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Review

Maintaining the Many Societal Benefits of Rangelands: The Case of Hawai'i

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Abstract: Well-managed rangelands provide important economic, environmental, and cultural benefits. Yet, many rangelands worldwide are experiencing pressures of land-use change, overgrazing, fire, and drought, causing rapid degradation. These pressures are especially acute in the Hawaiian Islands, which we explore as a microcosm with some broadly relevant lessons. Absent stewardship, land in Hawai'i is typically subject to degradation through the spread and impacts of noxious invasive plant species; feral pigs, goats, deer, sheep, and cattle; and heightened fire risk. We first provide a framework, and then review the science demonstrating the benefits of well-managed rangelands, for production of food; livelihoods; watershed services; climate security; soil health; fire risk reduction; biodiversity; and a wide array of cultural values. Findings suggest that rangelands, as part of a landscape mosaic, contribute to social and ecological health and well-being in Hawai'i. We conclude by identifying important knowledge gaps around rangeland ecosystem services and highlight the need to recognize rangelands and their stewards as critical partners in achieving key sustainability goals, and in bridging the long-standing production-conservation divide.

Keywords: conservation; cultural values; ecosystem services; land policy; natural capital; stewardship; sustainable development; grazing

1. Introduction

Rangelands, farms, and other working landscapes are increasingly recognized as providing important benefits for ecosystems and people [1–3]. Rangelands, including grasslands, pastures, savannas, and other ecosystems dominated by grasses and grass-like plants that support grazing and browsing animals, are the most extensive global land cover, and an estimated 1–2 billion people worldwide rely directly on these social-ecological systems for their livelihoods [4,5]. Moreover, rangelands provide a suite of ecosystem services beyond their immediate livelihood value, with benefits including wildlife habitat, climate and water regulation, recreation, open space, aesthetic beauty, and cultural connection to place [6]. However, without proper management—through either unsustainable use or failing to mitigate threats such as invasive plants, feral ungulates (hoofed mammals), fire, drought, and development pressures—rangelands can become degraded, reducing the ecological, economic, and social value of these systems [4,5]; indeed, an estimated 20% of rangelands have been degraded globally [7]. Particularly in urbanizing areas and under climate change, the risks of losing the vital tangible services and intangible cultural values of these landscapes are real and the losses are growing [8,9].

In Hawaiʻi, rangelands are the most extensive agricultural land use, with actively managed pastures spanning over 300,000 hectares (ha) or 20% of the land area across the islands [10]. Yet despite the substantial extent of these landscapes and the multi-generational knowledge and heritage related to their management, Hawaiʻi's rangelands have received relatively little attention in terms of the benefits these landscapes can provide beyond economic earnings [11,12]. Indeed, ranching in Hawaiʻi continues as a meaningful contributor to Hawaiʻi's agricultural base and efforts to increase local food production, but its continued support is also motivated by the ecological, relational, cultural, and heritage values of the practice [10].

The vital connections between rangelands and society may remain unrecognized or undervalued until severe decline or loss, when often it is too late. To address this, a working group was convened by The Natural Capital Project and the Hawaiʻi Cattlemen's Association in 2019. The group included Hawaiʻi -based scientists and ranchers who steward lands in Hawaiʻi to discuss, explore, and summarize the available published evidence on the links between well-managed rangelands and a suite of ecosystem services—the many benefits people co-produce and receive from rangelands. Ecosystem service assessments are an important way to describe and to comprehend more deeply the ways that people use, perceive benefits from, and interact with nature and natural resources [13]. Moreover, ecosystem service assessments play a central role in environmental and resource management decision-making [14–16]. The goal of this particular assessment was to understand current benefits, and also explore opportunities for improvement.

We define well-managed rangelands as those that: (1) manage livestock and pasture areas in ways that maintain and promote soil health, productive vegetation cover, and live roots; (2) apply resources and protocols to control highly invasive plant and animal species such as gorse and feral goats and pigs that negatively impact both pastures and conservation areas; (3) have managers who actively acknowledge, support, and engage with the rights and interests of their neighbors and surrounding communities; and (4) apply management practices that protect other valuable habitat such as forests and streams. While many ranches across the State fit into this category of well-managed rangelands, it is challenging for some ranches to meet these criteria for various reasons including leases with short terms or lacking agriculture-friendly provisions, difficult terrain, weather patterns, and invasive species threats [17]. By outlining the suite of benefits that well-managed rangelands provide, this article aims to inform and support practices and policies that enable a greater proportion of the lands to be well-managed. As recognized ways that landscapes matter to people in Hawaiʻi, we specifically consider biodiversity, carbon sequestration, soil health, watershed services, fire risk mitigation, and cultural ecosystem services.

2. Rangelands in Hawaiʻi—History, Challenges, and Vision for the Future

Most scientific treatments of cattle in Hawaiʻi focus on the historical and contemporary negative impacts of ungulates on native ecosystems (e.g., [18–22]). The expansion of cattle throughout the 19th century clearly had devastating effects on forests as well as Hawaiian society. Cattle were first introduced by British Captain George Vancouver in 1793 as a gift to King Kamehameha I who placed a kapu (taboo) to prevent the killing of cattle. Over the next four decades, cattle quickly proliferated and roamed freely, destroying upland forests and cultivated lands of Native Hawaiians [23,24]. In 1830, in response to the damage cattle were causing, King Kamehameha III brought Spanish vaqueros from California to teach Native Hawaiians how to herd and manage cattle. By the 1870s a vibrant cowboy, hereafter paniolo, culture emerged that remains culturally important in Hawaiʻi [25].

In the aftermath of significant biodiversity loss and other environmental change, by the 1850s, Maly and Wilcox [25] suggest that Hawaiʻi had "come to terms with cattle ranching in the sense that range management practices were in place and had become part of the ranching and paniolo culture that incorporated stewardship values" [25]. With a foothold as both emerging livelihood and business in the islands, ranching and paniolo culture had adapted to ecological and political-economic disruptions, including the Māhele beginning in 1848, which resulted in privatization and commodification of land ownership across much of Hawaiʻi [26]. By 1929, there were 41 primary cattle ranches across all the islands, with the majority on Hawaiʻi Island and Maui and by 1937, c. 810,000 hectares (~two million acres) of land were classified as grazing across the state. Maly and Wilcox [25] describe the cultural practices of cattle ranching as "an accepted part of land and natural resource management, and an integral element of Hawaiʻi's rich cultural landscape throughout most of the present century [25]".

Changing political economic conditions have made ranching more challenging economically in recent decades. As of 2015, the area designated as pasture has declined by more than 60%; yet, with approximately 308,139 ha (~761,429 acres) remaining, ranching is still by far the most widespread agricultural land use across Hawaiʻi [10] (Figure 1). The overall decline is due, in part, to the increasingly challenging economics of ranches, leading to many losing money on ranching operations [27]. Remaining ranches have survived through a combination of improved operating efficiencies, better genetics, and diversifying management, and marketing strategies. Many ranches have had to reduce herd sizes and diversify operations towards more lucrative tourism-oriented ventures and develop broader more financially viable options, including forestry, renewable energy, land sales, and commercial leases [28].

Nonetheless, today many ranches continue to perpetuate stewardship practices, including holistic grazing, forest and watershed protection, restoration, and increasingly koa commercial forestry and silvopasture [28,29] (Figure 2). Yet, despite these efforts and a desire to maintain rangelands, many ranches have needed to sell part or, in some cases, all of their land because of economic pressures [27]. Ranches also face an increasing suite of biological threats, ranging from invasions of gorse (*Ulex europaeus*), a thorny shrub that chokes the land [30], to the recently introduced two-line spittlebug (*Prosapia bicincta*), which decimates pastures and increases the spread of noxious weeds [31]. Finally, many ranches operate on short-term leases from the State of Hawaiʻi or other large landowners, making long-term planning, investment, and management challenging. These conditions have contributed to a declining ranching sector in Hawaiʻi and a need to better understand and express the many values of these increasingly threatened landscapes, both environmentally and culturally.

Motivations to continue ranching often also stem from the desire to maintain cultural traditions, connections to landscapes that have been stewarded over generations, and to maintain vast areas of open space that would otherwise be overgrown and degraded by invasive plants and animals. This value underpins the strong commitment—by intergenerational ranches, and increasingly by the state, land trusts, and other entities—to their preservation [27,32,33]. Though ranching was introduced post-European contact, the storied history of ranching in Hawaiʻi since the late 18th century has fostered deep relationships of many Native Hawaiian and kamaʻāina (multigenerational resident) families with ranching as central to their way of life, culture, and connection to place [13,27]. In a context of rapid coastal development, ranches—particularly on Maui and Hawaiʻi Island—are highly valued for their role in preserving open space and rural landscapes for local communities. Ranches also participate widely in watershed partnerships focused on protecting and restoring native forests, protecting endangered species, and contributing to landscape-scale invasive species control and fire mitigation efforts. Recently, the role of well-managed rangelands in helping Hawaiʻi adapt to climate change has been highlighted by the Hawaiʻi Climate Mitigation and Adaptation Commission [34].

