NATIVE HABITAT RESTORATION IN THE EAGLE FORD SHALE OF TEXAS

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Table of Contents

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Abstract: Development of Eagle Ford Shale (EFS) oil and gas resources will continue to have considerable impacts on the native habitats of southern Texas. Diverse native plant communities are important habitat for many wildlife species and underlie the predominant land uses of the impacted region aside from oil and gas production. Major issues associated with EFS development are addressed in this management bulletin based on more than a decade of research. We provide management recommendations for minimizing habitat loss, fragmentation, and disturbance from oil and gas development, controlling exotic invasive grasses, protecting soil resources, and conducting restoration using locally-adapted native seed varieties. Restoration of wildlife habitat in the EFS is an important facet of wildlife conservation in South Texas. Achieving desired outcomes will be beneficial to sustaining the diversity and productivity of the region for future generations.

INTRODUCTION

The Eagle Ford Shale (EFS) is a globally significant oil and gas play located in South Texas (Figure 1). Although only 50 miles wide and 400 miles long as it traverses the southern third of Texas, the positive economic impacts of the EFS are far-reaching. Just as important to landowners in this region are the negative impacts of EFS development on native habitats and the wildlife that rely on them. Therefore, balancing oil and gas exploration and production while maintaining native plant communities and the wildlife they support presents both challenges and opportunities for restoration ecologists, landowners, and the energy industry.

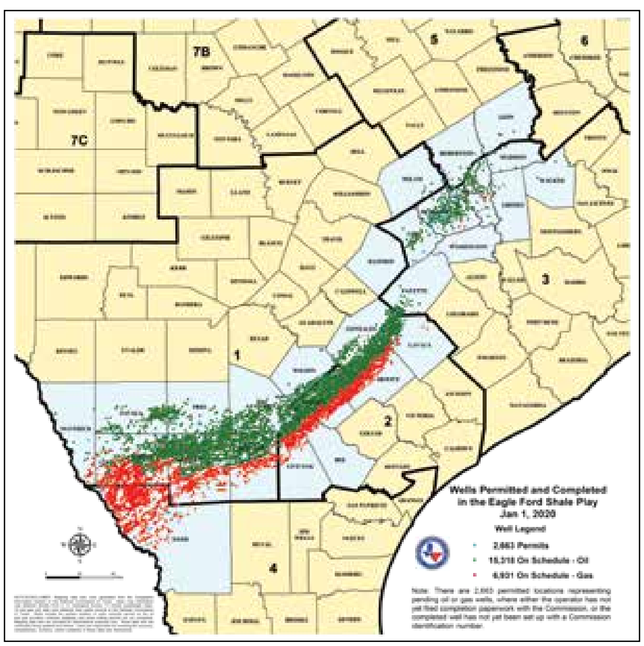

Figure 1. Map showing the Eagle Ford Shale oil and gas play in Texas (Railroad Commission of Texas 2019).

Basic guidelines exist in the field of restoration ecology for planning energy exploration, minimizing disturbance, and applying reclamation strategies following extraction of oil and gas resources. The EFS, however, poses unique challenges to restoration of native plant communities.

The EFS region is characterized by topographic variation and mosaics of soil characteristics that support many different plant assemblages. This inherent diversity is paired with the intensity of soil disturbance common in pipeline installation, construction of frac water ponds, or associated with large multi-well pad sites. Each of these has highly technical restoration methods, which affect subsequent range and wildlife management considerations. The threat of exotic invasive grasses in highly disturbed areas in the region further complicates native plant restoration efforts. These considerations call for an up-to-date and detailed synopsis of research findings on restoration practices for the EFS based on a decade of applied research by the

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Restoration needs common in the Eagle Ford Shale are inherently complex due to the intense soil and vegetation disturbances associated with development.

Caesar Kleberg Wildlife Research Institute (CKWRI) at Texas A&M University-Kingsville.

Land ownership in the EFS is largely private. This presents both an opportunity and a challenge to the implementation of effective restoration practices. In many cases, historical oil and gas leases limit the obligation of energy operators to conduct restoration. Many contemporary leases and easements, however, require some habitat restoration effort, often generically defined as restoring the "surface to its previous condition." Certainly for future leases, easements, or surface use agreements, the concepts and principles presented in this bulletin should be specifically considered and contractually required. Although energy operators can choose to address restoration concerns on their own to be good land stewards, this is not always the case.

We encourage the oil and gas industry to adopt the over-arching restoration philosophy that guides what we present herein. In essence, this philosophy is that when native habitats are negatively impacted by development, every effort to restore them as best as possible to native plant communities should be made. By implementing the principles and practices that we have developed as a result of our research, we believe this is possible—and we are heartened by the efforts of many in the industry who have already done so voluntarily.

Following the discovery of the EFS by Petrohawk in 2008 in La Salle County, we have had the opportunity to work with hundreds of private landowners and many oil and gas, pipeline, and industry operators on restoration projects in South Texas. Industry partners who have supported or cooperated in these efforts include ConocoPhillips, ExxonMobil, Pioneer Natural Resources, and Shell. Therefore, this management bulletin summarizes over a decade of applied research on restoration in the EFS conducted by or in cooperation with CKWRI scientists and our partners. Our goal in summarizing this research is to provide common-sense solutions for all constituencies to equip them in successfully restoring native plant communities that will benefit wildlife on impacted lands. We hope lessons learned and presented here can also inform future oil and gas play development operators elsewhere in order to minimize negative impacts on wildlife habitats. Our overall goal is to promote successful native habitat restoration in concert with responsible oil and gas development.

