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Livestock grazing and its effects on ecosystem structure, processes, and conservation

PREPARED BY
San Francisco Estuary Institute
with support from Point Blue Conservation Science

PREPARED FOR
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Introduction

The San Mateo coast has a long history of grazing. Prior to the introduction of domesticated livestock by European settlers, large herds of Tule elk and deer grazed the grasslands, oak woodlands, and shrublands of the region. For the past 200 years, grazing—predominantly by cattle, with some sheep, goats, and horses—has dominated the landscape throughout coastal central California, largely replacing the native ungulates and shaping the region's vegetation communities. With the addition of livestock to the region, European settlers also introduced, often unintentionally, a variety of non-native annual grass species, such as slender wild oat (*Avena barbata*), soft chess (*Bromus hordeaceus*), Italian rye grass (*Festuca perennis*), ripgut brome (*Bromus diandrus)*, and wild oat (*Avena fatua*). The non-native annual grasses are well-adapted to surviving California's annual and interannual droughts and can quickly take advantage of high rainfall periods. They have outcompeted many of the native forbs and grasses and now dominate the vegetation across the San Mateo coast. Today, roughly two-thirds of California's Mediterranean-type grasslands and oak woodlands are grazed by livestock (Huntsinger and Bartolome, 2014; Huntsinger and Oviedo, 2014), which plays an important role in maintaining and managing the remaining native vegetation and wildlife habitat. Over the past two centuries, however, grazing across the region has been in decline, due in part to pressures from urban development and conversion to cultivated agriculture (Brunson and Huntsinger, 2008; Huntsinger and Oviedo, 2014). The loss of rangeland in California affects both human communities and ecosystems, altering the character of historically agricultural communities, the matrix of vegetation in previously grazed lands, and the quality of habitat for wildlife.

Midpen lands on the San Mateo Coast include 6000 acres grazed by cattle, which are managed through conservation grazing leases with local ranchers. In acquiring these lands, Midpen committed to a coupled social-ecological coastside mission: "to acquire and preserve in perpetuity open space land and agricultural land of regional significance, protect and restore the natural environment, preserve rural character, encourage viable agricultural use of land resources, and provide opportunities for ecologically sensitive public enjoyment and education." This mission is premised on the long history of land stewardship and agriculture in the region, the wishes of local residents, and the concept that livestock grazing can support conservation. To evaluate this premise, this report reviews the science around conservation grazing—the use of grazing for biodiversity benefits—and Midpen's goal to *protect and restore the natural environment*. This report offers an overview and synthesis of the peer-reviewed scientific literature on (a) livestock grazing and grassland biodiversity, (b) livestock grazing and climate protection, and (c) alternatives to livestock grazing for meeting Midpen management goals, including wildfire risk management. To address the conservation grazing practiced on Midpen lands, this review places special emphasis on low-intensity grazing and the use of grazing to support specific ecological outcomes.

The effects of livestock grazing on ecological processes depend on ecosystem characteristics such as the vegetation composition, seasonal patterns of growth, and climate factors like precipitation and drought. California's Mediterranean ecosystems are characterized by mild, wet winters that foster abundant vegetation growth and a long summer period of drought. This combination makes California's ecosystems particularly vulnerable to wildfire, and high variability in the amount and timing of rainfall often confounds California-based studies of vegetation change and responses to management (Huntsinger et al., 2007). Indeed, the effects of various management and restoration practices in individual studies are generally constrained by the rainfall patterns during the study period. This leads to seasonal, interannual, and regional variability in effects, which make it challenging to make predictions across space and time on how livestock grazing influences ecosystem properties. In the context of this variability, this report prioritizes studies, as available, from the San Mateo coast or other similar ecosystems in coastal Central California.

HIGHLIGHT:

Several general trends emerge from the literature on livestock grazing and grassland biodiversity in central coastal California. Grazing often benefits native forbs, as livestock preferentially consume introduced grasses, reduce vegetation height and cover, and limit dead plant material, effects that also benefit native songbirds and other wildlife species. Targeted, seasonal grazing can be an effective tool to manage medusahead, yellow starthistle, and other invasive species of concern, and grazing can halt or limit the process of coyote brush encroachment that often occurs in coastal grasslands in the absence of fire. Maintaining a mosaic across the landscapes of grazed sites, ungrazed sites, and different grazing regimes can benefit the various plant and wildlife species present on Midpen lands.

