Coconstruction of Ecosystem Services Management in Tribal Lands: Elicit Expert Opinion Approach[✉]

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ABSTRACT

The Mescalero Apache Tribal Lands (MATL) provide a diverse range of ecosystem services, many of which are of fundamental importance for the Mescalero Apache Tribe's well-being. Managing forests on MATL, especially under climate change, involves prioritizing certain ecosystem services. We used an iterative survey of experts' opinions to identify those ecosystem services that 1) have high utility—services that the Tribe uses, or could use, and are obtained directly or indirectly from the MATL; 2) are irreplaceable—services that cannot be provided by any other natural resource; and 3) are under a high level of threat—services at risk of declining or being lost directly or indirectly by climate change and thus are critical for management. Both scientists and practitioners identified water and cultural services as management priorities. Management recommendations to mitigate and adapt to climate change effects include reintroduction of fire in the landscape, assisted migration, creation of age/size mosaics across the landscape, and incorporation of green energy. Incorporating human perspectives into natural resource management is a critical component to maintain and adapt social–ecological systems to climate change, especially for Indigenous communities with inherent rights of sovereignty who are deeply connected to natural resources. This study demonstrates how knowledge systems are complementary: diverse perspectives related to values and threats of ecosystems can be incorporated to coconstruct ecosystem management decisions.

1. Introduction

The diverse and unique ecosystems of the southwestern Sky Islands (Fig. 1), including the Sacramento Mountains—homeland of the Mescalero Apache Tribe in southern New Mexico—are threatened by rapid warming (Misztal et al. 2013). These islands of forested mountain ranges surrounded by deserts are habitat for numerous species of plants and animals (McLaughlin 1994; Felger and Wilson 1994). The unique assemblage

of plants and animals is the result of genetic adaptations of the species to climate: hotter and drier at lower elevation and cooler and wetter at higher elevation (Lowe 1961). Abrupt changes in these climatic patterns can result in species maladaptation (Urban 2006). Because of the isolation, climate change projections of warming and drying make the endemic species that inhabit the southwestern Sky Islands particularly vulnerable to climate change. The increase in average temperatures is already moving vegetation species upward in elevation or reducing their viable distribution (Brusca et al. 2013) as well as changing the life cycle of insects and parasites (Bale et al. 2002). The longer pest pressure due to lengthened growing seasons and increased number of generations per year over host plants (Waring et al. 2009), as well as the increase of temperature extremes and the decrease of average precipitation and snowfall,

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FIG. 1. Sky Islands are isolated forested mountain ranges in the southwestern U.S. regions and northern Mexico surrounded by deserts. Sky Islands support high biodiversity and are known for their remarkable levels of endemic species. The Sacramento Mountains Sky Island is shaded, and the MATL boundary is superposed.

may cause widespread vegetation mortality. Mortality risk from stand-replacing wildfire is also increasing because of moisture reduction and the high amount and continuity of dry coarse fuels (Westerling et al. 2006; Anderegg et al. 2012). In these drier and hotter conditions, wildfires have become uncharacteristically severe, intense and widespread (Westerling et al. 2006; Singleton et al. 2019). Stand-replacing fires not only reduce timber values and culturally important resources [e.g., teepee (tepee) pole] but also release the carbon stored in trees to the atmosphere in the form of CO₂, becoming a positive feedback to anthropogenic gas emissions (Bonan 2008). Another detrimental consequence of severe wildfires is the deterioration of soil conditions for plants to regenerate. High temperatures reduce soil fertility and increase soil hydrophobicity and soil erosion (DeBano et al. 1979), which increases the risk of shift in species compositions toward shrublands, which are weaker carbon sinks (Roccaforte et al. 2012; Dore et al. 2012).

Under climate change projections, water availability, food security, culture, health, and the economies of many Tribal nations are disproportionately at risk (Voggesse et al. 2013; Jantarasami et al. 2018). The degradation of biodiversity would reduce drastically the availability of food and medicinal plants at a time when human health may be at higher risk (Patz et al. 2005).

The Mescalero Apache Tribal Lands (MATL) in southern New Mexico provide a diverse range of ecosystem services, many of which are of fundamental importance for the Tribe's well-being (Mockta et al. 2018). Big game hunting, tourism through a resort hotel/casino, and a Tribally owned sawmill business have been good sources of revenue for the Tribe, but they are also in jeopardy with increasing risks of megafires and biodiversity loss. Managing forests on MATL, especially under climate change, involves prioritizing certain ecosystem services, which may lead to a decrease in other services (Smith et al. 2012). Although changes in ecosystem services can be measured in biophysical or ecological terms, their values are often defined by the recipients of those services (Baat and de Groot 2012). Groups within the Tribe might value services differently, and Tribal practitioners can add important outlooks to management strategies recommended by western science alone. To prioritize management decisions for collective resources, such as the MATL, multiple knowledge systems need to be accounted for and integrated in natural resource management (Sartor et al. 2014).

