Trade-Offs Among Ecosystem Services and Disservices on a Florida Ranch

By Hilary M. Swain, Elizabeth H. Boughton, Patrick J. Bohlen, and Laurent O'Gene Lollis

On the Ground

- We consider the trade-offs among "good" ecosystem services and "bad" ecosystem disservices attributable to past and current ranchland management and how such trade-offs depend on analysis at the scale of the ranch, the region, or the Earth.
- We focus on trade-offs in ecosystem services at one working ranch—Buck Island Ranch, location of the MacArthur Agro-ecology Research Center, lying in the headwaters of Florida's Everglades—and managed for 25 years as a full-scale cow–calf operation by Archbold Biological Station, one of the world's preeminent ecological research centers.
- The synthesis of how this ranch functions as an ecosystem (species, habitats, nutrient dynamics, hydrology, etc.) is set in the context of financial realities and economic viability.
- We develop a conceptual model to visualize trade-offs among ecosystem services and disservices, and provide insight into what it takes to be sustainable ecologically and economically.

Keywords: ecosystem services, ecosystem disservices, Florida ranchlands, Everglades.

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How can we sustain ecosystem services and productivity on rangelands while avoiding strong, adverse ecological impacts?[1] Defined as "the benefits people obtain from ecosystems," ecosystem services are categorized as *provisioning* (e.g., food, fiber, game harvest), *regulating* (e.g., ameliorating flood and drought, maintaining natural fire regimes), *cultural* (e.g., supporting cultural practices of native peoples, distinctive cultures), and a fourth category of *supporting services* (e.g., net primary productivity, carbon sequestration, soil formation).[2] Conversely, harmful ecological impacts such as excessive drainage, eutrophication, and introduction of invasive species are defined as ecosystem *disservices*.[3] Interdisciplinary approaches are needed to evaluate trade-offs among ecosystem services and disservices and to consider trade-offs at spatial scales from local to regional to global.[4] Further development of the ecosystem service concept in rangelands should consider the relative contributions of "goods" and "bads" and their influence on ecosystem and economic resiliency.

One remote fragment of rangeland that provides important ecosystem services is found in central Florida, the site of the 67th Society for Range Management Annual Meeting,[i] and isolated across a continent from western rangelands. Florida's rangelands differ from western counterparts in that they are temperate to subtropical, humid grasslands, dominated by C_4 bunchgrasses, receiving more than 1,300 mm of rain a year, mostly during the hot summer months, and experiencing dry winters with occasional freezes. Beef cattle production on Florida rangelands and pastures is typically cow and calf enterprises with calves sold at weaning. Florida ranks 11th in beef cows nationally with approximately 926,000 head distributed mostly on the acid, nutrient-poor grasslands throughout central and south peninsular Florida (Fig. 1). Although more than 16,000 producers are registered in Florida, 67% have gross sales of less than $5,000 per year and most cattle are managed in large commercial herds. Six of the top 20 beef cattle ranches in the United States are in Florida, accounting for 54% of the number of head in the nation's top 20 ranches.

Florida's grazing lands overlap extensively with the headwaters of the Everglades, a watershed of 1.062 million hectares draining south into Lake Okeechobee, which at 0.181 million hectares is the largest lake in Florida, and the 10th largest in the United States (Fig. 2). Downstream from Lake

[i] The 67th SRM Annual Meeting, *From Dusty Trails to Waning Wetlands*, will be held in Orlando, Florida, 8–13 February 2014. Join us there to learn more about Florida rangelands. For more information on the 2014 SRM Annual Meeting, see http://www.rangelands.org/events/.

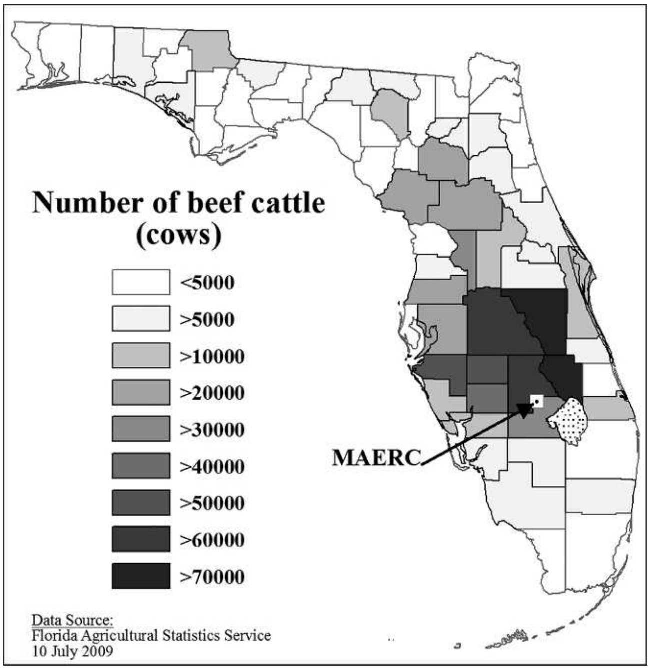

Figure 1. Distribution of beef cattle in Florida. The largest numbers occur in the counties that form the headwaters of the Everglades.