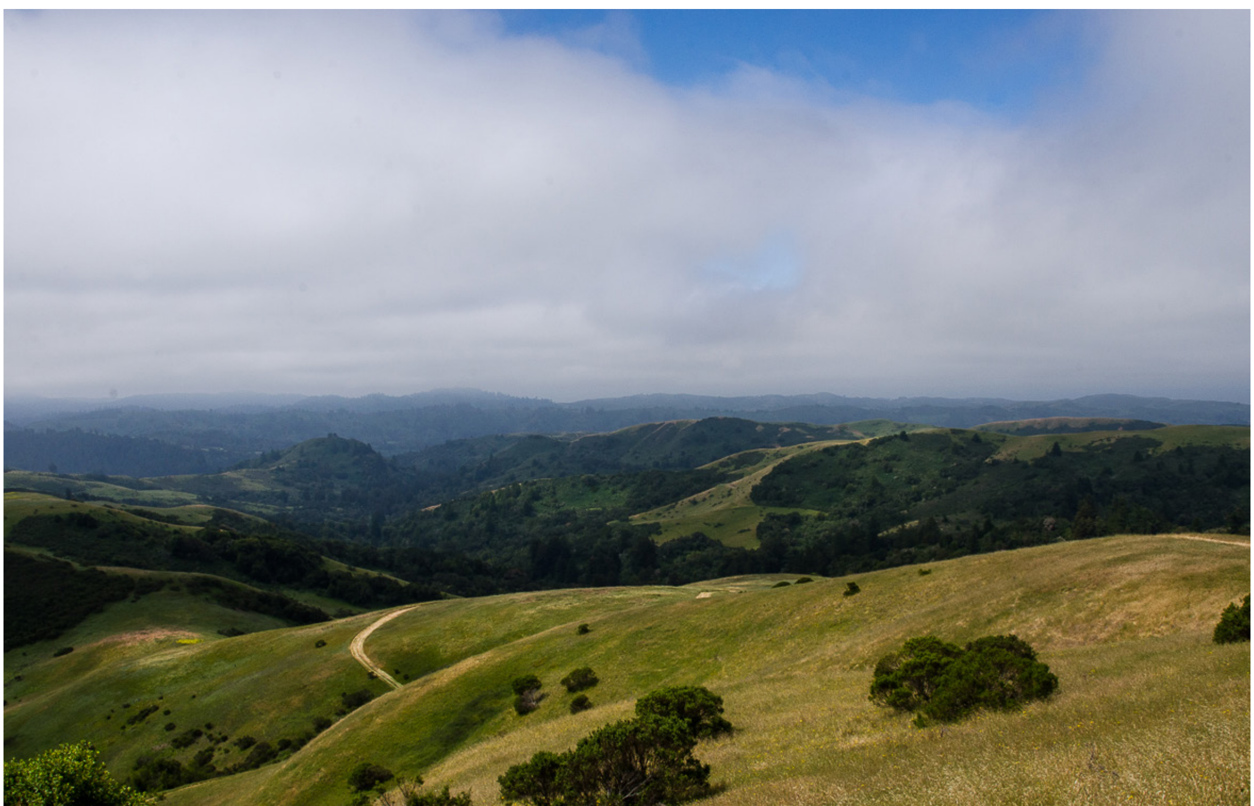
Grazing and grassland biodiversity

California grasslands are biodiversity hotspots. Though severely altered by exotic species invasions, these grasslands support a diverse community of native plants and animals with a large number of endangered and threatened species (Bartolome et al., 2014; Myers et al., 2000). Because of its unique climate and isolation by sea and mountain ranges, the state's grasslands have a high proportion of endemic species (Bartolome et al 2014). Livestock grazing in this region influences grassland biodiversity through effects on vegetation composition, function, and structure, by reducing the buildup of herbaceous vegetation and litter (dead plant material) and maintaining the heterogeneous mix of vegetation heights, and bare ground patches that certain native wildlife species require (Gennet et al., 2017). Additionally, grazing plays an indirect role in local biodiversity conservation by increasing the viability of local ranching operations that maintain large areas of open grassland. In the highly developed Bay Area, ranchers commonly rely on a combination of public and private rangelands (Sulak and Huntsinger, 2007), and access to public grazing leases can be critical for maintaining ranching operations and protecting private ranches from development (Brunson and Huntsinger, 2008).

EFFECTS ON NATIVE AND NON-NATIVE GRASSES AND FORBS

Given the long history of grazing in the central coast of California, numerous studies have evaluated the effects of livestock grazing on grassland vegetation composition in the region. These studies include experimental treatments with livestock exclosures (e.g., Hatch et al., 1999; Skaer et al., 2013) or livestock introductions (e.g., Gornish et al., 2018), observational studies across previously grazed and ungrazed sites (e.g., Hayes and Holl, 2003a), and simulated grazing through vegetation clipping and litter manipulations (e.g., Hayes and Holl, 2003b; Holl and Hayes, 2006). In general, such studies have found that livestock grazing significantly alters the cover and richness (number of species present) of the various plant guilds such as annual and perennial grasses and forbs. The nature of this relationship, however, depends on specifics of the site, grazing system, and study design, with the presence or absence of livestock on the landscape and/or the intensity or timing of grazing demonstrating varied effects on native and introduced grasses and forbs.

The historical composition of the region's grassland vegetation is not well understood, but ecological evidence and historical accounts suggest that the grasslands of the San Mateo coast were once dominated by native perennial bunchgrasses such as purple needlegrass (*Stipa [Nasella] pulchra*) and California oatgrass (*Danthonia californica*), with interspersed annual forbs (Evett and Bartolome, 2013). Studies evaluating the effects of livestock grazing on these native perennial grasses have reported mixed findings, with grazing shown in some cases to have no effect on native perennial cover or richness (Hayes and Holl, 2003a; White, 1967), or in other cases to either increase or decrease native perennial cover and establishment success, depending on the specific grass species, site, experimental treatment, and soil characteristics (George et al., 2013; Hatch et al., 1999). In general, the effects of grazing on native perennial grasses in California's Mediterranean grasslands are understood to be small relative to effects on native forbs or introduced species (reviewed in Bartolome et al., 2014; Huntsinger et al., 2007; Stahlheber and D'Antonio, 2013). Few of the existing studies, however, occurred on the San Mateo Coast or other coastal grasslands (e.g., Hatch et al., 1999; Hayes and Holl, 2003a), making it challenging to draw conclusions specific to Midpen lands.