TEXAS LAW AND LEGAL CONSIDERATIONS FOR EAGLE FORD SHALE DEVELOPMENT AND RESTORATION

Texas statutes impose almost no requirements on oil and gas operators to minimize the impact of development or restore the property. As such, surface owners face an uphill battle to negotiate surface protections unless the surface owner also owns an interest in the mineral estate of the property being developed. The mineral estate is the dominant estate. Absent specific contracting in a lease or surface use agreement, an oil and gas operator has the right to reasonable use of the surface in order to produce the mineral estate.

© Anthony Falk

Eagle Ford Shale pipeline easement in Wilson County restored using native grasses and forbs.

© Anthony Falk

Pipeline restoration should be addressed in easement agreements. Photo showing early stages of native plant restoration on a La Salle County pipeline.

Use and handling of the surface interest of the property may be covered in a Surface Use Agreement, which should be an integral part of any new or renegotiated oil and gas lease. However, this is unlikely to be an option on an existing lease (either held by production or held by term) unless the surface owner also has a significant ownership interest in the minerals. Older oil and gas leases in Texas, particularly those held under Producers 88 lease templates, contain limited surface use provisions, for which Texas law imposes no more stringent restoration requirements. Unlike some states, Texas does not have a surface damage act.

In some instances, federal law may have a bearing on surface operations of a particular facility or location. Federal law will also come into play where federal-trust organisms or resources occur, such as endangered species or waterways. For pipelines, Texas has few surface interest obligations aside from those negotiated in the easement agreement. For common carrier pipelines, the right of eminent domain ultimately gives operators leverage over how rights-of-way are built. Landowners may negotiate for restoration provisions, and often do so successfully, but implementation is ultimately up to the landowner to enforce.

Often, landowners can negotiate for reasonable restoration practices to be carried out by the operators or to be compensated for doing the restoration themselves. Because of the complexities and intricacies of Texas law, industry customs, and the critical impact that attorneys can have on legal agreements and their resulting administration of surface interests, we recommend consultation and retention of experienced attorneys for all legal matters dealing with mineral leases or easements related to EFS production and exploration. All agreements should be contractual and be as specific and enforceable as possible.

Of particular importance for modern EFS-related exploration followed by restoration, we recommend that landowners negotiate for financial incentives to minimize disturbance and fragmentation and for allocation of financial resources for restoration as part of the Authorization for Expenditure for each project. For all matters related to these legal issues, defining who, what, when, where, and how for each specific issue is very important. Of equal importance is diligent oversight of operations to ensure that agreements are followed, including remedies and actions to enforce such provisions when they are not.

CHARACTERIZATION OF EAGLE FORD SHALE HABITAT AND WILDLIFE

Vegetation and Soils

Development of EFS energy resources has an impact on non-urban land that provides valuable habitat for wildlife in three Texas vegetational areas: the Rio Grande Plains, Blackland Prairie, and Post Oak Savannah. Significant damage to native wildlife habitat occurs in each of these regions as a result of typical oil and gas activities. Habitats impacted include remnant prairies, savannahs, brushlands, and deciduous forests in riparian areas.

© Forrest Smith

Large portions of the Eagle Ford Shale occur in the Rio Grande Plains, characterized by diverse vegetation communities such as this site in Webb County.

© Forrest Smith

Eagle Ford Shale development in sandy soils can present restoration challenges because of the highly erodible nature of these soils when disturbed.

Native plant communities are inherently diverse across the EFS. This is the result of the combination of varied soils and climate, especially rainfall, which ranges annually from over 30 inches to less than 15 inches from east to west across the EFS. Soils within the EFS region vary from coarse sands, particularly in the Post Oak Savannah and in scattered outcrops of the Carrizo Geologic Formation in the Rio Grande Plains, to fine clays, which in the western South Texas Plains often are alkaline.

Both surface and subsurface soil characteristics are important to restoration within the EFS. For example, construction activities in coarse sands can result in difficult conditions for revegetation because of the low water holding capacity and high potential for wind and water erosion of these soils when they are disturbed. Alkaline clay soils are also difficult to restore, often because of the disruption of soil salinity, particularly when subsoil layers are brought to the surface of the soil profile during pipeline trenching. Extremely shallow, gravelly sites on uplands can also present difficulties because of thin soil profiles with high erosion potential and poor water holding capacity.

Natural plant communities exhibit particular diversity throughout the EFS because of soil and climate variability. In the western portion of the region, mid- and short-grass prairies or savannahs are common, but typically occur in a degraded state or have extensive brush invasion. In the central portion of the region, chaparral or shrub-dominated rangelands are common, but significant areas are more open, especially on certain soils or where mechanical or chemical brush management practices have been implemented.