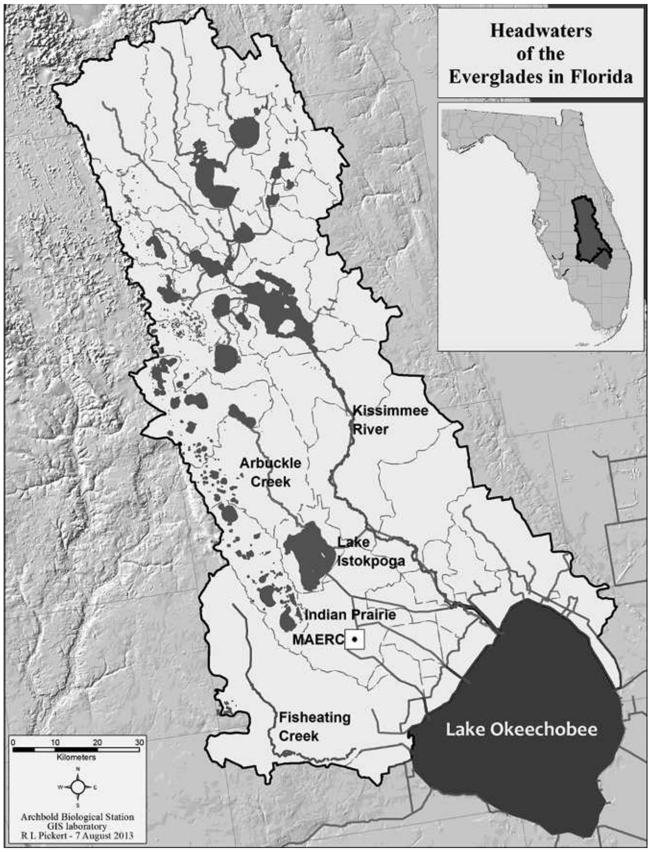

Figure 2. Ranches are the predominant land use in the headwaters of the Everglades, within the many watershed subbasins (dotted lines) that drain south into Lake Okeechobee. The headwaters are dominated by the Kissimmee River, Fisheating Creek, and the Arbuckle Creek–Lake Istokpoga–Indian Prairie watershed basins. MAERC is located in the Indian Prairie subbasin.

Okeechobee waters flow south into the Everglades, although much of the historic southerly flow is now diverted to the east and west coasts of Florida via large canals.[5] The headwaters of the Everglades differ fundamentally from the quintessential Everglades marshes south of the lake. Lands north of the lake are largely privately owned, with only 22% under conservation management (public or private) compared with more than 50% south of the lake. In the southern portion of the headwaters watershed land use is 70% agricultural including dairies, row crops, citrus groves, and mostly extensive beef cow–calf operations.[6] There has been extensive conversion from rangeland to pastures planted with warm-season, perennial forage grasses. The geographical location, climate, and low elevation of the land is unlike other rangelands or pastureland in North America and more like the grazing landscapes of ranches in South America.

To sustain ecosystem services from Florida rangelands it is imperative to understand the trade-offs among services and their counterpart disservices, and to examine these in relation to economic return.[7] We address these issues by integrating multidisciplinary research from a cow–calf operation in the headwaters of the Everglades, Buck Island Ranch, which is the location of the MacArthur Agro-ecology Research Center (MAERC). In 1988, Archbold Biological Station established MAERC and assumed management of the ranch under a lease from the John D. and Catherine T. MacArthur Foundation. MAERC, at 4,249 ha and more than 3,000 head, is among Florida's top 20 beef cattle producers. The ranch is managed as a full-scale commercial beef cow–calf operation providing a real-world infrastructure for agro-ecology research on a working ranch.

We start with a history of MAERC including land conversion, drainage, and fertilization. These activities transformed ecosystem processes and the spatial structure of the landscape, resulting in ecosystem disservices that continue to this day. We then describe the ecosystem services that continue to be derived from this land—provisioning, supporting, regulating, and cultural services—and the trade-offs among these services and converse disservices. Our comparison of trade-offs is conducted at three relevant spatial scales[4]—local (the ranch), regional (headwaters of the Everglades), and global. Ecosystem services are considered in terms of economic returns from provisioning services. Finally, we contrast the trade-offs under ranch management with trade-offs likely under alternate land use scenarios—intensive cropland, suburban development, or restoration to natural areas—allowing us to compare the ecosystem contributions of retaining ranching vs. alternative future land uses in this globally important watershed.

A History of Ecosystem Disservices

Buck Island, a name attributed to local Native Americans, was originally a 1,800-ha island of Florida dry prairie (Fig.

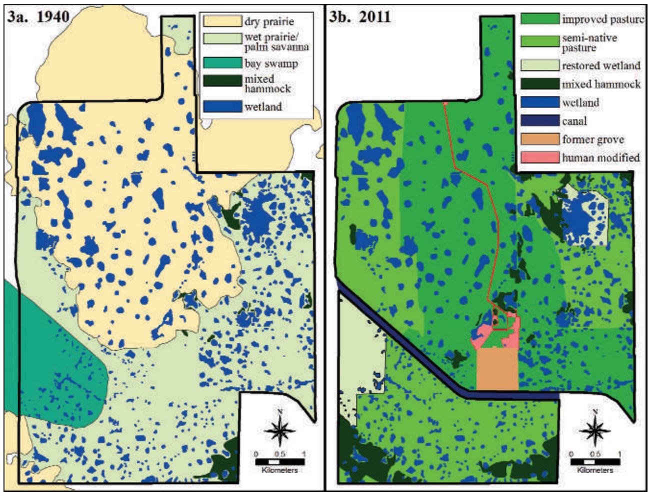

Figure 3. Changes in land cover over 70 years at the MacArthur Agroecology Research Center (black outline is the ranch boundary) based on interpretation of **a,** 1940 aerial photography and 2005 LIDAR imagery and **b,** 2011 aerial photography (see Table 1 for cross tabulation).

3a), a flat, treeless landscape of grasses and shrubs maintained by a combination of lightning-caused fires and seasonal flooding. Embedded within this dry prairie were seasonal wetlands and connecting sloughs. Surrounding the dry prairie was the Indian Prairie, an extensive sheet-flow system of wet prairies and palm savannas with scattered cabbage palm (*Sabal palmetto*) and oak hammocks.[8] The Indian Prairie flowed southeast from Lake Istokpoga to Lake Okeechobee.[5] The bay tree swamp in the southwest of the ranch (Fig. 3a) was fed by flow from a seepage stream called Hickory Branch. The first aerial photographs from 1940 show native communities largely intact except for ditches connecting some seasonal wetlands and two north–south canals: Kuhn Grade, and a ditch that later became the C41 Canal.

The ranch was heavily drained and modified during 1940–1970. By 1970, the US Army Corps of Engineer's Central and Southern Florida Project (CSFP) had expanded the capacity of regional canals north of Lake Okeechobee. The goal was to reduce flooding and to use the lake as water storage for agriculture south of the lake.[5] The CSFP included a new section of the C41 Harney Pond Canal that was dredged through the dry prairie along the northern boundary of the ranch, thus lowering the groundwater table and facilitating ranchwide drainage via more ditches.

