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Review

Understanding and overcoming obstacles in adaptive management

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Adaptive management (AM) is widely promoted to improve management of natural resources, yet its implementation is challenging. We show that obstacles to the implementation of AM are related not only to the AM process per se but also to external factors such as ecosystem properties and governance systems. To overcome obstacles, there is a need to build capacities within the AM process by ensuring adequate resources, management tools, collaboration, and learning. Additionally, building capacities in the legal and institutional frames can enable the necessary flexibility in the governance system. Furthermore, in systems experiencing profound changes in wildlife populations, building such capacities may be even more critical as more flexibility will be needed to cope with increased uncertainty and changed environmental conditions.

Highlights

Adaptive management (AM) is a stepwise iterative process in which interventions are implemented, their effects monitored and evaluated, and the next intervention adapted according to knowledge gained.

In theory, this process of learning and adaptation leads to increased understanding of ecological processes and improved management. However, the AM approach faces many obstacles to its effective implementation.

These obstacles may be exacerbated by emerging challenges related to a rapidly changing environment. In the face of large-scale climate and land use change, AM's stepwise learning may not keep pace with environmental changes.

To inform future AM schemes, a transdisciplinary approach is needed to address obstacles in technical and social components of AM, but also obstacles related to the ecosystem and governance system.

Addressing challenges in adaptive management of wildlife

For decades, **AM** (see Glossary) has been widely touted as an approach to decision-making capable of handling complexities and uncertainties when managing natural resources [1–4]. AM is a stepwise process of learning and adaptation, using structured decision-making to reach management goals [5–7]. Often referred to as a 'loop', AM involves the iteration of several stages, including set-up (framing of the problem and identification of objectives, hypotheses, and management actions), implementation, monitoring, and evaluation (Figure 1). Based on the knowledge gained from the latter stages, original goals and interventions are reviewed and adjusted if necessary, and a new 'AM loop' ensues [1,6,7]. This stepwise and structured process of 'learning by doing' [2] is assumed to lead to improved understanding of the system and thereby an ability to design more effective interventions to fulfil objectives.

AM is widely promoted in both the scientific literature [4,8,9] and international agreements, for example, as part of the ecosystem approach endorsed by the Convention on Biological Diversity and implemented through the Malawi principles [10]. AM is deemed applicable in the management of both scarce and abundant natural resources [4], and it has been implemented to manage slow as well as rapid changes in resource availability [4,11,12]. When it comes to wildlife populations, AM has been applied on spatial scales ranging from local to biome [13,14]. Despite the wide range of actors advocating AM, only a few projects have used it to deliver improved management outcomes [4,15]. The literature proposes that the lack of successful examples may have several and interacting causes [4,16]: for example, complexity in terms of ecological processes and administrative levels when AM is carried out over large spatial scales [17]. Moreover, as AM is conducted as part of a **social–ecological system**, its implementation in many instances depends on transdisciplinary and multi-actor understanding.

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Current global megatrends – including climate change, overexploitation of natural resources, and environmental degradation [18–21] – cause additional challenges for AM, as its stepwise learning approach may be too slow to keep pace with the effects of these changes [22]. Wildlife populations may change quickly and profoundly, from rarity to abundance and vice versa. For example, several successful conservation interventions have drastically changed the status of red-listed mammals and birds to full recovery [19,23,24]. This may require a swift shift in management strategy and objectives to avoid either continued population decline in exploited species, or increased impact on ecosystems and human livelihoods by superabundant populations [22,25]. Such prompt decision-making and innovation require certain **capacities** of management systems or organisations: for example, **governance systems** that allow for flexibility. Several reviews of AM have identified and listed possible obstacles [4,26,27], but few if any have systematically quantified their frequency. Such quantification is valuable to highlight particularly problematic obstacles, and to be able to present solutions as part of a coherent framework. Moreover, with current megatrends, such quantification can assist putting more focus on challenges related to profoundly changing conditions and management goals. This analysis is timely, as large environmental changes are set to become more frequent in the near future. Furthermore, challenges facing AM, such as profoundly changing conditions and mega trends, are in many respects similar to obstacles facing decision-making in natural resource management, adaptive or otherwise. Lessons learnt in AM of wildlife may therefore provide valuable insights also for the management of natural resources more generally.

We review the literature about AM of wildlife to systematically quantify the frequency of different categories of obstacles to the implementation of AM, with special emphasis on systems with

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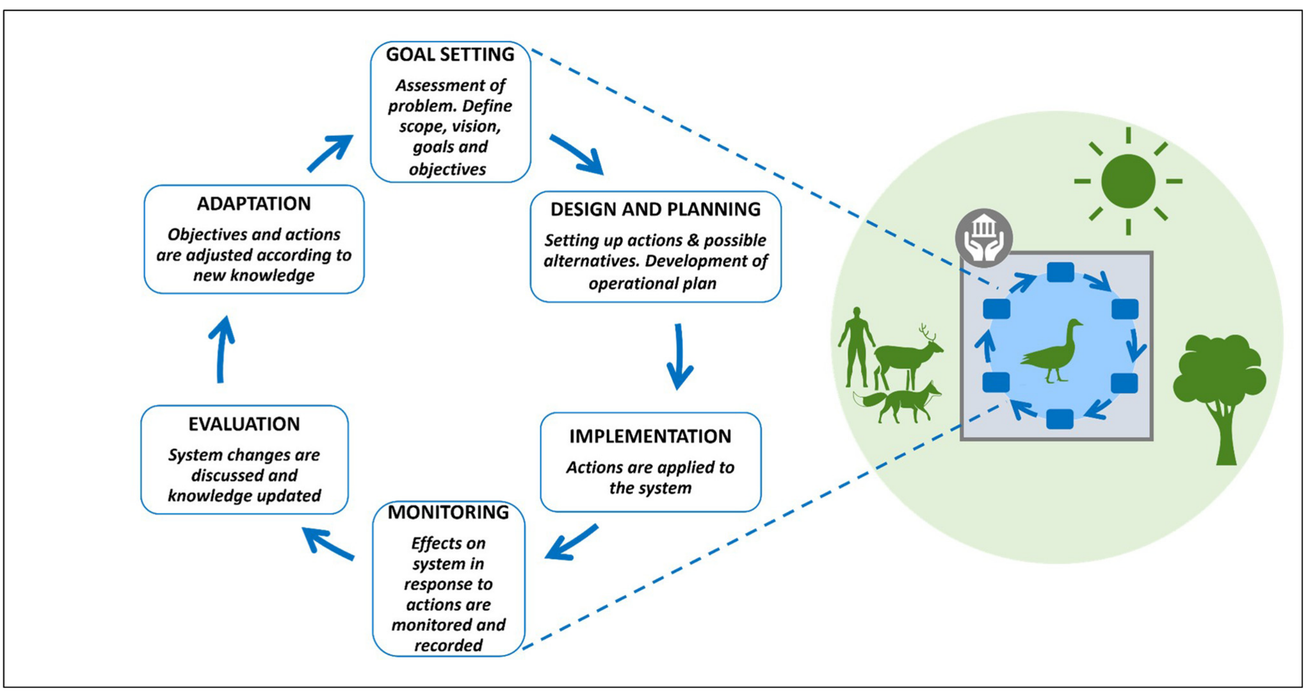

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Figure 1. The adaptive management (AM) loop, demonstrating the continuous process of goal-setting, design and planning, implementation, monitoring, evaluation, and adaptation. When the AM process is applied, for example to geese, many other components and interactions in the ecosystem (illustrated by the green icons) will affect the performance of AM. The implementation of AM also needs to be in concordance with and within existing governance frameworks (illustrated by the grey frame). Icons by N. Style, F. Brönnimann, Visual world, B. Mania, C. Pyper, Suliyanto, and Verry from NounProject.com.

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profoundly changing scenarios and objectives (Appendix S1 in the supplemental information online). We then identify solutions to formulate recommendations on how to build capacities to improve the implementation of AM. As an illustration of how obstacles to AM can be addressed in practice, we present a case study currently engaging practitioners and policy makers, namely, the adaptive flyway management of European goose populations (Box 1).