Coastal grasslands. (photo by Midpeninsula Regional Open Space District)

A number of studies from central coastal California have found that livestock grazing benefits native forbs, more so than native grasses (reviewed in Bartolome et al., 2014; Stahlheber and D'Antonio, 2013). Cattle preferentially consume introduced grasses and maintain low levels of residual dry matter, two preferences that generally have the effect of favoring the success of native annual forbs over introduced grass species. Specific findings, however, have been mixed across sites, plant guilds, and studies (e.g., Gornish et al., 2018; Hayes and Holl, 2003b, 2003a; Holl and Hayes, 2006; Mariotte et al., 2017). One of the most well-cited studies from the region, for instance, surveyed paired grazed and ungrazed sites along a coastal California transect, finding that grazing increased native annual forb richness and cover but decreased the cover of native perennial forbs (Hayes and Holl, 2003a). Other studies have found either no effects of grazing on native forb cover (Hayes and Holl, 2003b) or a range of outcomes, such as a field experiment near Santa Cruz that found cattle exclusion to have highly variable effects on native plant cover when compared across years and plots (Hayes and Holl, 2011). At the same site, vegetation clipping was found to increase the seedling survival and flower production of Santa Cruz tarplant (*Holocarpha macradenia*), an endangered native annual forb (Holl and Hayes, 2006), suggesting that by maintaining short-statured vegetation, grazing enhances the viability of certain native forb species. Given the breadth of effects of livestock grazing on individual plant guilds and species, a common recommendation of many of these studies is to maintain a mosaic across the landscape of grazed sites, ungrazed sites, and different grazing regimes.

In addition to these effects on native vegetation, livestock grazing has been found to have significant impacts on non-native forbs. On the one hand, livestock grazing has been found to increase the cover and richness of non-native forbs (Harrison et al., 2003; Hayes and Holl, 2003a; Skaer et al., 2013). On the other hand, grazing can be strategically applied to benefit native forbs and control non-native species, particularly invasive species of concern. Grazing targeted to specific species and seasons may be more effective than continuous, year-round grazing (Stahlheber and D'Antonio, 2013). By targeting seed production of medusahead *(Taeniatherum caput-medusae),* yellow starthistle *(Centaurea solstitialis),* and other invasive species, late-spring and early-summer cattle grazing have been shown to reduce invasive cover and increase native cover, more so than year-round or summer-fall grazing (George et al., 2013; Harrison et al., 2003). A study in the Western Sacramento Valley foothills found that high-intensity sheep grazing in April and May reduced medusahead cover by 86-100% and increased forb cover, native species richness, and plant diversity, effects that were not observed with early spring or fall grazing (DiTomaso et al., 2008). Removal of wet-season grazing for four years increased medusahead percent cover in a blue oak woodland (Reiner and Craig, 2011), and a meta-analysis of CA-wide studies found that winter or early spring grazing benefits native grassland species, particularly forbs (Stahlheber and D'Antonio, 2013).

EFFECTS ON SERPENTINE GRASSLANDS

Within the matrix of grasslands in central coastal California, serpentine grasslands offer hotspots of native biodiversity and are home to a large number of endangered or federally listed species, many of which are endemic (Murphy and Weiss, 1988; Safford et al., 2005). The low nutrient availability, low calcium levels, and high metal concentrations in serpentine grasslands limit invasibility by introduced species and provide a refuge for native vegetation and wildlife. However, nitrogen deposition from vehicles and other combustion sources has been shown to favor non-native vegetation over native species, threatening the sensitive communities persisting in these systems (Weiss, 1999).

While Midpen's grazing program does not currently include any serpentine sites, a large portion of the literature on grazing and grassland biodiversity from the central coast of California pertains to serpentine grasslands. Several studies from central California have demonstrated the importance of livestock grazing in maintaining serpentine grassland communities, finding that grazing generally benefits native plants and decreases non-native cover, particularly in the presence of background nitrogen deposition (Beck et al., 2015; Funk et al., 2015; Harrison et al., 2003; Pasari et al., 2014). In a Coyote Ridge serpentine grassland, for example, a livestock grazing and nitrogen fertilization experiment found that livestock exclusion decreased native plant richness and that non-native plant cover decreased with increased grazing intensity, effects that were more pronounced in fertilized plots (Pasari et al., 2014). An additional report from the same site found that grazing decreased non-native plant cover and increased the native vegetation cover, diversity and temporal community stability, a potentially important factor for insect pollinators (Beck et al., 2015). Other studies from the San Mateo coast have linked livestock grazing in serpentine sites to the persistence of dwarf plantain (Plantago erecta), an important host plant for the endangered Bay Checkerspot Butterfly, endemic to Bay Area serpentine grasslands (Funk et al., 2015; Weiss, 1999).

EFFECTS ON WOODY VEGETATION

In addition to its effects on herbaceous vegetation, livestock grazing in coastal California plays a role in the distribution of herbaceous and woody vegetation and may limit shrub encroachment, notably by coyote brush (*Baccharis pilularis*). Coyote brush encroachment into coastal grasslands has been extensive in coastal California over the past 100 years, and is widely attributed in part to exclusion of livestock grazing and fire suppression, though climate change may also play a role (Callaway and Davis, 1993; Keeley, 2005; McBride and Heady, 1968; McBride, 1974). Both observational and experimental studies have documented patterns of encroachment over both the short term (1-3 year experiments) and long term (20-50 years) associated with fire removal and the absence of grazing. Repeated aerial imagery from the central coast showed that unburned plots without livestock transitioned from grassland to coastal sage scrub at higher rates than unburned, grazed plots (Callaway and Davis, 1993), and aerial images of four parks in the East Bay showed widespread shrub expansion between 1935 and 1965 (McBride and Heady, 1968). In a seedling exclosure experiment at the same site, all coyote brush seedlings in unfenced plots were eaten or trampled by livestock within weeks, leading the authors to conclude that exclusion of fire and livestock likely contributes to coyote brush encroachment (McBride and Heady, 1968).