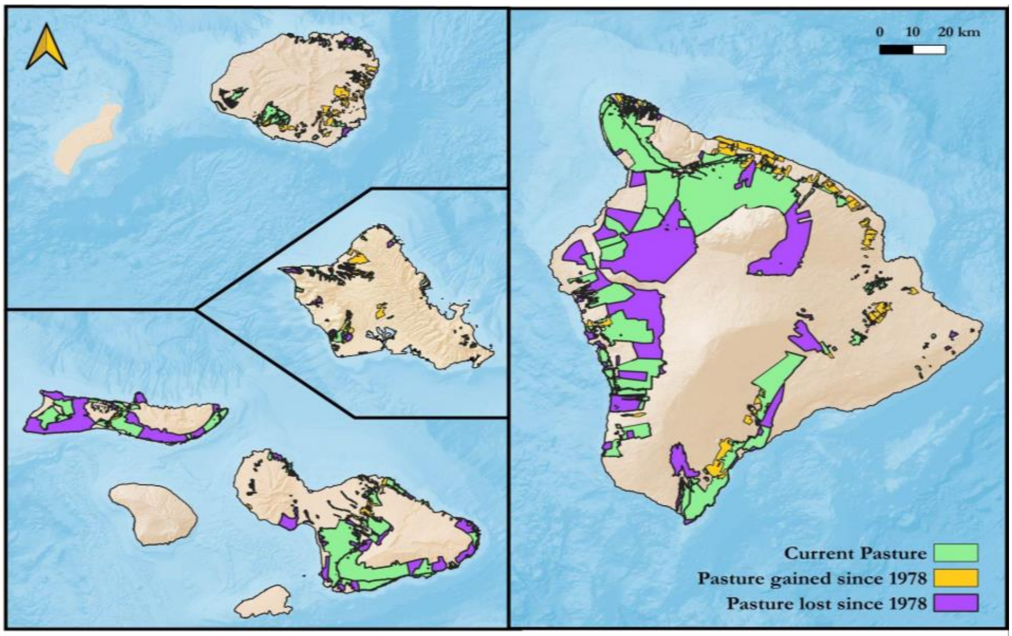

Figure 1. Change in pasture area in Hawai'i from 1978 to 2015. Light green are areas classified as managed pasture in the 2015 Hawai'i Agricultural Baseline that have been pasture since at least 1978 [10]. Purple represents land that was classified as pasture in 1978, but not in the 2015 baseline. The orange-yellow represents areas classified as pasture in 2015, that was not classified as such in 1978. From 1978–2015, there was a total decrease of 180,055 ha of pasture (purple), and a gain of 41,088 ha (orange-yellow). A 2020 Agricultural Baseline update [35] of a subset of islands found an additional decrease of 175 hectares of pasture on O'ahu, 891 hectares on Hawai'i Island, and a gain of 167 hectares on Kauái. Pasture gained was primarily sugar plantation in 1978, and pasture lost is now primarily fallow agricultural land or used for military training or restoration, with small areas converted to residential development [10].

Figure 2. Ranching activities that support ecosystem services in Hawaiʻi: (**A**) rotational grazing for food production and local livelihoods (*PC: Leah Bremer*); (**B**) high elevation silvopasture restoration with *Acacia koa* with the goal of diversifying livelihoods, restoring native tree cover, and potentially increasing fog interception (*PC: Jordan Jokiel*); (**C**) control of high-water-use invasive tree species; invasive black wattle (*Acacia mernsii*) shown here on the edge of grazing lands (*PC: Leah Bremer*); (**D**) *Acacia koa* restoration for diversified livelihoods and potential carbon sequestration benefits (*PC: Leah Bremer*); (**E**) fire break using grazing as a tool to reduce fire risk (*PC: Clay Trauernicht*); (**F**) Conservation of wiliwili (*Erythrina sandwicensis*) remnant forest in low elevation grazing lands, which would otherwise be threatened with development (*PC: Jordan Jokiel*); (**G**) protection of biodiversity through setting aside conservation easements such as Waikamoi reserve on Maui (*PC: Jordan Jokiel*); (**H**) support and perpetuation of paniolo culture and knowledge through intergenerational practices (*PC: Jordan Jokiel*).

3. Ecosystem Services Provided by Ranches in Hawaiʻi

3.1. Local Food and Livelihoods

Historically, the clearest and most direct benefits that rangelands provided was a supply of local food and livelihoods. While ranches were often linked to sugar plantations with grazing focused on marginal lands, unlike growing sugar for export, up until the 1970s cattle production was for local consumption [25]. Prior to the late 1980s, the Hawaiʻi cattle industry imported high energy feeds which, together with locally produced corn, sugar, and pineapple byproducts and local slaughterhouses, allowed for on-island grain-finishing of Hawaiʻi's cattle so that more than 90% of the cattle produced on the island were consumed locally [11]. Thereafter, rising costs to import feeds led to the closure of Hawaiʻi's feedlots and two major packing houses, resulting in a shift to exporting most cattle to the US mainland. Today >80% of local beef production is exported to the US mainland, although that export trend is shifting as the development of a grass-fed market for local consumption continues to grow [10,36], in line with local sustainability goals focused on increasing local food production (https://www.hawaiigreengrowth.org/ (accessed on 23 May 2021)). There are currently seven small slaughterhouses in Hawaiʻi, which are considered relatively expensive to operate, but critical to the local beef industry and to the State's goal of producing more local food [10]. Collectively, livestock production on ranches is estimated to employ 850 people directly across the state [37], with many other jobs provided by diversified activities such as conservation, forestry, and tourism.

3.2. Watershed Services

Watershed services include the regulation of ample and clean water supply, as well as the regulation of peak flows (reducing risk of flooding), maintenance of base flows (reducing risk of water scarcity), and groundwater recharge [38]. We highlight two critical categories of watershed services across Hawaiʻi: regulation of water quality (through sediment and nutrient retention) and groundwater recharge.

First, replenishing groundwater or aquifer reserves is one of the most highly valued ecosystem services in Hawaiʻi [39], as 99% of drinking water is from groundwater sources [40,41]. As a highly isolated archipelago, Hawaiʻi has no viable alternatives to groundwater in fulfulling water consumption needs beyond desalination which is costly and has many environmental and social tradeoffs [42]. In addition to supporting direct human consumption, groundwater is a key input to coastal and stream ecosystems, including fish ponds, anchialine ponds, nearshore ecosystems, and spring-fed agriculture (e.g., lo'i kalo or taro fields), and wetlands [43,44], all of which support culturally and nutritionally important species.

Second, land management practices that improve sediment and nutrient retention are highly valued in Hawaiʻi and elsewhere given that sediment leaving streams and groundwater high in nutrients can negatively impact the links between stream and groundwater quality and the health of culturally, ecologically, and economically valued aquatic and nearshore ecosystems [45–53]. Excessive sediment can also increase water treatment costs [54], which is important in some areas in Hawaiʻi (e.g., Maui) where surface water is used for drinking.

3.2.1. Role of Well-Managed Rangelands in Providing Watershed Services

Well-managed rangelands are an important part of a landscape approach to protecting and enhancing watershed services. While the reduction of native forests that accompanied the growth of ranching in the 19th and early 20th Centuries clearly altered the natural hydrologic regime, well-managed pasture with high vegetation cover (>75% minimum) help water infiltrate into the subsurface and retain sediment [55,56] compared to urban areas or to un-managed or abandoned grasslands, which quickly become overgrazed with feral ungulates and subject to repeated fires and spread of noxious weeds [57].

3.2.2. Groundwater Recharge

Land management and vegetation type influence groundwater recharge through: (1) changes in rain and fog interception at high elevations; (2) rates of evapotranspiration (the transfer of water from the land to the atmosphere through evaporation from soils and transpiration of water from plants); and (3) the amount of water that infiltrates into the soil and the aquifer, influencing the amount of groundwater recharge compared to surface water flow [58–60]. Grasslands (including rangelands) generally have lower rates of actual evapotranspiration compared with forests because short roots have less access to water and short-statured grasses reduce land-atmosphere mixing [61]. In Hawaiʻi, where fog is common (~750 m asl (~2500 feet)), tall forests with high surface area generally have higher fog interception than grasses [62]. Recent in research in Hawaiʻi has found that forests generally have higher saturated conductivity (a measure of infiltration) than grasslands [59], but how this translates to the overall water balance was not addressed. In general, in areas with low water inputs from fog interception, lower rates of evapotranspiration in grasslands compared to forests will generally lead to increased groundwater recharge under rangeland [63].

In the most comprehensive field study of pasture, forest, and silvopasture in Hawaiʻi (carried out in Kona) [58,62,64,65], dense high elevation native forests were found to have slightly higher recharge rates than pasture due to higher fog interception than pasture; however both land cover types had high recharge rates (96–106% of above-canopy rainfall recharging the aquifer). Interestingly, both dense native forest and pasture were found to have higher recharge rates than silvopasture (87% of above-canopy rainfall recharging the aquifer) [65] (Figure 3).

In a scenario modeling study in Kona, Bremer et al. [8] found that current pasture (grasslands) cover likely would have equal or greater rates of groundwater recharge than if reforested with dry and mesic forest (mostly below the fog zone) and higher rates of recharge than if replaced by coffee. Using similar methods, Wada et al. [66] found that recharge increased when pasture was restored to native forest in high elevation areas with significant fog interception, but that restoration in lower areas increased evapotranspiration without fog interception benefits, resulting in a decrease in recharge. Just as not all forests are the same, not all pastures are the same, and while results will vary by place, these studies suggest well-managed grasslands—particularly in lower elevation areas—contribute to groundwater recharge, particularly in comparison to unmanaged grasslands or grasslands invaded by high-water-use invasive trees. They also suggest that efforts to increase forest cover for groundwater recharge should focus primarily in higher elevation areas with significant fog interception or in areas where vegetation and soils are highly disturbed.

