ASSESSMENT OF THE STAKEHOLDER ENGAGEMENT AND MONITORING STAGES IN THE ADAPTIVE MANAGEMENT OF A NATIONAL FOREST IN WESTERN COLORADO, USA

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ABSTRACT
Adaptive management (AM) is often defined as a structured and iterative process of 'learning by doing' to reduce social-ecological uncertainty and improve decision-making. The use of AM for managing natural resources has become increasingly popular since it was conceptualised in the late 1970s. Research has emphasised the need to increase the documentation and publication of AM implementation cases. Our study focuses on the following case, however the lessons learned, and recommendations are broadly applicable. In 2016, the United States Forest Service (USFS) implemented a novel AM programme known as the Spruce Beetle Epidemic and Aspen Decline Management Response (SBEADMR) in response to a destructive spruce beetle outbreak and sudden aspen decline occurring on national forests in western Colorado. Federal land agencies, including the USFS, have increasingly institutionalised AM. This study focuses on two critical stages of the AM method: stakeholder engagement and monitoring and evaluation (M&E). These stages are necessary for facilitating social and technical learning, essential ingredients for adaptively managing natural resources successfully. Despite the importance of these two stages, their inadequate implementation is often highlighted as a main cause of failure in AM applications. We compared the SBEADMR–AM's stakeholder engagement and M&E processes to good practices, challenges and pitfalls reported in literature. Various methods were used to gain knowledge on the SBEADMR: extensive review of SBEADMR documentation, in-depth interviews and participation in a stakeholder meeting. Our analysis detected numerous strengths as well as multiple areas in need of improvement or additions to the process for both AM stages. The findings provide useful insight for policy formulation and refinement in new and ongoing AM initiatives.
Keywords: adaptive management, forest management, stakeholder engagement, monitoring, evaluation, policy, decision-making.

1 INTRODUCTION

Adaptive management (AM) is an increasingly popular decision-tool for filling knowledge gaps, reducing uncertainty, and linking science with policy and implementation in the arena of social-ecological management [1]–[4]. Two stages in the AM approach of particular importance for ensuring a successful AM implementation are: (a) the process of stakeholder engagement; and (b) monitoring and evaluation (M&E) of the progress and lessons learned [1], [4]–[9]. Despite this importance, inadequate stakeholder engagement and M&E are reported as common sources of failure in AM efforts [3], [5], [9]–[11]. Aceves-Bueno et al. [5] found that poor application of these two stages are often the most reported sources of failure in AM. Multiple authors point out that there is a need to enrich the information and the body of knowledge on experiences and lessons learned on the real-world application of AM to improve future AM outcomes [6], [8], [12], [13]. This information will provide a better understanding of AM and facilitate more institutions and practitioners to be confident in using AM with its benefits and strengths.

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On one hand, flexible, transparent and inclusive stakeholder engagement and decision making that involves the relevant stakeholders enables managers to incorporate diverse concerns and priorities, as well as to capture local/traditional social-ecological knowledge and values that are important in the set up and iterative stages of the AM processes [1], [6], [14], [15]. Among other benefits include increasing ecological literacy of stakeholders, building trust and support, and reversing the trend of top-down and centralised planning and decision-making which has often led to adverse ecological outcomes [6], [15], [16]. On the other hand, a well-designed and appropriately applied M&E plan informs managers and stakeholders about the efficacy of management actions in relation to their management objectives, resource status and trends, and emergence of diverse issues in the development of each of the stages of the AM approach [1], [17]–[19]. With this information, M&E helps to increase transparency and accountability as well as determine the accuracy of predictive models [1], [17]. Both stakeholder engagement and M&E have the power to facilitate learning, reduce uncertainty and improve decision-making over time.

All these findings in previous AM studies led us to concentrate our study in the analysis of the AM critical stages of stakeholder engagement and M&E in a study case of an ongoing AM approach for the management of the forests in western Colorado. To our knowledge, the documentation and analysis of this project has not been done to date with the risk of losing important experiences and lessons that would benefit AM practitioners and institutions.

