In total, 34% of respondents agree to a certain extent with the statement that adaptive management is something they were doing all along (statement 1), while another 43% score this statement as neutral. Evaluations of adaptive management [58] cite an increase in risks and costs linked to adaptive management, which is a view not shared by the majority of respondents (statement 14). In total, 79% of the respondents do, however, slightly to highly agree with the statement that adaptive management encourages experimentation (statement 34). This suggests that experiments are carried out in such way that the risks are highly controlled. In total, 79% of respondents somewhat disagree with the statement that current practice effectively prevents lock ins and lock outs, with exemplary statements that "locking something out is inevitable". This may particularly hold true in the densely populated Netherlands, where "each square meter has been claimed".

4. Discussion

The results confirm the relevance and criticality of complex adaptive systems thinking in an uncertain future for the case study of freshwater management in The Netherlands. In line with scientific progress, policy makers and practitioners have moved beyond stationarity and fixation as paradigm, to embrace natural dynamics and build adaptive capacity under an uncertain future.

It may not be a surprise that key concepts of complexity—in this case, explored as robustness and flexibility around water management in The Netherlands—are interpreted in diverse ways by the actors involved. There have been recent attempts to introduce case-specific definitions (e.g., [35,59]), but achieving a common understanding as a solid basis for co-management or co-governance will require more time and effort and may only happen as a negotiation within one organization rather than be guided by national norms [60].

Even among people sharing a similar understanding of key concepts of complexity, their views on how these developed over time vary strongly. A joint analysis of the historical development of these concepts could provide an opportunity for decision makers to establish common grounds for negotiating definitions at organizational or national level.

Despite the limited significance in the results of the experimental mapping exercise per se, the method proved to offer valuable guidance for further discussion during the semi-structured interview. Many participants initially indicated their lack of confidence on the graphs they had drawn but used it as basis to structure their further reasoning and even to question their own assumptions. This constructivist approach, using free and non-exact interpretation of the concepts, therefore, gives good insights into the participants' view of the situation. Results may, however, be skewed by the fuzzy system boundaries, which could be further improved in a second application of the experimental method. Such follow-up research could also be expanded in terms of number of participants.

While the Q methodology exercise confirmed the existence of two dominant viewpoints linked to the dichotomy described in literature (command and control versus adaptive management), the narrative analysis and literature review point to a much less polarized situation. As indicated above, elements of adaptive management may be introduced without losing control over a system. Furthermore, most participants indicate that The Netherlands' ecosystem is fundamentally artificial or engineered, including nature. An example given is the existence of highly valued nature in some freshwater lakes in west-Netherlands, which would have been saline with a very different type of nature had large infrastructural works not changed the water system.

Rather than thinking in paradigm shifts or transitions, it may be more useful to assess which elements of adaptive management have been adopted, which have not, and why. If there is a lack of acceptance by traditional regimes [61], is it because of a loss-of-face effect where organizations rather pretend to have certainty [58] or are there other reasons? Many participants interpreted adaptive management primarily in terms of looking forward and using scenarios, and in some cases using adaptation pathways. Other elements of adaptive management as defined in literature, such as participation (in the sense of adaptive co-management, see [62]) and the concurrent testing of management alternatives, were rarely cited. In a similar vein, the elements of using nature's self-organization has been primarily as a substitution for hard engineered interventions. Building with nature, the paradigm promoted, does not look at nature as a purpose in itself [63].

There is a strong view among participants that "the big steps have been made" in terms of increasing robustness through supply-side measures, and that further improvements to both robustness and flexibility are limited by physical and economic operating space. As a case in point, after the major interventions in the 20th century, the government struggles to implement recent more small-scale interventions such as the small-scale water supply as economic feasibility assessments give only marginal economic return rates and the (potential) negative environmental impact is high. This corresponds to the robustness trade-off theory of Janssen [64] who states that "when all 'low-hanging fruit' is taken to increase robustness cheaply, SESs will eventually reach a point at which it is no longer possible to generate additional robustness without a cost to performance and/or decreased robustness somewhere else in the system".

Finally, there is a certain paradox in the sense that freshwater is not scarce enough to encourage use efficiency, yet the abundance of water is engineered. The large-scale interventions in the 20th century created new freshwater areas in The Netherlands, where farmers and other water users now have a sense of entitlement to freshwater. Some argue that this robustness at the system level has decreased flexibility on the side of the users and many state that small "collapse" is needed to increase flexibility, linking to the theory of transition management that states that short periods of non-equilibrium offer opportunities to direct the system in a desirable direction [65].

5. Conclusions

This case study provided some novel insights on how complex adaptive system aspects are understood and used by ecosystem managers in practice, when applied to water management. By analyzing and discussing emergent system properties such as 'robustness' and 'flexibility' and by analyzing responses to statements around complexity, insights are gained on how familiar these ecosystem managers are with underlying complexity adaptive systems concepts, how they use these in their work and how these concepts can help in creating adaptive capacity to deal with environmental change.

The case study is particularly relevant as an example of an ecosystem that has become highly human dominated, but where the management paradigm is shifting towards adaptive management and nature-based solutions. In creating more space for natural processes and dynamics, complexity thinking will be essential to understand these emergent properties at the system level.

Though the results of this study show great diversity in the way ecosystem managers use complex adaptive systems theory, they also point to an opportunity for valorization of this type of explorative study. While the concepts related to complex adaptive systems thinking may not be used to predict future behavior, participatory diagnostic application offers an opportunity for establishing a common understanding of system dynamics and emergent properties. Such an exercise, as put forward in this case study, would be a starting point for establishing locally negotiated definitions of system attributes such as resilience, robustness and flexibility.

Understanding the viewpoints of actors in complex adaptive systems, furthermore, provides useful information for research and policy. The often-suggested dichotomy between command and control on the one hand, and adaptive management on the other hand, is not confirmed by the case study. Instead, the findings suggest that adaptive management is being introduced while maintaining control over the system. Furthermore, the results demonstrate areas of concern among practitioners that are currently not or insufficiently addressed in applied research.

Future in-depth research into the emerging findings of this case study could contribute to developing a more reality-based, integrated ecosystem management paradigm where control and self-organization can reinforce each other, and where the lack of operating space is considered when devising policies and strategies. An integrated approach of scientific advances combined with practitioners' views as solicited in this case study would be the right starting point to guide applied research in this field.

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