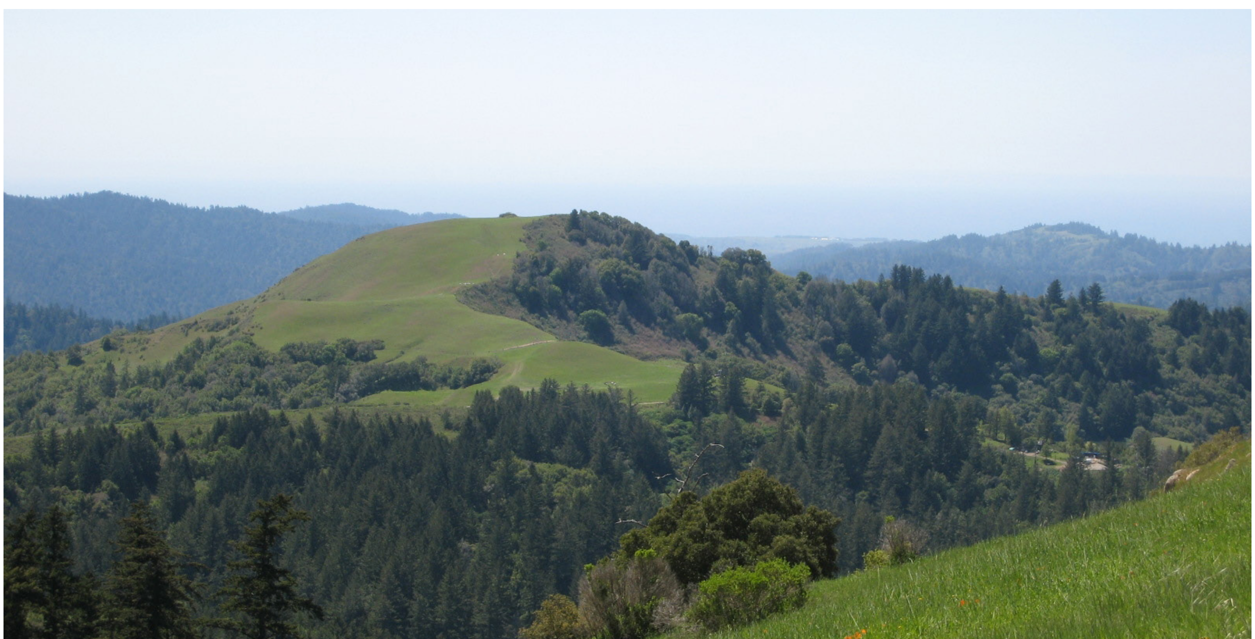
Effects of coyote brush encroachment into coastal California grasslands include a loss of abundance and diversity of herbaceous species and an increase in fire hazard. At Jasper Ridge, abundance of all herbaceous species have been shown to decline greatly where coyote brush forms a closed canopy, (Hobbs and Mooney, 1986), and a Tule elk exclusion study at Point Reyes has linked increased shrub cover to a loss of plant richness due to declines in herbaceous species that do not grow beneath shrubs (Johnson and Cushman, 2007). At the same time, coyote brush is broadly considered "fire-hazardous." As stands age, the proportion of highly flammable dead material increases, and shrubs can increase fire hazard and fire intensity (Schwilk, 2003). Additionally, shrub expansion in central coastal California has been linked to broader changes in the matrix of vegetation communities. Successional patterns in coastal California indicate that shrub encroachment facilitates grassland transition to woodland (Callaway and Davis, 1998; Hsu et al., 2012; McBride, 1974), as in a Jasper Ridge study in which coyote brush stands at least 15 years old were seen to facilitate oak recruitment (Zavaleta and Kettley, 2006).

EFFECTS ON NATIVE WILDLIFE

Through its effects on vegetation, livestock grazing is understood to benefit wildlife species that rely on native host plants, short or heterogeneous vegetation, or distributed water bodies for food, movement, refuge, or breeding. The endangered Bay Checkerspot Butterfly is a well-studied example of a species whose persistence has been linked to livestock grazing. A study from serpentine sites on the San Francisco Peninsula documented population crashes of the Bay Checkerspot Butterfly following the cessation of grazing, due to the replacement of host plant and nectar sources by non-native grasses (Weiss, 1999). For grassland birds, grazing has been shown to maintain foraging and breeding habitat. Burrowing owls require the short vegetation and matrix of open sites maintained by grazing livestock (Haug and Oliphaunt 1990), and a study in the Diablo range linked livestock grazing to native songbird conservation through the positive effects of grazing on native vegetation cover and structural heterogeneity (Gennet et al., 2017). Grazing has various benefits for California red-legged frog (Bartolome et al., 2014), as ground squirrel burrows in grazed lands offer refuge from predation (Fehmi et al., 2005; Schieltz and Rubenstein, 2016; Tatarian, 2008) and stock ponds are used for breeding or foraging (Alvarez et al., 2013). Stock ponds also provide foraging habitat for the endangered San Francisco garter snake (Preston and Johnson, 2012).