Our study case is the AM approach followed in the Spruce Beetle Epidemic and Aspen Decline Management Response (SBEADMR) programme developed by the United States Forest Service (USFS) in the Grand Mesa, Uncompahgre and Gunnison (GMUG) national forests in western Colorado. The purpose of this paper is to document and analyse the experiences and lessons learned in this ongoing AM implementation by answering the following question: How well are the stakeholder engagement and M&E stages conducted in the SBEADMR AM approach when compared with best practices, common challenges and other experiences reported in the AM literature? With this analysis, we aim to inform the SBEADMR programme and others modelled after it, educate resource managers, scientists, policymakers, and stakeholders that are involved in starting or carrying out these two critical stages of the AM approach, and contribute to the body of knowledge and reported experiences regarding the implementation of the AM approach for the management of natural resources in the U.S. and around the world.

2 BACKGROUND ON AM

2.1 Defining AM

The first mention of AM in the context of natural resource management was in the late 1970s in the book *Adaptive Environmental Assessment and Management* [20]. Since then, it has been applied in multiple natural resources management contexts such as forest, rangeland, wildlife harvest and watershed management. AM is often defined as a structured and iterative process of learning by doing and adapting based on what is learned to reduce uncertainty across multiple types of scales (e.g., spatial, temporal, jurisdictional and institutional) facilitating the movement towards the achievement of desired management outcomes [1], [21]–[25]. However, there have been varied definitions of AM and few examples of successful implementations. Some authors report that this lack of consensus and successful case studies has led to confusion on what exactly AM is, how it should be applied and what are the essential elements for success [4], [21], [22], [26], [27].

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When conducted properly, the main promises of AM are an increase in information flow and knowledge acquisition rates to reduce uncertainty and the provision of opportunities for formulating shared understandings [9]. Often AM is misinterpreted as a process of trial and error. In strong contrast with this approach, AM incorporates clearly defined goals and objectives and a well-structured iterative process for decision making that typically incorporates the following steps as shown in Fig. 1: defining the problem, identifying objectives, developing models to predict outcomes, deciding on management actions, implementing the decisions, monitoring and evaluating the outcomes, and adjusting management actions based on what is learned [1], [21], [22], [24].

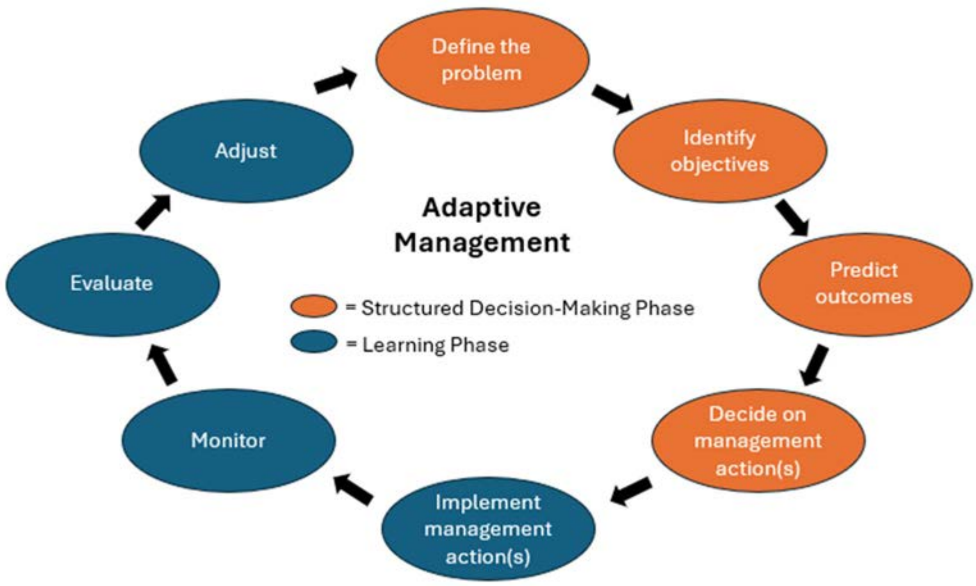

Figure 1: AM framework. *(Source: Adapted from Allen et al. [21].)*

2.2 Uncertainty and learning in AM

Research has found that AM is best suited to be used in situations when there are high levels of both uncertainty and social-ecological controllability since this management approach rests on the belief that resources will respond to management actions and that the results of these actions are not known [21]. AM is driven by learning between managers, scientists and relevant stakeholders [18]. As more loops of learning are completed, uncertainty decreases and decision-making becomes more informed as management outcomes become increasingly predictable [8]. Learning through the use of AM can help to mitigate impacts from global problems such as climate change by reducing uncertainties [21], [28], [29]. There are four common sources of uncertainty in environmental management: (1) environmental variation (e.g., climate variability); (2) partial observability (e.g., limited monitoring); (3) partial controllability (e.g., regulations); and (4) structural or process uncertainty (e.g., lack of understanding or agreement about ecological relationships) [1]. Within the context of AM, structural uncertainty is given a special emphasis [1].