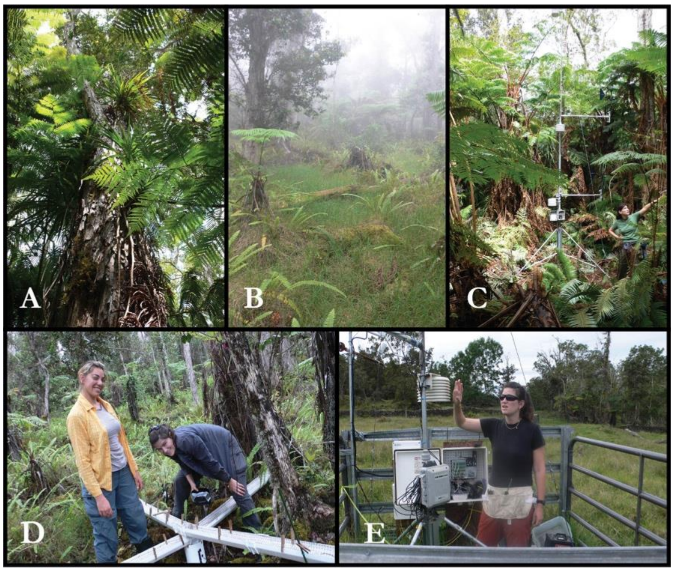

Figure 3. Taking micrometeorological measurements of water fluxes in native forest and pasture in Kona, on the west side of Hawaiʻi Island, to measure groundwater recharge, the sole source of water for the coastal community [52–54]. (**A**) Large, complex, and multi-layered leaves within Kahalu'u Forest have high surface area that intercepts fog and contributes to groundwater recharge; (**B**) Fog interception by leaves is somewhat lower in this more open forest; (**C**) Kate Brauman setting up a micrometeorological station in forest; (**D**) Kate Brauman and Heather Tallis setting up devices for measuring the amount of precipitation that falls through the forest to the ground (as opposed to evaporating from leaf surfaces; (**E**) Kate Brauman taking meteorological measurements on Palani Ranch (*PC: Gretchen C. Daily*, **A**–**E**).

In addition to management of pasture areas, well-managed rangeland landscapes are characterized by efforts to protect and restore native forest and reduce the spread of fast-growing, high-water-use invasive species [58]. Ranches accomplish this through direct restoration and conservation work on their land, by participating as partners in watershed partnerships, and through conservation easements such as the Waikamoi preserve in East Maui managed by The Nature Conservancy. In terms of hydrologic benefits, much of this restoration and protection occurs in high elevation areas with substantial fog interception, likely providing groundwater recharge benefits [61]. Efforts to reduce the spread of fast growing, non-native species [58], which often have high evapotranspiration rates [67], likely serve to maintain groundwater recharge in areas both pasturelands and adjacent native forests that would otherwise be invaded [61].

3.2.3. Water Quality

Well-managed rangelands can also contribute to improved water quality with implications for a variety of valued stream and coastal ecosystems. Rangelands that retain >75–80% vegetative ground cover help to reduce erosion and retain sediment on the land, particularly in comparison to over-grazed grasslands, intensive agriculture, and urban development [55,56]. Ranching impacts can also be reduced by redistributing grazing pressure away from areas vulnerable to erosion such as gullies and streambanks [56]. In Hawai'i (and elsewhere) ranchers often see themselves as managing grass as much as managing cattle, and a key component of this is ensuring adequate forage and high ground cover. While these grassland ecosystems are composed of introduced grass species, they still provide diversity and resilience as ranchers actively manage a diversity of grass and other herbaceous plant species, which together maintain high ground cover across equally diverse gradients of climate and elevation [68].

Well-managed grasslands also have low nutrient inputs, as they generally do not use fertilizer [69], and also retain nutrients from upstream sources at a much higher rate than developed areas [70]. While there will be some nutrient input in the form of manure, this is well distributed across the landscape and, where feasible, is often managed to be out of waterways. Nutrient input rates are much lower than urban development and intensive cropping systems, and local observations suggest that in well-managed rangelands, manure breakdown is rapid and facilitated by populations of dung beetles. Falinski [70] compiled estimates of nutrient export rates from land cover types in Hawai'i and found grazing lands to export an estimate of 8.3 kg ha^{-1} yr^{-1} compared with 350, 424, 140, 437, and 100 kg ha^{-1} yr^{-1} for sugarcane, pineapple, coffee, golf courses, and impervious land, respectively [70]. Grazing lands are in the range of nutrient export rates of open space (7.5 kg ha^{-1} yr^{-1}), shrubland (5.5 kg ha^{-1} yr^{-1}), and native forest (11.3 kg ha^{-1} yr^{-1}) [70].

3.2.4. Limitations of Rangelands in Providing Watershed Services

It is important to note that while a growing number of ranches are involved in active forest protection and restoration today, ranching practices included the introduction of new forages historically resulted in a reduction of native forest cover, and in so doing, significantly altered local and regional hydrological regimes in ways that are poorly understood. Tropical water cycles with respect to plants and soils are also poorly understood [49,60,71]. Thus, the hydrological services of rangelands, compared to other ecosystems, are often hard to predict. Landscape-scale efforts to maintain or increase watershed services could think about strategic partnerships with ranches to support good management of grassland range areas as well as restoration of key areas for groundwater recharge (e.g., areas with high fog interception) or riparian corridor areas (for sediment retention). Moreover, ranchers can provide knowledge and resources which can support the protection of adjacent, high value land covers such as native forest.

3.2.5. Future Research

There are a number of important research areas that would improve knowledge around rangeland ecosystem services. First, characterizing and mapping rangeland management practices and resulting vegetation cover across the landscape would improve our ability to assess and model current ecosystem services provided by rangelands, such as through ecosystem services modeling tools (e.g., Bremer et al. [8]; Sharp et al. [72]). Second, further ecohydrology studies that characterize the evapotranspiration, fog interception, and infiltration rates of different types of rangeland (e.g., well-managed versus degraded) compared to alternative land covers—including native and non-native forest, agriculture, urban development—would help to better characterize the relative services provided by these lands. Finally, it will also be essential to improve understanding of how forest restoration practices—including native reforestation, koa forestry, and different types of silvopasture—affect valued watershed services, through both field and modeling studies.

3.3. Carbon Sequestration and Soil Health

3.3.1. Definition of Service

Carbon sequestration and storage is one of the most integral strategies for drawing heat-trapping carbon dioxide gas from the atmosphere and back into soils and vegetation. This is key, and must be done quickly to avoid catastrophic consequences of climate change [73]. While energy demand and total emissions significantly decreased in 2020 due to the COVID-19 pandemic, 30.6 Gigatons of CO_2 were still released to the atmosphere during the year [74]. Since these levels are not expected to drastically decline in the immediate future, enhancing the carbon sequestration and storage potential of our ecosystems plays a critical role in mitigation.

Ecosystem carbon consists of both above- and below-ground pools. Above-ground, carbon is stored in plant stems, tissues, and litter, while below-ground carbon consists of detritus and sloughed roots from plants that have been broken down by microbes and incorporated into the soil, as well as microbial byproducts and microbial mass. The majority of ecosystem carbon in most terrestrial systems is belowground, or soil carbon [75,76]. Sequestering carbon into the soil provides additional benefits related to soil health (See Box 1).

3.3.2. Role of Well-Managed Rangelands in Providing the Service

Above-Ground Carbon Sequestration and Storage

While discussions of rangelands and carbon primarily focus on soil (see next section), there is great potential for above-ground sequestration and storage through forestry (primarily with native trees like *Acacia koa*), native forest and agroforest restoration (with a mix of tree and understory species), and silvopasture (the combination of pasture/grazing with trees) [28,77,78]. Many ranches have engaged in native forest protection and restoration activities, with clear carbon sequestration and storage benefits. For example, Haleakalā Ranch seeks to restore 164 ha of high elevation pasture to native forest in its Ukulele project and also donated more than 2000 ha of important native forest in the Waikamoi Preserve to The Nature Conservancy (see Box 2 in biodiversity section). Haleakalā Ranch and other ranches have also engaged in koa forestry projects for income diversification, biodiversity, and carbon benefits.

Silvopasture (a mix of pasture and trees), is another promising option to increase above-ground carbon storage in rangelands. Much of Hawaiʻi's pasture is ecologically suitable for agroforestry (which includes silvopasture) [78], as compared to much of the world's rangelands which are likely too dry to support tree growth [79]. Project Drawdown [79], a non-profit organization focused on evidence-based climate solutions, estimated the potential carbon sequestration of silvopasture at 2.7 Mg of carbon per ha per year (or 9.9 Mg of CO2e (carbon dioxide equivalent) per ha per year) based on a meta-analysis of 8 studies [79,80]. However, the global rates are determined using an average soil type [79], whereas the majority of Hawaiʻi rangelands are dominated by Andisols, a volcanic soil that stores much more soil carbon than other orders due to its mineralogy [81,82].

While silvopasture may increase soil carbon storage in Andisols, it is also possible that disturbing the established soil of Hawaiʻi pasture to introduce trees may actually release more carbon than can be captured by new trees [80,82]. Additionally, the adoption of silvopastoral techniques can be a complicated subject for Hawaiʻi ranchers. Some have suggested that pasture would need to be taken out of production for at least ten years to allow for adequate establishment of the trees [78]. However, in other cases, ranches (e.g., Haleakalā Ranch) are developing fencing and spacing strategies that will allow for tree growth simultaneous to grazing [69]. There is a clear need for research into the impacts of silvopasture, particularly in high elevation Andisols to manage any potential trade-offs between above- and below-ground carbon.