Knowledge coproduction is understood as the collaboration of multiple knowledge systems such as Indigenous knowledge and western science (Leimona et al. 2015) and among researchers and stakeholders (Meadow et al. 2015). It has been increasingly used in a time of rapid change and high uncertainty for ecosystem management (e.g., Tengö et al. 2014). Collaboration between local and Indigenous knowledge holders, with long interaction with their natural surroundings, and western science research can generate new coproduced knowledge that enables effective action to cope with climate change and propose comanagement initiatives in setting management goals and priorities (David-Chavez and Gavin 2018). To understand ecosystem services that the MATL provide, we invited experts to participate in our study, which employed a survey method that incorporates the idea of anonymous iteration among participants and asked about the use, substitutability, and level of threat for each ecosystem service. These experts were selected to represent a broad range of researchers and practitioners in the MATL. The purpose of this research was to identify those ecosystem services that are ecologically and culturally important to the Tribe and critical for management. We asked the participants 1) which services that the Tribe uses or could use, obtained directly or indirectly from the MATL, thus have high utility; 2) which services are irreplaceable—services that cannot be provided by any other natural resource; and 3) which services are highly threatened—services at

FIG. 2. Vegetation along the Sacramento Mountains elevational gradient in response to varying environmental conditions. Average temperature and total precipitation are from three climate stations in and near the MATL. The stations are Mescalero at 1897 m, Cloudcroft at 2639 m, and Ruidoso at 2097 m (data are from the Western Regional Climate Center, accessed April 2018).

risk of declining or being lost directly or indirectly by climate change.

2. Materials and methods

a. Study area

The MATL are located in south-central New Mexico in the Sacramento Mountains. The Tribe was federally recognized in 1873 and identified as the Mescalero Apache Tribe, which includes today the Mescalero, the Chiricahua, and the Lipan Apache with approximately 4900 Tribal members. For the Mescalero Apache Tribe, the Sacramento Mountains are considered to be part of their traditional territory, which included vast areas of the southwestern United States and northern Mexico in precolonial times (Worcester 1979). Mescalero's culture, religion, and identity are connected with the Sacramento Mountains, which are sacred and recognized as medicine mountains by the Tribe.

The MATL comprise approximately 186 320 ha, and forested lands occupy 85% of the area. The forests are managed jointly between the Bureau of Indian Affairs (BIA) and Mescalero's Division of Resource Management and Protection (DRMP). Changes in temperature and precipitation along the elevational gradient of the mountain range create a biological altitudinal zonation (Fig. 2). At lower elevations, grasslands are dominated by blue grama (*Bouteloua gracilis*) associated with other grasses and by semidesert brush in poor soil conditions. Pinyon juniper woodlands dominate between 1980 and 2590 m.

The most common tree species in the pinyon-juniper woodland are pinyon pine (*Pinus edulis*) and alligator juniper (*Juniperus deppeana* var. *deppeana*). Madrean oak-pine woodlands are dominated by Gambel oak (*Quercus gambelii* var. *gambelii*) with a variable mixture of conifers. Mixed-conifer forests are found in mid-elevations, between 2100 and 3000 m. Dry mixed-conifer forests are found in the lower band. Most common species are ponderosa pine (*Pinus ponderosa* var. *scopulorum*), Douglas fir (*Pseudotsuga menziesii*), southwestern white pine (*Pinus strobiformis*), and Gambel oak. Cold mixed-conifer forests are found in the higher band, between 2225 and 3017 m, and have higher dominance of Douglas fir, white fir (*Abies concolor* var. *concolor*), quaking aspen (*Populus tremuloides*), and Engelmann spruce (*Picea engelmannii*). Spruce-fir forests are found on the top of the mountain, at 2500 to 3600 m. The common tree species in spruce-fir forests are quaking aspen, Engelmann spruce, white fir, Douglas fir, blue spruce (*Picea pungens*), and corkbark fir (*Abies lasiocarpa* var. *arizonica*).

b. Panel selection

We selected an expert opinion approach to gather Indigenous knowledges and scientific understanding on the use of ecosystem services by the Tribe. Iterative surveys to elicit expert opinions have been employed successfully for ecosystem service valuation (Navrud and Strand 2018) and perspectives on species research priorities (Turner et al. 2017) and to rate forest aesthetics indicators (Lim and Innes 2017). This method

offers a way to better understand knowledges from experiences and experts' perspectives when the topic is lacking in the literature (Martin et al. 2012). Drawbacks from this method are lack of statistical rigor and more demanding respondent involvement, which might lower participation rate.