Obstacles to adaptive management

We identified three main categories of obstacles related to: (i) the 'AM process' per se (e.g., lack of resources, inadequate actor involvement, or shortcomings in operational processes), (ii) the 'ecosystem', focusing on the environment to which AM was applied, and (iii) 'governance', comprising the frame of institutions and legislation in which AM was implemented (Appendix S1 in the supplemental information online and Figure 2).

AM process obstacles

Eleven of the 16 identified subcategories of obstacles relate to the 'AM process' and constituted 73% of the total obstacles with empirical support (Figure 2). Obstacles related to the AM process arise all the way from initial planning and goal-setting to the adaptation of management according to knowledge gained in the iterative loop.

In the initial phase, obstacles are associated with 'set-up', and are linked to the failure to establish clear, realistic, and mutually agreed objectives among stakeholders. Several studies also pointed at vaguely defined timelines, experimental protocols, and management alternatives [22,28].

'Resources' – including time, monetary resources, staffing, and staff training – are also seen as limiting to achieve AM objectives [16,29]. Staff are often said to lack experience and adequate know-how about AM, and there are also examples of high turnover rates among staff, reducing its capabilities and leading to issues of continuity [16,30]. Additionally, a variety of 'methodological' and 'monitoring' problems are evident: for example, lack of knowledge of how to build predictive models and survey programmes, but also that experiments are less prioritised [30–32].

Obstacles in the 'organisational culture and leadership' subcategory include examples of discouraging cultural patterns in management agencies (i.e., core values, ethics, beliefs, and behaviours), impeding political considerations (e.g., risk of bad publicity due to failure to reach objectives), and poor leadership [16,33,34]. All these may hamper flexibility and collaboration. Obstacles are also related to 'actors and relations' and 'engagement': for example, relevant stakeholders are not included in the process due to low engagement or because they are not identified [35,36]. There are also examples of lack of coordination, confusion over roles, and decision power [15,37].

Key stakeholders often lack the 'understanding of AM'. In some cases, managers believe that they are enacting AM when they are in fact using a 'trial-and-error approach' rather than a structured management process and experimentation [38]. There is also evidence that AM tends to become too technical and theoretical, creating difficulties in transforming theory into action [39]. Limited 'knowledge exchange' and 'connectivity and communication' between participants in different roles may also lead to information asymmetries, and to lack of transparency and diffusion of knowledge [39,40]. Finally, the lack of, or poor evaluation of, socioeconomic aspects and different learning outcomes (i.e., 'evaluation of AM outcomes') are also noted as obstacles to the implementation of AM [38,41].

Ecosystem obstacles

In total, 13% of the obstacles with empirical support were related to the ecosystem (Figure 2). Lack of 'initial knowledge' about the ecosystem to be managed (e.g., deficient information

Glossary

Adaptive management (AM): a stepwise process of learning and adaptation, using structured decision-making to learn, incorporate new information, reach set management goals, and improve future decision-making.
Capacities: operational abilities of, for example, management systems or organisations, that can be created and strengthened by diverse assets such as financial, organisational, and human resources.
Governance system: a system composed of laws, rules, institutions, and norms governing (in the present context) the management of natural resources. It may also have adaptive features to promote learning (i.e., adaptive governance).
Reflexive learning: a learning process in which assumptions, values, and actions are consciously and critically examined and re-examined.
Social–ecological system: a coupled ecological and social system present in a specific time and place, embracing dynamics and interrelations of ecological processes and the social system, including its institutions and social actors.
Transition management (TM): an iterative learning-based approach, similar to AM, but with an explicit multilevel framework and the potential for more rapid change. This is an approach developed in research of transitions in energy systems.

about species' life history traits and scale dependence) may cause problems for formulating hypotheses and building predictive models [22,42]. For example, recently emerged conditions due to invasive species or rapidly recovering populations decrease the possibility of predicting possible detrimental effects on the ecosystem [43]. Moreover, unanticipated events and variables – such as major weather events (e.g., wild fires and flooding) reflecting a 'complexity of systems' – may disrupt experimental trials and hence also AM procedures [4,16]. Additional obstacles related to the managed system involve 'scale' issues, considering the challenges of matching spatiotemporal scales at which management is planned and performed to the scale of ecological processes [44].

Box 1. Case study: adaptive management of European geese

AM of European goose populations is an illustrative example of the complexity that wildlife practitioners currently need to handle. It involves uncertainty, conservation of declining species, harvest strategies of increasing species, and mitigation of ecosystem disservices (e.g., ecosystem impact, crop damage, air safety concerns). Goose management has recently changed profoundly from managing rare and threatened species to handling the same species when superabundant [11,19,80,88]. As goose species migrate across nations with different legislations, objectives, cultures, and norms [89,90], coordinating management becomes a challenge [91,92].

To cope with these challenges, the secretariat of the African–Eurasian Migratory Waterbird Agreement (https://www.unep-aewa.org/) approached countries sharing migratory goose species. Important parts of the proposed AM were to create forums and discussion groups to enable communication, consensus-building, and engagement among stakeholders, and to form platforms where national delegations (authorities, scientific experts, and interest groups) meet for decisions and information sharing (Figure I). Goose management meetings are now arranged annually, and several task force groups continuously work with issues related to crop damage and species-specific questions related to population conservation and control (e.g., data collection). Practitioners are supported by scientists via a data platform (collecting and compiling data) and a modelling consortium (providing predictive population models). Using this structure, several international goose management plans have been launched [11,12,93,94], all striving for viable populations while minimising 'ecosystem disservices' [95]. The management plans are based on predictive population models, coordinated monitoring, and common hunting quotas [11,12]. One of the plans (pink-footed goose, *Anser brachyrhynchus)* has been implemented and the population size is now approaching the set goal [12]. Yet, implementation requires that actors at the local level support nationally agreed goals and actively contribute to achieving them [96]. This suggests a further need for capacity-building within countries, particularly at the regional and local levels.

The goose management platform is a good example of how to strengthen capacities to handle obstacles to AM. However, some obstacles remain, one of which can be illustrated by the successful legal protection of the barnacle goose (*Branta leucopsis*) (Figure II), which has permitted the species to become superabundant [19,93]. At present, this protection makes it impossible to set goals to reduce the barnacle goose population, the most abundant goose species in Europe, while hunting remains open for much less common species [12,93]. Thus, the legislative precautionary AM approach to rescue critically small goose populations may sometimes need to shift focus in order to prevent possible irreversible 'ecosystem disservices'. Such shifts will require changes inside and outside of the AM process (i.e., in legislation and institutional structure) [20,25].

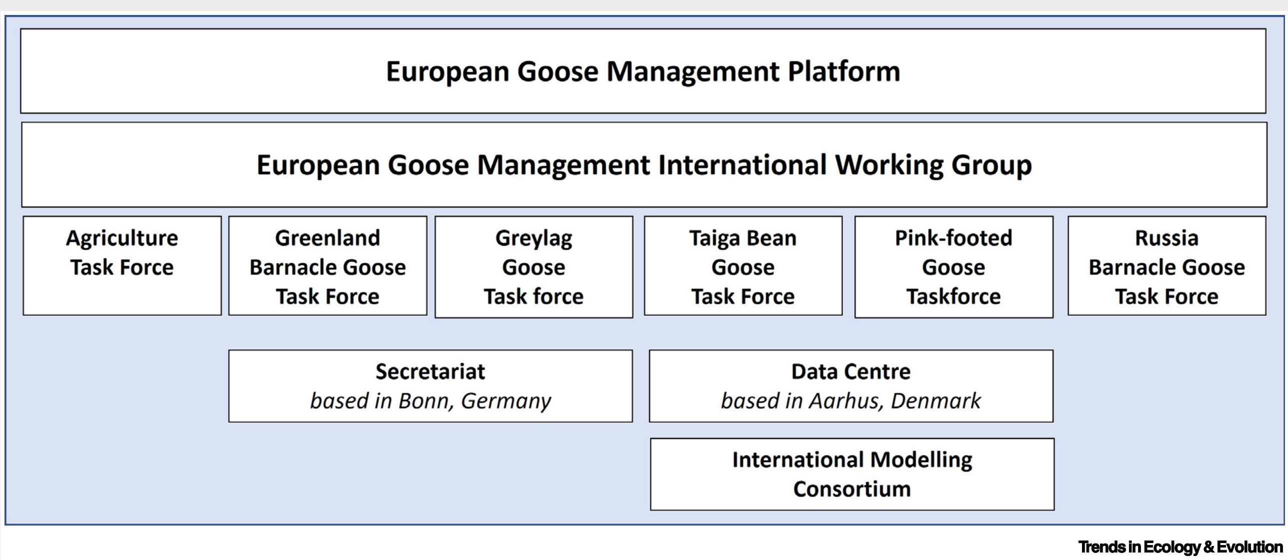

Figure I. Organisational structure of European adaptive goose management (the European Goose Management Platform) initiated by the African–Eurasian Migratory Waterbird Agreement. The platform consists of different forums and task forces facilitating technical support, learning, communication, consensus-building, and engagement within the AM process.