Box 1. Five main management principles for soil health in rangelands.

Soil Health

Healthy soils support ecosystem services such as: improved air and water quality, groundwater recharge, carbon sequestration, nearshore ecosystem resilience, increased drought tolerance, reduced impacts of flooding, crop and livestock productivity, and more. Soil scientists struggle to define soil health, and for these reasons scientifically identifying "healthy soil" can be elusive at the farm or ranch scale. The most commonly agreed upon definition of soil health is "the continued capacity of soil to function as a vital living ecosystem that sustains plants, animals, and humans [83]." University of Hawai'i researchers are developing consistent guidelines for soil health evaluations, including a list of soil health indicators (including soil C and other physical and biological indicators) that can be used in Hawai'i and throughout the Pacific Islands (https://soilhealthhawaii.org/, accessed on 23 May 2021).
The Natural Resource Conservation Service identifies five key principles that support soil health [84]:

1. Keep the soil covered

Rangelands that are covered with vegetation help prevent soil erosion from wind and water, which may otherwise impact air and water quality. [They also] generate plant litter and aid in soil organic matter generation, a key component of healthy soil [85].

2. Minimize Disturbance

Good grazing practices that prevent overgrazing help maintain a level of vegetative cover that minimizes soil disturbance. Managed grazing lessens disturbance by reducing the amount of plant material that is actively removed and allowing it to recover faster. Minimizing disturbance can increase plant recovery and forage quality, as well as build soil carbon which is associated with increases in water infiltration [86]. In Hawai'i, unmanaged grazing from feral ungulates can also lead to overall decreases in native overstory and understory species, and invasive weeds are more likely to establish. Many [local] rangeland managers have dedicated land to preserves, restoration sites and native tree establishment areas where all ungulates including invasive wild boar, goats and deer are excluded, further promoting minimization of disturbance.

3. Maximize diversity

Diversity in rangelands promotes resilience to pests and disease and allows for various species populations to fluctuate and adapt to changes and stressors such as fire and drought [87]. For example, Haleakalā ranch and other ranches actively diversify pastures with a mixture of grasses, legumes, and forbs, as a management goal to improve feed while also increasing ecosystem resiliency [69].

4. Maintain Living Roots

Good grazing practices can promote abundant plant growth and living roots [88,89]. These roots provide a constant food source for soil biota which is a key indicator of soil health and ecosystem function. Roots also prevent soil compaction by maintaining and improving structure that allows the soil to maintain water in micropores during dry conditions and filter through macropores when it is in excess [85]. Continuous root production also supports the soils ability to build and maintain carbon. Perennial grasslands can be net carbon sinks when managed to improve forage and below-ground biomass [90].

5. Integrate livestock

Livestock play an integral role in supporting soil health on both rangelands and integrated crop-livestock systems. Grazing can improve nutrient cycling in nutrient-limited grassland ecosystems, and infrequent disturbance helps to incorporate manures and other plant material that help build soil organic matter [91,92]. With increasing stocking and forage utilization rates using multi-paddock adaptive grazing management, more nutrients are returned via manure and urine in a homogenous way that results in less nutrient loss.

3.3.3. Soil Carbon and Health

Grass- and rangelands store a higher proportion (89%) [93] of their total carbon stocks below-ground than other ecosystem types. Yet soil carbon stocks are significant even in forested ecosystems with larger amounts of above-ground carbon, for context. For example, Sierra et al. [94] recorded 59 and 84% of ecosystem carbon being belowground in secondary and primary forests, respectively. In addition to total stock, having a higher proportion of ecosystem soil carbon being stored belowground is beneficial for ecosystem carbon stability, since belowground soil carbon is more stable than aboveground carbon stocks, especially in areas where wildfires are prone [95]. This is not to say that grasslands always have more total ecosystem carbon stocks than forests—many times they have less or equal—but that a larger proportion of ecosystem carbon is stored more stably in grasslands than in forests.

The majority of grazing lands in the state are situated on volcanic soils (Andisols) (Figure 4) that can store ten times more carbon than typical continental U.S. soils due to their unique and complex mineralogy [96,97] (Figure 4). This puts rangeland stewardship in a particularly critical role in maintaining, managing, and increasing soil carbon stocks in Hawai'i, yet relevant data that could be used to guide local producers is lacking.

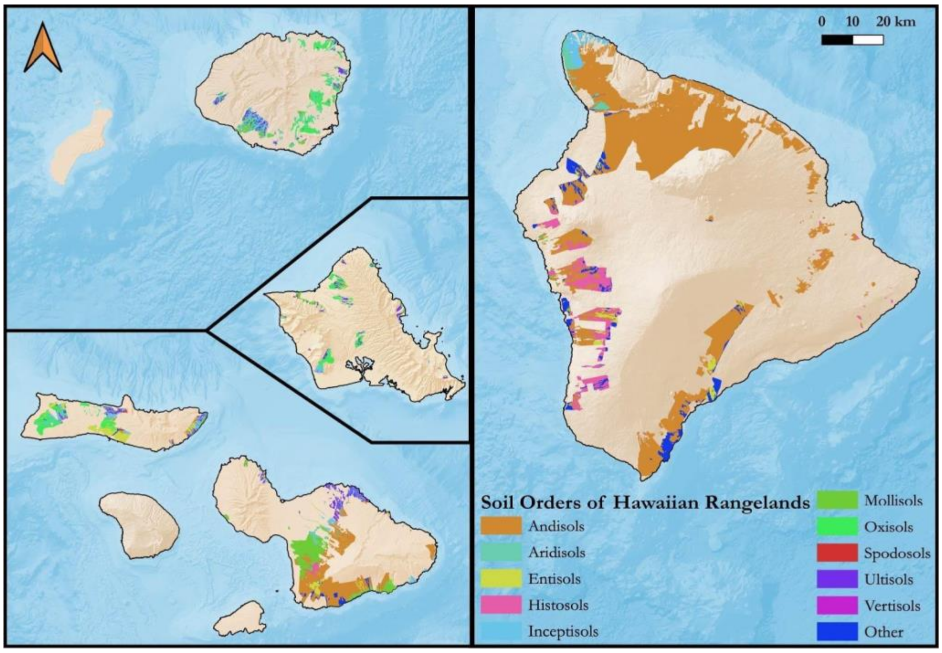

Figure 4. Soil orders that exist within pasture land in Hawai'i (https://www.nrcs.usda.gov/wps/portal/nrcs/surveylist/soils/survey/state/?stateId=HI (accessed on 16 March 2021)) demonstrating that the majority of rangelands in the state occur on Andisols, a volcanic soil order that can store several times the amount of carbon as many other soil orders.

Grazing has been recorded as having a wide variety of positive and negative effects on soil carbon [98]. Pineiro et al. [99], in a survey of 36 previously published studies, found 12 studies that reported increases of soil carbon after grazing, 12 with no change, and 12 that reported a decrease. Much of the variation in results is attributable to differences in soil type, site history, previous land use, and management [100]. Generally, overgrazing is most deleterious to soil carbon stock, whereas practices such as managed grazing, nitrogen fertilization, legume interseeding, and restoration efforts on degraded lands foster more soil carbon sequestration [101]. The Intergovernmental Panel on Climate Change [102] listed grazing management as having the potential of sequestering more than 300 Megatonnes of carbon (MtC) per year globally.

In a synthesis of published literature, Conant et al. [103] found that initiating grazing on previously ungrazed lands resulted in an almost ten percent increase in soil carbon concentration. The same authors found that grazing resulted in an additional 0.28 Megagrams/metric tons (Mg) ha^{-1} yr^{-1} than on ungrazed lands. Additionally, Schuman et al. [100] found both light and heavy grazing (35% lower and 33% higher than National Resource and Conservation Service recommended rates, respectively) for 12 years resulted in higher soil carbon stocks in the surface 30 cm of soil, which the authors attributed to higher root turnover in the grazed treatments.

Soil carbon accretion rates in rangelands have been recorded to vary from 0.1 to 3.0 megagrams/metric tons (Mg) C ha^{-1} yr^{-1} [104], with the recent Project Drawdown report, estimating that well-managed grazing could sequester 0.67 Mg C ha^{-1} yr^{-1} (2.46 tons of CO_2e ha^{-1} yr^{-1}) in tropical humid grasslands based on a meta-analysis of existing studies [80,105]. Gross et al. [80] further suggest that sequestration may be higher in Hawaiian pastures on Andisols and Histisols given the high capacity for carbon storage among these soil types. In terms of these sequestration rates as a percent of total soil carbon there is large variability, since in Hawai'i soil organic carbon stocks can vary from less than one to over 650 Mg C per hectare [106]. The higher rates of accretion generally occur after a shift from "poor" to "good" management, which could include the addition of improved forage cultivars or legumes, longer pasture rest times, or adjusting stocking rate [103,104]. The lower rates of sequestration, such as 0.1 Mg C ha^{-1} yr^{-1} were found for poorly managed rangelands [107]. That being said, operations with a history of practicing good grazing management observe gains in soil carbon more rapidly (0.3 Mg C ha^{-1} yr^{-1}) [107]. For comparison, Silver et al. [108] measured soil carbon sequestration rates of 1.4 Mg C ha^{-1} yr^{-1} after planting trees on abandoned croplands and pastures in the humid tropics, yet other studies of afforesting abandoned agricultural lands estimated lower rates, between 0.04 and 0.57 Mg C ha^{-1} yr^{-1} [109]. Also, worth noting were the findings of Paul et al. [110], which found that afforestation generally decreases soil carbon in the first five years, but that levels recover over longer rotations (~30 years).