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Learning occurs in AM by conducting management experiments aimed at enhancing knowledge about ecosystems and comparing the predicted outcomes of these experiments and other factors with actual outcomes through M&E [8], [11], [30]. However, learning can also occur through the participation of stakeholders in forums such as stakeholder meetings, workshops and other similar forms of deliberation [4], [15]. What is learned within these technical and social mediums serves as the foundation for future changes in management and policy and thus, helps to link science with policy and implementation which has remained a problem in many conventional natural resources management approaches [4], [31], [32].

If the activities of stakeholder engagement and M&E are well-designed and conducted, AM can facilitate a 'double loop learning' in which participants learn about: (a) the effects of the management treatments applied to the system under management (technical and scientific issues); and (b) the AM process itself (socio-cultural, planning and managerial issues) [1], [4], [7]. This level of learning is central to AM due to its power to answer management questions that reduce uncertainty at multiple spatial, temporal, jurisdictional and institutional scales which ultimately optimises management decisions over time. From the previously mentioned literature, it is evident that stakeholder engagement and M&E are important tools for facilitating social and technical learning to ensure successful applications of AM.

2.3 AM in the USFS

AM was first utilised in the USFS in 1994 in the 10-million-hectare Northwest Forest Plan in response to over harvesting of the old-growth forests which serve as habitat for endangered wildlife such as the Northern Spotted Owl (*Strix occidentalis caurina*) [33], [34]. Lessons learned from over 25 years of applying AM in this plan are collaboration amongst stakeholders is key for achieving social-ecological goals and objectives, M&E in AM is vital for learning at multiple scales and for minimising uncertainty, AM can be costly, and that the plan is not adequately addressing climate change, wildfires, trade-offs and social values [33], [35]. The plan has been deemed a success in conserving old-growth forests and wildlife as originally intended [35]. Since then, AM has become further institutionalised within the USFS. For example, there is now a unit in the USFS known as the Adaptive Management Services Enterprise Unit (AMSET). This unit is currently comprised of 30 employees who are dedicated to support AM implementations through offering specialised services including, but not limited to, stream restoration planning, evaluation and reporting of fuel treatment effectiveness, support for ecosystem assessments and planning, meeting facilitation and note taking, and website design and maintenance [36].

Other forms of institutionalisation include the modification of key agency rules and regulations. For example, the most recent planning rule known as the 2012 Forest Planning Rule emphasises the use of best available scientific information and adaptive approaches more than any previous planning rule implemented by the USFS [37]. This rule sets out an AM framework of monitoring, assessment and revision for national forest plans.

The USFS is currently in a broad shift from conventional to more collaborative governance approaches. As a result, collaborative AM projects have emerged, especially through the Collaborative Forest Landscape Restoration Program (CFLRP) as illustrated by projects detailed in papers and reports by Schultz et al. [38], Butler and Esch [39] and Markus et al. [40]. The CFLRP is unique in the context of U.S. public land management as it requires collaboration throughout the planning and implementation of its projects on national forest lands [38]. Researchers have reported numerous challenges and benefits generated by the element of collaboration in participatory forms of AM in the CFLRP [41]–[43].

3 BACKGROUND ON STAKEHOLDER ENGAGEMENT AND M&E

3.1 Stakeholder engagement in AM

Allowing a wide range of stakeholders to come to the table in AM helps to improve the effectiveness of the management approach. The following list is not comprehensive but provides commonly reported benefits of engaging stakeholders in AM: capturing local and indigenous knowledge, increasing social learning, improving scientific understanding of social-ecological systems amongst stakeholders, building support and stakeholder–stakeholder and stakeholder–managerial relationships, reducing conflict, conducting monitoring and assessment, discovering new ways for stakeholders to participate, identifying issues and questions for evaluating AM, challenging paradigms, improving trust and communication, diversifying the overall information input, leveraging resources, boosting morale and investment, generating creative ideas and solutions, enhancing stakeholder empowerment, altering norms and beliefs of stakeholders, and ensuring that the management objectives and models represent the stakeholders' priorities, issues and concerns [6], [15], [16], [18], [43]–[47].