We purposively selected experts who could provide perspectives about the MATL ecosystems. These participants were selected to represent a broad range of academic research and practitioners in the MATL. To select the group of academic researchers, we used the Web of Science database to search for peer reviewed literature with the key words "Sacramento Mountains," "Mescalero," "MATL," "MAIR," or "Sky-Island*" and found 32 studies from 1967 to 2018, many of which share authors. We contacted the authors and/or coauthors of the most recent papers, which include scientists with expertise in one or many of the following areas: fire ecology, soil, plant genetics, plant physiology, and/or wildlife. To select the group of Indigenous knowledge experts and practitioners, T. Padilla, coauthor of this research paper and a Mescalero manager and Tribal member, identified an initial list of natural resource managers and practitioners from the BIA and DRMP as well as medicine men and women of the Mescalero Apache Tribe and consulted them to make sure the list represents all major groups of practitioners.

c. Survey design

We used an iterative process of questioning and sharing the results, with participant anonymity outside the research team. The process was carried out online using a survey form (Google Forms). The online format enabled the research to be conducted among geographically spread-out participants. The participants were able to answer according to their schedule and the anonymity helped the participants to provide their perspective in a nonconfrontational format (Van Selm and Jankowski 2006). To facilitate the process, we asked Jacob Daukei, a Mescalero medicine man, to assist the participants with limited access to the internet. We also sent a reminder to the participants shortly before the due date and extended the deadline by a week in each round. The process spanned a period of three months, during which we conducted two rounds of surveys. After we received the responses from all the participants in the first round, we analyzed and summarized the results to be sent back via email to the participants with a follow-up round of questions. We selected this technique rather than a focus group discussion to avoid the possible influence of dominance of one individual (Runge et al. 2011). The sequence of rounds helped to clarify and expand on experts' opinions and coconstruct the levels

of utility and irreplaceability of the MATL ecosystems and their services and threats that they face.

We provided the participants with an exhaustive list of all ecosystem services identified in the literature relevant to the MATL. The research team has been working in close collaboration with the Tribe since 2014 and includes a Mescalero manager and Tribal member. The personal communications, observations, and lived experiences of the research team helped form the initial lists of ecosystem services in the survey. To help participants to organize the expansive list of services from the MATL ecosystem, we grouped the ecosystem services into four categories following the [Millennium Ecosystem Assessment \(2005\)](#): regulating (e.g., erosion control and moderation of extreme events), provisioning (e.g., timber, water, and teepees), cultural (e.g., sense of place and cultural value), and supporting (e.g., habitat for game animals) services. We also categorized the MATL into five ecosystem types, roughly from highest to lowest elevation: cold mixed-conifer forests, ponderosa pine/dry mixed-conifer forests, oak–pine woodlands, pinyon–juniper woodlands, and grasslands.

This survey was not intended to compare perspectives between scientists and practitioners or Tribal and non-Tribal members. Tribal and non-Tribal members are both scientists and/or practitioners. Therefore, our analysis was not broken into groups but rather was analyzed collectively.

1) FIRST ROUND

The first-round e-survey was structured in four sections to understand the overall perspective of the participants on ecosystem services provided by the MATL. The first section included five questions to elicit what the participants perceived as irreplaceable ecosystem services. We asked the participants to rank the MATL ecosystem services within each category in a five-point Likert scale from "not important at all" to "absolutely essential." We asked the participants to rate the following ecosystem services provided by the MATL: 1) 10 provisioning services (timber, pinyon seeds, water, crop/agricultural, game animals, firewood, wild products, teepee poles, cattle, and other plant products); 2) 6 regulating services (conservation of drinking water quality, moderation of extreme events, control of plant's pests and diseases, global climate change, erosion control, and maintenance of air quality); 3) 8 cultural services (cultural importance, sense of place, spiritual value, education value, inspiration value, enjoyment of scenery, social relations, and environmental quality for recreation); and 4) 5 supporting services (forests' structural diversity, wildlife diversity, ecosystem diversity, plant diversity, and landscape diversity). We also included an open-ended

question to ensure that we did not leave any ecosystem service out. In the second section, we asked the participants to select the most important five ecosystem services from each of the five ecosystem types. The third section included a four-point Likert scale question from “not at all” to “to a great extent” for rating elicit participants’ perspective on 11 threats to MATL ecosystems: wildfires, climate change, feral horses, invasive species, grazing, mistletoe and other pests, deforestation due to human activity, hunting (for subsistence, cultural meaning, and livelihood such as trophy hunting), recreation, silvicultural practices, and tourism. The fourth section included an open-ended question to elicit the participants’ perception of threats to MATL ecosystems.