In Hawai'i, few studies have addressed soil carbon in rangelands. Crow et al. [82] found almost equal amounts of soil carbon stock in grazed pastures and established eucalyptus forest. Osher et al. [111] found that conversion of tropical forest to pasture resulted in an overall soil carbon gain, due to increased carbon storage in deeper depths of the soil. Bashkin and Baily [112] found no increase in total soil carbon to a 1 m depth after 10–13 years of afforestation of sugarcane land with *Eucalyptus saligna* (Sm.) on the Hamakua coast of the Big Island. Li and Mathews [109] found slightly higher soil carbon stocks in abandoned sugarcane lands that were converted to *Eucalyptus* than those that were converted to pasture in the 10–25 cm depth range, but no difference in the surface soil (0–10 cm) after 22 years of changed management. Krueger et al. [113] found some of the highest soil carbon stocks recorded in the state under rangeland that has been grazed for over one hundred and twenty years. This suggests that responsible grazing in this context can at least maintain, if not increase, inherent soil carbon stock in these areas.

Elmore and Asner [18] recorded decreasing soil carbon stocks with increasing grazing intensity on Pu'u Wa'a Wa'a rangelands, due to soil degradation of overgrazed regions via erosion, as well as reduced plant production in more heavily grazed areas. The same authors also found higher soil carbon stocks in patches of 'ōhi'a lehua (*Metrosideros polymorpha*) forest throughout the kikuyu (*Pennisetum clandestinum*) and fountain grass (*Pennisetum setaceum*) dominated research site, yet soil samples only reached a depth of 10 cm, which does not encompass the full extent to which soil carbon dynamics occur. Nevertheless, these findings show how grazing management can determine the success or failure of rangelands to sequester carbon, while also illustrating how large an effect different vegetation classes can have on overall carbon stocks.

3.3.4. Limitations of Rangelands in Providing Carbon Sequestration and Storage Benefits

It is important to note, that, because annual accretions of soil carbon are slight and variability of soil carbon over a landscape can be high, it can be a number of years before increases in soil carbon can be reliably measured [114]. Therefore, it is critical that if rangeland stewards are managing for increasing soil carbon, the strategies and land tenure systems (e.g., long-term leases) that are put into place must be able to remain active for a large number of years to be effective.

Additionally, although grazing systems have been shown to accrue carbon in the soil, these systems inherently include methanogenesis via enteric rumen fermentation. The amount of methane released to the atmosphere in grazing systems is dependent upon stocking density, forage quality, and stand management, among other factors [115,116]. More detailed quantification of methanogenesis is currently required for accurate determination of greenhouse gas balance in these systems [117], but previous research has estimated methane production on a land-basis of 602 kg CO_2e ha^{-1} yr^{-1} [118]. Although this is a significant amount, research by the same authors showed that when soil carbon sequestration was accounted for in grazed beef cattle finishing systems, net negative GHG emissions were possible. These authors also noted that for other research projects, including soil carbon in lifecycle analyses of GHG's decreased emission estimates by 24–535%.

Although methane emissions from grazing systems can be significant, they are dwarfed by emissions from natural processes such as wetlands [116,119].

3.3.5. Future Research

There are a number of useful future areas of research in regard to soil carbon and soil health. A major challenge of understanding grazing and grazing management effects on soil carbon stocks in Hawai'i is the lack of investigation and publications showing the entire picture of long-term change and contributions from soil mineralogy. Therefore, more research is warranted to (a) establish baseline soil carbon stocks in Hawaiian rangelands and their variability, (b) assess effects of grazing management on soil carbon stocks by comparing different grazing (intensity) systems, and (c) measure soil carbon sequestration rates for different grazing systems over different soil types (resampling areas after obtaining a baseline). The results of these types of research would directly aid in ranchers' ability to manage for carbon sequestration, and to provide them a quantitative, annual carbon sequestration rate that could be used for participation in potential future state and other policies related to carbon sequestration and soil health. The US Climate Alliance Hawai'i Natural and Working Lands Research group, for example, has drafted a Climate Smart Incentives Program that would provide some financial and technical assistance to producers who implement climate smart practices that improve soil health and build soil carbon. This particular initiative is not yet funded, but hopes to work with ranchers as they seek to quantify these and other ecosystem services.

Furthermore, research demonstrating potential co-benefits of increasing soil carbon and overall soil health such as improving infiltration and ground water recharge capacity, reducing runoff and nearshore ecosystem impact, and especially increasing forage and livestock productivity, can help increase the adoption of best management practices. Demonstration and quantification of these more holistic characteristics of soil health may aid in ranchers' participation in programs geared towards payment for ecosystem services, and may help quantify ongoing ecosystem services provided by good rangeland and soil health management [120].

3.4. Fire Risk Reduction

3.4.1. Definition of Service

Fire risk reduction refers to the potential of land management to reduce the risk of fire [57]. Practices like grazing, prescribed burning, and forest thinning allow people to enhance a given ecosystem's ability to provide the "service" of reducing wildfire risk to valued assets [121]. Fires in Hawai'i pose a year-round threat to human lives and infrastructure, degrade native forests by killing trees and favoring nonnative grasses (increasing future fire risk), and contribute to coral reef declines by increasing erosion [57,122,123]. People cause most wildfire ignitions worldwide [57,124], and also modify wildfire risk via land use and management that alters vegetation type or structure [125,126]. In Hawai'i, the area burned by wildfire each year has increased by 300% in recent decades. Abandonment of agricultural land (often formerly sugar or pineapple land) is a key driver of this change [57] (Figure 5).

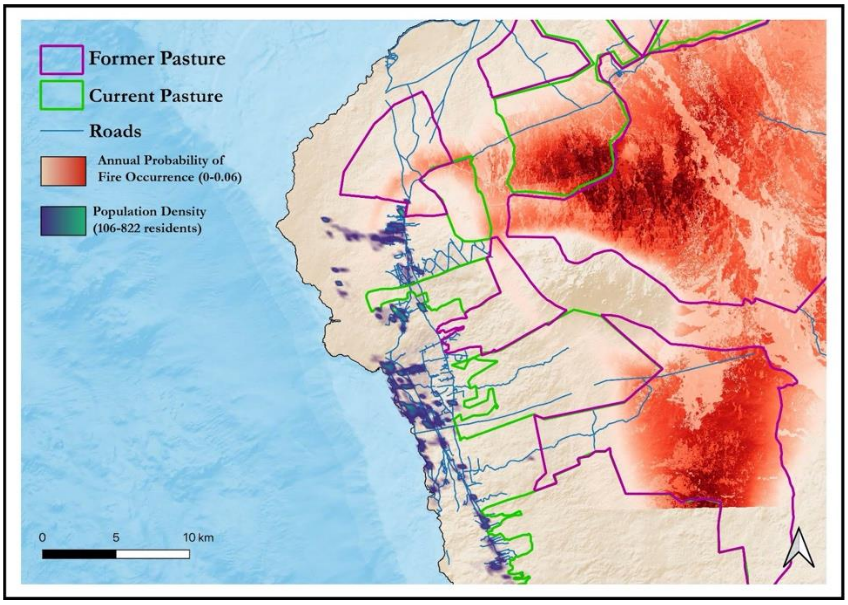

Figure 5. Map depicting fire risk in the Northwest area of Hawaiʻi Island. Areas outlined in purple represent former pasture (in 1978), and areas in green represent current pasture (in 2015) [10]. Population density shows where people are in relation to high-risk areas.

3.4.2. Role of Well-Managed Rangelands in Reducing Fire Risk

More than 70% of Hawaiʻi's burned area occurs in grasslands and shrublands, which currently cover more than 400,000 ha, or 25%, of Hawaiʻi's land surface [57]. A large portion of these lands (~324,000 ha) were cleared and managed for livestock production over the past century, which introduced a variety of fire-adapted, nonnative grasses to the islands [19,25]. The majority of recently abandoned agricultural farmlands in Hawaiʻi (typically former sugarcane or pineapple) have reverted to grasslands and shrublands dominated by nonnative, fire-prone plant species that dramatically increase fire risk [57,127] (Figure 5).

In contrast, however, the continuation of ranching preserves critical fire mitigation resources—personnel, local knowledge, roads, water, heavy equipment, as well as eyes on-the-ground—that historically supported firefighters [128]. The decline of rangeland stewardship, whether due to the decrease in available rangeland or the challenges of sustaining a viable cattle business, compound the increased risk of wildfire when coupled with hotter temperatures and less predictable rainfall under climate change [129].

Ample research demonstrates that livestock grazing in Hawaiʻi effectively reduces the quantity of grassy fuels and therefore decreases fire risk in Hawaiʻi [20,125,130,131]. Research also indicates grazing results in a larger and longer-lasting reduction in wildfire risk than herbicide and/or mowing [125,132]. In many instances, reducing fire risk may simply be an indirect co-benefit of grazing and not the grazers' direct goal. However, grazing intentionally for fuels reduction in high-risk areas, such as roadsides, has long been practiced by ranchers in Hawaiʻi [133].