These benefits provide a variety of services to the AM process. For instance, benefits such as improving trust are important for managing conflict and, thus, reaching and implementing decisions in AM [15]. Good communication with stakeholders and providing them with power can better ensure continued support and involvement in adaptive resource management [48]. Further, increasing social learning enables the opportunity for altering relationships which possesses the ability to increase appreciation of diverse views amongst participants and formulate new ways to facilitate teamwork [6]. Lastly, capturing local/ indigenous knowledge aids managers in AM by providing valuable information about social-ecological systems and management strategies that are traditionally absent from mainstream scientific information [15].

An often-cited root of failure in AM is the lack of adequate stakeholder engagement (e.g., insufficient coordination, discounting non-scientific forms of knowledge, not paying sufficient attention to processes that help achieve shared understandings, lack of transparency, not learning with stakeholders, etc.) [3], [9], [11], [13], [44], [49]. This is generally due to institutional barriers such as a lack of expertise and training in multi-stakeholder collaboration, limited learning capacity and reluctant managers [11], [13], [44], [50]. The failure to conduct stakeholder engagement appropriately can hinder progress and undermine a project as well as impede the ability to conduct management experiments that are crucial for learning [11], [44]. For instance, without directly involving stakeholder in AM, they can become disappointed in management decisions, file lawsuits, and refuse to provide support for a project [11]. There is a need for new policies and strategies that enable and facilitate successful engagement of stakeholders in AM.

3.2 M&E in AM

According to Williams [1], M&E serves four key purposes in AM: (a) to assess how well goals are being met; (b) to gauge the current state of resources and decide on the right management actions; (c) improve understanding of how resources change by comparing predictions with actual data; and (d) to update and enhance models of resource dynamics as necessary. M&E enables managers and stakeholders to obtain a better scientific understanding of resource dynamics and management effectiveness. With this improved understanding, management and policy can be adjusted accordingly in an iterative learning

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process [1], [11], [18]. M&E also helps to address the challenge of non-stationarity (constant change) in social-ecological systems by tracking and assessing environmental and socio-cultural-economic drivers of change [1].

Inadequate M&E due to legal and institutional constraints and limitations on financial, human, and technical capacity tends to be a common source of failure in many AM efforts [5], [11], [18], [44], [51]–[54]. Poor M&E leads to a slower rate of learning and misleading data that misinforms management and can be counterproductive. AM cannot be used without the use of well-funded and effective M&E schemes as they are critical for fostering learning and reducing uncertainty [18].

4 CASE STUDY: THE AM APPROACH IN THE SBEADMR

The novel SBEADMR programme was developed by the USFS in the GMUG National Forest unit in western Colorado in 2013 and started operations in 2016. Its main goal is to address an outbreak of spruce beetle (*Dendroctonus rufipennis*) and the sudden aspen decline (SAD) by learning about dynamics related to spruce and aspen regeneration following various disturbances [55]. In the intermountain west of the U.S., SAD is causing quaking aspen trees (*Populus tremuloides*) to decline at a rapid rate and is, therefore, leading to large-scale mortality in aspen stands and landscapes [56]. Likewise, spruce beetle outbreaks are occurring in the intermountain west in areas like the Southern Rocky Mountains [57]. The outbreaks typically kill off numerous acres of spruce tree stands. In the GMUG National Forest unit, over 300,000 acres of Engelmann spruce (*Picea engelmannii*) stands and 230,000 acres of aspen stands have been affected as of 2017, which is approximately 40% of the spruce and aspen stands in the forest.

The SBEADMR AM will be applied over 8–12 years, and it has a three-pronged purpose: (a) to enhance the resilience of at-risk trees to the outbreaks; (b) to increase public safety through minimising the risks of falling trees that have been affected by mortality; and (c) to treat affected stands via recovery of salvage timber and restoration of forest conditions [58]. The trifold purpose was adapted from the USFS's western bark beetle strategy [59]. The programme plans on treating a total of 120,000 acres (60,000 for commercial and 60,000 for non-commercial purposes). Two new programmes known as the Taylor Park Vegetation Management Project and Wilder Highlands Mountain Pine Beetle Response have been modelled after the SBEADMR.