LIMITATIONS TO THE SCIENTIFIC LITERATURE

While numerous studies have evaluated the effects of grazing on native grassland biodiversity, variations in study design and site-specific outcomes make it challenging to draw clear and specific conclusions. Observational paired-plot studies such as Hayes and Holl (2003a) capture long-term, regional-scale differences between grazed and ungrazed sites, but obscure potentially important effects of variable grazing practices. With more focused experimental studies, the scope of inference is limited to the specific system and the specific experimental treatment, and results of short-term grazing manipulation studies may differ from long-term effects (e.g., Hayes and Holl, 2003a vs. Hayes and Holl 2003b). Livestock exclosure experiments test the effects of livestock *removal*, but may not pertain equally to the effects of grazing per se. Finally, the effects of grazing on grassland biodiversity may depend on a particular site's land management history. Historical cultivation, for example, which was widespread in grasslands of the San Mateo coast, can influence the effects of grazing on grassland vegetation communities (Stromberg and Griffin, 1996).



Coastal grasslands. (photo by Midpeninsula Regional Open Space District)

HIGHLIGHT:

Grazing on Midpen lands confers a number of ecological benefits, but the presence of livestock, particularly cattle, entails a cost to the climate from methane and other greenhouse gas emissions. To minimize this tradeoff between climate impacts and other land stewardship goals, conservation grazing may be coupled with other strategies to offset carbon emissions. Increased riparian fencing to promote natural regeneration is an example of such a strategy, which can sequester carbon in vegetation and soil while improving habitat for local wildlife.

Grazing and climate protection

Livestock grazing is a net source of greenhouse gases to the atmosphere. Methane, a powerful greenhouse gas, is produced in the guts of cattle, sheep, and other ruminants by microbes that aid in their digestion. Globally, methane emitted by livestock accounts for nearly a third of total anthropogenic methane emissions (Jackson et al., 2020), and is a well-known contributor to climate change. A single grass-fed cow emits approximately 80-100 kg of methane to the atmosphere each year (Allard et al., 2007; Harper et al., 1999), roughly equivalent to half the annual carbon dioxide emissions from a gas-powered car.[1] With low stocking rates and seasonal land use, methane emissions from Midpen's grazing program are far lower than those from industrial livestock systems, when considered on a per-acre basis. Nevertheless, cattle grazing on Midpen lands is a source of methane and other greenhouse gases, presenting a tradeoff between climate protection and other management goals.

LIVESTOCK MANAGEMENT AND SOIL CARBON SEQUESTRATION

Given the carbon footprint associated with livestock production, numerous studies have evaluated opportunities to reduce or offset these greenhouse gas emissions (Crosson et al., 2011; DeRamus et al., 2003; Harper et al., 1999; Henderson et al., 2015; Herrero et al., 2016; Pelletier et al., 2010; Smith et al., 2008). Management interventions to reduce livestock emissions include agricultural intensification (increased agricultural production per acre), improvements to livestock feed, manure management, and enhanced soil carbon sequestration through altered stocking rates, fertilization or compost applications, land conversion, fire management, and high-intensity rotational grazing (where paddocks are rotated between periods of intensive grazing and rest) (Conant et al., 2017; Schuman et al., 2002). In general, these interventions can offset some, but not all, of the greenhouse gas emissions associated with livestock production (Herrero et al., 2016).

Among the suite of livestock-related greenhouse gas management strategies, managing rangelands to sequester soil carbon is the most relevant to conservation grazing on Midpen lands. In California rangelands, livestock grazing affects soil carbon through a variety of mechanisms (reviewed in Conant et al., 2017; Piñeiro et al., 2010; Schuman et al., 2002). Grazing can alter carbon input rates into soils by changing aboveground and belowground vegetation production, and can increase or decrease soil carbon losses through decomposition and leaching. On longer timescales, grazing influences these carbon input and output rates indirectly through effects on vegetation composition, soil quality, and nutrient availability. Given this complex suite of interacting factors, livestock grazing affects soil carbon storage in variable and system-dependent ways (Abdalla et al., 2018; Conant et al., 2017; McSherry and Ritchie, 2013), making it challenging to predict how livestock management may translate to soil carbon sequestration, particularly under California's highly variable precipitation regimes.

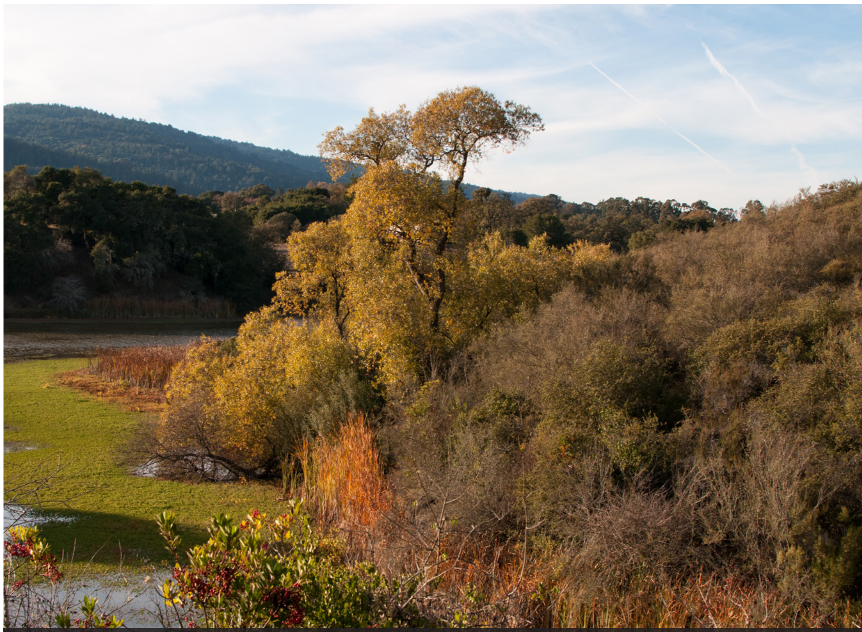
1 Estimated using the 100-year global warming potential for methane