In many parts of the continental US and Europe, grazers are paid by local governments for targeted grazing, or managing livestock for deliberate fire risk reduction in rangelands, as part of coordinated, regional fire risk reduction plans [134–139]. The most obvious effects of grazing are reductions in quantity and connectivity (i.e., continuity) of fine, grassy fuels through consumption and trampling [125,136,140]. Grazing also reduces the amount of fuel load in the form of standing dead grass relative to live grass, thereby increasing the "greenness" of grasslands which also reduced fire risk [130,140,141].

3.4.3. Limitations of Rangelands in Reducing Fire Risk

Managing rangelands for reduced fire risk using livestock may not be a viable management option under certain conditions. Targeted grazing requires access to and adequate infrastructure (water and fencing), which may not be available where resources are most threatened, such as adjacent to communities and forest reserves. Wildfire risk in smaller parcels or rangelands adjacent to developed areas may be more difficult to manage due to access, livestock transportation issues, and homeowner preferences (e.g., Toman et al. [142]). Still, there are examples in Hawai'i where large landowners support grazing on lands adjacent to urban areas to manage vegetation and reduce fire risk. Some rangelands that are dominated by unpalatable or nutritionally poor grasses, such as fountain grass, may be less suitable for targeted grazing (but see Castillo et al. [125]). Livestock grazing may be incompatible, or require additional management intervention, in areas where the survival and regeneration of native Hawaiian plants is a priority [21,143]. However, there is evidence for integrating grazing for weed control in silvopastoral systems with native tree plantations (e.g., Acacia koa) [22].

3.4.4. Future Research

There is an urgent need for better information on how much, and how frequently, areas should be grazed to balance fire risk reduction with maintaining forage quality and other benefits of rangeland management (e.g., soil carbon storage). Rangeland plant community dynamics and species distributions are also poorly understood in Hawai'i, especially with respect to how potential range shifts may alter fire risk under climate change. Developing local land use histories that outline historical grazing patterns and livestock densities may help to quantify the risk reduction benefits related to fire in well-managed rangelands compared to abandoned or unmanaged areas.

3.5. Biodiversity Conservation

3.5.1. Definition of Service

Biodiversity is defined as the variety and variability of life on Earth, at all levels from genetic diversity to the variety of species—of plants, animals, and microbes—and on up to ecosystems and whole biomes, such as the tropics or polar regions [144]. Agricultural biodiversity is a subset encompassing everything relating to food and agriculture, and it is absolutely essential for ensuring food and livelihood security across the globe [145]. Biodiversity is the engine underpinning many ecosystem services, including tangible benefits of soil formation, air quality and climate regulation, control of disease and pests [146], and promotion of mental and physical health [147,148], and also provision of intangible senses of belonging, aesthetic and creative stimulation, cultural richness and meaning, and spiritual dimensions of well-being. When biodiversity is lost, options are foreclosed, and all of us in the web of life are poorer [149].

3.5.2. Role of Rangelands in Biodiversity Conservation

The introduction of cattle to Hawai'i, and the subsequent spread of feral herds, caused widespread damage of native forests across Hawai'i [25]. This and other threats (i.e., invasive plant species, the sandalwood trade, avian disease) led to high rates of extinction, leading to Hawai'i being known as the endangered species capital of the U.S. However, as cattle were reigned in and ranchland clearly delineated, ranches also became important advocates for protecting remaining biodiversity and are active in large-scale restoration efforts. They now constitute an important part of these landscapes and are central to managing major threats to remaining biodiversity including fire and invasive species.

There is an interdependence between a well-managed rangeland operation and the natural environment. Ranchers rely on land for their livelihood and lifestyle and are often important advocates for land protection [150,151]. While grass pasture in Hawai'i rarely hosts native plant species, ranchers utilize a diversity of grass species to maintain vegetation cover [68]. Moreover, it is relatively common for ranches to support remnant elements of native vegetation, such as forest patches or mature trees along deep gullies that are inaccessible to cattle because of steep terrain. These can serve as sources of seed for regeneration of native vegetation if land management supports it and can also support native birds [152] and insects [153]. For example, at Hakalau National Forest Wildlife Refuge, the US Fish and Wildlife Service designed forest restoration corridors along such gulches, inspired by native birds using these long, linear habitat remnants on former ranchlands. Finally, ranches support broader native biodiversity conservation through conservation and restoration of larger forests, as well as landscape-scale invasive species and fire control efforts.

In Hawaiʻi, multiple large (>400 ha) rangeland operations are located adjacent to native forests. The land stewardship practices on these lands, like active weed control, grazing for wildland fuel reduction, feral ungulate control, and maintenance of large, open spaces serve as important buffers to these native forests. These agriculturally productive lands also help limit urban, residential, and industrial expansion, which further protects the biodiversity of our natural areas.

Ranches dedicate significant resources to invasive species control, both of invasive plant species and feral ungulates. Widespread displacement of native forest species by exotic introductions is the single greatest threat to the health of Hawaiʻi's forests [154]. Grazing and wise pasture management, including high-intensity, methodical rotational grazing, prevent the proliferation and spread of invasive forests and forest species into adjacent native and/or working forests [155]. In the absence of well-managed grazing pressure or other responsible land management practices, fallow lands and un-managed pastures quickly become dominated by a very few, highly invasive forest species, some of which may also compromise groundwater recharge. These include strawberry guava (*Psidium cattleianum*), black wattle (*Acacia mearnsii*), *Morella faya*, *Eucalyptus* sp., gorse (*Ulex europeaus*), tropical ash (*Fraxinus uhdei*), and other aggressive forest species [129].

As with highly invasive plant species, damage to native species and ecosystems by feral animals is well-documented [156–158]. Feral ungulates are widespread across the state, demolishing forests by trampling, uprooting, and devouring plants, exposing large areas of bare ground, spreading invasive species, and helping to spread avian malaria. Feral animal control, via managed recreational hunting and/or deliberate and methodical animal control is a common practice used by many ranches to minimize animal damage. Removing all invasive feral hoofed animals from priority watershed areas is an essential first step for forest watershed protection [137], and ranches are a critical partner in doing so.

In 2015, Haleakalā Ranch initiated an ambitious ranch-wide axis deer control program with the goal of reducing the total deer population by several thousand animals to enable native forest restoration and to help secure the biodiversity dependent on it. This program may be expanded to include large-scale control of feral goats in the leeward portions of the ranch, adjacent to Nakula Natural Area Reserve, Kahikinui Forest Reserve and Department of Hawaiian Homelands watershed restoration lands on Maui. This initiative is expected to significantly reduce damage to the Ranch's natural resources as well as those regional native species on adjacent lands (see Box 2).

Ranchers across Hawaiʻi have also engaged in many voluntary conservation efforts. On Maui, for example, over 7200 hectares of ranch lands have been excluded from Critical Habitat designation under the U.S. Endangered Species Act because of the voluntary conservation activities on ranchlands that support the protection and recovery of threatened and endangered Hawaiian plants and animals [159]. Likewise, 9 of 10 Watershed Partnerships, regional collaborative land conservation and management programs, include ranches as partners together with other public and private landowners and managers.

Ranches also provide benefits for some rare Hawaiian species, which prefer open habitats. This includes the Pueo (*Asio flammeus sandwichensis*), a subspecies of the Short-eared Owl, which occupies a variety of habitats, including wet and dry forests, but are most common in open habitats such as grasslands, shrublands, and montane parklands. Maintaining pastureland in upcountry Maui, for example, is seen as crucial to the Pueo's persistence [160,161]. The Nene, the Hawaiian Goose (*Branta sandvicensis*) also thrive in short grasses, and a grazing regimen can help maintain grassland habitat where they can forage [162]. Haleakalā Ranch, for example, actively supports endangered Nene recovery in its leeward pastures, which provide ideal habitat for the species, and voluntarily entered into a Safe Harbor Agreement with state and federal agencies, with the goal of establishing a breeding population of 200 birds on over 1200 has of pastureland (see Box 2).

Beyond protection of existing forest and control of invasive species, ranches have also engaged in substantial forest and silvopasture restoration efforts, and many seek to do more (Figure 6). On Maui, examples of rangelands that are actively managed and being restored back into diverse, native forest ecosystems include Auwahi and Puʻu Mahoe on Ulupalakua Ranch, Ukulele and Puʻu Pahu on Haleakalā Ranch, and the Nāholokū region at Kaupo Ranch [163–165].

Figure 6. Restoration of native forest in Hawaiʻi requires significant up-front investments. (**A**) Scarification of land with a bulldozer (evident in the torn up soil) is often necessary to trigger koa seeds in the soil to germinate, now that the native birds that ate them, and in the digestive process opened their seed coats, are extinct. Sometimes mechanical or chemical interventions are needed to reduce non-native grass cover to give native tree seedlings a chance in competing for light and water; (**B**) Installation and maintenance of costly fencing is required to keep feral ungulates out of areas designated for restoration; (**C**) Koa seedlings, germinated in a nursery, are planted in corridors such as this one several hundred meters long, in a design to facilitate future seed dispersal and forest regeneration by birds (*PC Gretchen C. Daily, all photos*).

Ranches, including Haleakalā Ranch are also pioneering restoration strategies which utilize grazing as a weed control mechanism which reduces herbicide needs. Ranches often have the labor, planning, and knowledge capacity to carry out large-scale restoration efforts and partner extensively with non-profits, state and federal agencies, and watershed partnerships to do so. Working lands and their stewards are core to many conservation and restoration efforts in Hawai'i and worldwide, focused on biodiversity and ecosystem service benefits as goals [166,167].