We pretested the first-round survey with 15 Northern Arizona University (NAU) graduate students majoring in forestry or environmental science to ensure appropriate wording and to test the applicability and timing of the first-round survey. All pilot participants finished the survey within 20 minutes. As they did not have knowledge of the MATL ecosystems or the Tribe’s values, we asked them to think of an ecosystem with which they were familiar. Pilot participants suggested including a glossary of terms and examples to help the participants have a common understanding of the ecosystem services categories. On the basis of this feedback, we included, at the beginning of the first-round e-survey, a “question and answer” form and images representing different ecosystem types (see the survey in section S1 in the online supplemental material).

2) SECOND ROUND

The second-round e-survey was structured in four sections to further evaluate ecosystem services utility and to coconstruct appropriate forest management goals under a climate change scenario. In the first section, we provided the participants with a summary figure for each of the five MATL ecosystems. The figure represented the frequency of selected ecosystem services from the second section of the first round, where we identified the ecosystem services rated as the most important, that is, those selected with higher frequency. As a follow-up question, we asked the participants to relatively rate the other less frequently selected ecosystem services on a scale of 1 to 5 against those selected in the first round as 1. In the second section, the participants were asked to provide, in an open-ended question, their perspectives toward the expected changes in MATL ecosystem services under climate change. To represent the impacts of climate change to ecosystem services in MATL, we provided a figure that represented potential changes in land cover from 2014 to 2094 (Fig. 3). We used the most

recent forest inventory data to characterize the land cover in 2014 and simulated a mild climate change scenario (RCP4.5) in the future (2034, 2064, and 2094). See section S2 in the online supplemental material for the method. Additionally, we invited the participants to propose management actions to reduce the loss of ecosystem services.

The fourth section was introduced in the second round, prompted by comments in the first round. Some of the participants stated that the listed threats to the MATL ecosystems would become damaging only with the abuse of some business entities and lack of oversight. Common themes are 1) erosion and overgrazing by cattle and feral horses, 2) human impacts on wildlife, 3) removal of predators, and 4) water quality issues. In an open-ended question, we asked the participants for initiatives to help the Tribe manage those issues.

d. Ethics statement

The procedure was reviewed and found to be exempted from continuing review by the Northern Arizona University’s Institutional Review Board (IRB) satisfying the requirements concerning consultation as defined by the Arizona Board of Regents (ABOR) Tribal Consultation Policy. While the purpose of the IRB is to protect the rights and welfare of the participants, it does not warrant the Tribe’s consent (Harding et al. 2012). The overall research project was reviewed and approved by the Mescalero Apache Tribal Council (Resolution 13-21) with a letter of support from coauthor T. Padilla.

We also provided the selected participants with a cover letter informing the organization behind the study, the aim of the study, the process, the consent form, and a questions and answers form.

e. Data analysis

We used three categories to value the importance of ecosystem services. We determined the first category, the degree of utility, by averaging the rating by the participants for each ecosystem service and ecosystem type. We estimated the second category, the degree of irreplaceability of each ecosystem service, based on the frequency for which the participants selected “absolutely essential” to rate an ecosystem service. An essential service is required for survival and can be described as irreplaceable (Farley et al. 2015). Therefore, the higher frequency of “absolutely essential” rating, the higher the irreplaceability of the ecosystem service. The third category, threat level, was assessed by aggregating coded terms that participants used to describe concerns. For example, threats to “springs” and “watershed” as well as other direct

FIG. 3. Changes in land cover from 2014 to 2094. We used the last forest inventory data to characterize the forest cover in 2014 and simulate a mild climate change scenario (RCP4.5) to the future (2034, 2064, and 2094). Areas colored in green represent conifer forests (spruce–fir, cold mixed-conifer, dry mixed-conifer, and ponderosa pine forests). Areas colored in yellow and orange represent woodlands, and white areas represent nonforested lands. We defined forest as canopy cover > 30%, woodlands as canopy cover between 10% and 30%, and nonforested as canopy cover < 10%.

descriptions of water and watershed related services were coded as a threat to “water.” All the MATL ecosystems provide water and therefore counted as one occurrence of threat per ecosystem. On the other hand, we counted some of the terms associated with three categories of ecosystem types—forests, woodlands, and grasslands—separately. For example, concerns for firewood from woodlands include those from pinyon–juniper woodlands and from oak–pine woodlands, each counting as one occurrence of threat for woodland ecosystem. In cases where a participant referred to a specific MATL ecosystem, for example, grasslands, all the services provided by that ecosystem counted as one occurrence of threat. We estimated the level of consensus on threats to MATL ecosystem services using the frequency of affirmative responses to a four-point Likert question. We set the threshold for defining consensus to 75% or greater agreement among participants (Diamond et al. 2014).