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Figure II. The barnacle goose (*Branta leucopsis*) is an example of a species that has shown a profound population change, going from threatened to superabundant over 3–4 decades, causing challenges to adaptive management (AM).

Governance obstacles

'Legislation' and 'institutional structure' of management present significant obstacles to successful implementation of AM; 14% of the obstacles with empirical support were related to the governance system (Figure 2). For example, legal frameworks may be too rigid, and not capable of keeping pace with changing environmental conditions, as in cases where populations have rapidly recovered from low numbers but are still legally protected [20,22,36]. Moreover, inadequate institutional structures, with poor linkages between governance actors, can obstruct synergy between large-scale political agendas, such as conservation efforts, and local needs on the ground [45]. Inadequate structures may not only limit knowledge exchange but also cause ambiguity regarding accountability and legitimacy [29,38]. For example, one study shows that a regional informal management initiative to control rapidly increasing seal populations, to decrease damage to fisheries, was hindered by a lack of regional bodies that could take legal responsibility for decisions [20].

Building capacities to overcome obstacles

We have grouped solutions needed to remove or reduce obstacles to the implementation of AM into four overarching capacities (Figure 3). Concrete examples of how to achieve solutions to build each of these capacities are given in Table 1.

Structure and resource capacities

By ensuring 'structure and resource' capacities within the AM process, obstacles associated with resources, the set-up phase, and the organisational culture can be addressed. A clear framework for structured decision-making is needed from the start, and it should be realised and agreed among all participants (Table 1). Availability of decision support tools (e.g., management option matrices and 'triggers') is key to direct managers' attention towards crucial issues in each step of the process [43]. Goal-setting may be further guided by the aim to achieve SMART goals (specific, measurable, achievable, relevant, time bound), thereby reducing uncertainty and facilitating evaluation of set goals [46]. The involvement of clearly designated leaders (e.g., key knowledgeable individuals) may further improve decision-making [29]. Efficient use of resources (e.g., staff and technology) in the AM process may be obtained by building partnerships to share costs, engage

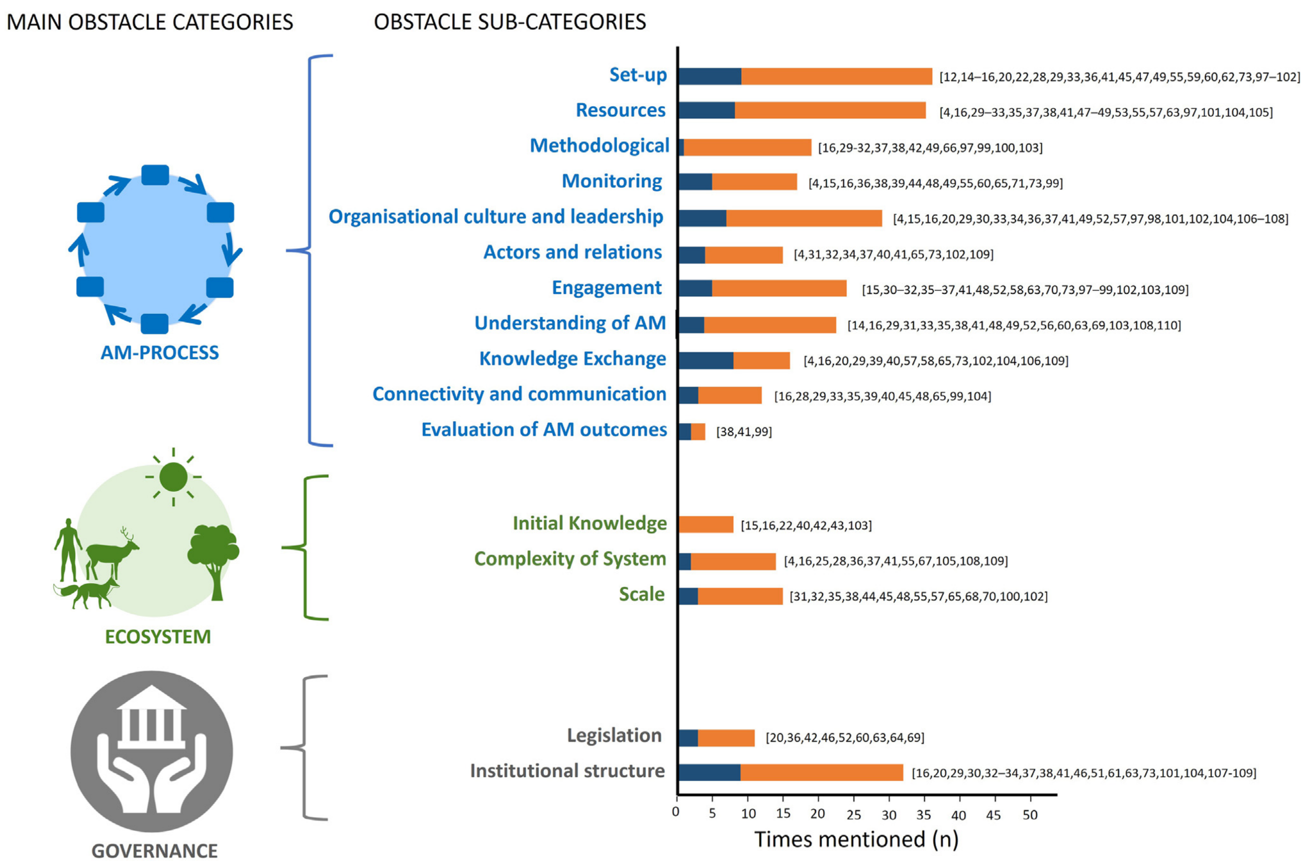

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Figure 2. The number of times that obstacles to adaptive management (AM), by main categories and subcategories, are mentioned in the reviewed papers (*n* = 65; references in brackets). Colours denote the relative proportion of two categories of support in the literature: obstacles with an 'empirical' basis (blue) and those based on 'references' (orange), that is, merely citing previous literature (including those citing anecdotal experience). Categories of obstacles are as identified in the thematic analysis (Appendix S1 in the supplemental information online). See also [4,12,14–16,20,22,25,28–49,51–53,55–71,73,97–110]. Icons by N. Style, F. Brönnimann, Visual world, B. Mania, C. Pyper, Suliyanto, and Verry from NounProject.com.

coordinators, carefully select indicators to monitor, and develop citizen science schemes for monitoring and online management tools.

Collaborative capacities

One obstacle with relatively strong empirical support is knowledge exchange (Figure 2). This obstacle, but also those associated with connectivity and communication, may be reduced by enhancing 'collaborative' capacities in AM. Stakeholder coordination – for example, jointly developing and implementing management measures – may encourage collaboration [47], as may explicitly facilitating stakeholder engagement via direct involvement in goal-setting and ensuring motivation to participate [41,48] (Table 1). Developing avenues for exchange and partnerships between scientists, practitioners, and policy-makers, removing barriers to communication, and explicitly dealing with conflicts to strengthen relationships may also be necessary to facilitate collaboration [20,33,49]. In that perspective it is also important to ensure that all stakeholders have trust in monitoring data, as this creates a common view of the present situation and thus a common ground for decisions [50].