The stakeholders involved in the SBEADMR are composed of staff from state forest management agencies, forest loggers and processors, local counties, fish and wildlife groups, community at large representatives, environmental conservation groups, and groups with interests in water resources, recreation and education [60]. Each stakeholder group brings to the process their own unique values and perspectives which often leads to conflict for decision-making. To our knowledge, our study is the first one that has critically analysed the SBEADMR AM model.

4.1 The SBEADMR AM approach

The SEADMR has carefully designed a strong group of interdisciplinary project teams composed of scientists, decision-makers, subject matter specialists and local stakeholders. There are four different project teams that play active roles in guiding and assessing the SBEADMR AM approach: (1) Science Team: Is composed of scientists from various institutions including the Rocky Mountain Research Station, Colorado Parks and Wildlife, Colorado State University, Western Colorado University and Colorado Forest Restoration Institute; (2) Forest Leadership Team: Consists of various decision-makers from the USFS (e.g., forest supervisors, district rangers, etc.) and resource specialists; (3) Adaptive Management Group: Is a citizen-based and cross-sector collaborative group that is composed of a wide array of representatives of stakeholder groups (e.g., recreation, education, fish and wildlife, etc.). This group also operates an M&E subcommittee with similar composition to the Adaptive Management Group; and (4) Interdisciplinary Team: Made up of subject matter specialists from various disciplines.

The SBEADMR AM process can be illustrated through its structured and iterative 'plan, do, check and act' loop (Fig. 2). In the first phase of the loop, 'plan', the NEPA decision is consulted for direction on priorities for treatments, design features and other parameters surrounding implementation. Afterwards, forest treatments are selected through the consideration of best-available science and input given at the mid-winter meeting, an annual field trip, off-season workshop and the 30-day informal public comment period. Stakeholders and the public can participate in the meetings, workshops and comment period along with field trips where they can perform their own evaluation on one treatment annually.

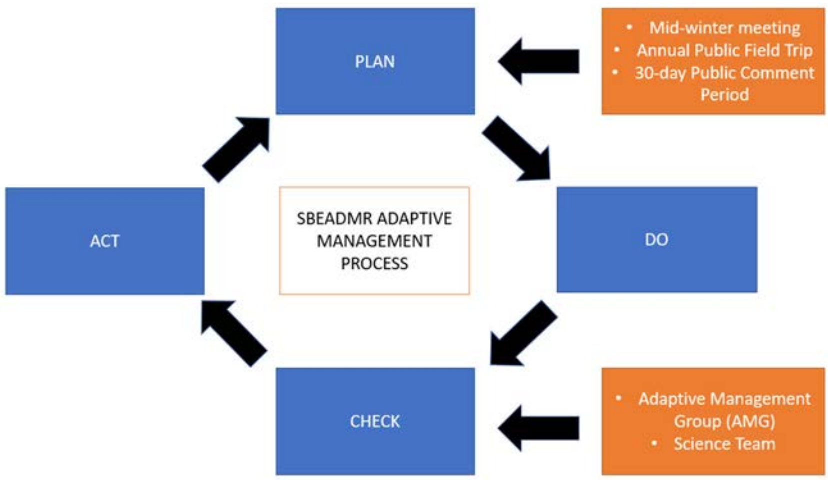

Figure 2: SBEADMR AM process. *(Source: Speas [61].)*

SBEADMR staff seeks specific comment and recommendations from stakeholders related to monitoring parameters, topics and questions, selection and scheduling of treatments, types and locations of planned treatments, information useful for treatment planning (e.g., cultural resource information, presence of species, etc.), design features, operational elements (e.g., stakeholder conflict), and conformance with environmental regulations and forest management plans [62]. The forest treatment plans prepared in this phase detail the layout, design features and monitoring requirements. Finally, field surveys for treatments and finalisation of the treatment design checklist are completed.