During 1948–1968, the dry prairie was cleared and converted to warm-season forage grasses, mostly Bahia grass (*Paspalum notatum*), and subsequently classified as improved pasture (Fig. 3b). Regional conversion to improved pasture, although key to economic cattle production, resulted in extensive habitat and species loss at a local, regional, and global scale (Figs. 4d–4f). Dry prairie is now one of the most endangered grassland types in North America.[9] The wet prairies and savannas, which are harder to drain, less intensively ditched, and not fertilized, were only partially converted to nonnative forage grasses. They are classified as seminative (or unimproved) pastures.

Under the ownership of John D. MacArthur, from 1968 to 1978, the drainage, irrigation, and fertilization of improved pastures were expanded. Fields adjacent to Harney Pond Canal that had been cleared for row crops were purchased and converted to pasture. Like many other ranches regionally, hundreds of miles of additional ditches were added in a "two-way" control system. During the winter dry season, water was pumped from the Harney Pond Canal with three large pumps, and gravity-fed via an extensive network of main ditches and lateral swales, all equipped with riser culverts and elevated boards to disperse irrigation for white clover (*Trifolium repens*). Phosphorus (P) fertilizer was applied at high rates (45 kg/ha). The same ditch-and-riser culvert system, with the boards removed, allowed for rapid drainage during the summer wet season. By the mid-1970s, clover production failed because of nematode infestations and the rising cost of diesel fuel for the pumps, and the improved pastures reverted to Bahia grass. Pumping was abandoned except for filling ditches for watering cattle in the dry season (to supplement drinking water from shallow wells), but wet-season drainage continued unimpeded. The cumulative impact of drainage created major regional ecosystem disservices including reduced wetland hydroperiods, increased peak flows downstream into Lake Okeechobee, and decreased water storage capacity of the watershed (Figs. 4d and 4e).

Fertilizer was applied on improved pastures for approximately 20–30 years until 1986. Thereafter applications were nitrogen (N) only, with lime to increase pH. Earlier fertilization created a P legacy in the soil.[10] Nearly 20 years after P fertilization ceased at MAERC, the P loadings in run-off were still five to seven times higher from previously fertilized improved pastures than from seminative pastures, whereas cattle stocking density had no measurable effect on P loadings.[11] Although beef cattle ranches represent low-intensity agriculture, they are the most extensive land use in the watershed, and continue to be a major regional source of legacy P causing eutrophication locally and downstream in Lake Okeechobee (Figs. 4d and 4e). Despite adoption of agricultural best management practices to reduce nutrient loadings, the lake still receives, on average, more than four times the annual target loading of P. Elevated N loadings have impacts on estuaries downstream. Fertilization has resulted in large-scale manipulation of nutrient dynamics, changing ecosystem services and disservices at the local and regional scale (Figs. 4d and 4e).

Since 1988, when Archbold Biological Station established MAERC at Buck Island Ranch and assumed management of the ranch, there has been no further habitat loss or fragmentation and 748 acres of wetland restoration have been completed on two USDA Wetland Reserve Program (WRP) sites (Fig. 3b). MAERC consists of about half improved and half seminative pastures and the former 160-acre orange grove (Fig. 3b; Table 1). Despite the cumulative magnitude of ecosystem dis-

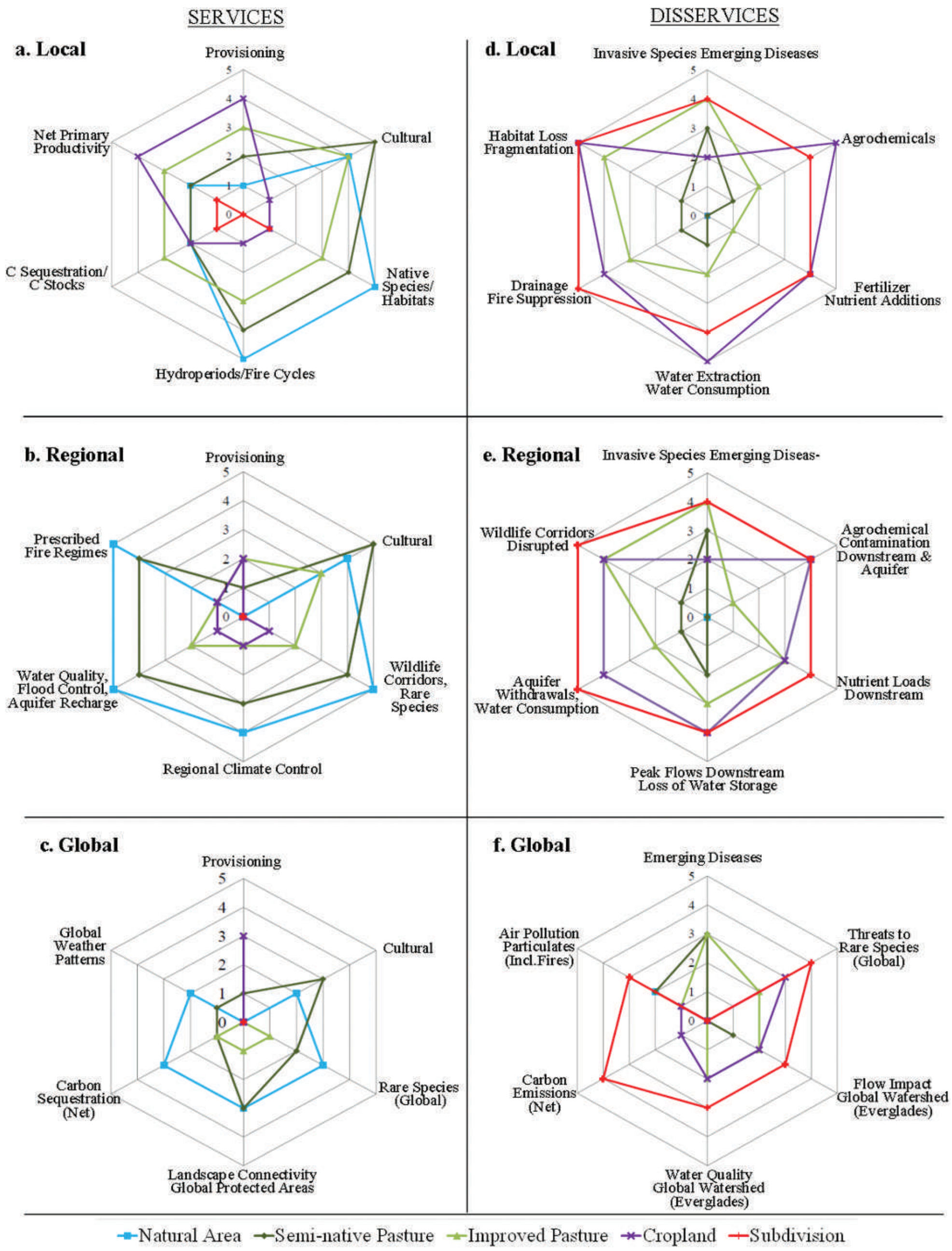

Figure 4. Comparison of **a–c,** ecosystem services and **d–f,** disservices derived from five land use types (a gradient from natural lands, improved pasture, seminative pasture, cropland, to subdivision) in south central Florida. Services and disservices are shown at three spatial scales from **a and d,** local to **b and e,** regional to **c and f,** global. The conceptual values on the radar plots, increasing outward from 0 to 5, represent increasing levels of services or disservices.