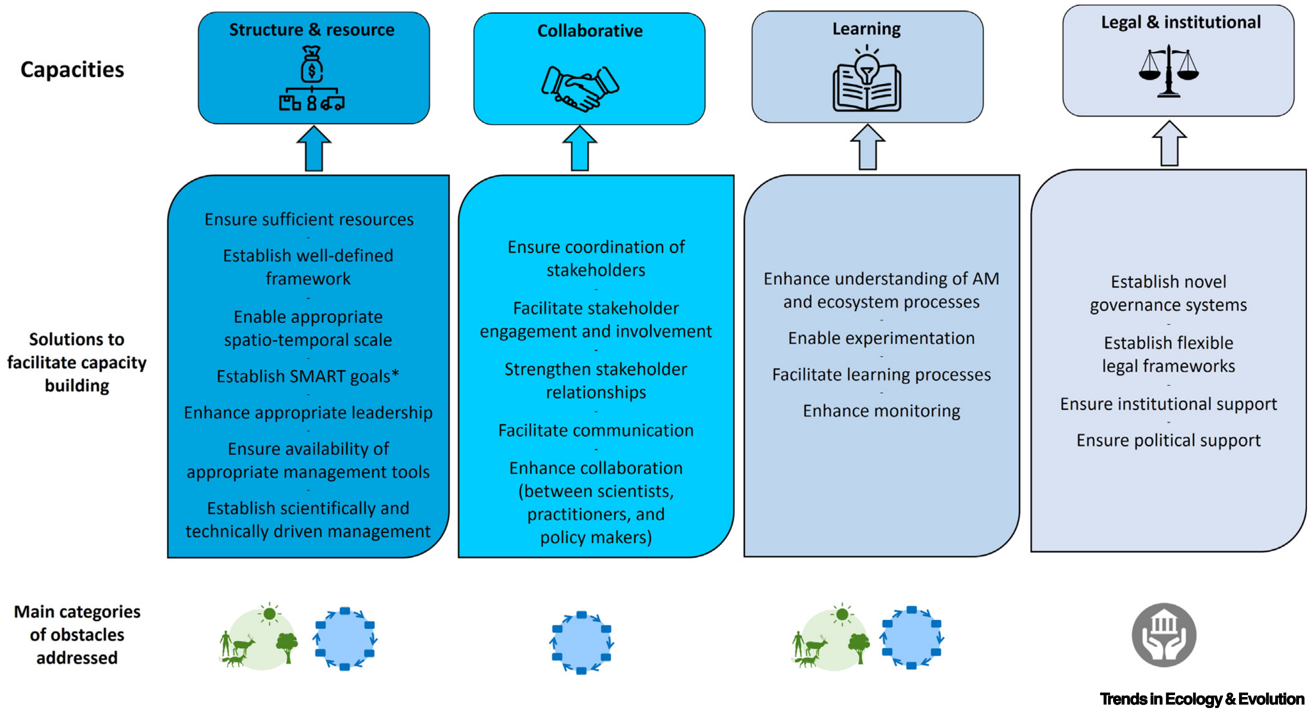

Figure 3. Four main types of capacities needed to reduce obstacles to implementation of adaptive management (AM) and solutions to build these capacities. 'Structure & resource', 'Collaborative', and 'Learning' are capacities within the AM process, whereas 'Legal & institutional' are in the governance frame. The lower part of the figure shows the main categories of obstacles these solutions and capacities can alleviate. *SMART, specific, measurable, achievable, realistic, and timely. Icons by N. Style, F. Brönnimann, Visual world, B. Mania, C. Pyper, Suliyanto, Verry, I. Rhomadhani, Denimao, T. Sookruay, and Popcornarts from NounProject.com.

Learning capacities

Enabling 'learning' capacities in AM can reduce obstacles in several ways. Although learning through a structured decision-making process constitutes the core of AM, learning might still need to be facilitated further [38,41,51]. To enhance the understanding of AM and the ecosystem, misconceptions and the complexity of learning processes need to be recognised [52,53] (Table 1). By increasing the effectiveness and quality of monitoring through new technology, training, and citizen science programmes [38,48], ecosystem obstacles and methodological and monitoring obstacles in the AM process may be addressed. This will allow for long-lasting experimentation and hypothesis testing. Moreover, scientists, policy-makers, and managers need platforms for sharing knowledge, thereby encouraging learning [49]. Arrangements are also needed to support social learning (i.e., situated learning among actors in a network or community) to alleviate barriers related to engagement, connectivity, and communication. Such arrangements should ensure openness to share diverse knowledge, understanding, and respect among actors [41]. Social learning can even, in addition to management goals, be included as an explicit goal of AM. Learning can ultimately be facilitated by considering how obstacles to implementation can inform and improve AM.

Legal and institutional capacities

Legal and institutional capacities can resolve obstacles associated with the governance system in which AM is carried out. In particular, the institutional structure is a prevalent challenge when considering obstacles with empirical support (Figure 2). Solutions to these obstacles might involve establishing novel governance structures to allow for adaptive governance, that is, when institutions and policy may adjust to changing conditions (Table 1). These structures are often characterised by polycentricity (multiple but interdependent authorities), participation, and learning [28,54].

Table 1. Concrete examples on how to build capacities (Structure and resources, Collaborative, Learning, Legal and institutional) and achieve solutions to reduce obstacles to AM

Capacities	Examples of how to build capacities	Refs
Structure and resources		
Ensure sufficient resources	• Provide physical and technical infrastructure through, for example, implementing technical solutions and leveraging institutional infrastructure • Develop capacity in local staff to build in flexibility to deal with locally varying conditions • Develop partnerships to increase financial and technical capacities • Assure resources for programmes requiring long-term monitoring to ensure continuity • Include provisions to engage citizen scientists and make attempts to include community members, rather than only volunteers • Decrease cost by, for example, 'piggy-backing' on other existing management, limiting monitoring to a subset of informative indicators, and change policies to support local institutions with implementation and management of transaction costs • Outline key or fundamental component of the AM process	[4,20,38,48,49,55]
Establish well-defined framework	• Define a clear framework of AM at the outset • Ensure that planners begin to develop an explicit framework for AM implementation considering both programmatic learning (i.e., pertaining to natural resource ethics and values) and project learning (i.e., the science and management of the natural resources) • Develop an applied science framework to create an understanding of how the managed system works • Design decision-making structures to incorporate a collaborative process	[15,56–58]
Enable appropriate spatiotemporal scale	• Delineation of management units at an appropriate bioregional level • Monitor key elements at appropriate temporal and spatial scales • Use coordinators in large-scale AM programmes	[38,48]
Establish SMART goals (specific, measurable, achievable, relevant, time bound)	• Consider management objectives at the start of the decision- making process • Form a foundation of clear objectives set in a common vernacular • Make social learning (i.e., learning based on interactions in groups, networks, systems) an explicit objective • Generate flexible goals • Characterise uncertainty and develop management options matrices • Include triggers (i.e., predefine points at which an AM plan will be revisited and re-evaluated) to increase accountability • Balance economic and environmental stakeholder needs to manage for a sustainable future • Centralise governmental involvement for establishing overarching goals rather than resolving local issues	[40,41,46,49,56,57,59,60]
Enhance appropriate leadership	• Involve key individuals as leaders • Involve knowledgeable people	[29,61]

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Table 1. (continued)

Capacities	Examples of how to build capacities	Refs
Ensure availability of appropriate management tools	• Develop online management tools (e.g., databases) • Ensure access to a diversity of management measures • Develop decision support (e.g., checklists) and guidance manuals	[16,43,61]
Establish scientifically and technically driven management	• Develop an external advisory committee to establish independent peer review mechanisms of the AM programme	[33]
Collaborative		
Ensure coordination of stakeholders	• Develop collaborative efforts to facilitate institutions' adoption of a common set of adaptive management standards • Develop joint management strategies • Implement measures jointly (e.g., fencing and buffer zones)	[39,47]
Facilitate stakeholder engagement and involvement	• Include all stakeholders (no limits), including locals and those with diverging or conflicting interests • Engage in community engagement to improve programme sustainability • Use management suggestions from stakeholders • Co-develop goals, objectives, management strategies, and monitoring indicators in an inclusive manner • Ensure that managers provide appropriate motivation and incentives for participation • Create coalitions of multiple stakeholders • Deal with conflict	[22,38,41,47,48,62–64]
Strengthen stakeholder relationships	• Improve dialogue between stakeholders (e.g., between resource management and government actors on the one side and industry actors on the other)	[20,40]
Facilitate communication	• Mitigate communication barriers through interpersonal and electronic communication channels • Communicate why evidence-based approaches are important and the advantages of AM in that sense	[4,33]
Enhance collaboration (between scientists, practitioners, and policy-makers)	• Recognise and document the full AM process using a multidisciplinary approach • Implement collaborative monitoring • Improve communication between researchers and applied sectors via, for example, in-person and problem-based exchange focused on real decisions and utilising social networks • Support managers by synthesising research articles and agency reports, as well as guidance on how to interpret adaptation plans • Provide avenues for conveying knowledge between scientists, policy-makers and managers • Encourage partnerships among people from different institutions with different expertise and sets of skills • Include active participation in the review of AM programmes by stakeholders and outside evaluators	[38,53,65]

