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Adapting Tropical Forest Policy and Practice in the Context of the Anthropocene: Opportunities and Challenges for the El Yunque National Forest in Puerto Rico

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Abstract: Tropical forest management increasingly is challenged by multiple, complex, intersecting, and in many cases unprecedented changes in the environment that are triggered by human activity. Many of these changes are associated with the Anthropocene—a new geologic epoch in which humans have become a dominating factor in shaping the biosphere. Ultimately, as human activity increasingly influences systems and processes at multiple scales, we are likely to see more extraordinary and surprising events, making it difficult to predict the future with the level of precision and accuracy needed for broad-scale management prescriptions. In this context of increasing surprise and uncertainty, learning, flexibility, and adaptiveness are essential to securing ecosystem resilience and sustainability, particularly in complex systems such as tropical forests. This article examines the experience to date with and potential for collaborative, adaptive land and resource management in the El Yunque National Forest (EYNF)—the only tropical forest in the U.S. National Forest System. The trajectory of EYNF policy and practice over time and its capacity for learning, flexibility, and adaptiveness to change and surprise are analyzed through an historical institutionalism approach. EYNF policies and practices have shifted from an early custodial approach that focused mostly on protection and prevention to a top-down, technical approach that eventually gave way to an ecosystem approach that has slowly incorporated more flexible, adaptive, and active learning elements. These shifts in EYNF management mostly have been reactive and incremental, with some rarer, rapid changes primarily in response to significant changes in national-level policies, but also to local level conditions and changes in them. Looking to the future, it seems the EYNF may be better positioned than ever before to address increasing uncertainty and surprise at multiple scales. However, it must be able to count on the resources necessary for implementing adaptive, collaborative forest management in a tropical setting and on the institutional and organizational space and flexibility to make swift adjustments or course corrections in response to system changes and surprises.

Keywords: adaptive management; tropical forest; Anthropocene; U.S. Forest Service Planning Rule; El Yunque National Forest; Luquillo Experimental Forest

1. Introduction

Humans use and value tropical forests for a range of objectives, from the preservation of biodiversity to the production of wood products, but these objectives increasingly are challenged by multiple, complex, intersecting, and in many cases unprecedented changes in the environment that are triggered by human activity. Because land use change, habitat fragmentation, pollution, and other anthropogenic processes have spurred new environmental conditions and novel habitats, many in

the scientific community have come to agree that we now are living in the Anthropocene—a new geologic epoch in which humans are a dominating factor in shaping the biosphere [1–3]. As human activity further affects the environment in continued, new, and unprecedented ways, changes in social-ecological systems are expected to become less predictably cyclical, while system responses become less certain [4]. Change is nothing new in nature, which has always produced surprises. Likewise, societies have and will continue to change in terms of their interests in, needs from, and demands on tropical forests and other natural resources. Nevertheless, unpredictability and surprise can present significant challenges to those who depend on forests for their livelihood and for those who manage them for multiple purposes, particularly if management aims to maintain current conditions or restore them to some ideal from the past.

People have managed tropical forests for millennia, intentionally manipulating them for desired composition, goods, and services, and in some cases successfully adapting to shifts and even surprises in them. For example, the Amazon Basin, once thought to have been dominated by 'virgin' forest prior to European arrival, was inhabited by sizable, 'sedentary' societies that cleared areas of interior forest for agriculture and managed other forested areas for the optimal distribution of useful species [5]. In Central America, the Mayan civilization developed a complex system of land use that cycled from closed canopy forest, to open field cropping (*milpa*), to tree gardens, and, eventually back to diverse, hardwood forests shaped in part by purposeful plantings and species selection [6]. The presence of many economically important plant species (e.g., mahogany (*Swietenia macrophylla*), Spanish cedar (*Cedrela odorata*), chicle (*Manilkara* spp.)) in the Maya forest today reflect their careful selection and management by the Maya of the past [7]. Some of these and other traditional forest practices have demonstrated a holistic understanding of complex forest processes and an ability to adapt to environmental change for exceptions [8,9], as do many contemporary forest management approaches. However, the changes that are likely to occur in tropical forests in the context of the Anthropocene will test further our capacity to cope with uncertainty and surprise, particularly in already complex systems.