Mesquite is a dominant woody plant over most of the Rio Grande Plains impacted by EFS development, though a wide diversity of other shrubs is common. Other plant species include cenizo, granjeno, brasil, lime prickly-ash, coma, blackbrush acacia, guajillo, huisachillo, huisache acacia, desert yaupon, Texas persimmon, and wolfberry. Prickly pear cactus is also common over much of the area. In the eastern part of the EFS, alternating belts of Post Oak Savannah and Blackland Prairie occur, and true prairies occurred historically. Today, many areas formerly representing mid- or tall-grass prairie are under cultivation, whereas others have been replaced with exotic grass pastures and post oak, blackjack oak, live oak, and cedar elm woodlands and savannahs.

Grasslands and savannahs in the western Rio Grande Plains are typically dominated by native grasses common to arid regions such as curly mesquite, buffalograss, slim tridens, sideoats grama, pink and whiplash pappusgrass, cane and silver bluestems, plains bristlegrass, Arizona cottontop, and false rhodesgrass. These grasses intergrade with mid- and tall-grasses, including multiflowered false rhodesgrass, big cenchrus, and longspike silver bluestem on tight soils and soils with greater moisture availability, and little bluestem and tanglehead on sandier soils.

In the eastern portion of the EFS, prairies were historically dominant. On Blackland Prairie sites, vegetation was historically dominated by tallgrasses such

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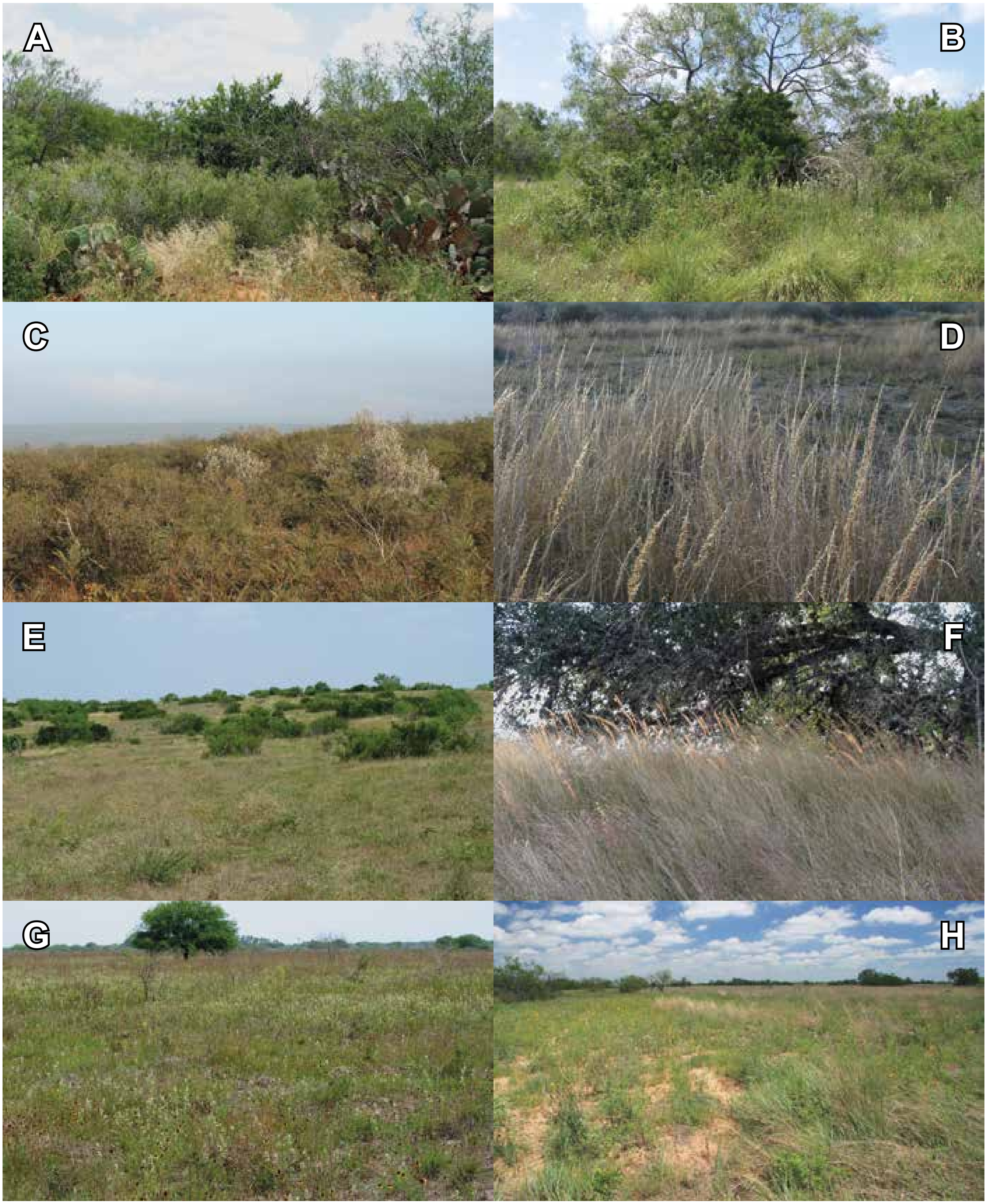
Native grasses such as plains bristlegrass, pink and whiplash pappusgrasses, and false rhodesgrass are important habitat components of grasslands and savannahs in the western Rio Grande Plains.