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Table 1. (continued)

Capacities	Examples of how to build capacities	Refs
Learning		
Enhance understanding of AM and ecosystem processes	• Increase understanding of underlying structures or ecosystem processes through collaboration between scientists and practitioners • Broaden the understanding of AM in order to make best use of the framework • Recognise misconceptions of AM • Educate managers that variation is okay • Change managers' focus from reducing uncertainty to dealing with irreducible uncertainty • Recognise path dependency when making decisions, since earlier decisions constrain the set of options available • Increase awareness of the complexity in learning process (e.g., recognise that learning is part of the process) • View obstacles as complexities for learning	[12,15,25,41,52,53]
Enable experimentation	• Include hypotheses and experimentation in management	[28,37]
Facilitate learning processes[a]	• Ensure openness to share diverse knowledge • Use success stories, technical guides, and scientific literature • Improve models to resolve ambiguity about the efficacy of management and to update knowledge • Employ a social learning approach to monitoring, for example, by being reflexive and involve decision-makers • Strive towards relational and normative social learning by providing opportunities for participants to develop understanding and respect for each other • Develop and integrate single (incremental), double (reframing), and triple (transforming) loop learning across multiple governance levels to ensure reflexive learning • Use multidisciplinary teams to evaluate the AM programme holistically • Employ systematic evaluation for learning and management outcomes	[30,32,38,41,51,56,61,66,67]
Enhance monitoring	• Improve monitoring via an understanding of the institutional and policy context (e.g., determining which institution is most appropriate to monitor and how this institution can be supported) • Frame wildlife monitoring by well-articulated indicators that are closely linked to management goals • Invest in training programmes and build relationships to improve capacities for monitoring at the local level • Increase effectiveness of monitoring [e.g., by remote sensing, automated analysis (AI), UAV (drones)]	[38,55,68]
Legal and institutional		
Establish novel governance systems	• Develop adaptive governance with the ability to adjust to change through a learning-based approach often involving multiple actors at multiple levels • Introduce polycentricity including nested decision-making authorities with numerous degrees of freedom at multiple levels	[28,48,57,62]

Table 1. (continued)

Capacities	Examples of how to build capacities	Refs
	• Use gained knowledge for adapting governance system, that is, transforming the structural context, so-called triple loop learning • Introduce a regulative AM authority ensuring agencies' commitment to AM • Implement legal and institutional frameworks supporting the emergence of co-management where decision-making powers are shared between the state and the community • Ensure that decision-makers are accountable to stakeholders	
Establish flexible legal frameworks	• Introduce specialised 'adaptive management track' of administrative procedures while still adhering to the core values of administrative law (public participation, judicial review, and finality) • Change acts/bills • Ensure commitment to implement AM, under certain circumstances • Pass legislation with specific requirements for AM plans (i.e., measurable goals, testable hypotheses, evaluative criteria) • Induce compliance to rules • Include provisions that allow citizens to legally challenge, for example, AM plans, commissioned monitoring, and commitments	[22,46,60,62,63,69]
Ensure institutional support	• Ensure commitment to long-term institution-building • Ensure institutional support to ensure resources and capacity • Integrate AM into an institutional framework and development of technical guidance • Implement organisational change and adopt an organisational culture that promotes flexibility and learning • Develop a flexible co-management structure with shared decision-making powers • Introduce cross-scale institutional coordination and communication (especially important in polycentric systems) (including groups with local focus non-governmental organisations s and government agencies) • Develop venues and forums for deliberation, sharing information, and facilitating collaborative learning • Create a neutral space (e.g., an institutionalised regional consortium)	[20,33,47,57,61,62,70]
Ensure political support	• Ensure a supportive political environment, including financial support and encouragement to engage in AM (e.g., experiments to evaluate management actions)	[71]

[a]Examples to explicitly facilitate learning processes. Since learning can be considered key for AM, several subcategories contain examples with this aim.

Sufficiently flexible legal frameworks will further ensure that legislation does not prevent adjusted management goals (e.g., when populations have recovered). Equally important to ensure sufficient resources for AM is institutional and political support: for example, incorporating AM into the institutional framework and developing a flexible co-management structure where decision-making powers are shared [57,62]. The provisioning of forums for collaboration and an institutional culture encouraging AM can further reduce obstacles to AM [20].

Turning obstacles to insights for management

In some of its applications, AM has been a successful framework to deliver improved management outcomes [e.g., 72–74] (Box 1). However, our study finds that AM still largely struggles to fulfil management objectives. Westgate *et al.* [4] reviewed the AM literature related to biodiversity and ecosystem management. They conclude that challenges in AM to a great extent limit the ability to improve the understanding of ecological processes and management of biological systems. Challenges linked to funding cuts, changes in policies and staff, but also sudden events like flooding and fires destroying experiments are highlighted as explaining failure of AM projects [4]. We show that these challenges are common, but also that the obstacles have a wider spectrum of origin, rooted not just in the process of AM but also in the wider governance system and ecosystem in which it is embedded. To successfully implement AM, we suggest that obstacles need to be addressed and capacities created and strengthened simultaneously within the AM process and the social–ecological system.

Our compilation of AM obstacles, along with suggested solutions to build capacities, can serve as a planning and diagnostic tool to identify issues and provide solutions in existing and future AM programmes. Focusing on the AM loop, we find that obstacles in the initial phase are related to goal-setting and planning, and that these were equally common as obstacles related to resources, including funding and appropriate staffing. Our results further illustrate obstacles relating to technical as well as social components of AM. Thus, it is vital to focus on methods (e.g., predictive modelling and experimentation) and monitoring design in AM, but it is also important to consider social interactions, engagement, and knowledge exchange among all stakeholders involved.

Suggested solutions direct attention towards core issues for effective implementation of AM. It illustrates a need to create an appropriate frame for AM, but also to continuously invest in collaboration and learning over time. There is further potential for synergies, as building financial resources through partnerships may also facilitate collaborative capacities [38]. Learning is at the core of AM, and we highlight diverse activities specifically designed to encourage it (e.g., striving towards **reflexive learning** by working in multidisciplinary and multi-actor groups). As management systems with multiple actors and governance levels are complex, technical learning about management is not sufficient, and social learning among researchers, stakeholders, managers, and agency representatives is generally required [28]. Adaptive governance could provide an institutional framework for flexible and collaborative governance encouraging continuous learning and potentially addressing several of the obstacles to AM [54].

The issue of profoundly changing wildlife populations

The future is always uncertain, but scenarios predict profound future changes in environmental conditions and a higher risk of unexpected events and challenges for wildlife management [75–77]. The few available studies addressing AM of profoundly changing wildlife populations highlight a need for further studies. Nevertheless, by comparing these papers with the broader wildlife literature we see useful insights for future AM. In the reviewed literature, five of the subcategories of obstacles – set-up, initial knowledge, monitoring, legislation, and institutional structure – are more common (compared to the other papers reviewed) in papers related specifically to management of profoundly changing wildlife populations (Appendix S1 and Figure S1 in the supplemental information online). To address these obstacles, solutions to build all four capacities are identified.

New conditions create a higher demand for solutions, increasing knowledge about the managed system in order to predict management outcomes. For example, gaps in current knowledge about ecological consequences of rapid population increase cause challenges for predicting future outcomes in the initial phase of the AM loop [22]. Limited ecological understanding of recently established alien species creates similar challenges [43]. Monitoring schemes, too, may have to be modified in order to facilitate learning capacities in response to changes in distribution and population size (e.g., when populations expand into new areas or habitats) [15,44].