Acknowledging that the tropical forests of the future may differ in terms of composition, structure, and even function from those of the past and present, pushes us to consider how policies and practices shape human–environment interactions and to determine what adjustments, if any, are necessary to resist, respond, or adapt to system shifts and surprises. Some control may be exerted over the projected and unexpected changes associated with the Anthropocene through existing land and resource management strategies, but these are bound to need reconfiguring in the least, to better address sustainability and other societal goals, particularly as these also may shift over time. So far, there is no magic bullet or exact science for managing forests in the context of the increasing environmental variability associated with modern times. Management strategies range from passive to reactive to anticipatory and may be combined in a tool-box approach that depends as much on probabilities and predictions as societal interests and demands [10,11]. While these may differ, for example by system, scale, or objectives; flexibility, adaptiveness, and active, ongoing learning emerge as common attributes among many strategies designed to address uncertainty and surprise [12–15].

This paper examines the practice of and prospects for flexibility, adaptiveness, and learning in the El Yunque National Forest (EYNF) in Puerto Rico to understand better its capacity to address the uncertainty and surprise expected to increase in the context of the Anthropocene. Tropical forests, like the EYNF, are on the front lines of global change, forcing scientists and practitioners to grapple with critical questions, such as the degree to which these ecosystems can persist in human-modified landscapes, and which management strategies will be most effective at maintaining their structures and functions at different spatial and temporal scales. Evaluating the management policies and practices of the EYNF and their potential to effectively address the expected and unknown changes that are likely to occur in this new geologic epoch provides important feedback for the EYNF and its stakeholders, and for the U.S. Forest Service, the federal agency to which it pertains. Outcomes of this study also provide important policy and practical inputs for other tropical forest dwellers, managers,

and decision-makers confronted with the imminent changes, uncertainty, and surprise associated with the Anthropocene.

2. Study Setting and Approach

The EYNF is located in northeastern Puerto Rico—a region that has seen significant changes in land use over the past 100 years, similar to the rest of the island. In 2010, the region was covered mostly by forest (43 percent), followed by pasture (36 percent), urban area (10 percent), shrubland (6 percent) and wetland (3 percent) [16]. The EYNF encompasses much of the forested area of northeastern Puerto Rico and protects one of the largest remnants of primary forest on the island. It extends across 11,735 ha and ranges in elevation from 120 to 1074 m above sea level [17]. It is the most biologically diverse forest in the USFS National Forest System, harboring more than 800 native species of plants and wildlife [18]. The EYNF also is highly valued for its recreation and water resources, receiving more than 600,000 visitors per year and producing about 20 percent of the island's total municipal water supply [18,19].

Average temperatures in the EYNF range from about 22° Celsius in the winter to about 30° Celsius in the summer [20]. Average annual rainfall in the forest is about 3000 mm, ranging from about 2500 mm at its lower elevations to more than 4500 mm at the peaks [21]. Records show decreasing annual rainfall and increasing temperatures in and around the EYNF over the past 65 years or so [22]. Statistical models of Puerto Rico's future climate vary, but generally predict increasing average annual temperatures (ranging from 4 to 9° Celsius) along with slightly decreasing total rainfall and increasing extreme weather events by the end of the 21st century [22–24].

The documented and predicted changes in climate in the EYNF are expected to affect its structure and function, possibly leading to shifts in species composition and their distribution along the elevational gradient, as well as leading to effects on water supplies and flows [25–28]. Changes in climate and weather patterns also may affect recreational activities in the forest and lead to changes in visitor use and visitation patterns [29]. Moreover, climate change and the associated effects are likely to intersect with projected and unexpected changes in demographics, economies, land use, and other issues, which may lead to compounding effects on the EYNF and surrounding area.

Land and resource management policies and practices of the EYNF were examined through an historical institutionalist approach, which aims to understand and explain a specific real-world policy process or outcome by studying the historical legacy of related institutional structures and feedbacks [30]. This approach can be used to study the creation, persistence, and change in institutions through time, focusing on pathways of institutional development, patterns of institutional path dependence, and critical junctures of institutional evolution [30–33]. This paper focuses on the extent to which learning, flexibility, and adaptiveness to changes in local and larger conditions are incorporated in EYNF policy and practice and the factors that influence stasis and change in policy and practice over time. Common aspects or characteristics of active, ongoing learning (e.g., monitoring, analysis, and feedback on management effects), flexibility (e.g., proclivity to stakeholder collaboration and coordination, responsiveness to new information), and adaptiveness (e.g., to changes and surprises in environmental and social conditions) were drawn from the literature and considered throughout the analysis [12–15]. Examining EYNF policies and practices, with a specific focus on learning, flexibility, and adaptiveness through an historical institutionalist lens sheds light on the ways and means through which this national forest has dealt with change, uncertainty, and surprise in the past. It also provides a frame of reference for assessing the EYNF's prospects for active learning, adaptiveness, and flexibility under increasing uncertainty and surprise anticipated in the context of the Anthropocene.