Predicting the effects of grazing on soil carbon storage is particularly difficult for coastal California, where there is a limited amount of primary research. In general, California-based studies have found that effects of cattle grazing on soil carbon storage are small relative to the effects of vegetation composition (Camping, 2002; Carey et al., 2020; Dahlgren et al., 1997; Silver et al., 2010). However, most studies from California are from other regions of the state and compare only the presence or absence of grazing rather than specific management systems. Of those studies that report grazing intensity or seasonality, very few evaluate very low- or high-intensity grazing or year-round or dormant season grazing (Carey et al., 2020). In sum, existing research suggests that optimizing livestock grazing for soil carbon sequestration is probably not an effective strategy to offset greenhouse gas emissions. Given the scarcity of literature, however, management decisions may benefit from future site-specific research targeting specific management practices such as high-intensity rotational grazing.

OTHER APPROACHES FOR RANGELAND CARBON SEQUESTRATION

To offset livestock carbon emissions, compost amendments are an alternative strategy to sequester carbon in California rangeland soils. Supporting this approach, data from two California sites suggest that compost applications may sequester ~0.16 metric tons of carbon per acre per year over a 10-year period (Ryals et al., 2015) while increasing the productivity and drought resilience of vegetation (Ryals et al., 2016; Ryals and Silver, 2013), important co-benefits for ranchers. While these findings are promising from a carbon sequestration perspective, they are based on a very small number of measurements from only two sites that may not reflect the conditions and sequestration potential of other California grasslands (Carey et al., 2020). Additionally, the effects of compost on vegetation communities are not well understood, particularly whether increased nitrogen availability and increased drought resilience benefit more nitrogen-loving and drought-intolerant species (Hallett et al., 2017; Ryals et al., 2016). For Midpen lands, where native grassland biodiversity is a primary management priority, widespread compost applications may present a risky approach to offset cattle-based greenhouse gas emissions. Further research or pilot projects would be warranted to evaluate the potential carbon gains and biodiversity tradeoffs of organic matter amendments.

While much of the research on rangeland carbon is focused on soil carbon sequestration, livestock grazing in California influences carbon storage through the distribution of woody and herbaceous vegetation. In Jasper Ridge, 25 years of shrub encroachment was found to increase ecosystem carbon storage by 40 metric tons per acre, or roughly 1.6 tons of carbon per acre per year (Zavaleta and Kettley, 2006). While much of this increase was in aboveground vegetation, soil carbon stocks were seen to increase as well, a finding that aligns with other California-based studies that have found no differences in soil carbon storage between grazed and ungrazed plots, but up to 2x the carbon storage in soils beneath woody vegetation relative to open



Jasper Ridge. (courtesy of CC 2.0, photo by quintin) annual grassland (Camping, 2002; Dahlgren et al., 1997; Silver et al., 2010). A recent review of the literature on California rangelands identified silvopasture, or managing for the presence of oak trees, as an effective means to increase soil carbon storage and fertility in grazed California grasslands (Carey et al., 2020), and restoration or natural regeneration of riparian forest has been seen to sequester carbon in vegetation and soils at rates of ~1.5 tons per acre per year over the first 2-3 decades (Dybala et al., 2019; Matzek et al., 2015; Matzek et al., 2020). These findings support managing for woody cover to sequester carbon in rangelands, with the caveat that these effects have not been well studied in California perennial grasslands, where deep-rooted perennial grasses promote higher soil carbon storage than annual grassland systems (Koteen et al., 2011). In annual-dominated rangelands, research suggests that targeting areas for woody regeneration—by promoting oak regeneration or fencing riparian areas that are currently grazed—offers a promising opportunity to sequester carbon without detracting from biodiversity goals (Dybala et al., 2019).

HIGHLIGHT:

In the absence of cattle grazing, several alternatives exist for managing fire risk or native grassland biodiversity. Commonly used practices include mechanical approaches, herbicide, prescribed fire, and grazing with multiple or alternative species such as sheep, goats, or Tule elk. Used in combination or alone, these practices have been widely applied in other settings for weed and brush control, but vary in their suitability across the diverse terrain, vegetation, and management needs of Midpen lands. Where these practices are too expensive, risky, ineffective, or otherwise poorly suited for large-scale management of Midpen lands, livestock grazing has been shown to be an effective alternative or complementary method.

Management alternatives to cattle grazing for coastal California grasslands

Where conservation grazing is practiced on Midpen lands, it continues to shape the composition and structure of vegetation, on both small scales and landscape scales. Livestock grazing on Midpen lands not only supports Midpen's commitment to preserve the rural agricultural heritage of the region, but also contributes to vegetation management in support of native biodiversity. Across California, livestock grazing is also widely used to limit the risk of wildfire, a management need of increasing importance as climate change and urban development increase wildfire risk across the state (Goss et al., 2020). Since the mid-20th century, an increase in wildfire across federally-managed rangelands in California has been attributed to a decline in grazing (Starrs et al., 2018), and transitions from grassland to coyote brush-dominated shrublands increase the risk of high-intensity fire (Russell and McBride, 2003). These findings suggest that by reducing herbaceous biomass and limiting certain woody fuels, grazing can change wildfire behavior to reduce fire intensity and decrease flame height, important for the success and safety of firefighting efforts (Davies et al., 2016). On longer timescales, carbon sequestered in California rangelands may be more stable and resilient than forest carbon stocks due to climate change-induced increases in wildfire risk (Dass et al., 2018).