In addition, challenges related to the set-up of the AM process may in the case of changing populations be even more critical. There may be a need for adjusted goals, even paradigm shifts, for example when management needs to change from conservation to population control, or the other way around [19,22,43]. In this context, a long tradition of conservation-oriented mindset among practitioners and the public may hamper the process of agreeing on new goals to reduce and control populations [25]. Reaching a common understanding takes time and may need to be explicitly encouraged, and platforms facilitating collaboration are needed to enhance the knowledge exchange and understand the need for change [12]. Goose management in Europe is an illustrative case in which many of the abovementioned challenges are being handled by providing 'structure and resource' capacities, while also building capacities for 'learning' and 'collaboration' (Box 1).

Legislative and institutional barriers to AM were more evident in situations of changed management objectives. This is potentially due to earlier decisions having an impact on future alternative options, constraining possibilities for institutional change [20,22,78]. When conditions change, the governance system needs to be flexible, yet too high a degree of flexibility decreases predictability. A solution could be to agree on explicit critical levels ('triggers', e.g., a certain population size or rate of change) at which management should change direction as part of the legislative framework and thereby allow for both flexibility and predictability [60].

However, even if governance systems are adapted to allow more flexibility in AM [28,69], an AM process characterised by stepwise learning may still not be fully prepared to handle a major change in ecosystem state [79]. For example, too much focus on learning about the impact of superabundant populations before acting may in some situations make management too slow to prevent negative impact on ecosystems or human livelihoods (Box 1). The AM approach needs to become better prepared to handle scenarios of rapid and profound ecosystem change [22,80], potentially by drawing on alternative management approaches with a similar focus on reducing uncertainty, such as **transition management (TM)** [81,82]. AM and TM are not mutually exclusive. TM has evolved alongside AM aiming to understand and manage transitions of socio-technical systems, in particular energy systems. Just like AM, TM builds on an iterative, learning-based approach to manage complex systems, but the pace of change in management actions is generally faster in TM [83]. When faced with challenges associated with profound ecosystem changes, it may be useful to consider how TM manages to build capacities (e.g., by innovation), and how to explicitly incorporate institutional change in the short, mid, and long term to support AM.

Since the particular focus of AM and TM is to handle uncertainty, both are often included into various governance or management frameworks such as the ecosystem approach, resilience thinking, or robustness for social–ecological systems [84–86]. In particular, AM is often seen as an integral part of these approaches, aimed at achieving, for example, ecological integrity, ecological identity, or maintenance of system performance [87]. AM can thus be evaluated based on its own merits (i.e., to manage uncertainty in relation to specific management actions), but it can also be evaluated as an integral part of a broader management regime, such as resilience thinking. While the focus in this review is on the former, our study shows that it is often necessary to put AM in a wider context. We therefore call for further studies that assess the extent to which AM can contribute to achieving more overarching objectives such as ecological integrity or identity.

Concluding remarks and future perspectives

Many previously identified obstacles to AM still prevail, and some of these may even play a more significant role in the future due to global change. Even though some obstacles are explicit for the structured AM decision-making loop, most of the solutions identified here can be used for natural resource management more generally.

So far, finding solutions has been focused on obstacles related to the process of AM, partly neglecting the role of external factors setting boundaries for its implementation. In many cases the governance system is not adapted to facilitate AM (see Outstanding questions), particularly when conditions in the ecosystem and goals are profoundly changing and when there is an urgent need for more flexible management. Again, goose management in Europe is an illustrative case: legislation is too rigid to allow adaptation to new conditions, thus hindering a timely AM process; vulnerable species are still legally hunted, whereas the most numerous goose species in Europe is protected from hunting (Box 1). It is also worth noting that governance obstacles may be more prominent and numerous in AM than is shown in this review. This is due to our explicit focus on AM and the fact that items like 'adaptive governance' were not used in our search for articles. In addition, we only included peer-reviewed literature and did not engage directly with practitioners and policy-makers. However, as the majority of the reviewed papers are evaluations of practical AM initiatives, we argue that our results mirror the actual situation for wildlife managers regarding important challenges and relevant solutions.

There is a growing number of studies of AM and adaptive governance within the social science disciplines. Social learning as part of the AM process has also received increased attention recently, with calls for a need to evaluate not only technical learning and management outcomes, but to also explore to what extent social learning is taking place [41]. Nevertheless, little attention has been given to obstacles associated with actors and stakeholders involved in AM (e.g., psychological barriers for participation or paradigm shifts). To inform future AM schemes, we advocate considering how obstacles to technical and social components of AM may be addressed by building capacity in the AM framework and its processes from the start. Therefore, we see a need for increased transdisciplinary research to fully address the link between ecological and social systems. AM is an appealing framework as it is developed to handle uncertainty. However, AM of natural resources needs to be able to tackle ecological and social processes simultaneously to remain attractive in the toolbox for management on the road ahead.

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Declaration of interests

No interests are declared.

Supplemental information

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References

1. Holling, C.S. (1978) *Adaptive Environmental Assessment and Management*, John Wiley & Sons
2. Walters, C.J. and Holling, C.S. (1990) Large-scale management experiments and learning by doing. *Ecology* 71, 2060–2068

Outstanding questions

Can a stronger integration of research about AM and adaptive governance provide new insights to overcome obstacles to AM? Social science research of AM is increasing, and research on adaptive governance is steadily growing. However, more transdisciplinary approaches are needed where different scientific disciplines are better integrated.

What changes are needed in the governance system to prepare for future scenarios predicting profound changes in environmental conditions and unexpected events? Transdisciplinary research merging natural and social sciences is needed to strike a balance between flexibility needed for the AM process versus predictability and protection of habitats and species within the governance system.

Can we use critical trigger points in the legal framework to enable flexibility and at the same time retain predictability? In some management systems, critical trigger points are used to signal when to change direction in management (paradigm shifts). Similarly, such triggers alongside continuous reassessment could be included in the legal framework, but then improved knowledge is needed to find relevant trigger points and step-length for reassessments.

Can insights from TM help to overcome some of the obstacles to AM? The literature suggests that these two approaches in several aspects are similar, but that the pace of change in management actions is generally greater in TM. However, TM is a dark horse when it comes to management of natural resources, as it has evolved alongside interest to understand transitions of socio-technical systems, in particular energy systems.

How do the interpretations and reactions (e.g., emotions) of actors and stakeholders taking part in AM influence implementation? To find appropriate ways of improving AM, system knowledge needs to be complemented by knowledge of the actors and stakeholders involved in AM (e.g., psychological barriers for participation or paradigm shifts).