3. Shifting Approaches to Land and Resource Management in the EYNF

Over time, the land and resource management policies and practices of the EYNF have shifted from an initial custodial approach that focused mostly on protection and prevention to top-down, technical/scientific management that eventually gave way to an ecosystem management approach

that has slowly incorporated more flexible, adaptive, and active learning elements. These shifts in EYNF management mostly have been reactive and incremental, with some rarer, rapid changes primarily in response to significant changes in national-level policy, but also to local level conditions and trends. The trajectory of EYNF land and resource policy and practice is presented in the following sections, which focus on the ways and means through which this forest has confronted system changes, uncertainty, and surprises.

3.1. Custodial Management

Forest reserves in northeastern Puerto Rico and other parts of the island predate political association with the U.S., having been established by the Spanish government in 1876, mostly to protect remaining timber supplies and water sources following decades of forest conversion to agriculture and intensive harvest of timber species that occurred primarily in the lowlands [18]. These forest reserves were ceded to the U.S. government after the Spanish–American War in 1898. Shortly thereafter, in 1903, President Theodore Roosevelt proclaimed the reserved lands in northeastern Puerto Rico as the Luquillo Forest Reserve (eventually renamed the EYNF) and placed them under the direction of the USFS [18].

As part of the National Forest System, early work in the EYNF was guided by the Forest Reserve Act of 1891 (P.L. 51–561), which allowed for lands in the public domain to be set aside as forest reserves (later, renamed as national forests). Also, the Forest Service Organic Administration Act of 1897 (16 U.S.C. § 473 et seq.) provided direction for national forest management, including provisions to secure water flows and permit timber harvests. In its early years, the USFS worked primarily in a custodial approach to resource management, focusing on the acquisition of national forests lands and the protection and later development of resources within their boundaries [34].

Land managers in Puerto Rico followed suit, embarking on early endeavors to survey, map, and mark the EYNF along its boundaries, divert water for downstream communities and towns, and install forest roads, trails, and other construction projects, but did not allow for timber extraction in its earliest years [35]. After Hurricane San Felipe passed over Puerto Rico in 1928—the first of five major hurricanes that have significantly affected the EYNF under USFS administration, land managers shifted part of their focus, permitting the extraction of downed trees and initiating periodic surveys of the forest to determine timber stocking and regeneration in a turn towards timber management [18]. Extensive reforestation in areas surrounding the EYNF that had been deforested prior to U.S. association began in the early 1930s. Shortly thereafter, timber stand improvements (TSI) were initiated, which were later complemented by the first study plots established in 1938 to monitor TSI results. Long-term research in permanent plots to study species composition, stand characteristics, and timber production potential began in earnest in the early 1940s [18].

In these early years, the EYNF implemented policies and practices for a range of activities including livestock grazing, mining, recreation, water supply, and timber production, largely through a custodial approach to land and resource management. Important aspects of active learning were established fairly early in the life of the EYNF through research and monitoring and a close association with the USFS Tropical Forest Experiment Station (now known as the International Institute of Tropical Forestry), which was established in Puerto Rico under the McSweeny–McNary Act in 1939. Throughout much of the early 1900s, decisions on land and resource use in the EYNF followed agency policy and guidance, but were made locally, at the discretion of the forest supervisor. During this period, though there was limited outside input or coordination in forest-related decision making, the EYNF demonstrated some measurable flexibility in management practices and approaches and in its capacity to adapt to new and changing conditions, particularly those associated with the uniqueness of being the only tropical forest in the National Forest System.