A number of methods can be used to manage wildfire risk and control invasive species in California grasslands. In addition to cattle grazing, these methods include mechanical vegetation removal, herbicide applications, prescribed fire, and grazing or browsing by species other than cattle. Each of these methods may be applied beneficially on certain terrain or habitat types within Midpen lands, but each has shortcomings or challenges. In many instances, these methods are most effective when used in combination rather than alone (DiTomaso 2000). For example, grazing combined with prescribed fire or mechanical shrub removal has been identified as the best way to control fuels for wildfire risk management (Nader et al., 2007). Accordingly, each of these options may best be seen as a complement, rather than an alternative, to conservation livestock grazing.

MECHANICAL APPROACHES

Mowing, hand-pulling, and other mechanized treatment can be used to maintain open grassland and target invasive species. Mowing and hand control are commonly used invasive species control measures in other systems (Aslan et al., 2009; DiTomaso, 2000; Kephart, 2001; Matzek and Hill, 2012) and can be highly effective at reducing the cover of non-native and invasive species. These methods, however, are expensive, are only feasible on gentle terrain, carry a large carbon footprint, and are not likely to lead to the type of structural heterogeneity created by livestock grazing (Aslan et al., 2009; DiTomaso, 2000; Kephart, 2001; Wolf et al., 2017). In serpentine outcrops, for example, mowing is largely infeasible due to rocky and steep terrain, whereas grazing has been shown repeatedly to benefit native vegetation and wildlife (Beck et al., 2015; Funk et al., 2015; Harrison et al., 2003; Pasari et al., 2014). Midpen uses biological monitors during mowing to avoid direct wildlife mortality, particularly important due to the widespread presence of the federally threatened California red-legged frog on the San Mateo coast. This monitoring adds to the expense of treatment, as do annual pre- and post-treatment assessments that Midpen requires when mowing is used for brush management. Mechanical treatment can also contribute to erosion by disturbing soil and in some cases can worsen species invasions, for example by spreading seeds (Aslan et al., 2009).

HERBICIDE

Herbicide application is one of the most effective management strategies for invasive species control and is widely used in rangelands across the western United States (Aslan et al., 2009; DiTomaso, 2000; Holl et al., 2014; Kephart, 2001; Nafus and Davies, 2014; Peters et al., 1996). Herbicide applications are used in targeted applications on Midpen lands. To mitigate environmental and human health concerns, Midpen incorporates a thorough review of the scientific literature, screening each herbicide for toxicity to humans and other organisms, persistence and mobility in the environment, and efficacy against target invasive species. Herbicide applications, however, are more expensive than grazing, and several of the herbicides used (e.g., glyphosate or imazapyr) are non-selective and toxic to all woody and herbaceous plants, making them appropriate for spot applications to individual plants rather than broadcast treatments (DiTomaso 2000). With these considerations, herbicide offers an effective complement to Midpen's grazing program to be used in targeted applications, rather than a replacement for the large-scale vegetation management that conservation grazing offers.

PRESCRIBED FIRE

Prescribed fire is commonly used in California to manage invasive species, maintain open grassland, and reduce the risk of high-intensity wildfire (Halstead et al., 2019; Keeley, 2002; Newman et al., 2018;

Potts et al., 2010; Potts and Stephens, 2009). Fire is a natural process on the San Mateo coast, but fire suppression and cessation of Native American burning have reduced the frequency of fire on Midpen and surrounding lands (Keeley, 2002). Controlled burns, or prescribed fire, aim to reintroduce fire to the landscape in ways that reduce the risk of severe wildfire while benefiting the local ecosystem.

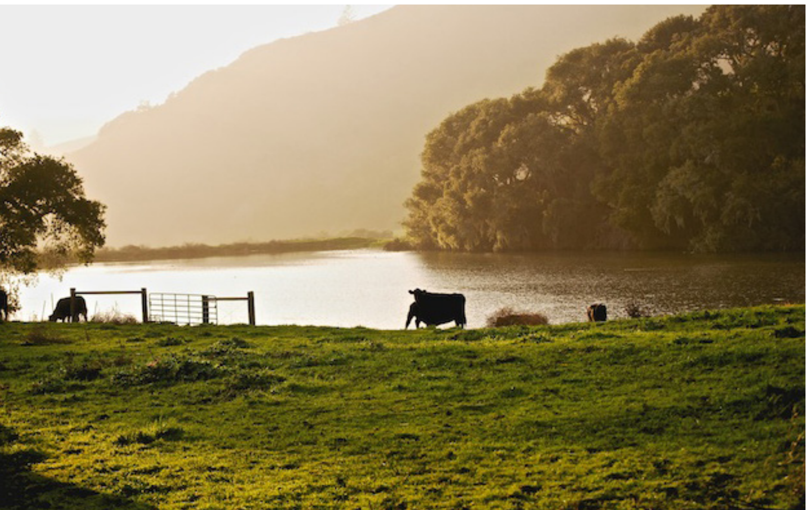
In coordination with local fire agencies, Midpen's wildfire management policy includes the use of prescribed fire to manage fuel loads and invasive species. The scientific literature generally supports this policy, indicating that prescribed fire can be an effective component of open space management. However, the effects of prescribed fire on invasive and native species may depend on site characteristics, burning frequency, and the timing of the burn. In particular, multiple consecutive years of prescribed burning are often required for effective invasive species control. Selective burning has been used as an effective management strategy for medusahead control, but burning must be timed to coincide with late spring seedhead production, which can be dangerous in dry years, and repeated burning in consecutive years may be needed to sufficiently reduce the viable seedbank (Nafus and Davies, 2014). In central California, fire has been successfully used to manage barbed goatgrass, but only with two consecutive years of burning (DiTomaso et al., 2001), and prescribed fire has been seen to reduce yellow starthistle cover and seedbank while benefiting native vegetation, more so after two or three consecutive annual burns (DiTomaso et al., 1999). Similarly, a study in Point Pinole Regional Shoreline found that two consecutive years of prescribed burns yielded a significant reduction of coyote brush encroachment relative to unburned plots, with minimal impacts on native herbaceous species of concern (Hopkinson et al., 2020).