Examples of native plant communities found in the Eagle Ford Shale: (A) Atascosa County South Texas brush country, (B) Frio County mesquite savannah sandy loam soils, (C) Kinney County brushland, (D) Kinney County desert grassland-shrubland, (E) Live Oak County open savannah, (F) Wilson County oak savannah tallgrass prairie, (G) Victoria County coastal prairie, (H) Dimmit County little bluestem dominated grassland on Carrizo Geologic Formation.

© Forrest Smith

A saline rangeland site in La Salle County that is dominated by Gulf cordgrass.

as little bluestem, big bluestem, Indiangrass, sideoats grama, silver bluestem, tall dropseed, switchgrass, and eastern gamagrass. Several of these species, along with purpletop tridens, brownseed paspalum, threeawns, and Pan-American balsamscale are common in the sandier Post Oak Savannah sites as well. Mid- and short-grasses are common on degraded blackland sites, especially Texas wintergrass, Texas grama, shortspike windmillgrass, and buffalograss. On degraded sand, loamy sand, and sandy loam soils throughout the region, red lovegrass, hooded windmillgrass, hairy grama, thin paspalum, slender grama, and sand dropseed can be common grasses.

Saline sites are common in the central and western EFS. These areas support a unique grass community tolerant of these conditions. Common grasses include curly mesquite, whorled dropseed, alkali sacaton, spike lovegrass, whiplash pappusgrass, big sacaton, Gulf cordgrass, and plains bristlegrass.

Non-grass vegetation is extremely varied and is based on soils, recent and historical disturbance, climate, and location. Common forbs in the Rio Grande Plains on tighter soils include prairie acacia, awnless bush sunflower, orange zexmenia, prostrate bundleflower, Engelmann's daisy, and Indian blanket. On sandy soils of the Post Oak Savannah and South Texas Plains, extremely diverse forb communities are found, often comprised of hundreds of species. Examples include erect dayflower, Indian blanket, greenthread, horsemint, crotons, and various legumes. In native plant communities on Blackland Prairie sites, common forbs include Engelmann's daisy, Maximilian sunflower, plains coreopsis, Illinois bundleflower, and purple prairie clover.

Much of the native vegetation in the EFS has been altered by the purposeful introduction and subsequent spread of exotic invasive grasses (Table 1). Large areas of rangeland in the western and central Rio Grande Plains are impacted by buffelgrass. Old World bluestem grasses, especially yellow (King Ranch) bluestem in the northern parts of the EFS and ringed dichanthium (Kleberg bluestem) in the central and western portion, are common and frequently form dense monocultures on heavy textured soils. Other Old World bluestems including silky bluestem, Caucasian bluestem, Angleton bluestem, and Australian bluestem can be locally abundant as well.

Pastures and former cropland in the eastern portion of the region are commonly sprigged to and maintained as Bermudagrass pasture. Other exotic grasses of note in the EFS include Lehmann lovegrass, Wilman lovegrass, guineagrass, natal grass, Kleingrass, and blue panicum. Many of these exotic grasses have been established to increase forage for livestock, whereas others have been used in soil conservation activities or for revegetation. From the standpoint of wildlife, areas dominated by or including these grasses are considered poorer habitat than native habitats; for livestock production, exotic grasses are viewed more favorably.

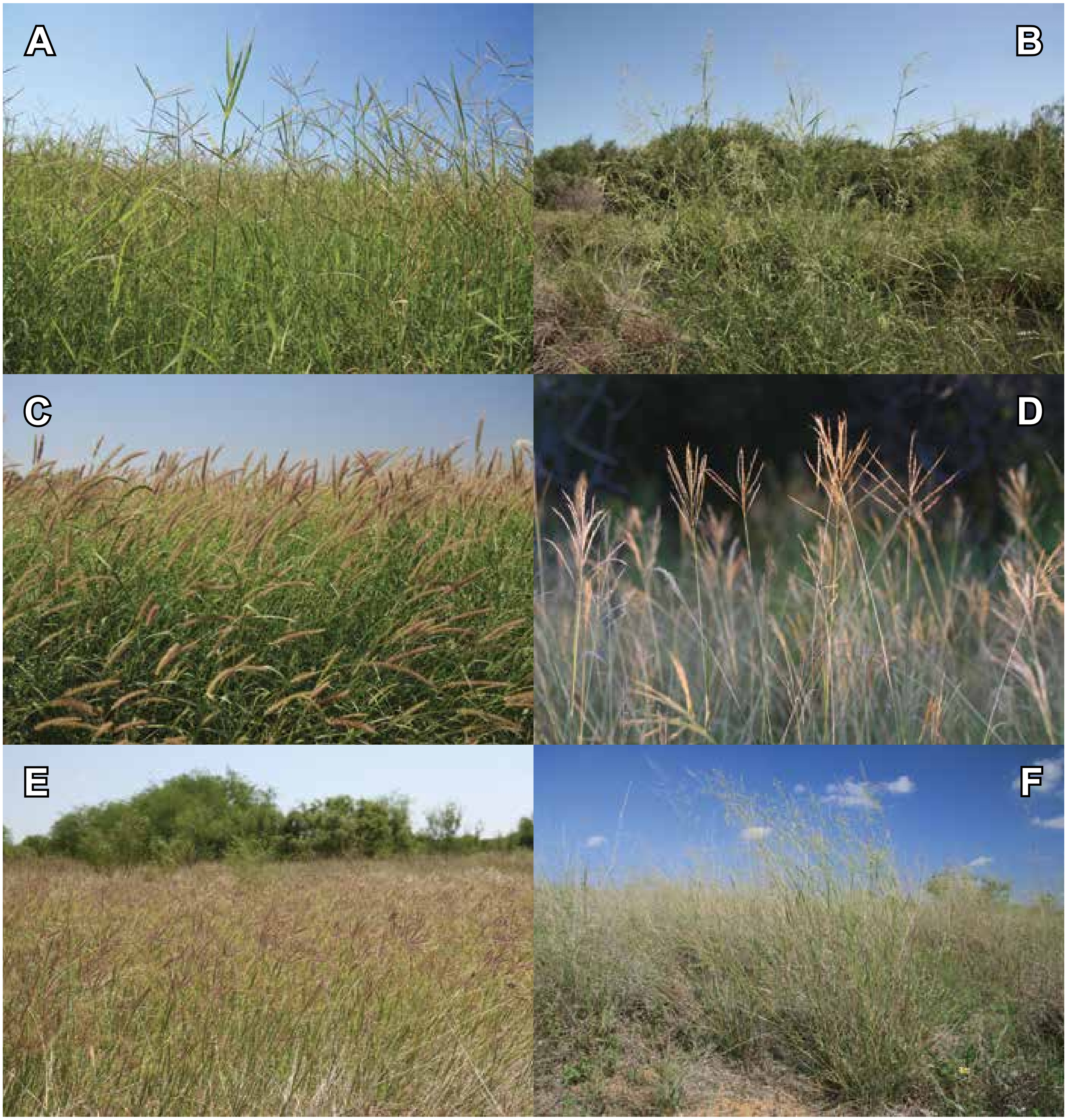
Table 1. Exotic invasive grasses found in the Eagle Ford Shale region of South Texas.