services incurred during earlier years, including habitat loss, reduced hydroperiods, and nutrient loadings from legacy P (Figs. 4d and 4e), MAERC continues to contribute extensive supporting, regulating, and cultural ecosystem services as well as cattle provisioning (Figs. 4a–4c). Understanding how to maintain economic viability from provisioning services while retaining and restoring ecosystem services from the remaining mosaic of pastures, wetlands, and scattered hammocks is crucial for MAERC, and for the other privately managed ranches in this iconic headwaters watershed of the Everglades.[7]

Provisioning Services and Disservices

MAERC has produced an average of 2,176 calves per year during 1994–2011, with higher production in recent years. As on many Florida ranches, cows at MAERC are maintained with a Brahma influence (~0.375) for heat tolerance and parasite and disease resistance, combined with an English-type breed (Hereford or Angus) for higher productivity. Cows are crossbred to Angus or Charolais bulls; and bred heifers are generally purchased as herd replacements. Improved pastures facilitate a higher stocking density (allowing

Table 1. Conversion of historic land cover types (area based on 1940 aerial photos and LIDAR imagery) to current land cover at the MacArthur Agro-ecology Research Center (MAERC; based on 2011 aerial imagery). Harney Pond Canal (excluded from the 2011 MAERC area) was a medium-sized ditch in 1940, occupying an immaterial area. See also Figure 3

Historic (1940 aerial) land cover			Current (2011) land cover type (area ha)							
Type	Area (ha)	%	Improved pasture	Seminative pasture	Mixed hammock	Wetland	Restored wetland	Human-modified	Former grove	Harney Pond Canal
Dry prairie	1,604	37	1,149	385	42	0	1	27	0	0
Wet prairie/ palm savanna	1,771	41	466	970	107	0	58	12	76	82
Bay swamp	323	7	0	146	1	0	176	0	0	1
Wetland	544	12	1	0	0	542	0	2	0	0
Mixed ham-mock	94	2	2	0	91	0	0	3	0	0
Total	4,336		1,618	1,501	241	542	235	44	76	83
			37%	34%	6%	12%	5%	1%	2%	2%

MAERC to graze more cows), increased weight gain, and greater provisioning services (Fig. 4a). Large amounts of forage are produced during the long growing season but warm-season perennial grasses lack sufficient quality (too wet in summer; too dry, cold, and daylength-limited in winter) to sustain production without supplemental feed during winter and minerals year-round. Historically, molasses was the supplemental feed but increasing costs caused a shift to haylage (harvested on site) or purchased corn silage. In winter, seminative pastures offer higher nutritional value from native bunchgrasses, but can only support low stocking densities with lower provisioning. In addition to grazing, provisioning services include Bahia grass sod, lifted intermittently from improved pastures since 2000, and game harvesting of white-tailed deer (*Odocoileus virginianus)* and wild turkey (*Meleagris gallopavo*), enabling economically important hunt leases.

The provisioning services from a beef cow–calf operation like MAERC are marginal with an average annual net return per cow of approximately $50 (1994–2011). After accounting for additional provisioning revenue such as hunt leases and sod harvesting, there is less than 1% annual return on land value. Like other regional ranches, MAERC relies on a matrix of improved and seminative pastures to remain economically viable. Were it not for conversion to approximately 50% improved pasture, together with drainage and fertilization, the cattle stocking density on MAERC would be approximately 525 cows, about 20% of the current herd size and not economically viable. There is intense interest from some members of the public for a switch to grass-fed beef, but to be economical this would require further conversion of seminative pasture to improved pasture, more imported feed and fertilizer, and additional irrigation in winter. All are related to significant ecosystem disservices. Shifting to grass-fed or organic production is not yet feasible because narrow economic margins do not allow for raising grass-fed calves to economic slaughter weight on current grass production. Furthermore, there are challenges of marketing such a large calf crop annually for a niche market, particularly in a region without a reliable slaughterhouse for calves.

Disservices associated with provisioning cow–calf operations include pasture management (fertilization, drainage, etc.), introduction of invasive species, the potential negative effects of grazing, and increased carbon emissions. Impacts of cattle production on other supporting and regulating disservices are discussed below. The presence of cattle poses the disservice of higher risks of introducing diseases and nonnative animal pests (Figs. 4d and 4e), although animals such as invasive feral swine, nonnative reptiles, and feral pets can also be sources of these disservices. The disservice of agro-chemical applications is generally low for beef cow–calf operations (Fig. 4d). Agro-chemical use on MAERC cattle is limited largely to vaccinations, fly spray, and ivermectin (worming) for herd health, external and internal. MAERC has intermittently implanted growth hormones in calves for weight gain. Antibiotic use is limited to medical purposes only. Herbicides are used regularly to treat invasive plants.

Supporting Services and Disservices

Carbon Sequestration

Carbon sequestration via photosynthesis, using rates for improved pasture in Florida, gives an estimate of 17,813 metric tons CO_2 equivalents (CO_2eq) per year for MAERC. Based on analyses of 11 years of data, total annual emissions from cattle and other agricultural activities at MAERC is 10,883 metric tons of CO_2eq emitted annually.[12] Emissions contribute to global carbon emissions (Fig. 4f) but are apparently offset by annual sequestration, such that MAERC may operate locally as a net carbon sink. Carbon cycling is under further study at MAERC. Scientists seek to improve measures of sequestration and to differentiate between CO_2 and methane emissions in relation to grazing in improved and seminative pastures, and in wetlands. No attempt is made here to evaluate the impacts of further emissions from calves shipped from MAERC to stocker grass and feedlots in midwestern and western states.