3.2. Scientific Management

Through the mid-20th century, the management of the EYNF increasingly focused on multiple resources and services, including the provision of recreation, conservation of watersheds, protection of parrot habitat, research, and wood production, which was mostly for fuelwood and charcoal production to meet the energy demands of a rapidly growing post-war population in Puerto Rico [18]. By 1955, logging within the EYNF had ceased, due mainly to decreasing demands for timber and fuelwood given rising imports of kerosene and mahogany [36]. Then, in 1956 the EYNF was officially dually designated as the Luquillo Experimental Forest (LEF) throughout its geographic extension. Experimental forests and ranges were established throughout the NFS to address large scale problems of forest, range, and watershed management through a broad range of basic and applied studies with short- to long-terms planning horizons. Designating the EYNF as an experimental forest across the entirety of its range was unique in the system and reflected the recognition of the complexity inherent in tropical forests and their management.

The passage of the Multiple Use Sustained Yield Act (MUSYA) in 1960 officially expanded the USFS mandate, giving the agency permissive and discretionary authority to administer national forests for outdoor recreation, range, timber, watersheds, wildlife, and fishing (P.L. 86–517). Following MUSYA and other agency guidance, the EYNF continued to plan and practice forest restoration, recreation, research, and other activities. Though timber was no longer extracted from the EYNF, line plantings of mahogany and additional timber stand improvements were conducted throughout the 1960s and 1970s anticipating future wood harvests from forest areas designated for timber production.

In 1976, the National Forest Management Act (NFMA) (P.L. 94–588) was passed, requiring a systematic approach to land and resource management for all national forests and grasslands, setting standards for timber sales, and providing criteria for timber harvests. The NFMA also required the development of forest planning regulations, which were first issued in 1979 and later superseded by revised regulations in 1982. The 1982 USFS Planning Rule focused on the maximization of multiple public benefits and for the first time required public input on forest planning, but also prescribed a complicated and elaborate planning process that was not easy for the public to access [37]. Under these directives, the EYNF began work on a comprehensive forest management plan in the early 1980s, which was developed internally, largely based on prescriptive guidelines that included the use of scientific and technical information. The final plan adopted a multiple use approach to land and resource management, encompassing several management alternatives, including timber production in suitable areas [38]. This plan was approved by the regional forester in 1986 and submitted to the public for comment along with an environmental impact statement and record of decision.

The 1986 EYNF land and resource management plan was strongly contested by local communities and conservation organizations, who had been largely excluded from the decision process. Major concerns were associated with the proposed timber harvests and new roads and trails, as well as with the fact that the plan and related documents had not been made available in Spanish [18]. On 19 November 1986, thousands of people marched on the grounds of the EYNF in protest of the plan. Soon thereafter, the plan was appealed in court by 12 environmental and recreational organizations, culminating in a court order to provide a Spanish translation of official EYNF documents submitted to the public for comment and to reconsider logging throughout the plan area [39]. Subsequently, the EYNF began a process of plan amendments and revisions that included increasing public input and involvement over the course of the next decade.

In the latter half of the 20th century, decisions about the EYNF increasingly were shaped by agency direction, which increasingly dictated a scientific approach to management that focused on the objective application of scientific methods and technical information to control natural systems and changes in them [40]. However, the scientific management approach also often discounted or excluded other types of nonscientific information, knowledge, and input that made prescriptions messy or more difficult, but which were inextricable from the natural system and its management [40,41]. In its first forest plan submitted for public input, the EYNF had incorporated considerable scientific and technical

information, some of which was produced from ongoing research and monitoring throughout the forest, demonstrating important aspects of active learning. However, the relative exclusion of local communities and other stakeholders from internal decision-making resulted in a major setback for the EYNF and its land and resource practices and projects. During this time, there was limited flexibility in decision-making, particularly in terms of incorporating outside perspectives, which only were addressed after mandated by a court order.