We rescaled and aggregated the ratings of utility U , irreplaceability I , and level of threat T to obtain a measure of ecosystem service importance (importance value IV). All three variables had different range of values. For example, the ratings ranged from 1 to 5 for utility, from 1 to 14 for irreplaceability, and from 4 to 17 for threat. The adjustment of the irreplaceability and threat scales to a common scale [1, 5] followed the formula $Y = n(X - X_{\min})/X_{\text{range}}$, where Y is the adjusted variable value between 1 and 5; n is the upper limit of the adjusted scale, that is, 5; X is the original variable value; $X_{\min}$ is the minimum observed value on the original scale; and X_{range} is the difference between the maximum potential value and the minimum potential value on the original scale. We then calculated the importance value using the formula $IV = U + I + T$, where the MATL ecosystem services critical for management are those with IV value ≥ 10 (or 75th percentile; Tallis and Polasky 2011).

3. Results

Of the 26 experts that received the invitation to participate, 15 responded to the first-round e-survey:

4 scientists, 8 natural resource managers, and 3 medicine men (medicine women were also contacted but did not respond). Nine respondents were Mescalero Tribal members. All of the respondents of the first-round e-survey received the second-round e-survey; 12 responded to the second-round e-survey: 4 scientists, 6 natural resource managers, and 2 medicine men (Table 1). Two rounds of the survey were successful to identify the ecosystem services that were perceived by the participants as having high utility, being irreplaceable, and under a high level of threat. We were also able to gather forest management ideas to mitigate and adapt to threats, especially to climate change impacts to ecosystem services in the MATL.

a. Ecosystem services utility

Fifteen participants rated the utility value of each ecosystem service per each of the MATL ecosystem. Unfortunately, five participants selected more than five, and their responses for this question were excluded from the analysis.

Each of the MATL ecosystem types has specific utility for the Tribe. In the first round, all participants identified “pasture and grazing for cattle” from grasslands ecosystems, “firewood” from woodlands, “timber” from ponderosa pine/dry mixed-conifer forests, and “water” from cold mixed-conifer forests as having the most utility (Fig. 4). However, 75% of the participants selected “water” as being as important as “pasture and

TABLE 1. Participants contacted and responses received in the first- and second-round e-survey. Medicine women and Tribal/scientist were also contacted but did not respond.

Participants	Contacted	Round 1	Round 2
Medicine men	5	3	2
Medicine women	4	0	0
Tribal/practitioner	8	6	4
Non-Tribal/practitioner	2	2	2
Other Tribal/practitioner	2	0	0
Non-Tribal/scientist	4	4	4
Other Tribal/scientist	1	0	0

FIG. 4. Ecosystem services utility for each of the MATL ecosystems, as based on the rating responses from the participants ($n = 10$) to the first-round e-survey (C-MC: cold mixed-conifer; D-MC: dry mixed-conifer; PJ woodlands: Pinyon-juniper woodlands).

grazing for cattle” in grasslands. For pinyon-juniper woodland ecosystems, “water” and “other plant products” were rated as important as “firewood” by 42% of the participants. In the case of oak-pine woodlands, “water” was rated by half of the participants as important as “firewood.” For ponderosa pine/dry mixed-conifer forests, “water” was rated higher than any of the other 17 ecosystem services and was rated as important as “timber” by 83% of the participants. Last, cold mixed-conifer forests, “teepee poles,” and “cultural importance” were rated by one-half of the participants as important as “water.” For more details, see Table S1 in section S3 of the online supplemental material.

b. Irreplaceable ecosystem services

Provisioning and cultural ecosystem services were identified as the most irreplaceable for the Tribe. All the participants selected water as “absolutely essential,” and 80% selected game animals as “absolutely essential” (Fig. 5). More than 80% of the participants selected conservation of drinking water quality as “absolutely essential,” and 80% selected moderation of extreme

events (Fig. 5). Most cultural services were selected as either “very important” or “absolutely essential” for the Tribe. All supporting services were ranked at least of “little importance,” and 40% of the participants selected “very important” for all supporting services. The open-ended question did not highlight any additional ecosystem service. Water and erosion control were the individual ecosystem services most frequently mentioned by the participants, dry mixed-conifer and cold mixed-conifer were the most frequently mentioned ecosystem types, and within the groups of services, the category of provisioning services was most frequently mentioned:

Water—if we are truly practicing watershed management, then I believe we are working toward having fully functional ecosystems, that are providing all the essential services we have come to depend upon. (Tribal/practitioner)

c. Threats to ecosystem services

Wildfires and climate change were identified as the most important threats to the MATL ecosystem services.