Net Primary Productivity

Net primary productivity (NPP) in improved and seminative pastures provides forage for cattle and serves as the base for biodiversity. At MAERC, cattle consume an average of 32% of production in improved pastures, which have higher NPP than seminative pastures.[13] Statewide estimates for NPP in improved pastures are 3.5–11.5 tons/ha with NPP in improved pastures driven by soil fertility. NPP for seminative pastures at MAERC is 10.65 tons/ha, driven more by fire regimes and grazing than by levels of N and P.[14] More than 600 seasonal wetlands are embedded throughout the pastures at MAERC (Fig. 3b) with NPP values of approximately 6–8 tons/ha.

Soil Formation and Soil Biota

Soil formation and soil biota are essential for biogeochemical cycling, supporting plant production, grazing, and other ecosystem services such as water retention and groundwater infiltration. Soils at MAERC range from Spodosols associated with the former dry prairie, to fine, sandy or loamy Alfisols overlain by a thin layer of muck associated with the original wet prairies and savannas, to Histosols in some wetlands. Ranchland soils in central Florida provide important carbon storage services (Figs. 4a and 4b), with higher levels of soil carbon in improved pastures with increased fertility than in native range.[15] Statewide soil organic carbon values for Alfisols, Spodosols, and Histosols are 7.9 kg/m^2, 16.14 kg/m^2, and 60.95 kg/m^2, respectively, based on an average 0–176-cm profile. At MAERC, the average total soil C on Alfisols is 7.86 kg/m^2 (0–15cm). Wetland soils within improved and seminative pastures have higher total C (0–15 cm) of 10.25 and 12.47 kg/m^2, respectively.[16] More intensive management of improved pastures is associated with wetland soils that have less detritus, higher N concentrations, enriched P levels, lower C:N ratios (0–15 cm), and higher microbial biomass than are found in wetlands within seminative pastures.[17] One wetland under restoration has Histosol C values of 13.6 kg/m^2 in the organic layer and 11.8 kg/m^2 in the upper meter of mineral soil. Soil carbon data for MAERC Spodosols are not yet available.

Soil biota are key to soil ecosystem function. Soil nematodes show strong seasonal responses at MAERC, varying in numbers from year to year, possibly related to soil moisture. Cattle grazing increases soil microbial biomass and alters nematode communities, although the effects of grazing varies among nematode genera.[18] Earthworms comprise the greatest proportion of soil macrofauna biomass but are mainly nonnative species (*Pontoscolex corethrurus*, 23.4%; *Ocnerodrilus occidentalis*, 9.15%; and *Dichogaster saliens*, 6.28%) with unknown impacts on soil processes. Improved and seminative pastures have similar soil macrofauna, but grazing has a significant impact on macrofauna diversity and richness in improved pastures. Soil macrofauna in seminative pastures are associated with the location of tall bunchgrasses, whereas improved pastures provide few bunchgrass microhabitats for soil macrofauna.

Native Species, Habitats, and Invasive Species

Despite the disservice of habitat loss stemming from conversion to pasture (Fig. 4d), the matrix of remaining improved and seminative pastures, more than 600 wetlands, the bay tree swamp, and the oak and palm hammocks (Fig. 3b) still provides the supporting services of a high proportion of regional native species diversity (Table 2), including several species that are regionally or globally threatened (Figs. 4a–4c). (Here we describe some of the species on MAERC and their relationships to ranch management, a focus of Archbold research.).

Plant diversity. Plant diversity at MAERC (Table 2) includes 371 native plants (approximately 40% of central Florida native plant diversity), as well as seven planted forage grasses or legumes, and 66 other nonnatives often associated with conversion to improved pastures. Improved pastures support lower plant species diversity than seminative pastures.[13] One area of palm savanna within a restored wetland is particularly diverse. Wetlands in improved pastures, when compared to wetlands in seminative pastures, have lower plant diversity, more less-palatable species, more nonnative plants, and more homogenous plant communities.[19, 20] Unpalatable plants can, however, serve as important localized refugia from grazing for palatable grasses and native plants.[21]

Table 2. Numbers of plant and animal species that have been recorded at the MacArthur Agro-ecology Research Center, the percentage of regional and statewide diversity these species represent, and how many species have been listed by state and federal agencies

	Native to Florida	% of Florida native species at MAERC	Native to region	% of regional native species at MAERC	Number of species recorded at MAERC					Federally listed USFWS		Listed by state of Florida		
					Total	Native	Breeding	Introduced	Invasive	T	E	T	E	SSC
Birds	496	33	95*	56%	171	166	53	5		1	2	2	2	8
Mammals	49	47			30†	23		7	2		1		1	
Amphibians	55	31	20	85	19	17	19	2	1					1
Reptiles	89	35	46	67	34	31	34	3		1		2		
Fishes	142	11	45	33	18	15	18	3	3					
Plants	2,609	14	1,122‡	40‡	444	371		7	66				1	

*Only breeding birds.
†Excludes bats.
‡Includes nonnative plants.
MAERC indicates MacArthur Agro-ecology Research Center; USFWS, US Fish and Wildlife Service;T, threatened; E, endangered; and SSC, state Species of Special Concern.
Note: Source for numbers of native species in Florida and regionally (if available) from Florida Natural Areas Inventory.