3.3. Ecosystem Management

As the EYNF worked to revise its land and resource management plan during the late 1980s and early 1990s, ecosystem management had emerged as a new management approach centering on the conservation of multiple resources and the preservation of structures and processes across multiple scales through the integration of ecological, economic, and social information; collaboration and coordination with stakeholders; and adaptation of management through continuous learning or experimentation [42,43]. The ecosystem approach represented a paradigm shift in natural resource management in the U.S., triggered in part by ongoing conflicts over clearcutting and other environmental issues on federal lands and growing demands from scientists, practitioners, and other stakeholders to move away from a traditional focus on a single species or deliverable, towards a more integrated focus on the ecosystem as a whole [44]. In June 1992, the USFS became the first federal agency in the U.S. to adopt (on paper at least) an ecosystem management approach [45]. Related agency guidance laid out specific means and ends for advancing forest sustainability through integrated scientific information (i.e., ecological, economic, social), collaborative stewardship, interagency cooperation, and adaptive management [44–46]. However, there was no related statutory mandate requiring the use of ecosystem management or its components parts. Consequently, there was very limited funding to fully implement ecosystem management, for example through intensified monitoring or adaptive management, and slow organizational uptake throughout much of the USFS [47,48].

By the late 1990s, the EYNF had adopted an ecosystem approach to land and resource management, which influenced decisions about projects and practices, as well as the forest plan revision process, particularly in terms of plan components and public input and involvement. During this time, the EYNF continued to confront environmental and anthropological processes, pressures, and surprises, further shaping local policies and practices. For example, Hurricane Hugo passed very near to the EYNF in 1989, causing significant loss of standing biomass and wildlife, short-term changes in the water regime, and road and infrastructure damage among other effects throughout many parts of the forest, affecting its functions and services [49]. Additionally, the island's population expanded throughout the latter half of the 20th century (e.g., Pop. in 1950: 2.22 million, Pop. in 2000: 3.81 million), producing increasing pressures on the EYNF, particularly for water and recreation, leading to increasing water withdrawals and visitation rates. Land uses around the EYNF also were shifting during this time, with significant reversion of agriculture and pasture to forest, but also conversion of pasture, agriculture, and even forest to urban and suburban development, in some cases in violation of local zoning rules aimed at protecting a buffer zone around the EYNF [50–52]. Land use changes and their effects on forest connectivity within the region prompted the EYNF to become ever more engaged in local level planning efforts and community outreach.

Ultimately, agency direction on ecosystem management, conditions and trends within and outside the EYNF, and more than a decade of appeals and subsequent public consultation on the previous forest plan all contributed to shaping the 1997 Revised EYNF Land and Resource Management Plan [53]. Reflecting stakeholder priorities, the 1997 forest plan focused largely on forest protection (e.g., wilderness, wild and scenic river segments, research natural area) and human activities (e.g., recreation, environmental education, research) and eliminated opportunities for commercial timber harvesting except within a relatively restricted area designated for the demonstration of sustainable timber production. Several key aspects of the broader ecosystem management approach,

such as collaborative stewardship, interagency cooperation, and the integration of scientific information are reflected in this plan and its implementation. Conversely, there was comparatively limited integration of economic and social information relevant to the EYNF. Moreover, though forest monitoring was a requisite part of the plan; in practice, monitoring of forest conditions and responses to management and other effects was limited, as were mechanisms for continuous learning and adaptation through established feedback loops. These disparities in management approach and practice limited EYNF capacity for adaptiveness to environmental and socioeconomic shifts and surprises. Furthermore, though the EYNF gradually opened to stakeholder collaboration and horizontal and vertical inter-agency and inter-sectoral coordination, its flexibility to respond to new conditions or trends was limited, in part, by an expanding legal framework affecting all federal lands, as well as by an inherent aversion to risk and organizational change, which was common throughout much of the agency [47,48].

3.4. Towards Adaptive, Collaborative Management?

With the approval of its 1997 Land and Resource Management Plan, the EYNF set on a course of action that deviated very little for the next 15 years or so. Policies and practices focused mostly on conservation, for example of at-risk species, wilderness, and wild and scenic rivers, often in collaboration with stakeholders and local partners, and on human demands and needs, such as recreation, environmental education, and water supplies. Timber harvesting remained taboo for most stakeholders and was not reactivated in the EYNF, even in the designated demonstration sites, but long-term research continued to expand through the International Institute of Tropical Forestry and the NSF-funded Luquillo Long-term Ecological Research program, as did community engagement and environmental education [19].