FIG. 5. Irreplaceable ecosystem services for the Mescalero Apache Tribe: ecosystem services selected as “absolutely essential” by participants. We used the term “essential” to describe irreplaceability. The higher the frequency of “absolutely essential” was, the higher is the irreplaceability ($n = 15$).

The majority of the participants selected wildfires (12 of 15) and climate change (11 of 15) as the threats “to a great extent” to MATL ecosystem services. Feral horses, invasive species, grazing, and mistletoe were recognized as “somewhat” or “to a great extent” threats. At least one participant perceived all of the threats (except for tourism) as “to a great extent” (Fig. 6). The following two comments provide a synopsis of the diverse observations:

When I listed hunting as having threats “to a great extent,” I am referring to lack of oversight for wildlife management. It seems like the Big Game Hunt Program through the Inn of the Mountain Gods has a lot of say in how the hunts are structured/scheduled. There seems to be a lot of hunting pressure, when combined with other pressures, like collecting elk/deer sheds in the springtime, creates too much human pressure overall for the animals. Also, there is “hunting” that is sanctioned through predator control programs, targeting all of the big cats. This removes the natural controls that regulate grazing by the ungulates. I think we are damaging the quality/health of the wildlife by removing predators. (Tribal/practitioner)

FIG. 6. Threats to MATL ecosystem services, from participants' perception on the MATL ecosystems levels of threat selected in the first round ($n = 15$) and rated using a four-point Likert scale from “not at all” to “to a great extent.”

I think most of those [threats] are dependent upon the quality of management and/or enforcement of restrictions. At this moment in time, I find wild horses to be a very big threat—we do have regulations, but they are not enforced. We manage the other large mammals (big-game, cattle), but horses are treated like harmless pets (just like dogs that aren't taken care of and allowed to roam all over). So I guess if I distill that threat down to the root cause, it would be lack of enforcement across the board. Our lackadaisical approach as a Tribe to “management” and “enforcement of regulations” is the biggest threat, because we can very easily do something about it. We also have very significant drinking water quality violations, but they are all related to perceptions that the Tribe doesn't have to abide by EPA regulations, and our management approach to those systems. The quality of water coming out of the ground is great, but we do not take care of our infrastructure. (Tribal/practitioner)

The participants agreed that improving youth and public education, better resource management, and feral horses' population control were the best methods to overcome threats:

Educating youth about their natural resources, including highlighting the cultural values associated with different ecosystems and how caring for the resource collectively preserves those for future generations. (non-Tribal/scientist)

Press on to manage, i.e. treat these resources. Worse case is do nothing. It's easier though!!! (non-Tribal/practitioner)

To educate the public on the benefits of some of these issues and also to take into considerations the not so good benefits of these issues which is key to the preservation of

TABLE 2. Frequency of terms used in the first-round e-survey to describe MATL ecosystem services under threats of climate change effects (C-MC: cold mixed-conifer forests; D-MC: dry mixed-conifer forests; PJ: pinyon-juniper woodlands; *T*: threat level).

		Participants															<i>T</i>	
		Other terms/synonyms		1	2	3	4	5	6	7	8	9	10	11	12	13		14
Services																		
Provisioning						1	1											2
Cattle								1										1
Firewood	Biomass; “cut more just out of fear of running out”	1		1	2			1										4
Other products				1							1							2
Pinyon seeds	Pinion																1	1
Teepee poles	“Cut more just out of fear of running out”	1	1	1	2						2				1			6
Timber	Biomass, productivity, “cut more just out of fear of running out”	1		1	2				2		1							5
Water	Springs; watershed	2	1		1		1	2	1		2	1				1	1	10
Regulating										1								1
Air quality	Carbon							1										1
Erosion		1					1	1	1									4
Extreme events	Severe wildfires							2		1								2
Cultural							1	1										2
Appeals to visitors	Tourism							1										1
Cultural importance		1																1
Sense of place	“Protect what would be left”	1		1		1										1		4
Supporting																		0
Endangered species			1															1
Game animals								1										1
Plants		1						1										2
Wildlife		1			1			1		1								4
Ecosystems																		
C-MC	Fir trees; forests		1	2			1	2										4
D-MC	Forests						1	2				1	1	1				5
Oak–pine	Woodlands						1	1			1							3
PJ	Woodlands						1	1			1		1					4
Grasslands				1			1	1			1							4

cultural and natural resources sought out by our tribe. (medicine man)