Grass Name	Ecoregion[1]
Ringed dichanthium (Kleberg bluestem)	RGP, POS, BLP
Yellow bluestem (King Ranch bluestem)	RGP, BLP
Australian bluestem	RGP, POS
Angleton bluestem	RGP, BLP
Caucasian bluestem	RGP, BLP
Silky bluestem	RGP, BLP
Bermudagrass	RGP, POS, BLP
Guineagrass	RGP, POS
Johnsongrass	RGP, BLP
Lehmann lovegrass	RGP, POS
Wilman lovegrass	RGP, POS, BLP
Buffelgrass	RGP
Natal grass	RGP, POS
Kleingrass	RGP, POS, BLP
Blue panicum	RGP

[1] RGP = Rio Grande Plains; POS = Post Oak Savannah; BLP = Blackland Prairie

Wildlife

The diversity of habitats within the EFS supports a wide array of wildlife. White-tailed deer and northern bobwhites are of particular importance to private landowners and are the primary motivation behind much of the land management effort and ownership interest in land with native habitats in the region. Providing habitat for white-tailed deer is the most dominant land management focus, likely rivaling if not exceeding use of land for livestock production or other uses combined. Managers often attempt to manipulate brush density and coverage to provide optimal deer habitat and enhance hunting opportunity. There are often efforts to provide supplemental feed to deer and manage population



Six common exotic invasive grasses found in South Texas: (A) Bermudagrass, (B) blue panicum, (C) buffelgrass, (D) yellow bluestem, (E) ringed dichanthium, (F) Lehmann lovegrass.

Deer Photo © Anthony Falk; Quail Photo © Forrest Smith

White-tailed deer and northern bobwhites are the primary wildlife species influencing land management in much of the Eagle Ford Shale.

dynamics through selective harvest, and in some cases introduction of breeding stock.

Northern bobwhites, which occur throughout the EFS, and scaled quail, found in the central and western portions of the EFS, are of interest to most private landowners. Typically, the emphasis for quail management is on maintaining native grassland habitats, manipulating plant succession, and managing for optimal combinations of nesting, brood rearing, escape (brush), foraging, and loafing cover that favor quail production and aid hunting activity.

Other important wildlife species in the EFS include charismatic and state trust reptiles such as the Texas indigo snake, Texas horned lizard, Texas tortoise, massasauga, and southern earless lizard. Mammals of note include javelina, bobcat, mountain lion, eastern spotted skunk, hognose skunk, raccoon, Virginia opossum, black-tailed jackrabbit, cottontail rabbit, and American badger. Notable avian species include Rio Grande wild turkey, Harris's hawk, scissor-tailed flycatcher, painted bunting, and eastern meadowlark.

The EFS and South Texas represent essential habitat for hundreds of migratory bird species, especially many grassland birds that are declining in abundance throughout their North American breeding ranges. Much of the EFS provides habitat for significant populations of mourning doves and white-winged doves, which represent valuable resources to hunters and ranch owners and operators as game species. Waterfowl also provide hunting opportunities on some ranches. Other diverse, lesser-known wildlife, including amphibians, fishes, and arthropods are also naturally abundant in the region.