The Interdisciplinary Team identifies appropriate design features and implements the treatments during the 'do' phase. The pre-treatment design checklist is also implemented during this phase which is a tool used by the Interdisciplinary Team to ensure that all required surveys and compliance checks have been carried out in accordance with the SBEADMR final environmental impact assessment and GMUG forest management plan. Changes to the checklist are relayed to stakeholders through the SBEADMR annual report.

The Adaptive Management Group and Science Team are involved in the 'check' phase by conducting a formal post-treatment review led by the Interdisciplinary Team, implementation and effectiveness monitoring and the development of an annual report of findings. The Science Team also interprets the data for stakeholders. The Adaptive Management Group monitoring committee was appointed to monitor: (a) community understanding and engagement; (b) socio-economic data and impacts; (c) the AM process and outcomes; and (d) scientific studies and collaborative monitoring efforts [60]. The committee meets with the Science Team and Forest Leadership Team to jointly discuss ways to achieve these objectives and relays information to the Adaptive Management Group regularly.

Lastly, the Forest Leadership Team was appointed by the USFS to review monitoring data and recommendations in the annual findings report through a formal 'management review'. Results and feedback are used to develop proper and informed actions to improve environmental outcomes or administrative processes during the 'act' phase. The process loop is completed once per fiscal year and then it is repeated to reduce social-ecological uncertainty and make more informed decisions over time.

5 ANALYSING THE SBEADMR AM APPROACH

The best practices, successful experiences, challenges and impediments reported in previous relevant reports and literature were used to compare them against the SBEADMR's experiences and approach within the context of stakeholder engagement and M&E to analyse its efficacy. This comparative analysis allowed us to identify good practices and needs for improvement in the SBEADMR AM approach. To obtain information for these comparisons, we carried out three activities. First, we extensively reviewed documentation specific to AM in the SBEADMR, through conducting searches on the official SBEADMR NEPA web page, the Colorado Forest Restoration Institute and the Public Lands Partnership website and went over relevant documents that were obtained from the SBEADMR facilitator, scientists and management staff.

Second, we participated in the annual all-day SBEADMR stakeholder meeting held on 27 February 2020 in the city of Montrose, Colorado to acquire additional documentation and consult attendees to obtain insight for better assessing the characteristics of the stakeholders' collaboration and M&E activities. Attendees included the public, stakeholders, USFS staff, SBEADMR Adaptive Management Group members and the Science Team.

Third, we conducted semi-structured interviews with a USFS employee from the GMUG National Forest and an independent scientist from the Science Team. All subjects have multiple years of experience with the SBEADMR. These interviews allowed us to garner expert-level knowledge and perspectives from key and experienced members of the SBEADMR AM programme regarding the efficacy of the programme's stakeholder engagement and M&E schemes.

6 RESULTS OF THE ANALYSIS OF THE STAKEHOLDER ENGAGEMENT IN THE SBEADMR

6.1 Stakeholder engagement in the SBEADMR: Good practices

The stakeholder engagement activities in which the SBEADMR AM matches best practices or successful AM applications are numerous and they include: (1) using stakeholder assessment reports [63]; (2) using a stakeholders' advisory group [48]; (3) consulting with stakeholders groups and the general public multiple times per year [48]; (4) restating AM policy periodically to stakeholders using ‘layman terms’ [48]; (5) using multiple digital information channels to engage stakeholders [64]; (6) informing promptly about changes in funding [48]; (7) bringing managers and stakeholders together to evaluate new information [65]; (8) developing shared goals and measurable objectives [65]; (9) empowering stakeholders by providing them with access to be heard, legitimate standing, and opportunity to influence [46]; (10) using highly skilled facilitation [66], [67]; (11) engaged stakeholders in the planning phase and offering opportunities for stakeholder participation early and throughout the AM implementation cycle [18], [48], [67]; (12) giving stakeholders the technical capacity to engage meaningfully [67]; (13) the scope, management alternatives and objectives were identified in collaboration with stakeholder groups [18]; (14) communicating stakeholder roles and responsibilities clearly [15], [18]; (15) using traditional in-person consultations with stakeholders (e.g., meetings, workshops, etc.) [68]; (16) using field trips [69]; (17) involving citizens in M&E [5]; (18) incorporating scientists committed to transparency by attending meetings and field trips regularly and are well-versed in sharing complex scientific information to a general audience (e.g., university professors) [70]; (19) using well-defined joint fact-finding protocols [71]; (20) integrating participatory modelling exercises [72]–[74]; (21) produced a Memoranda of Understanding [42]; (22) allowing for stakeholders to assist in the design of collaborative processes [49]; (23) clear objectives for the participatory process was agreed upon by stakeholders at the outset [67]; (24) developed a chartering document that provides details on the timing and sequence of actions and who is responsible for those actions using ‘will/shall’ language (e.g., Appendix E of the SBEADMR EIS) [42]; (25) using small group activities (e.g., poster board sessions) [15]; (26) using a wide variety of involvement methods [15]; (27) encouraging participation (e.g., public announcements for meeting via social media and newspapers) [18]; and (28) embracing shared learning [65].