Fortunately, extensive disturbance and ditching on MAERC predated the arrival locally of two of Florida's worst invasives—Brazilian pepper (*Schinus terebinthifolius*) and melaleuca (*Melaleuca quinquenervia*)—and they never became widely established. However, many of the other nonnative plants that are present are invasive, and represent a significant disservice (Fig. 4d). Pastures with invasive plants such as cogon grass (*Imperata cylindrical*), smut grass (*Sporobolus indicus*), and tropical soda apples (*Solanum viarum*) require repeated herbicide use (although tropical soda apples are now also reduced by an introduced biocontrol leaf-feeder [*Gratiana boliviana]*). Natural areas, less vulnerable to invasion, still require herbicide use for species such as climbing fern (*Lygodium microphyllum*) in forested wetlands. West Indian marsh grass (*Hymenachne amplexicaulis*) now occurs in wetlands. Invasive plant distribution and abundance within MAERC wetlands is related to landscape context; in wetlands within seminative pastures the invasive plants are positively associated with higher nutrient status and negatively associated with the abundance of perennial C_3 grasses, whereas in wetlands in improved pastures such relationships are weak.[21]

Arthropods and other invertebrates. Diverse butterfly populations associated with dry prairie habitat[9] were presumably lost from MAERC and regionally when this habitat was cleared. Other invertebrate species likely disappeared with earlier habitat loss (Fig. 4d). However, numerous invertebrates are still associated with pastures and wetlands. Grasshopper diversity is known to be lower in improved pastures at MAERC than in natural communities or ditch margins.[22] A wide diversity of dung, terrestrial, and carrion beetles, many of which are highly noxious, are known to be consumed by birds such as the crested caracara (*Caracara cheriway*)[23] and burrowing owls (*Athene cunicularia*). Aquatic invertebrate communities have higher diversity in lower-nutrient wetlands in improved pastures than in grass-dominated wetlands in seminative pastures.[24] Invertebrate communities in wetlands within improved pastures are less diverse with increasing distance from permanent water, whereas invertebrate communities in wetlands within seminative pasture are negatively affected by cattle stocking density. Experimental removal of vegetation to simulate heavy grazing can significantly decrease the abundance and diversity of aquatic invertebrates.[24]

Invasive arthropods and other invertebrates on MAERC are prevalent, although evaluating their cumulative impacts on supporting processes is hard to determine (Fig. 4d). Fire ants (*Solenopsis invicta*) are present throughout the ranch pastures with average densities of 1,000 mounds/ha, of which about 20% are active. There are more fire ant mounds, and more active mounds, in the wetter *Andropogon*-dominated seminative pastures during the dry season, whereas improved upland Bahia pastures have more active mounds during the wet season. Fire ant mounds result in higher rates of N mineralization year-round and an increase in P availability during the wet season. Fire ant mounds in seminative pastures are less stable and show more "boom and bust cycles" than the more stable mounds in improved pastures that exhibit cumulative annual effects. It is widely documented that fire ants negatively affect grassland birds, mammals, and herptiles, but this has not been evaluated at MAERC. A preliminary study suggests fire ants may alter dung beetle communities at MAERC as they are present in over 70% of dung pats, individual dung beetles are stung and removed by fire ants, and there is a general absence of the "dweller dung beetle" functional group. But many dung beetles are themselves also nonnatives; 55% of the dung beetles trapped on MAERC are the native tunneler *Onthophagus hecate,* but nonnative species account for 31%, including the African *Onthophagus depressus* and another tunneler, *Onthophagus gazelle*. The large native dung beetles such as *Phaneous vindex* and *Canthon piluarius* have not been found. The effects of grazing, parasiticides such as ivermectin, interactions with fire ants, and decomposition rates are the subject of ongoing dung beetle studies. One new invasive arrival over the last 2 years is the island apple snail (*Pomacea insularum*), which is spreading through MAERC ditches rapidly, but not replacing native apple snails (*Pomacea paludosa*), since the latter were never present before. Island apple snails feed on rooted aquatic vegetation but impacts on ranch wetlands and ditches are not yet known. These snails are novel food items for snail kites (*Rostrhamus sociabilis)* and likely account for the first records of this endangered bird on MAERC in 2012, as well as for increased numbers of limpkins (*Aramus guarauna*), which also feed on these snails.

Amphibian, reptile, and fish communities. The rich diversity of amphibians (five salamanders, 14 anurans; Table 2) is similar to that found in Florida's natural communities regionally, although extensive ditching has adversely affected amphibian assemblages by reducing hydroperiods and altering connectivity among wetlands (Fig. 4d). Ranch wetlands, although extensively modified, still provide dynamic habitats and a landscape context that offers varying amphibian breeding opportunities that are highly dependent on rainfall and hydrology.[25] Ranch ditches contain many lesser sirens (*Siren intermedia*). Thirty-four reptile species (seven turtles, one crocodilian, eight lizards, and 18 snakes; Table 2) are known from MAERC, again associated largely with wetlands. The federally threatened indigo snake (*Drymarchon corais couperi)* maintains extensive territories on ranchlands regionally. Only 18 species of fishes occur, of which three are nonnative; this represents a lower percentage of regional diversity than other taxa (Table 2) but MAERC does not have any lake or riverine habitat. Fish distribution in seasonal wetlands is shaped primarily by large-scale landscape processes (connectivity to permanent water bodies) and wetland hydroperiods.[26] Of two introduced amphibians, the Cuban tree frog (*Osteopilus septentrionalis)* is invasive, but restricted around buildings. Three of 34 reptiles present are invasive; these are introduced geckos and lizards. It is probably only a matter of time before the python (*Python molurus)* and other invasive reptiles arrive from southern Florida.

Birds. MAERC has a diverse bird list with 171 species, of which 53 nest on site (Table 2). Although resident and migratory grassland birds are declining nationally, the improved and seminative pastures provide habitat for a variety of resident and migratory grassland birds (Fig. 4a), including species such as eastern meadowlarks (*Sturnella magna*) and loggerhead shrike (*Lanius ludovicianus*), as well as the northern bobwhite (*Colinus virginianus*). More intense grazing on improved pastures leads to declines in total avian species richness and abundance, but lower levels of grazing (1.3 ha per animal unit [AU] and 2.1 ha/AU on improved and seminative pasture, respectively) may maintain spatial heterogeneity of vegetation and avian abundance.[27] A 20-year study (1989–2008) of ditches on MAERC documented 14 species of wading birds, including the federally endangered wood stork (*Mycteria americana*). The most abundant species are white ibis (*Eudocimus albus*, 30%) and great egret (*Ardea alba*, 25%), but species composition has been variable, with no discernible trends; 35% of the variation in total numbers of wading birds is explained by rainfall and climate indices. Amphibians (and crayfish) in wetlands and ditches form a rich prey base for dense populations of raptors, and reproductive success of common species such as red-shouldered hawks (*Buteo lineatus*) is tied to wetland hydroperiod.[28]

MAERC provides habitat for rare and threatened birds (Figs. 4a and 4b) such as burrowing owls, wood storks, snail kites, and crested caracara. There are about 10 breeding caracara territories established annually on, or partially on, MAERC and this threatened bird nests throughout central Florida's ranchlands.[29] Territory sizes of caracara are smaller in improved pastures, indicating higher resources, than in seminative pastures or open rangeland. Large roosts of nonbreeding caracaras are also documented on MAERC, as well as roosts of approximately 20–30 swallow-tailed kites (*Elanoides forficatus*). The white-tailed kite (*Elanus leucurus*), a rare breeding species of Florida's prairie, was discovered nesting at MAERC in 1996. The Florida grasshopper sparrow (*Ammodramus savannarum floridanus*), a globally threatened bird endemic to this region and now close to extinction,[9] was likely lost from MAERC when the dry prairie was cleared.