3.5.3. Limitations of Rangelands in Providing Biodiversity

It is important to note, however, that rangelands are designed and maintained with the goal of animal health and agricultural production in mind. While rangeland management does provide for and facilitate biodiversity, it does not, by itself, necessarily present a diverse, native ecosystem. Wooded pastures support considerably higher native understory plant diversity and abundance, and lower non-native species and abundance, than open pastures [166]. Restoring partial tree cover on rangeland is most attractive for native birds, while native understory plants require higher investment in fuller forest restoration [28].

Grazing can also have a negative impact on biodiversity on all levels. Over-grazing, trampling, insufficient rotations, inadequate containment of livestock (leaky fences) can adversely impact any ecosystem, as can the accidental incursion of cattle into native ecosystems.

3.5.4. Future Research Needs

Making conservation and restoration more feasible economically, on both public and private grazing lands, remains a key challenge. In the realm of science, a key priority is targeting investments in conservation and restoration for greatest benefit. For example, recent research shows that large-scale tree planting in corridors (such as in Figure 6C) adjacent to mature, native forest can catalyze rapid recovery of forest birds (in both abundance and distribution), and that it is possible to design reforestation to benefit native species in novel ecosystems [168]. In the realm of economics, exploring ways of diversifying income streams to support biodiversity and livelihoods (including cattle, if desired) is a top priority in Hawai'i and worldwide [16,28,39,169]. In the realm of policy and finance mechanisms to support conservation and restoration, there is an urgent need for more options that allow landholders to realize the values of biodiversity and suites of ecosystem services [29], such as through habitat exchange credits, tourism, and native tree forestry [167]. Strategic focusing on enhancing habitat connectivity at larger landscape scales is crucial [170,171].

Despite these urgent needs, there are tremendously inspiring and impactful conservation activities occurring on rangelands today. It would be valuable to document better their extent and other characteristics, including those implemented with watershed partnerships, the State Department of Land and Natural Resources (DLNR), land trusts, and other key players. More research is required to understand the use and potential dependence of native bird species including Pueo, Nene, 'Io (Hawaiian Hawk; *Buteo solitarius*) and other species on rangelands. It would also be useful to identify the areas of critical habitat, for example, that have been excluded by the U.S. Fish and Wildlife Service from rangelands as a result of voluntary conservation. It would also be useful to clearly identify the specific invasive plants that take over pastures if they are left fallow or unmanaged, as well the consequences and cost of managing them or not managing them over time.

Box 2. Case study on Haleakalā Ranch and their various conservation programs and reserves they manage.

Haleakalā Ranch: Leading by Example

For five generations, Haleakalā Ranch has stewarded nearly 14,000 hectares of land in Upcountry Maui. Alongside cattle production, they implement conservation programs and manage several reserves within their property.

Conservation Programs

- In 2015, Haleakalā Ranch initiated an aggressive ranch-wide axis deer control program with the goal of reducing the total deer population by several thousand animals. This program may be expanded to include large-scale control of feral goats in the leeward portions of the ranch, adjacent to Nakula Natural Area Reserve, Kahikinui Forest Reserve and Department of Hawaiian Homelands watershed restoration lands. This initiative is expected to significantly reduce damage to the Ranch's natural resources as well as those regional native species on adjacent lands.
- Haleakalā Ranch actively supports endangered Nene recovery in its leeward pastures, which provide ideal habitat for the species. They voluntarily entered into a Safe Harbor Agreement with DLNR and the USFWS with the goal of establishing a breeding population of 200 birds on over 1200 hectares of pastureland.
- Haleakalā Ranch is an active member of and plays a leadership role in the East Maui Watershed Partnership and the Leeward Haleakalā Watershed Restoration Partnership. Collectively, these two partnerships manage close to 60,000 hectares on east Maui, including at least nine Critical Habitat units.

Established Reserves

- Waikamoi Preserve: In 1983 Haleakalā Ranch provided The Nature Conservancy with a perpetual Conservation Easement for the creation of Waikamoi Preserve. The Preserve encompasses 2080 has along the northern border of Haleakalā National Park on east Maui and includes eight proposed Critical Habitat units for plants. The Preserve is a model for effective management and there exists multiple formal conservation agreements with State, County and Federal agencies, all of which support the Ranch's and TNC's long-term collaborative conservation efforts.
- Puʻu Pahu Reserve: In 2001, Haleakalā ranch entered into formal conservation agreements with the Service and the Natural Resources Conservation Service, which provided funding and support for management actions to conserve and protect the endangered plant Geranium arboretum and subalpine Critical Habitat at Puʻu Pahu on the northwestern slopes of Haleakalā. These management actions include construction of ungulate-proof fences followed by removal of ungulates and invasive plant species within the fenced area. The area is also being outplanted with rare and endangered plants, including *Geranium arboreum*. This protected area is adjacent to fenced conservation lands at Haleakalā National Park and greatly compliments management actions by the National Park Service.
- Puʻu o Kali: The site of a voluntary conservation project between the Partners for Fish and Wildlife, USGS-BRD, and the Department of Hawaiian Homelands for Critical Habitat protection at Puʻu o Kali, on the west slope of Haleakalā. The project involves protection of native dryland forest, fence construction to exclude axis deer and feral goats, invasive plant control, and propagation and out-planting of native plants. Haleakalā Ranch provides regular management access by the Leeward Haleakalā Watershed Partnership to the project area.
- Ukulele Pasture: This 40 ha pasture is being taken out of grazing to protect and restore native plants, wildlife, and other important resources. The project area is characterized by a relatively intact native Acacia Koa and *Metrosideros polymorpha* (*ʻōhiʻa lehua*) with a remnant diverse native understory, especially in the steep gulches that dissect the site. It is adjacent to Makawao Forest Reserve, The Nature Conservancy's Waikamoi Preserve, and other active grazing lands owned by Haleakalā Ranch.

3.6. Cultural Services

3.6.1. Definition of Cultural Ecosystem Services

Cultural ecosystem services (CES) are most commonly described as the non-material benefits that humans receive from their interactions with the environment [144]. However, expanding upon early interpretations and definitions, CES have also become a valuable way to characterize benefits as they are experienced and understood by groups or individuals who experience and relate to the environment through their connections or attachment to a place [172], through particular value systems or worldviews [173], and through aspects of well-being and cultural identity [174]. A recent Hawaiʻi-focused exploration has since adapted and redefined the concept of CES to encompass the ways place-based and Indigenous groups interact with their surroundings to derive all forms of sustenance and maintain connection to place [13].

Recreation, tourism, and scenic values are among the most commonly assessed CES, yet a growing number of studies acknowledge the limitations of prioritizing these particular CES in areas where recreation may be valued, but is not a foundational motivation or priority outcome for place-based communities [13,175,176]. Other examples of CES that appear in ecosystem service assessments include perceptions of benefits surrounding place/heritage, spirituality, inspiration, social cohesion, activity, employment, identity, knowledge, existence/bequest values, option values, and aesthetic values [144,172,177].

CES are subjective, meaning they derive from personal opinions. Therefore, clearly understanding local and cultural contexts is necessary in order to identify CES that may be most meaningful in a particular geographic, social, cultural, or environmental setting. While there is limited published literature on CES specifically as they relate to rangelands in Hawaiʻi, anthropological studies describe the important role of intergenerational families of Native Hawaiian, Portuguese, Chinese, Filipino, Japanese, and European descent in shaping and maintaining cattle ranching practices, values, and lifestyles in Hawaiʻi [178]. In the context of CES, much remains to be learned from the shared values and worldviews of those who associate or otherwise self-identify with what has come to be described as Hawaiʻi's rich paniolo culture. This section focuses on cultural ecosystem services as they relate to paniolo culture in Hawaiʻi. However, it is also important to note that Hawaiʻi rangelands are inbued with rich layers of meaning—including values surrounding historical and present deay land ownership, land uses, and continued access to ancestral landscapes—some of which are beyond the scope of this review.

3.6.2. Role of Well-Managed Rangelands in Providing Cultural Ecosystem Services

While there is indeed overlap between the CES that may be described across diverse ecosystems and those that are perhaps more specific to rangelands, some believe that exploring rangeland-specific CES requires revisiting the theoretical framings of the CES concept. For example, in an exploration of CES in California rangelands, Huntsinger and Oviedo [3] explain that rangelands are working landscapes that must include both human and environmental components. They use this as a premise to explain that in one view of CES, rangeland landscapes are inherently imbued with cultural value, independent of human presence or activity. However, in the authors' view, rangeland CES are in fact co-generated by the dynamic, complex, and adaptive interactions that occur between ranchers, livestock, and rangelands in rangeland stewardship practices. Said another way, Huntsinger and Oviedo posit that rangeland cannot be accurately assessed, evaluated, or perhaps even fully understood, in the absence of cattlemen and livestock production. This has strong resonance with preliminary discussions between select Hawaiʻi Cattlemen's Council (HCC) members and HCC Ecosystem Service Subcommittee members at Haleakalā Ranch in August 2019, where meeting participants asserted that rangelands in Hawaiʻi are anthropogenic—in other words, they would not exist in the absence of humans.