One arthropod that seasonally occurs in the region, the monarch, has been petitioned for listing under the Endangered Species Act. This butterfly species is receiving considerable management attention by conservation organizations, some landowners, and select industry operators. The EFS is along the migration corridor of monarchs, and the insect can be common each autumn, especially in the western part of the EFS. Native milkweeds, particularly zizotes milkweed in the Rio Grande Plains and green antelopehorn milkweed in the eastern portion of the region, are important plants for monarch caterpillars, and are desired as habitat components by many landowners. Native forbs that provide nectar for monarchs are also very important. Fall blooming species such as cowpen daisy, frostweed, Maximilian sunflower, tropical salvia, and various mistflowers are noted nectar sources and are critical to fall monarch migrations.

© Colin Shackelford

Monarchs are common in the Eagle Ford Shale during the species' spring and fall migrations.

© Ty Runge

Cattle ranching is an important agricultural activity and can serve as a wildlife habitat management tool in the Eagle Ford Shale region.

Along with land management for wildlife in the EFS, agriculture plays an extremely important economic role. Ranching to produce beef cattle is a common practice. Many ranches manage rangeland in the EFS with a goal of providing livestock forage for cattle and habitat for white-tailed deer and northern bobwhites simultaneously as a guiding principle. In some cases, exotic grasses are established on rangelands or in monotypic pastures for hay production. Row crop agriculture is also common in the region, with grain sorghum, corn, cotton, potatoes, and peanuts being the most common crops. In the western and central EFS, irrigation infrastructure has been developed, whereas crops elsewhere in the region are mainly grown under dryland production.

WILDLIFE HABITAT CONSIDERATIONS IN EAGLE FORD SHALE DEVELOPMENT

Habitat Loss

Direct loss of native habitat in the EFS is the most notable concern for wildlife. Habitat loss can occur from construction of pad sites, frac ponds, processing facilities, and the addition of all-weather surface roads in former wildlife habitat. Unless restored after use, these areas represent a net loss of available habitat for the majority of wildlife and may negatively impact populations of many species. Furthermore, such areas may represent habitat sinks even when they are occupied or used by wildlife because the animals they support may have poor health, lower survival, or decreased production of young. Additionally, inadequate resources coupled with new threats for survival may result in direct mortality. An example is vehicle-caused mortality along new roads that are frequently used by reptiles and northern bobwhites.

Habitat Fragmentation

Much of the EFS is located in a highly fragmented region of Texas. Even before the discovery of the EFS, much of this region suffered from wildlife habitat fragmentation because of pasture establishment, brush management, and hunting and recreational land management activities. However, in the western and southern portions of the EFS, habitats generally were less fragmented.

Because of EFS activities, the EFS region has experienced increased fragmentation. Core areas, or blocks of contiguous habitat, can be degraded by bisecting developments such as those necessary for pipeline or road construction. Removing connectivity between habitat patches can be especially harmful to ground-dwelling wildlife such as reptiles, and even some bird species such as scaled quail.

As development of the EFS progresses, habitat fragmentation is likely to increase further. Restoration of corridors, or avoidance of disturbance in areas still linking habitat fragments, will be important because they can act to reduce negative impacts to some wildlife. Conservation of natural habitat corridors, such as the extensive network of drainages in the region, is of great importance to minimizing future effects of habitat fragmentation in the EFS.

© Keith Pawelek

Duplicative road and pipeline construction leads to greater amounts of habitat fragmentation.

Habitat Disturbance

Soils and plant communities can be negatively altered by mechanical land disturbance associated with oil and gas, seismic, and pipeline-related activities. Such disturbances can alter the current composition and structure of plant communities and affect future ecological trajectories of natural habitats. In extreme cases, these changes may not be reversible without intervention through restoration. In other cases, disturbance can promote successional changes in natural plant communities that are viewed positively for some wildlife, resulting in greater diversity or compensatory growth in some brush species. Some EFS disturbances, such as mulching lanes in dense brush to provide access for seismic surveys, are not altogether different from common management practices such as roller chopping or aeration of brush. Generally, however, soils in disturbed areas may be more susceptible to invasion by exotic invasive grasses.

Exotic Invasive Grasses

Exotic invasive grasses are of particular concern for wildlife conservation in the EFS region. Researchers have found significant negative effects on the abundance of northern bobwhites and scaled quail, and on the abundance and diversity of native plants and arthropods in areas dominated by exotic invasive grasses such as Lehmann lovegrass, ringed dichanthium, and buffelgrass. Research also indicates that disturbed soils in much of the EFS are more susceptible to exotic invasive grass invasion with effects not apparent in some cases until years after the soil disturbance occurred.

© Forrest Cobb

The prevalence of non-native grasses around well pads is of concern to many landowners trying to maintain native habitat in the Eagle Ford Shale region.

© Forrest Smith

Soil disturbance generally results in increased potential for exotic invasive grasses, such as is shown in this photo with ringed dichanthium growing along the fence line and road.

There are clear correlations between use of native rangeland for oil and gas production pads and the occurrence of certain exotic invasive grasses, especially buffelgrass and Old World bluestems. Studies in regions adjacent to the EFS indicate invasive grass prevalence is typically higher on and adjacent to pipeline easements than in the surrounding landscape. Again, the negative effects do not become evident until years later. Without successful restoration of native plant communities, disturbed soils in most of the EFS are likely to be invaded by exotic invasive grasses, the result of which is degraded habitat for wildlife.