3. Allen, C.R. and Gunderson, L.H. (2011) Pathology and failure in the design and implementation of adaptive management. *J. Environ. Manag.* 92, 1379–1384
4. Westgate, M.J. *et al.* (2013) Adaptive management of biological systems: a review. *Biol. Conserv.* 158, 128–139
5. Johansson, J. *et al.* (2018) Inspired by structured decision making: a collaborative approach to the governance of multiple forest values. *Ecol. Soc.* 23, 1–11
6. Bunnefeld, N. *et al.* (2017) *Decision-making in Conservation and Natural Resource Management: Models for Interdisciplinary Approaches*, Cambridge University Press
7. Williams, B.K. *et al.* (2009) *Adaptive management: The U.S. Department of the Interior Technical Guide*, U.S. Dept. of the Interior, Adaptive Management Working Group
8. Perino, A. *et al.* (2022) Biodiversity post-2020: closing the gap between global targets and national-level implementation. *Conserv. Lett.* 15, e12848. https://doi.org/10.1111/conl.12848
9. Folke, C. *et al.* (2002) Resilience and sustainable development: building adaptive capacity in a world of transformations. *Ambio* 31, 437–440
10. Prins, H.H.T. (1999) The Malawi Principles: clarifications of the thoughts that underlay the ecosystem approach. In *Proceedings of the Norway/UN Conference on the Ecosystem Approach for Sustainable Use of Biological Diversity* (Schei, P.J. *et al.*, eds), pp. 23–30, Norwegian Directorate for Nature Management/Norwegian Institute for Nature ResearchTrondheim
11. Marjakangas, A. *et al.* (2015) *International Single Species Action Plan for the Conservation of the Taiga Bean Goose (Technical series No. 56), AEWA, Bonn, Germany*.
12. Madsen, J. *et al.* (2017) Implementation of the first adaptive management plan for a European migratory waterbird population: the case of the Svalbard pink-footed goose Anser brachyrhynchus. *Ambio* 462, 275–289
13. Cummings, J. *et al.* (2005) Adaptive restoration of sand-mined areas for biological conservation. *J. Appl. Ecol.* 42, 160–170
14. Nichols, J.D. *et al.* (2007) Adaptive harvest management of North American waterfowl populations: a brief history and future prospects. *J. Ornithol.* 148, 343–349
15. Richardson, S. *et al.* (2020) A systematic review of adaptive wildlife management for the control of invasive, non-native mammals, and other human–wildlife conflicts. *Mamm. Rev.* 50, 147–156
16. Gillson, L. *et al.* (2019) Finding common ground between adaptive management and evidence-based approaches to biodiversity conservation. *Trends Ecol. Evol.* 34, 31–44
17. Cash, D.W. *et al.* (2006) Scale and cross-scale dynamics: governance and information in a multilevel world. *Ecol. Soc.* 11, 1–12
18. IPBES (2019) *Global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services*, IPBES secretariat, Bonn, Germany
19. Fox, A.D. and Madsen, J. (2017) Threatened species to superabundance: the unexpected international implications of successful goose conservation. *Ambio* 46, 179–187
20. Meek, C.L. *et al.* (2011) Adaptive governance and the human dimensions of marine mammal management: implications for policy in a changing North. *Mar. Policy* 35, 466–476
21. Walther, G.R. (2010) Community and ecosystem responses to recent climate change. *Philos. Trans. R. Soc. B Biol. Sci.* 365, 2019–2024
22. Cammen, K.M. *et al.* (2019) Predator recovery, shifting baselines, and the adaptive management challenges they create. *Ecosphere* 10, e02579. https://doi.org/10.1002/ecs2.2579
23. Apollonio, M. *et al.* (2010) *European ungulates and their management in the 21st century*, Cambridge University Press
24. Chapron, G. *et al.* (2014) Recovery of large carnivores in Europe's modern human-dominated landscapes. *Science* 346, 1517–1519
25. Tyre, A.J. and Michaels, S. (2011) Confronting socially generated uncertainty in adaptive management. *J. Environ. Manag.* 92, 1365–1370
26. Gregory, R. *et al.* (2006) Deconstructing adaptive management: criteria for applications to environmental management. *Ecol. Appl.* 16, 2411–2425
27. Williams, B.K. and Brown, E.D. (2018) Double-loop learning in adaptive management: the need, the challenge, and the opportunity. *Environ. Manag.* 62, 995–1006
28. Sandström, A. *et al.* (2020) Adaptive capacity in different multi-level governance models: a comparative analysis of Swedish water and large carnivore management. *J. Environ. Manag.* 270, 1–9
29. Dreiss, L.M. *et al.* (2017) Adaptive management as an effective strategy: interdisciplinary perceptions for natural resources management. *Environ. Manag.* 59, 218–229
30. McFadden, J.E. *et al.* (2011) Evaluating the efficacy of adaptive management approaches: is there a formula for success? *J. Environ. Manag.* 92, 1354–1359
31. Dunning, K.H. (2016) Missing the trees for the forest? Bottom-up policy implementation and adaptive management in the US natural resource bureaucracy. *J. Environ. Plan. Manag.* 60, 1036–1055
32. Rist, L. *et al.* (2013) Adaptive management: where are we now? *Environ. Conserv.* 40, 5–18
33. Jacobson, S.K. *et al.* (2006) Understanding barriers to implementation of an adaptive land management program. *Conserv. Biol.* 20, 1516–1527
34. Schultz, C. and Nie, M. (2012) Decision-making triggers, adaptive management, and natural resources law and planning. *Nat. Resour. J.* 52, 443–521
35. Fabricius, C. and Cundill, G. (2014) Learning in adaptive management: insights from published practice. *Ecol. Soc.* 19, 1–8
36. Fischman, R.L. and Ruhl, J.B. (2016) Judging adaptive management practices of U.S. agencies. *Conserv. Biol.* 30, 268–275
37. Huitema, D. *et al.* (2009) Adaptive water governance: assessing the institutional prescriptions of adaptive (co-)management from a governance perspective and defining a research agenda. *Ecol. Soc.* 14, 1–19
38. Brownson, K. and Fowler, L. (2020) Evaluating how we evaluate success: monitoring, evaluation and adaptive management in Payments for Watershed Services programs. *Land Use Policy* 94, 1–14
39. Redford, K.H. *et al.* (2018) Assessment of the Conservation Measures Partnership's effort to improve conservation outcomes through adaptive management. *Conserv. Biol.* 32, 926–937
40. Dimmock, K. *et al.* (2014) Stakeholders, industry knowledge and adaptive management in the Australian whale-watching industry. *J. Sustain. Tour.* 22, 1108–1121
41. Fernández-Giménez, M. *et al.* (2019) Complexity fosters learning in collaborative adaptive management. *Ecol. Soc.* 24, 1–21
42. Johnson, F.A. *et al.* (2002) Conditions and limitations on learning in the adaptive management of mallard harvests. *Wildl. Soc. Bull.* 30, 176–185
43. D'Amato, A.W. *et al.* (2018) Evaluating adaptive management options for black ash forests in the face of emerald ash borer invasion. *Forests* 9, 1–17
44. Aronsson, M. and Persson, J. (2017) Mismatch between goals and the scale of actions constrains adaptive carnivore management: the case of the wolverine in Sweden. *Anim. Conserv.* 20, 261–269
45. Butler, J.R.A. *et al.* (2015) Evaluating adaptive co-management as conservation conflict resolution: learning from seals and salmon. *J. Environ. Manag.* 160, 212–225
46. Frohlich, M. *et al.* (2018) The relationship between adaptive management of social-ecological systems and law: a systematic review. *Ecol. Soc.* 23, 1–19
47. Ehrhart, S. and Schraml, U. (2018) Adaptive co-management of conservation conflicts – an interactional experiment in the context of German national parks. *Heliyon* 4, e00890. https://doi.org/10.1016/j.heliyon.20
48. Aceves-Bueno, E. *et al.* (2015) Citizen science as an approach for overcoming insufficient monitoring and inadequate stakeholder buy-in in adaptive management: criteria and evidence. *Ecosystems* 18, 493–506
49. Swaisgood, R. *et al.* (2011) Can science save the giant panda (Ailuropoda melanoleuca)? Unifying science and policy in an adaptive management paradigm. *Integr. Zool.* 6, 290–296