Mammals. At the end of the Pleistocene, MAERC presumably sustained large grazers such as mammoth (*Mammuthus)*, llama *(Hemiauchenia*), and giant ground sloth *(Megalonyx*). They all disappeared in the megafaunal extinction around 10,000 years ago. Of the larger Florida mammals that remain, black bear (*Ursus americanus)*, river otter (*Lutra canadensis*), and bobcat (*Lynx rufus*) are observed frequently, and males of the globally threatened panther (*Puma concolor coryi)* occasionally move across MAERC. The vast, contiguous, roadless areas of MAERC and surrounding ranches provide breeding habitat for mammals (birds and reptiles, too) with extensive home ranges. Private ranches, in conjunction with public conservation lands, serve as essential components of wildlife corridors that provide landscape connectivity for large animals to move throughout central and southern Florida (Figs. 4d–4f).

Invasive feral swine (*Sus scrofa*) arrived in Florida with the Spanish about 500 years ago; now the state supports one of the densest populations in the country. Feral swine create disturbances in pastures and wetlands, causing widespread conversion to dense stands of the native plant Carolina redroot (*Lachnanthes caroliana*) as well as other unknown impacts on wetland and soil processes. During the last 3 years, trapping 250–300 swine annually has had no discernible impact on population size at MAERC. Trapping swine generates some revenue (gross $30–40 per head), but the ecosystem costs of swine include degraded wetlands, pasture disturbance, and threats of disease transmission to humans and cattle. These are all the subject of ongoing research. Elk (*Cervus elaphus*) at MAERC, not native to Florida, are still found as a remnant breeding population stemming from six individuals released on Buck Island Ranch by John D. MacArthur in about 1968, and which grew to a herd as large as 28–29 individuals in the 1970s. The population has declined but the elk persist and are problematic browsers in neighboring orange groves.

Regulating Services and Disservices

The primary regulating services and disservices derived from ranches in this region are water, climate, and fire. These act at the local and regional scales (Figs. 4a and 4b). The cumulative contributions of Florida ranches may affect global-scale regulating services.

Water

About 55–60 billion liters of rain fall annually on the grasslands and natural habitats of MAERC. Most water is returned as evapotranspiration or as groundwater recharge, contributing to regional and global water services (Figs. 4e and 4f). Only a minor fraction of this water, about 83 million liters per year, is consumed by cattle on the ranch, although no attempt is made here to evaluate the impacts of further water consumption by calves shipped from MAERC to stocker grass and feedlots. Wetland habitats remaining on MAERC provide important hydro-ecological services locally (Fig. 4a), although the extent of current wetlands (18% of the ranch) is far less than the original wetland extent (60%; Table 1). Miles of ditches and canals result in rapid run-off, contributing to destructive peak flows downstream during the wet season, and the loss of regional water storage during the dry season, all disservices in this globally important watershed (Figs. 4e and 4f). The most significant water disservice is P loadings flowing from improved pastures to Lake Okeechobee and downstream (Figs. 4e and 4f). The construction of the Harney Pond Canal and the loss of regional sheet flow means there can never be full restoration to presettlement hydrology, but reversing excessive surface drainage via ditches is a key to restoring many water services. Wetland hydrology has been partially restored on 300 ha in two USDA WRP sites on MAERC. Under enrollment in the Northern Everglades Payment for Environmental Services (NEPES) program (*see Shabman et al., this issue*), originally known as FRESP,[30] MAERC is paid a fixed fee by South Florida Water Management District to retain an average 185 hectare-meters of water annually. New riser boards on 43 culverts hold back more water in ditches, wetlands, and pasture soils across ~1,200 ha. Such dispersed water management on private ranchlands is a complement to large-scale projects on public lands. The overall goal is to add 125,000 hectare-meters of water storage in the watershed, and to reduce annual P loads to Lake Okeechobee from more than 400 metric tons per year to 140 metric tons.

Regulating Climate

The presence of a wetland on a ranch provides some freeze protection locally for surrounding land (Fig. 4a). Many ranches, including MAERC, established orange groves next to wetlands for this reason. The cumulative loss of wetlands in this region over the last century, including extensive drainage of agricultural lands, has impacted climate regulation and appears responsible for the climate disservices.[31] Colder winter minimum temperatures and more freeze days are reported in rural interior south central Florida now than were experienced in the early 1900s. Summer maximum temperatures are also warmer now. Climate change predictions using regional downscaling models show no clear future trends for temperatures in rural south central Florida, and anticipate high variability in rainfall, from potentially drier to potentially wetter. Under such variable scenarios, the retention and restoration of remaining wetlands on ranches is prudent climate mitigation.

Maintaining Fire

Virtually all of Florida's natural communities associated with cattle grazing are ecologically fire-dependent; they require natural fires or prescribed burns. The US Forest Service and Florida Forest Service began campaigns against burning in the 1920s, but Florida cattlemen continued to burn rangeland, pastures, and woods, and they fought restrictions with observations like those of S. W. Greene[32] "that controlled woods burning …as practiced by cattlemen and turpentine producers, to be a very great value to the production and conservation of forest and game in Florida." Cattlemen played a significant role in maintaining a culture of ecosystem burning until the vital role of fire was recognized by authorities. Prescribed fires at the end of the dry season (mimicking lightning-induced fires in late April or May) are most favorable to grasses and forb species in flatwoods and rangeland and limit shrub encroachment in pastures. Although ranchers usually burn for forage during the dormant winter season (January–February), as opposed to the growing-season fires more typical of natural fire regimes, any prescribed burning—regardless of season—is preferable to fire suppression. MAERC staff burns about one-quarter of the ranch annually. Chopping is also used to reduce shrubby vegetation. Assuming a very light approach, chopping can restore growth of herbaceous groundcover species.