Vegetation Restoration

Restoration of natural habitats impacted by EFS activities is commonly recommended to reduce the negative impacts of oil and gas operations on wildlife. Most efforts center on reestablishing the most important and common native plant species on disturbed sites, particularly former pad locations, pipeline rights-of-way, and along roads. Reseeding desired plant species is the most common method of restoration. Other efforts include transplanting seedlings of desired woody plants and cacti, or planting containerized plants of larger woody species.

Careful handling of the soil is important to preserve native plant seed banks, which in turn facilitate natural restoration of disturbed sites. Often, exotic invasive grasses are used to restore vegetation. Such grasses are commonly sown after disturbance, and they often establish unwanted monocultures. In addition, exotic

© Forrest Smith

Successful restoration seedings using native plants can minimize the effects of pipeline construction on surrounding habitats.

invasive grasses can spread into the surrounding landscape, thereby negatively impacting wildlife habitat on a larger scale.

TYPES OF HABITAT DISTURBANCE IN THE EAGLE FORD SHALE

Drilling, hydraulic fracturing, extraction, and transport of EFS oil and gas resources each entail specific land uses, infrastructure, and facilities. These include drill pad sites and processing facilities, pipeline and flow line rights-of-way, roads, and frac ponds. Specifications of each activity vary by property, operator, and landowner, but a general characterization of each is given below.

Drilling Pads and Processing Facilities

Pad sites host well drilling rigs and are one of the most prevalent disturbances in the EFS, accounting for 15% of landscape disturbance associated with the EFS footprint. Pads for processing facilities, tank batteries, gas compressor stations, and interim gathering and refining facilities are also found throughout the EFS. These areas essentially are large pad sites, some as large as 5 to 20 acres in size.

Many early estimates suggested that over 20,000 wells would be drilled in the EFS over time. As of January 2020, more than 20,000 had been completed, and over 2,500 more were permitted by the Railroad Commission of Texas. Current oil and gas development in the EFS uses directional drilling with lateral well bores. This allows multiple wells to be drilled from the same pad. These pads must be larger to accommodate the movement of drilling rigs and machinery necessary to undertake hydraulic fracturing.

Actual implementation of multiple wells per pad varies in the EFS. Many operators drill initial wells to hold the leases for production. According to data compiled for all hydraulically fractured oil and gas wells in Texas, the average pad development per added well bore is 3.7 acres, significantly greater than that of traditional oil and gas development. At an intensity of development of 20,000 wells, pad site impacts alone on wildlife habitat could easily reach 74,000 acres within the EFS region.

Most pad sites are constructed by mulching or bulldozing the existing vegetation, followed by root plowing, stacking, and burning the woody debris. In some cases, topsoil is then removed and stockpiled for future reclamation of the site. In other instances, the soil is leveled. Afterward, base material (usually caliche or limestone) is trucked to the site and compacted to provide a relatively smooth, all weather surface for vehicles, the drilling rig, and workers.

Most pads and processing facilities are maintained in a bare condition, with vegetation eliminated through herbicide applications. Upon completion of production from the well, infrastructure associated with oil and gas production is removed, the well bore is plugged, the pad base is removed, and the site is considered abandoned. Restoration of vegetation may then begin.

In some cases, the initial pad size is larger than needed for the production phase of the well, and may

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Drilling pads and processing facilities are common sources of habitat disturbance in the Eagle Ford Shale.

© Forrest Smith

Following drilling and completion of wells, many pad sites are reduced in size, presenting opportunities for native plant restoration relatively soon after initial disturbance.

be reduced following hydraulic fracturing. Interim restoration of the reduced area of the pad site is a common practice. Duration of use of the core pad site is often unknown, but many of them will not be abandoned until years later, thereby prolonging implementation of restoration efforts.

The potential future production life of EFS wells has not been determined, but decline rates in production in many portions of the EFS play suggest 20- to 30-year well life, unless some type of secondary recovery or re-stimulation method is used. Also, pads are unlikely to be removed if future additional drilling from the same location is possible. In much of the EFS, most well pads will not be candidates for restoration for decades. However, in many cases, pad site reductions may enable some interim restoration efforts within the first few years after construction.

In addition to habitat loss and fragmentation, a major concern of pads involves changes to hydrology and soil chemistry of the surrounding undisturbed sites. Such changes appear to make the areas around pad sites more prone to brush invasion and dominance by exotic invasive grasses. Some wildlife species (prairie grouse and mule deer) have been found to avoid pad sites in other areas of the United States, though this behavior varies greatly by species. In the EFS, researchers have found scaled quail decreased their use of pad sites and roads associated with development of energy resources, whereas northern bobwhite use was higher near developed sites than the surrounding landscape.

Pipeline and Flowline Rights-of-Way

Pipelines represent the major footprint of EFS oil and gas development and subsequent habitat impact, accounting for 85% of landscape disturbance (study by the University of Texas). Pipelines are used to move oil and gas from well bores to processing facilities and distant markets along the Gulf Coast of Texas and elsewhere. Pipeline development has been intense in the EFS because very little infrastructure existed in the region prior to the play. For example, in 2013 alone, 427 miles of pipeline were laid in the counties where EFS production was occurring. Minimum width of most easements is 50 feet, though larger workspace is often cleared and utilized, and larger rights-of-way with multiple pipelines are common. Smaller rights-of-way

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Native plant restoration of Eagle Ford Shale pipeline easements represents a huge opportunity to improve the availability of native grasslands beneficial to certain species of wildlife.