By 2012, after multiple attempts to revise agency regulations, the USFS had issued its National Forest System Land Management Planning Rule (36 CFR Part 219) (hereafter, the 2012 Planning Rule) and selected the EYNF as one of eight "early adopter" forests to revise its existing forest plan under the new directives and guidance [54]. The 2012 Planning Rule was developed in accordance with the NFMA, and for the first time, codified requirements for collaboration, integrated scientific information, sustainability, climate change considerations, and adaptiveness in federal land management planning. It prescribes a landscape-scale approach to land and resource management that takes into account conditions and trends beyond management unit boundaries and transfers some decision-making authority back to the local level, designating the forest supervisor with signatory authority for final plan approval and the record of decision (as opposed to the Regional Forester under the previous Planning Rule). Collaboration is required with local communities and other key stakeholders throughout the planning process versus the *ex post facto* consultation of previous Planning Rules. Additionally, the new Planning Rule requires monitoring of forest conditions and responses to management, as well as ongoing evaluation to determine whether new information from monitoring or other sources warrant changes in management direction. Overall, the prescribed process of 'Plan, Monitor, Assess, Repeat' is intended to make national forest plans dynamic and their management adaptive to existing and unforeseen conditions, outcomes, risks and stressors (Figure 1) [54].

In 2012, the EYNF initiated a collaborative, interactive process to revise its land and resource management plan under the new USFS Planning Rule. The first major step in the process was a comprehensive assessment of ecological, economic, and social conditions and trends in and around the EYNF. This assessment was led by an interdisciplinary team of resource managers, specialists, and scientists selected by the EYNF Forest Supervisor and based on the 'best available scientific information' and stakeholder input, as required under the new Rule. The assessment integrates data and findings from nearly a century of research in and around the forest, as well as other research and information sources, including local knowledge and stakeholder input. The EYNF assessment was published in 2014 as a living document (i.e., to be updated with new information as it becomes available and assessed) and providing critical information for determining a proposed action and need for change in

existing EYNF management direction [19]. The assessment also informed the development of a draft revised land and resource management plan and environmental impact statement for the EYNF, which incorporated extensive and ongoing public participation and interagency coordination. The EYNF draft revised land and resource management plan and environmental impact statement were officially submitted to the public for comment in September 2016 and are expected to published in final form in the fall of 2017 [17].

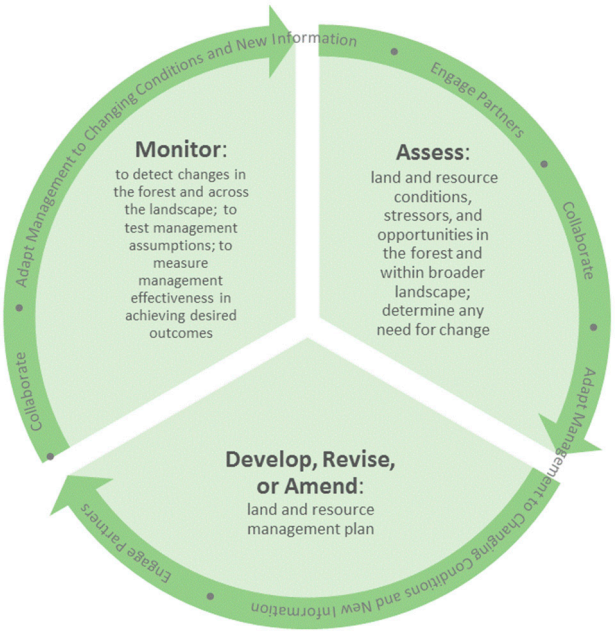

Figure 1. U.S. Forest Service Land Management Planning Process (USFS 2012) [54].

EYNF's revised forest plan focuses on the provision of sustainable ecological processes and socioeconomic benefits for local communities and other key stakeholders, recognizing the important role of people in nature and of their values, beliefs, and customs for sustainable forest management (Table 1) [17]. This plan integrates a systems perspective that focuses on species, communities, and ecosystems through a landscape scale approach that promotes management strategies to work beyond the forest's administrative boundaries. It provides for interagency coordination and stakeholder collaboration through an "all-lands" approach to land and resource management and adopts the concept of "*co-manejo*" (or shared stewardship), which developed through interactions with the public and key stakeholders during the planning process. In this context, *co-manejo* does not involve a delegation of decision-making authority from the USFS to partners or participants, but instead involves the strategic and site-specific engagement of the agency and active partners "who work together in general forest operations, conservation, and restoration activities with a practical sense of shared responsibilities to achieve the mission" [17].