As previously noted, CES can vary by geographic scope/scale and associated user group. For example, at the landscape scale, CES may include public perceptions and enjoyment of the natural beauty of rangelands [179]. At the individual ranch scale, landowner priorities and motivations are a key driver of CES, thus landowners may demonstrate values surrounding long-term planning and investment in the environment [3]. Finally, at the individual pasture scale, ranching can rely heavily on social networks of collaboration and support, especially if livestock production practices warrant movement across property boundaries for transportation and seasonal forage [3]. The importance of collaboration and support is especially significant in small-scale operations, for instance those that rely upon family participation. This synergizes with the social cohesion values described across the CES literature. For example, knowing you have others you can rely on when you need them is a social cohesion value. Strong social networks are also essential for all ranching practices in Hawaiʻi, including round-ups and drives, which was clearly articulated at the August 2019 Haleakalā Ranch meeting.

Individuals who have never visited a rangeland in person, but perhaps have seen one from afar or have seen videos, photos, or art about rangelands, can still experience rangeland-focused CES. For example, they may perceive existence values, drawing satisfaction from knowing something exists even if one has not visited or seen it in person [180]. In contrast, cattlemen who frequent rangelands on a more regular basis may experience CES such as enjoying natural beauty of rangeland landscapes (i.e., aesthetic and inspiration values), opportunities to live and work in the country (i.e., employment values), and activities like fishing and hunting (i.e., recreation and activity values) [181]. These CES are also likely to be experienced by individuals who live or work in close proximity to rangelands (for example, adjacent non-ranching households).

In 2018, results were published from a multi-year, collaborative research project which involved characterizing CES across place-based communities in Hawaiʻi, including in a ranching-oriented community in North Kona, Hawaiʻi Island [8]. This section draws primarily upon that particular ecosystem service exploration. Using a combination of community workshops, interviews, and focus groups, community members were asked to reflect on the ways they interact with and are sustained by rangelands (described then as land uses in pasture ecosystems). To further discussions, participants were then asked what would be missing from their lives if rangelands and ranching were not around. Using a Hawaiʻi -based CES framework (as described in Pascua et al. [13]), researchers found that rangeland CES could be described across four main categories: Knowledge (ʻIke), Social Interactions (Pilina Kānaka), Physical and Mental Well-being (Ola Mau), and Spirituality (Mana).

In terms of knowledge-focused Hawaiʻi rangeland CES, participants described placing high value on maintaining and passing on Indigenous and local knowledge associated with place-based rangeland stewardship practices. This included knowledge of place names and weather patterns associated with particular ranching areas (e.g., ranch, community, ahupua'a, etc.). This also included knowledge and application of stewardship and management techniques for a particular area (i.e., best management practices), including adaptive grazing, rotational patterns, and grazing to control fire fuel.

In terms of Hawaiʻi rangeland CES focused on social interactions, participants placed high value on the sense of community that comes from continuing ranching and stewardship practices that have gone on for generations and will ideally continue for generations to come. This includes family, friends, neighboring ranches, and communities coming together for cattle round-ups and branding. There was a high value placed on community and family connections (past, present, and future) supported via rangelands and rangeland stewardship practices. There was also a high value placed on livelihood opportunities that enable families to continue to live and work on their ancestral lands, to continue to provide for their families, and to be able to gift and/or exchange what they have with others. This may include sharing meat with coastal families who, in turn, share fish or other ocean foods.

In terms of Hawaiʻi rangeland CES surrounding physical and mental well-being, water was described as a central feature to well-being and participants explained that proper pasture management can be associated with clean and abundant water for consumption by humans and livestock, and to water and grow crops. Related to the previous CES categories, participants emphasized the sense of place and sense of belonging that comes from engaging in time-honored, place-based pastoral practices and, more broadly, from perpetuating rural lifestyles on living rangeland landscapes (e.g., ranching, horseback riding, attending rodeo, and playing music). They described the role of Hawaiian rangelands and ranching practices in supporting cultural identity as paniolo. For example, several individuals involved in the multi-year project are active participants in annual pa'ū riding processions—a practice dating back to 1906 where ornately gowned male and female rider "units" representing all eight of the main Hawaiian Islands parade through the streets atop lei-adorned horses. Participants also described a sense of personal security that comes from maintaining connections to ancestral landscapes. This sense of security was described as coming from knowing that those landscapes have supported generations past and could be around for generations to come.

In terms of Hawai'i rangeland CES surrounding spirituality, participants described values associated with maintaining ancestral and spiritual connections to land. These connections were described in a number of ways, but were most often related to perceived spiritual benefits that result from land tenure rights or other forms of physical access to rangeland. In some responses, spiritual values resulted from being able to physically access (and thus experience and establish a connection to) lands which were known to be frequented by generations before. In other instances, spiritual values came via the opportunity to continue ranching leases that had been originally held by family predecessors. This provided an opportunity to maintain connections to family members who have since passed on. In at least one instance, spiritual values came from knowing that they continue to care for lands that hold the bones of their ancestors, for instance via family graveyards or burial sites known and cared for by lineal descendants.

3.6.3. Limitations of Rangelands in Providing CES

A majority of the CES described on Hawai'i rangelands during the multi-year project involved physical access, specifically, maintaining lawful, temporary or permanent presence on rangelands. Accordingly, the largest threats surrounding Hawai'i rangeland CES result from anything that inhibits individuals ability to lease, own, or otherwise lawfully occupy rangelands for occupational duties. Specific threats include lease termination or increasing costs to operate on leased ranch lands. In some instances, short-term leases can impede rancher investments in necessary infrastructure like fences (given uncertainties surrounding the duration of use) and may also preclude eligibility for federal assistance programs. Access-related threats can also result in a reduced ability to apply and adapt place-based rangeland stewardship practices, which in turn feeds the loss of place-based knowledge of those management practices.

While the multi-year project originally intended to explore perceptions of climate change as a threat to ranching practices, respondents clarified that in their opinion, land-use conversion (e.g., development sprawl) was the largest and most immediate threat to rangelands. Others have noted that for commercial ranching operations, significant threats include the failure of the larger cattle industry, which would result in a broad suite of cascading impacts including threats to continued rangeland stewardship and impacts on related ecosystem services (for specific examples, see subsequent subsections of the complete ecosystem services report).

3.6.4. Future Research

Based on this scan of the literature on rangeland CES, future areas of work may include expanding Hawai'i-based explorations of CES associated with rangelands and rangeland stewardship. Such a project can be conducted through targeted focus groups or interviews and should include meaningful engagement of local actors who are involved in various aspects of rangeland management (e.g., landowners, ranching leases, ranch managers, livestock managers, ranch hands, etc.), from across the Hawaiian Islands, as may be the case with the Hawai'i Cattlemen's Council's membership. In addition to exploring present-day perspectives on CES benefits and values, it may be beneficial to branch out beyond the ecosystem service paradigm—for instance, conducting a complementary ethnohistoric review and synthesis of information on Paniolo culture more broadly (past, present, and future projections). The HCC's Paniolo Hall of Fame contains strong examples of ethnographic interviews with Hall of Fame inductees and could serve as preliminary source case data for future syntheses on paniolo culture [155]. Here in Hawai'i in particular, sharing stories by, from, and about Paniolo can be a meaningful pathway to articulate the importance of Hawai'i's rangelands and its rangeland stewards.

4. Conclusions: Pathways to Recognize and Support Rangeland Benefits

Rangelands and their stewards clearly provide a suite of important benefits to broader society in Hawai'i. These benefits are recognized by a number of land trusts and other land conservation organizations that seek to partner with and support ranches in maintaining and enhancing working and natural landscapes and open spaces into perpetuity [182]. These benefits are also increasingly highlighted in State sustainability policy documents, including the recent Climate Ready Hawai'i report [34], which situates rangelands as a central component of climate adaptation. The State of Hawai'i also recognizes rangelands as representing, "large conservation areas, and ranch owners work with government agencies, community groups, non-profits, and private companies to conserve the lands, watersheds, and forest zones of the Hawaiian Islands in trust for the Hawaiian people of tomorrow" [32].

While not always recognized by the general public, the ranching and conservation communities often have similar stewardship goals. Many of the state's watershed partnerships, for example, include ranches, and many ranches (as discussed above) have engaged in significant voluntary conservation efforts. Given the challenges of managing vast landscapes in Hawai'i, which require significant attention to controlling invasive species, mitigating fire risk, and responding to a suite of other threats, further collaboration among the ranching and conservation communities is key. Ranches often have important capacity, knowledge, and a stewardship ethic to address threats to both rangeland and embedded or neighboring forest conservation lands. They have also consistently demonstrated that, in addition to producing food, livestock can serve important roles in weed control, watershed and native species protection, and fire risk reduction.

Supporting ranches in continuing their stewardship efforts requires action on several fronts. Good stewardship is fostered by security that the required major investments of money, labor, and time will pay off. Finding ways to improve the conditions of ranch leases to better reflect the length, cost, renewal, other terms, and overall security that will facilitate good management of these lands is critical. There is also a need for funding to address invasive species threats, such as control of axis deer and recovery from the spittle bug pests that threaten rangelands and the long-term viability of ranching in Hawai'i. Ranches also need continued income and resources to support good stewardship and the ecosystem services that flow from them. This income comes from a viable local cattle business that is increasingly trending towards local grass-fed consumption. Many ranches are also working to secure their future by diversifying income streams through forestry, silvopasture, alternative energy, and visitor-oriented ventures [28,29].

As Hawai'i moves towards achieving multiple sustainability goals—including local food production, watershed protection, and enhancing connection to place—it is critical to recognize the important and sophisticated roles that rangeland managers provide, and to advance more holistic land management practices in policy.

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