Timber, teepee poles, and water were the most frequent terms used to describe ecosystem services highly threatened under the RCP4.5 climate change scenario (Table 2; Fig. 7). Many comments focused on individual ecosystem services such as timber or habitat for endangered species without reference to any particular MATL ecosystem.

d. Importance value

We identified four provisioning services, one regulating service, two cultural services, and one supporting services as the most important ecosystem services for the Tribe and a priority for management. Water had the highest importance values in all MATL ecosystem types followed by teepee poles and moderation of extreme events in dry and cold mixed-conifer and then by firewood in pinyon–juniper woodlands. Cultural importance and sense of place were identified as important ecosystem services for almost all MATL ecosystems.

Habitat for game animals and timber were also identified as highly important in dry mixed-conifer ecosystems of the MATL (Fig. 7; also see Table S1 in section S3 of the online supplemental material).

Dry mixed-conifer forests within MATL had higher utility, irreplaceability, and threat value and therefore were identified as the ecosystem that should be a priority for management. Cold mixed-conifer forests had similar irreplaceability but lower utility and level of threat. Oak–pine and pinyon–juniper woodlands had overall similar utility, irreplaceability, and level of threat, while grasslands had the lowest values of all three (Fig. 7; also see Table S1 in section S3 of the online supplemental material).

e. Management recommendations

All participants recommended reduction of tree density either by thinning and/or prescribed burnings. Some associated this forest management strategy with promoting ecosystem resilience. The participants provided ranges of tree density around 5.7–9.2 m² ha^{−1} (25–40 ft² acre^{−1}) or

FIG. 7. The importance of MATL ecosystem services as assessed in terms of utility, irreplaceability, and at higher threat level. In boldface type, we identified the most important MATL ecosystem services, those with ecosystem importance value ≥ 10 (or 75th percentile). The black line symbolizes IV values, and blue, purple, and red lines represent utility, irreplaceability, and threat levels, respectively.

“historic densities.” One participant recommended the removal of trees in the 0–23-cm-diameter (0–9 in.) class. Recommended frequency of prescribed fires ranged from every 2 years to every 30 years or longer and more broadly to mimic historical fire regimes. Mean fire interval ranged from 6 to 18 years in the MATL and was excluded after the early 1900s (Azpeleta Tarancón et al. 2018). Fires for managing resource benefits allowing natural ignitions in fire-adapted ecosystems to burn as a restoration tool (Williamson 2007) was also mentioned by one participant.

Two recommendations were made toward increasing genetic adaptation. The first recommendation was to increase landscape and forest structure diversity:

Create age/size mosaics across the landscape.... Creating landscape mosaics spreads the risk out on the landscape... The same structure across the landscape does not provide for uncertainty in the future, thus changing it up should help. (non-Tribal/scientist)

The second recommendation for assisted migration had differences in the urgency of its implementation. One participant noted that assisted migration should start immediately to help plants’ adaptation and avoid potentially more severe future climate conditions. Two other participants proposed testing the success of actual species on new locations by planting or seeding at higher elevations or where vegetation gaps occur:

Adding in other species or shifting species (assisted migration or assisted gene flow) could help maintain tall statured trees/forests and help with genetic adaptation. Regenerate and establish desired species now, to be proactive, not waiting until after the fire/harvest when conditions may not be conducive to regen of those same species. (non-Tribal/scientist)

Collect seed, and direct seed the openings that are formed through the various disturbances, so nature can choose what seeds where. (Tribal/practitioner)

Experiment with assisted migration by setting up test plantations or common gardens. . . . For wind-dispersed conifers . . . and aspen, more attention should be paid to planting uphill. (non-Tribal/scientist)

Other recommendations were toward moderation of extreme events and disturbances and the use of green

←

respectively. MATL ecosystems are C-MC: cold mixed-conifer, D-MC: dry mixed-conifer, PJ woodlands: pinyon-juniper woodlands, oak-pine woodlands, and grasslands).

energy as a measure to reduce the increase of greenhouse gases into the atmosphere to prevent feedback effects:

Deal with other problems as proactively as possible too: forest insects/diseases, fire hazard, etc., to prevent a forced reaction instead. (non-Tribal/scientist)

To help the efforts in climate change we do need to find healthier means of energy and modes of new Eco-friendly energy for things like power, gas consumption, and air polluting toxants to help create a better air quality for all of our ecosystems here on the reservation. (medicine man)

4. Discussion

The objective of this interactive two-round survey was to coproduce forest management priorities that would benefit the Mescalero Apache Tribe. We were able to identify, using the perspectives of experts in MATL, those ecosystems and services provided by the MATL that have higher utility, are irreplaceable, and face a high level of threat from climate change effects. With these three measures, we built a measure of ecosystem service importance that helped identify the most important ecosystem and services for the Tribe's well-being and that are therefore critical for management. We were also able to gather forest management ideas to mitigate and adapt to threats, especially to climate change impacts to ecosystem services in the MATL.