Components of the 2016 draft revised EYNF land and resource management plan focus on the protection of at-risk species; the sustainability of water production and quality; opportunities for sustainable recreation and other ecosystem services; protection of wetlands and riparian areas; and mitigation of and adaptation to climate change. This plan differs from the previous EYNF land and resource management plans in the integrated view of ecological, economic, and social sustainability, explicit connections to local communities, and adaptive approach to land and resource management. The adaptive aspects of the plan include a monitoring program that focuses on management effects and outcomes, as well as management strategies that promote partnerships with scientists, practitioners, decision-makers, and other stakeholders "who learn and work together to support a management system resilient to changes in social, economic, and ecological conditions" [17].

Table 1. El Yunque National Forest Core Management Themes (Adapted from USFS 2016) [17].

• Healthy ecosystems – Conserve and restore Forest ecosystems. – Protect and conserve functional wetlands and primary forest. – Maintain and improve watershed conditions throughout the Forest while monitoring, adapting to, and mitigating the effects of climate change.
• Sustainable recreation, access, and tourism – Provide for sustainable recreation throughout the Forest in harmony with the natural setting and with historical and cultural resources. – Develop public support and partnerships to improve recreation facilities and services on the Forest.
• "All-lands" management approach – Consider the ecological, social, and economic needs of the broader landscape in Forest plans and projects. – Provide for forest-community interface management area at the lower elevations of the Forest that is sustainably managed in accessible locations suitable for multiple-use management, including forest products.
• Collaborative, adaptive management – Sustain and develop partnerships and regional collaboration efforts engaged in conservation, management, land use, and research. – Shift priorities from primarily top-down to more collaborative land and resource management. – Integrate agencies, local landowners, and other key stakeholders in conservation efforts through the facilitation and coordination of a collaboration network. – Provide opportunities for research and monitoring and develop related initiatives with agencies and stakeholders.
• Environmental literacy and education – Connect the surrounding communities to the Forest's natural landscapes, identifying and overcoming barriers that inhibit their participation. – Provide opportunities to develop community capacity for participation in management activities, including interpretation, recreation, monitoring, etc.

Overall, this most recent EYNF management planning process demonstrates increased organizational and strategic flexibility in decision-making through its openness to extensive and ongoing public participation and interagency coordination, including listening sessions with key stakeholders; focus groups with local, state, and federal governments, regional protected area managers, youth groups, tourism operators, and others; and multiple public meetings, fora, and information exchanges. Following agency direction, the EYNF also has incorporated key aspects of adaptive, ecosystem management and the potential for active, ongoing learning important for dealing with complexity and uncertainty. In particular, the monitoring component of the draft revised plan outlines monitoring questions and associated indicators designed to inform management decisions by testing assumptions, tracking relevant changes, and measuring management effectiveness and progress toward desired conditions and objectives. These are significant developments that differentiate this plan from the ways in which the EYNF has been managed in the past and if put into practice will enhance learning and adaptiveness. Still, the monitoring program stops short of defining thresholds or triggers that signal when to adapt or change course, which are important for sustaining forest structures and processes.

4. Discussion and Implications

Since its inception, the EYNF has had to contend with complexity and uncertainty in the management of land, resources, and people. Scientific understanding of tropical forests as complex social-ecological systems certainly has increased since its establishment. Yet, so too has the associated

variability in and across systems and related processes—dynamics which are expected to increase in the context of the Anthropocene. So, how will the EYNF cope with the uncertainty and surprise associated with modern times? Are useful tools and arrangements already available? Or, are changes in policy or practice required for dealing with the Anthropocene?

Historically, the custodial and scientific approaches to EYNF land and resource management integrated important aspects of learning through the early establishment of long-term forest research and monitoring. However, these early policies and practices were not entirely conducive to the learning, flexibility, and adaptiveness needed for managing a complex system in increasingly unpredictable times [12–15]. A significant shift in overall agency direction was set into motion in the 1990s under the ecosystem management approach, but was only recently codified statutorily and expanded through the 2012 USFS Planning Rule. Under this new rule and related guidance, the USFS prescribes and promotes a more collaborative, landscape-level, learning approach to land and resource management that ultimately may permit more flexibility and adaptiveness to system changes and surprises, if adequately implemented on the ground. These changes are likely to be particularly important for managing tropical forests, like the EYNF, which as noted by Lugo (1995) [55] echoing Holling (1973) [56] "does not require a precise capacity to predict the future, but only a qualitative capacity to devise systems that can absorb and accommodate future events in whatever unexpected form they may take".