50. Tuvendal, M. and Elmberg, J. (2015) A handshake between markets and hierarchies: geese as an example of successful collaborative management of ecosystem services. *Sustainability* 7, 15937–15954
51. McLoughlin, C.A. *et al.* (2020) Reflexive learning in adaptive management: a case study of environmental water management in the Murray Darling Basin, Australia. *River Res. Appl.* 36, 681–694
52. Runge, M.C. (2011) An introduction to adaptive management for threatened and endangered species. *J. Fish Wildl. Manag.* 2, 220–233
53. Allan, C. and Watts, R.J. (2017) Revealing adaptive management of environmental flows. *Environ. Manag.* 61, 520–533
54. Koontz, T.M. *et al.* (2015) Adaptive institutions in social-ecological systems governance: a synthesis framework. *Environ. Sci. Policy* 53, 139–151
55. Gibbs, J.P. *et al.* (1999) Effective monitoring for adaptive wildlife management: lessons from the Galapagos Islands. *J. Wildl. Manag.* 63, 1055–1065
56. Fontaine, J. (2011) Improving our legacy: incorporation of adaptive management into state wildlife action plans. *J. Environ. Manag.* 92, 1403–1408
57. LoSchiavo, A. *et al.* (2013) Lessons learned from the first decade of adaptive management in comprehensive Everglades restoration. *Ecol. Soc.* 18, 1–11
58. Miles, J.P. (2013) Designing collaborative processes for adaptive management: four structures for multistakeholder collaboration. *Ecol. Soc.* 18, 1–8
59. Southwell, D.M. *et al.* (2016) Learning about colonization when managing metapopulations under an adaptive management framework. *Ecol. Appl.* 26, 279–294
60. Nie, M.A. and Schultz, C.A. (2012) Decision-making triggers in adaptive management. *Conserv. Biol.* 26, 1137–1144
61. Clark, D.A. and Slocombe, S. (2011) Adaptive co-management and grizzly bear–human conflicts in two Northern Canadian aboriginal communities. *Hum. Ecol.* 39, 627–640
62. d'Armengol, L. *et al.* (2018) A systematic review of co-managed small-scale fisheries: social diversity and adaptive management improve outcomes. *Glob. Environ. Chang.* 52, 212–225
63. Gardner, E. (2013) Adaptive management in the face of climate change and endangered species protection. *Ecol. Law Q.* 40, 229–270
64. Andréfouët, S. *et al.* (2018) Adaptive management for the sustainable exploitation of lagoon resources in remote islands: lessons from a massive El Niño-induced giant clam bleaching event in the Tuamotu atolls (French Polynesia). *Environ. Conserv.* 45, 30–40
65. Hagell, S. and Ribic, C.A. (2014) Barriers to climate-adaptive management: a survey of wildlife researchers and managers in Wisconsin. *Wildl. Soc. Bull.* 38, 672–681
66. Rumpff, L. *et al.* (2011) State-and-transition modelling for Adaptive Management of native woodlands. *Biol. Conserv.* 144, 1224–1236
67. Cundill, G. and Fabricius, C. (2009) Monitoring in adaptive co-management: toward a learning based approach. *J. Environ. Manag.* 90, 3205–3211
68. Camarretta, N. *et al.* (2020) Monitoring forest structure to guide adaptive management of forest restoration: a review of remote sensing approaches. *New For.* 51, 573–596
69. Craig, R.K. *et al.* (2017) A proposal for amending administrative law to facilitate adaptive management. *Environ. Res. Lett.* 12, 1–17
70. Wilson, D.C. *et al.* (2006) Cross-scale linkages and adaptive management: fisheries co-management in Asia. *Mar. Policy* 30, 523–533
71. Sims, K.R.E. *et al.* (2014) Improving environmental and social targeting through adaptive management in Mexico's payments for hydrological services program. *Conserv. Biol.* 28, 1151–1159
72. Hayes, R.D. *et al.* (2003) Experimental reduction of wolves in the Yukon: ungulate responses and management implications. *Wildl. Monogr.* 152, 1–35
73. Johnson, F.A. *et al.* (2015) Multilevel learning in the adaptive management of waterfowl harvests: 20 years and counting. *Wildl. Soc. Bull.* 39, 9–19
74. McGowan, C.P. *et al.* (2015) Implementation of a framework for multi-species, multi-objective adaptive management in Delaware Bay. *Biol. Conserv.* 191, 759–769
75. Jackson, S.T. (2021) Transformational ecology and climate change. *Science* 373, 1085–1086
76. Abrahms, B. (2021) Human-wildlife conflict under climate change. *Science* 373, 484–485
77. Bradford, J.B. *et al.* (2018) Anticipatory natural resource science and management for a changing future. *Front. Ecol. Environ.* 16, 295–303
78. Greener, I. (2005) The potential of path dependence in political studies. *Politics* 25, 62–72
79. Schultz, L. *et al.* (2015) Adaptive governance, ecosystem management, and natural capital. *Proc. Natl. Acad. Sci. U. S. A.* 112, 7369–7374
80. Buij, R. *et al.* (2017) Balancing ecosystem function, services and disservices resulting from expanding goose populations. *Ambio* 46, 301–318
81. Foxon, T. *et al.* (2008) Comparing adaptive management and transition management. *Ökologisches Wirtschaften - Fachzeitschrift* 2, 20–22
82. Loorbach, D. (2010) Transition management for sustainable development: a prescriptive, complexity-based governance framework. *Governance* 23, 161–183
83. Pahl-Wostl, C. (2007) Transitions towards adaptive management of water facing climate and global change. *Water Resour. Manag.* 21, 49–62
84. Folke, C. *et al.* (2010) Resilience thinking: integrating resilience, adaptability and transformability. *Ecol. Soc.* 15, 1–9
85. Polasky, S. *et al.* (2011) Decision-making under great uncertainty: environmental management in an era of global change. *Trends Ecol. Evol.* 26, 398–404
86. Anderies, J.M. *et al.* (2004) A framework to analyze the robustness of social–ecological systems from an institutional perspective. *Ecol. Soc.* 9, 1–17
87. Rist, L. and Moen, J. (2013) Sustainability in forest management and a new role for resilience thinking. *For. Ecol. Manag.* 310, 416–427
88. Montràs-Janer, T. *et al.* (2019) Relating national levels of crop damage to the abundance of large grazing birds: implications for management. *J. Appl. Ecol.* 56, 2286–2297
89. Bainbridge, I. (2017) Goose management in Scotland: an overview. *Ambio* 462, 224–230
90. Stroud, D. *et al.* (2017) Key actions towards the sustainable management of European geese. *Ambio* 46, 328–338
91. Tombre, I.M. *et al.* (2013) Towards a solution to the goose-agriculture conflict in North Norway, 1988-2012: the interplay between policy, stakeholder influence and goose population dynamics. *PLoS One* 8, e71912. https://doi.org/10.1371/journal.pone
92. Eriksson, L. *et al.* (2020) The public and geese: a conflict on the rise? *Hum. Dimens. Wildl.* 25, 421–437
93. Powolny, T. *et al.* (2018) *AEWA International Single Species Management Plan for the Greylag Goose (Anser anser) AEWA Technical Series No. 71. Bonn, Germany*.
94. Jensen, G.H. *et al.* (2018) *AEWA International Single Species Management Plan for the Barnacle Goose - Russia/Germany & Netherlands population, East Greenland/Scotland & Ireland population, Svalbard/South-west Scotland population. AEWA Technical Series No. 70. Bonn, Germany*.
95. Lefebvre, J. *et al.* (2017) The greater snow goose Anser caerulescens atlanticus: managing an overabundant population. *Ambio* 46, 262–274
96. Tombre, I.M. *et al.* (2022) Population control by means of organised hunting effort: experiences from a voluntary goose hunting arrangement. *Ambio* 51, 728–742
97. Fuentes, M.M.P.B. *et al.* (2014) Adaptive management of marine mega-fauna in a changing climate. *Mitig. Adapt. Strateg. Glob. Chang.* 212, 209–224
98. Gaylard, A. and Ferreira, S. (2011) Advances and challenges in the implementation of strategic adaptive management beyond the Kruger National Park – Making linkages between science and biodiversity management. *Koedoe* 53, 1–6
99. Haileslassie, A. *et al.* (2020) Changing agricultural landscapes in Ethiopia: examining application of adaptive management approach. *Sustainability* 12, 1–19

100. Yousefpour, R. *et al.* (2012) A review of decision-making approaches to handle uncertainty and risk in adaptive forest management under climate change. *Ann. For. Sci.* 69, 1–15
101. Stankey, G.H. *et al.* (2003) Adaptive management and the northwest forest plan rhetoric and reality. *J. For.* 101, 40–46
102. Stringer, L.C. *et al.* (2006) Unpacking "participation" in the adaptive management of social–ecological systems: a critical review. *Ecol. Soc.* 11, 1–22
103. Enck, J.W. *et al.* (2006) Integrating ecological and human dimensions in adaptive management of wildlife-related impacts. *Wildl. Soc. Bull.* 34, 698–705
104. Allan, C. and Curtis, A. (2005) Nipped in the bud: why regional scale adaptive management is not blooming. *Environ. Manag.* 36, 414–425
105. Moore, C.T. *et al.* (2011) Adaptive management in the U.S. National Wildlife Refuge System: science-management partnerships for conservation delivery. *J. Environ. Manag.* 92, 1395–1402
106. McDonald, J. and Styles, M.C. (2014) Legal strategies for adaptive management under climate change. *J. Environ. Law* 26, 25–53
107. Tompkins, E.L. and Adger, W.N. (2004) Does adaptive management of natural resources enhance resilience to climate change? *Ecol. Soc.* 9, 1–14
108. Williams, B.K. (2011) Adaptive management of natural resources—framework and issues. *J. Environ. Manag.* 92, 1346–1353
109. Islam, M.W. *et al.* (2019) Tourism governance in protected areas: investigating the application of the adaptive co-management approach. *J. Sustain. Tour.* 26, 1890–1908
110. Williams, B.K. (2011) Passive and active adaptive management: approaches and an example. *J. Environ. Manag.* 92, 1371–1378