6.2 Stakeholder engagement in the SBEADMR: Areas to consider for improvement

The areas in which the SBEADMR’s stakeholder engagement would benefit from improvements are few and include: (1) incentivise and engage omitted stakeholders (e.g., groups with interest in fire, tribes, etc.) [48], [49], [67]; (2) improve accessibility to all SBEADMR documentation particularly in its USFS website [15], [75]; (3) have more staff support to update and maintain the USFS website [75]; (4) work on avoiding stakeholder burn out due to the large demands on their time for forums and potential commitments to other projects in the region [53]; (5) document issues, questions, agreements and different points of view throughout the process to address the complexity of putting up to speed stakeholders that join the programme at different times [47]; (6) incorporate information monitoring software [64]; and (7) lack of common definitions and understanding regarding certain language (e.g., ‘resilience’) [70].

7 RESULTS OF THE ANALYSIS OF M&E IN THE SBEADMR

7.1 M&E in the SBEADMR: Good practices

The match between the activities in the SBEADMR M&E process and best practices for success reported in the AM literature are numerous and include: (1) citizens are incorporated into M&E activities and data interpretation for management [5]; (2) multiple parties and diverse interests are integrated into the M&E process [17], [54], [76], [77]; (3) the monitoring plan encompasses biophysical as well as socio-economic criteria and indicators [18], [54],

[78]; (4) control management areas are used to assess effectiveness of management treatments [79]; (5) monitoring data was collected before the application of management treatments [79]; (6) decision-making triggers and bench marks have been incorporated into the M&E process [26], [80]; (7) clear commitment of the SBEADMR managers to use M&E data in policy design and programme development (e.g., annual management review) [18], [54], [81]; (8) the M&E is modified as necessary based on new information generated through results and feedback [81]; (9) a neutral third-party is responsible for collecting and analysing data [70]; (10) indicator selection is conducted with stakeholders [82]; (11) the AM process and outcomes are monitored [17], [78]; (12) the costs of monitoring are accounted for [81]; (13) the procedures for how monitoring data will be used for making decisions are transparent and publicly accessible [54]; (14) secondary data is utilised when available (e.g., satellite imagery) [54]; (15) clear objectives for the monitoring have been established [78]; (16) annual monitoring reports are developed [83]; and (17) there is a person passionate and committed to high quality M&E in the SBEADMR programme [11], [18], [84].

7.2 M&E in the SBEADMR: Areas to consider for improvement

The areas the SBEADMR M&E process can consider for improvement based on what is reported in the AM literature as best practices and successful AM application include: (1) create a centralised location (e.g., new website operated by an external party) to share monitoring results for evaluation [47]; (2) increase, if possible, external funding for M&E due to uncertainty surrounding future budgets in the USFS and to capture additional data [44], [52], [53]; (3) develop a conceptual model for a more robust M&E of impact on Canada lynx (*Lynx canadensis*) and their prey [34], [84]; (4) periodically ensure that all monitoring information and reports are easily accessible to interested parties through better archiving practices [54], [82], [83]; and (5) accelerate development of indicators and methods for aspects of the social-economic M&E plan such as stakeholder engagement [85], [86].

8 DISCUSSION

The results of our study support suggestions and best practices reported in the AM literature, including studies such as Knight et al. [87] suggesting that AM works best when non-scientific knowledge is incorporated into the design and modelling of management practices, social-ecological and economic knowledge and interests are included, there is continuous communication and an institutional commitment to learning, data from management experiments is used to inform decision-making, and there is strong leadership. Also, the partnerships in the SBEADMR confirm Bulkan et al.'s [88] findings that community-based forestry groups play a significant role in providing resources and the extra capacity that government agencies lack. These groups like the Colorado Forest Restoration Institute are redefining the role that local actors and institutional collaborations can play in U.S. federal forest management.