With careful planning and execution, prescribed fire can be a beneficial vegetation management strategy for Midpen lands. Addressing concerns about sensitive wildlife species, studies have found prescribed fire to be compatible with conservation of San Francisco garter snake and chaparral bird communities (Halstead et al., 2019; Newman et al., 2018). As with mechanical approaches and herbicide, however, the use of fire may not present a viable replacement for livestock grazing. Prescribed fire is expensive, requires permitting, may not be practical over large areas, and cannot be conducted with enough frequency or selectivity to control annual vegetation (e.g., DiTomaso et al., 2001, DiTomaso et al., 1999, Nafus and Davies, 2014). It is broadly understood, also, that prescribed burning releases greenhouse gases and has negative impacts on air quality—though generally less severely than wildfire. Rather than a standalone management tool, prescribed fire may thus be most effectively used in conjunction with grazing to address wildfire risk and invasive species concerns across the variety of Midpen lands.

ALTERNATIVE HERBIVORE SPECIES

Herbivores other than cattle, such as sheep and goats, can be employed for targeted grazing to combat shrub encroachment, manage fire risk, and manage invasive species. For wildfire risk management, grazing and browsing by sheep and goats can reduce herbaceous and woody fuels, with goats particularly effective at limiting shrub encroachment and reducing ladder fuels (Tsiouvaras et al., 1989). While few peer-reviewed studies have addressed this topic, livestock—particularly goats—have been seen to be most effective at controlling woody vegetation when they are concentrated in small areas for short periods of time, which encourages them to consume less palatable woody forage (Nader et al., 2007). In addition to controlling woody brush, grazing by goats and sheep can effectively manage invasive herbaceous species such as yellow starthistle, if timed appropriately to match the plant's life stage with foraging preferences (Thomsen et al., 1993). As a complement to cattle, goats and sheep thus present an effective vegetation management strategy, particularly on steep terrain where other brush control methods may not be feasible. Like cattle, however, goats and sheep are ruminants, releasing methane to the atmosphere that is produced by gut microbes that break down fiber that is indigestible to other mammals. Additionally, a shift to grazing by smaller animals can increase the risk of livestock-predator conflict and may benefit from investment in a non-lethal predator deterrent such as guard animals or shepherds (Andelt, 2004; Macon et al., 2018).

Tule elk may also be managed to meet conservation objectives. Studies from point Reyes have found that in fenced/unfenced plots, grazing by Tule elk limited shrub encroachment and increased the richness of native annual plant species (Johnson and Cushman, 2007), and limited invasion in grassland habitat by a nonnative grass species (Ender et al., 2017). Elk are challenging to manage, however. They require more robust fencing than cattle and other smaller livestock (Watt, 2015), and managing herd sizes can present a challenge with elk reintroductions (Howell et al., 2002). Like the other herbivores mentioned above, elk are ruminants and release methane to the atmosphere as well.


Cattle at a stockpond. (photo by Midpeninsula Regional Open Space District)

Conclusions

The grasslands of central coastal California have been shaped in part by a long history of grazing, by native ungulates in the historical landscape and by introduced livestock for the past 200 years. Today, livestock grazing on the San Mateo Coast continues to influence the matrix of grassland and wooded sites, the composition and structure of herbaceous vegetation, and the quality of habitat for numerous wildlife species. By acquiring grazed lands on the San Mateo Coast, Midpen committed to preserving both the region's agricultural character and its open grassland systems that host a large number of sensitive plant and animal species.

There are many ways to graze. At the global scale, livestock grazing has had devastating consequences for biodiversity and the climate through land clearing, habitat loss, overgrazing, and greenhouse gas emissions (Asner et al., 2004). In stark contrast, livestock are managed on Midpen lands through a conservation grazing program that is tailored to the unique ecology of California's Mediterranean grasslands. This program entails low stocking rates, residual dry matter (RDM) targets, biodiversity monitoring to support data-driven management decisions, and fencing of riparian areas, while maintaining wetland habitat in Midpen's ~100 ponds, the majority of which are stock ponds. Following these practices, grazing by cattle and other livestock can be a beneficial management tool to protect open grassland, increase the richness and cover of native grassland plants, control the spread of invasive species, and offer suitable habitat for native wildlife, including sensitive species like California red-legged frog.

The existing scientific literature generally supports Midpen's use of livestock grazing to achieve its management goals. However, while numerous studies have evaluated the effects of livestock grazing on ecosystem properties, only a subset of studies have been conducted on the San Mateo Coast or other coastal California grasslands, making it challenging to draw conclusions specific to Midpen lands. As research in this field continues, findings may emerge that are directly relevant to management on Midpen lands on the San Mateo Coast. Opportunities for further research on Midpen lands would be particularly valuable for informing management decisions and contributing to the existing literature. An adaptive and science-based management approach is recommended as more research becomes available.

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