This research coconstructed priorities for ecosystem services management in the MATL through frequent two-way communications, the long-term relationship between our transdisciplinary research team and the Tribe, and engagement of the Tribal forest managers throughout the research process from forming research questions to disseminations of outcomes (e.g., coauthorship of this paper). These factors have been identified as the principles of deliberate process of science coproduction in the literature (Meadow et al. 2015). Our study complied with responsible research with Indigenous communities proposed by David-Chavez and Gavin (2018). We believe that our assessment, coauthored and coproduced with the Tribe at every step of the research, is in line with the highest standards for responsible research practice with Indigenous communities.

There were many agreements between the participants—Tribal and non-Tribal members and scientists and practitioners—to values and threats of the MATL ecosystems. One of the most important results of this study is the agreement that climate change presents an important threat to the MATL and the Tribe's well-being. This is fundamental for climate change adaptation and mitigation since stakeholders' perception of climate change is

an indicator of the willingness to implement strategies to mitigate climate change effects (Ameztegui et al. 2018). Also, it is clear that ecosystems within the Sky Islands share multiple services within MATL (Fig. 7), although the same services are rated differently in different ecosystem types. Our use of relative measure between services and Likert scale rating revealed different values for the same services in different ecosystems. We agree with Schmidt et al. (2017) that land-use preferences can only be elicited from ecosystem services valuation when a relative value is used. The Mescalero Apache Tribe has strong cultural traditions deeply connected to natural resources. For example, we expected Tribal members to value teepee poles because of their use in the Coming of Age Ceremony (Mockta et al. 2018), but even many non-Tribal members understood the value of teepee poles for the Tribe and perceived them as a priority to safeguard.

We acknowledge that our research study has several limitations. First, our survey only included experts' opinions. Our analysis may not represent the views of all the users of resources within the MATL. It is impossible to find a universal valuation of ecosystem services (Daily et al. 2000), but the Mescalero Apache Tribe might benefit from a survey targeted to include all different segments of the Mescalero Tribal members, especially elders, because coproducing knowledge increases the trust and improves the perception of the proposed actions and promotes their implementation (Wall et al. 2017). Second, we assumed that utility, irreplaceability, and level of threat are equally important to measure the ecosystem importance value. In much the same way that we coproduced every aspect of this research, the participants' perception on the appropriate relative weights of the three components can be added in the future study. In addition, our approach measured those ecosystems services provided directly, such as timber, and indirectly, such as moderation of extreme events, by the MATL. These values, marketed or nonmarketed, are, generally speaking, easy to conceptualize and measure. However, other values—such as option values of those assets that are not currently in use but might be used in the future or existence values (de Groot et al. 2010)—may not have been well represented in our study. Last, our pilot study group provided valuable feedback that helped guide the subsequent study. However, we acknowledge that it did not fully represent the targeted population.

We detected a potential inconsistency of our experts' opinions. Education value was not identified as of higher importance for the Tribe. In fact, only dry mixed-conifer forest was perceived as having high education value and was ranked between the 25th and 50th percentile in importance. However, education or equivalent terms

were the most frequent terms that the experts used for initiatives for the multiple threats to MATL ecosystems and specifically suggested for management such as setting experimental sites with common gardens, field trips, capturing mortality, monitoring, and adaptive management. The participants probably did not relate monitoring and adaptive management as education value under cultural services. Future studies should consider establishing a comprehensive glossary of terms with potential participants to ensure a shared understanding of the terminology.

5. Conclusions

Stakeholders' engagement, especially for Indigenous communities with inherent rights of sovereignty, is crucial to develop effective comanagement, evolving toward an integrated assessment of forest systems rather than focusing primarily on one ecosystem service. This study identified the most important ecosystem services for the Mescalero Apache Tribe based on expert opinions of researchers and practitioners. There are unique perspectives related to values and threats; thus, forest management strategies proposed here cannot be applied everywhere. However, a similar methodological approach can be applied in other forested ecosystems managed for multiple values.

MATL experts in this research study have provided multiple strategies for forest adaptation in warming climate. The next step for application of coproduced knowledge should be to develop climate-sensitive ecological model simulations incorporating different alternatives proposed here, specifically, reintroduction of fire at different frequencies, creation of landscape mosaics and forest heterogeneity, and assisted migration.

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