The forest management goals of the SBEADMR are critically important particularly in the context of rapidly changing ecological conditions brought in part by climate change. As a result, there is a need for more proactive and comprehensive approaches that use management tactics like monitoring to inform AM [89]. Our study on the SBEADMR adaptive vegetation management approach provides beneficial insights for actors involved in forests conservation and seek to manage them actively and adaptively.

Insect infestations like the ones present in the area managed by the SBEADMR cause ecological (e.g., reduced carbon storage), economic (e.g., bark beetle killed timber) and social (e.g., aesthetic loss) impacts. These infestations are expected to increase in response to

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climate change. As a result, natural resource managers will be challenged when managing these phenomena and facilitating recovery of impacted landscapes.

The case study of the SBEADMR is a notable example of the best management practices recommended by Pacheco-Aquino and Duran [90] to address bark beetle management through incorporation of more holistic, participatory, and adaptive strategies. Our study helps to fill the gap mentioned by these authors and Cottrell et al. [91] regarding literature on institutional dynamics and experiences with adaptive approaches in the context of bark beetle management. Additionally, our findings provide much needed insights into the human dimensions of forest management as pointed out by Bulkan et al. [88].

From our analysis, we detected that the programme is integrating the following policy recommendations proposed by Hlásny et al. [92] to address bark beetle outbreaks: maintaining multi-stakeholder dialogue, communicating management responses to the public, and sharing data (although this area could use some improvement). As stated by several scholars and illustrated by the SBEADMR, continuous dialogue and organisation among stakeholders can generate a sense of shared ownership and responsibility and thus promote collective monitoring and decision-making. Our findings support the view that stakeholder collaboration, when conducted properly, generates positive feedback that can mobilise resources needed for facilitating management operations and increasing comprehensive input, trust, and rapport.

Our findings indicate that the SBEADMR is integrating many stakeholder engagement and M&E best practices and dealing with some impediments and challenges reported in the AM literature. As such, the SBEADMR is an insightful and beneficial example of successful practices as well as pitfalls and challenges to avoid for engaging stakeholders and M&E in AM. This insight is well needed as many managers are not adequately trained or possess much expertise regarding the design and implementation of the two stages in AM.

Future research should incorporate structured interviews with a larger diversity of actors of the AM programme to understand what they perceive as the most and least effective elements of the collaboration and M&E processes. Additionally, carefully designing and applying surveys with stakeholders to obtain their level of satisfaction on the M&E and stakeholder engagement process using a Likert scale can potentially be a source of quantitative data that would improve the informational value of the research.

9 CONCLUSIONS

As the complexity and uncertainty of socio-ecological systems such as forests increase, the need and popularity of AM approaches are likely to increase also. Poor collaboration with stakeholders and M&E practices has led to failure in AM applications in the past, therefore, it is imperative that current and future efforts properly design and facilitate these two stages to ensure success. Our analysis contributes to addressing the need to document previous experiences and lessons learned in implementing AM approaches. This information enhances institutions and practitioners' confidence in using this management approach. Well-designed AM has the potential to facilitate proactive management of complex social-ecological systems, answer desired management questions, and reduce uncertainty across multiple spatial, temporal, jurisdictional, and institutional scales.

The strengths and good practices implemented in the SBEADMR AM approach can (but are not limited to) increase rapport and trust amongst stakeholders, ensure accountability, foster interactions between scientists, managers, and stakeholders, increase stakeholder buy-in, maximise information flow, build support, enhance transparency, create resilience in the face of staff and participant turnover and, most importantly, facilitate learning and improve decision-making. Depending on the specific social-ecological context of an AM programme, not every single good practice discussed in this paper will be relevant or feasible. Further, the detected areas for improvement provide insight to AM practitioners on what should be avoided when designing and implementing an AM initiative. The SBEADMR specifically and those currently modelled after it, and more broadly, current, and future AM practitioners in the U.S. and abroad can learn from the experiences and issues identified in our study.

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