Cultural Services

Florida has supported cattle grazing since the arrival of the Spanish some 500 years ago and many ranching families are into the sixth and seventh generations.[33] Until the 1930s, many Florida cattle were descendants of the early Spanish cows. Known as Florida Cracker cattle, they were the genetic progenitors of such iconic Western breeds as the Texas Longhorn and are now preserved as a rare breed. Several ranches, including MAERC, maintain small herds of Florida Cracker cattle for cultural interest. Native American culture in Florida is also tightly linked to the cattle industry, with the regional Seminole and Miccosukee tribes managing large ranches. The culture of the Florida cattlemen, less well-known than Western counterparts, is gaining in public awareness with the popularity of *A Land Remembered*, Patrick Smith's[34] 1984 fictional history of this largely unknown world, and Carlton Ward's[35] evocative photographs in his 2009 book *Florida Cowboys: Keepers of the Last Frontier*. Since 1987, the Florida Cracker Trail Association hosts an annual 120-mile trail ride across the state, and the Florida Wildlife Corridor Expedition released a Public Broadcasting System documentary chronicling a 100-day, 1,000-mile journey during 2012, from south Florida to southern Georgia, highlighting the importance Florida's ranches for wildlife movements. The public is enthusiastic about the handful of ecotours offering opportunities for wildlife viewing and learning about Florida's ranch culture (e.g., MAERC, Babcock Ranch, Forever Florida) but tour revenue is relatively insignificant (the MAERC tour barely breaks even) and tours expose landowners to considerable liability. Private hunt leases offer better financial returns (approximately $20–40/ha) and hunting serves as an important cultural force for the retention of natural communities and ecosystem services within Florida's ranches.

Combining Ecosystem Services and Economic Sustainability

How can a rancher achieve economic returns from provisioning without compromising other ecosystem services, or vice versa? Comparing the radar plots (Figs. 4a–4f) of ecosystem services and disservices derived from improved pasture, seminative pasture, and natural lands on private ranchlands illustrates the trade-offs. Although natural lands and seminative pastures provide a higher overall degree of ecosystem services of interest to the public, it is difficult to be economically viable without improved pasture for production. Many ranchers have achieved a balance by only partially converting to improved pasture—in the case of MAERC it is just over 50% of the ranch. Other ranches regionally have lower or higher percentages converted. Trade-offs stemming from the proportion of land that is natural, seminative, or improved accumulates at spatial scales from local to global.

Is ranching in central Florida's rangelands, and its associated ecosystem services, sustainable over the long term? What are the alternatives? Retaining ecosystem services by purchasing and restoring all the ranchlands in this watershed through public land acquisition or conservation easements would severely affect the region's economy and is neither fiscally possible nor publically desirable. Furthermore, although full ecological restoration from pasture to natural communities has been achieved at sites such as The Nature Conservancy's Disney Wilderness Preserve, this impressive but expensive undertaking provides little economic return and was paid for by mitigation dollars, which are limited. Decades ago many ranchers planted citrus groves to increase diversity of revenue, but citrus now faces citrus greening disease (among several other diseases) and challenging economic problems. Alternative crops—conversion from pasture to intensive cropland such as sugar or biofuels—could increase provisioning services, but would drastically reduce levels of most other ecosystem services (Figs. 4a–4c). Intensification for cropland would also incur the costs of multiple ecosystem disservices at all spatial scales, demanding further habitat and species loss, increased drainage, higher nutrient additions, greatly elevated water consumption, and more application of agro-chemicals (Figs. 4d–4f).

Development is by far the greatest threat to Florida's ranches and their ecosystem services, with one 2060 scenario for Florida suggesting extensive loss of ranchlands. This could be exacerbated if humans retreat inland from rising sea levels in coastal Florida. Regional land values for pasture were stable for years at $1,200–1,500 per acre then rose rapidly, from 2003 to 2007, to highs of $7,000–8,000 per acre. They have since fallen to current levels, closer to $1,500–2,000 per acre, but prices will rise again and sale for development is always attractive to those facing a marginal return. Development, typically for new subdivisions, diminishes all ecosystem services and greatly elevates disservices (Figs. 4a–4f).

If the rancher's predilections are for conservation, then being located in this globally important watershed offers some options for improved economic viability by providing and selling ecosystem services. Annual payments for participating in voluntary USDA conservation programs are helpful, and market-based payment for environmental services programs for water services are emerging such as NEPES (see above). Over the last 3 years at MAERC, such payments have supplemented agricultural revenue sufficiently to maintain overall positive economic returns, thus effectively retaining all of the other ecosystem services that MAERC provides. Carbon payments appear less economically attractive at present. Mitigation on private lands for listed species and wetlands is possible but involves complicated permitting. Sale of conservation easements can protect ecosystem services and provide a substantial economic return from land values as well as tax incentives for landowners. Easements on private lands have conserved > 50,000 ha in the headwaters of the Everglades, a significant achievement although less than 5% of the watershed. Easements may also reduce the level of provisioning services. Easement buyers in the past have been the South Florida Water Management District and Florida Forever, the state's signature conservation program, but there has been limited state funding since 2008, although this may improve. Federal easements have been predominately USDA WRP, but new programs with limited funding target lands to buffer the military mission around the Avon Park Air Force Range (US Department of Defense) and for the Everglades Headwaters National Wildlife Refuge (US Fish and Wildlife Service).

Integrated approaches such as this analysis of MAERC in Florida can help evaluate the trade-offs among ecosystem services and disservices from ranchlands in relation to economic return. Similar approaches elsewhere will increase the capacity of decision makers and the general public to understand the role of grazing lands, provide a basic understanding of the services and disservices of this widespread human intervention in the landscape, and give us the ability to assess management or restoration options for grazing lands in the context of sustaining economic viability.

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Authors are Executive Director, Archbold Expeditions and Senior Research Biologist, Archbold Biological Station, Venus, FL 33960, USA, hswain@archbold-station.org (Swain); Director of Research, MacArthur Agro-ecology Research Center, Lake Placid, FL 33852, USA (Boughton); Professor, University of Central Florida, Orlando, FL 32816, USA (Bohlen); and Ranch Manager, MacArthur Agro-ecology Research Center, Lake Placid, FL 33852, USA (Lollis).