Nevertheless, this major shift in approach to the management of the ENYF that embraces adaptive, collaborative, ecosystem management will require significant organizational change, which is no easy feat, particularly since institutions tend to be path dependent and "sticky", changing mostly through slow, incremental shifts [57]. Hence, it is not surprising, for example, that it took 20 years or more for the USFS to move from the adoption of ecosystem management as a policy to its codification and implementation through the new Planning Rule. Though the USFS has experimented some with adaptive management over the past few decades, managers and line officers alike have revealed persisting challenges to implementation, including the significant institutional changes that are required, the high costs and limited funding for monitoring, and the lack of public and private support, particularly for the risk involved in experimentation [58]. These obstacles are likely to be a challenge for the EYNF as well and will require innovation, experimentation, and collective learning locally and throughout the agency, especially since the effects of the Anthropocene occur and interact in different ways at different scales, requiring flexibility in policy and practice at all levels [15,59,60]. Ultimately, the 2012 USFS Planning Rule has codified for the first time many of the processes necessary for managing complex systems, like the EYNF, in the context of the Anthropocene—specifically, ongoing learning, flexibility, and adaptiveness. What remains to be seen is if critical elements like monitoring and feedback loops will be adequately developed, funded, and implemented on the grounds, and if aversion to the risks associated with experimentation and flexibility in management decisions will be overcome at local and larger scales.

5. Conclusions

Historically, land and resource managers of the EYNF in Puerto Rico focused mostly on the protection of resources and prevention of harm through a custodial approach to land and resource management. Research and learning on forest characteristics, functions, and processes were established early on in the EYNF. The custodial approach to land and resource management gave way to an increasingly scientific, top-down management approach focused on technically-founded decision making, often at the exclusion of outside input. This eventually opened up to a more holistic management approach focused on the forest as an ecosystem and incorporating collaboration and adaptive elements in forest management and decision-making. These changes in the EYNF management approach mostly have been reactive, slow, and incremental, with some rarer, rapid shifts primarily in response to major changes in USFS policy and guidance that have promoted increasing adaptiveness and flexibility, but also to significant processes or impacts on the ground, such as hurricanes and changes in land use.

Most recently, the EYNF has expanded its potential for learning, flexibility, and adaptiveness in land and resource decisions and practices, in large part through its early adoption of the 2012 National Forest System Land and Resource Management Planning Rule. With sufficient, committed, and consistent resources, this policy shift could provide a robust framework for managing the EYNF into the future—particularly, given the certain uncertainty and surprise that are expected to increase for this tropical forest in the context of the Anthropocene. Building on decades of incremental change, the processes prescribed in the new Planning Rule provide the EYNF with a significant opportunity to make significant changes and blaze the trail for collaborative and adaptive forest management in the tropics. The EYNF is particularly well positioned to do so given its long history of forest research and close relations with scientists and research programs at the ready to engage in long term monitoring, experimentation, and feedback loops. It also has developed an inclusive and stable structure for meaningful collaboration with local communities and other active partners to engage in resource assessments, management decisions and applications, monitoring questions and collections, and analysis and interpretation of new information, within an adaptive management framework.

Collaborative relationships with local level stakeholders, productive ties to research and monitoring, and political support for adaptiveness and flexibility are critical elements in managing for the future resilience and sustainability of tropical forests, like the EYNF. Though the EYNF increasingly counts these and other important elements within its toolbox, this forest is likely to confront challenges as it shifts towards an organizational learning culture ready for and responsive to system changes and surprises [44,57,59]. Likewise, the development of a robust monitoring system with reliable and effective feedback loops will be critical, but not easily or inexpensively established or maintained [60,61]. The EYNF, like other forests in the National Forest System and throughout the tropics, must be afforded the necessary financial, human, and technical resources and the flexibility to put this new management approach into practice, to learn while doing, and adapt when necessary. Considering progress to date in their land and resource management planning process, it seems quite probable that the EYNF will be well positioned to collaboratively and adaptively manage its land and resources for resilience and sustainability even in the context of the changes and surprises certain to come as we continue to move forward through the Anthropocene.

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