© Paula Maywald Stumberg

Proper soil handling of pipeline disturbed sites is extremely important for the success of restoration efforts.

called flowlines are also common, often with lines above ground to transport water or petroleum products within the drilling unit.

Construction of pipelines is similar to that of pad site construction. Brush and existing vegetation are removed by bulldozing. Typically, the immediate topsoil profile is bladed and windrowed to the side of the rights-of-way. Pipe trenches are excavated by a trenching machine or backhoe, ideally with soil layers segregated by horizons (commonly called double ditching). If done properly, this helps keep natural soil horizons separated, but if not done or done poorly, "mixed soils" result, which can make restoration difficult.

In some cases, especially in the central and western Rio Grande Plains, subsoils brought to the surface of rights-of-way during trenching can be highly alkaline or saline. This often results in poor reestablishment of previously occurring vegetation. After covering most pipelines in the EFS with soil, reseeding is a standard management practice, though choice of vegetation planted varies greatly, often ranging from exotic grasses to annual cover crops to native plants.

For all practical purposes, most pipelines installed in the EFS are permanent. Once completed, most rights-of-way are maintained in short- to mid-stature herbaceous vegetation by regular mowing and application of herbicides to limit woody vegetation. Long-term research has indicated that pipelines act as a source population for many exotic invasive grasses to invade surrounding native plant communities. Disturbance, soil alternation, vehicle dispersal of seed, use of exotic grasses for reclamation, and management practices such as mowing are hypothesized to play a role in this occurrence. There is at least one positive effect of pipelines. Because of the lack of brush over the buried pipelines, these areas often act as travel corridors for wildlife and are often grazed preferentially by livestock.

Roads

Oil and gas exploration results in extensive road networks being developed. All-weather road construction is common in association with EFS development and can have a significant impact on fragmentation and habitat loss in the region. New caliche roads in the less fragmented portions of the EFS are needed to link drilling and processing locations with existing all weather roads and the public transportation systems. Road construction is similar to pad and pipeline development in that vegetation is cleared and soil is disturbed. Most roads are surfaced with caliche, and are maintained according to the needs of the oil and gas operator and the tenants of the Surface Use Agreement (if one is associated with the oil and gas lease of the property).

Roads can be a source of direct mortality to wildlife and cause habitat fragmentation causing longer-term issues for some animals, particularly for less mobile species such as Texas tortoise, snakes, and small mammals. Additionally, they alter hydrology and can create dust issues that can negatively impact adjacent vegetation. Roads can also be a source of seeds of exotic invasive grasses and other unwanted invasive plants such as Russian thistle and are a major cause of long-term fragmentation because of gaps created in favorable vegetative cover.

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New roads to facilitate access to oil and gas infrastructure are a major source of habitat loss, fragmentation, and invasive species introduction.

Reclamation of low-growing herbaceous vegetation along new roads is often desired to limit water and wind erosion, provide a barrier to exotic invasive grass establishment, and improve the visual aspects associated with roads. Another concern of road construction is alteration of soil properties because of the leaching of limestone road substrates into adjacent soil profiles and altered hydrology, resulting in erosion, ponding, and sedimentation issues. These changes can lead to local and landscape level changes that impact the composition of the vegetation community adjacent to and some distance from the road. Such changes often lead to the invasion of exotic invasive grasses, brush encroachment in grasslands, or compositional differences in plant communities near roads compared to undisturbed landscapes.

Frac Ponds

A common landscape disturbance in the EFS is the construction of temporary water impoundments needed to store large volumes of water for hydraulic fracturing. These facilities are typically several acres in size. The impoundments are made by excavating a large square or rectangular pit, often 20 feet or greater in depth, using the excavated soil to construct a berm around the pit, and then lining the pond with a polyurethane liner. Duration of use of these sites depends on the drilling activity of the immediate area, but most are left in place for several years. Areas disturbed by frac pond construction can be difficult to restore because during the excavation and berm building processes soil layers, including very deep subsoils and topsoils, are mixed.

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Frac ponds are a unique type of Eagle Ford Shale infrastructure that can present considerable challenges in restoring native habitat.

Even when topsoil is removed first and salvaged, concerns over conservation of the natural soil seed bank and organic soil components can be inherent because of the volume of soil impacted and the depth of the storage pile. The results of attempting to restore vegetation to these disturbed areas can be very poor if soil handling is not done appropriately. In addition, because of the steep slopes on the sides of frac pond berms, they can be especially prone to erosion and could negatively impact adjacent watercourses and water quality.

HABITAT RESTORATION CONSIDERATIONS FOR THE EAGLE FORD SHALE

Overview and Key Concepts

Minimizing the size, distribution, and degree of disturbance of any kind to natural habitats should be the first priority to reduce the impact of EFS development on wildlife and their habitats. Even the most successfully restored habitats will never have the ecological value, diversity, or function of non-impacted native habitats. However, the reality of oil and gas exploration is that habitats will be impacted, and when this happens, restoration provides an opportunity to mitigate the negative effects, particularly for the long term. Several key concepts are important to the restoration process and are discussed in detail below.

Siting of Development and Infrastructure

Location is everything when it comes to later restoration success. Disturbances in certain soils, areas with extreme relief or varying topography, or other unique characteristics such as soil salinity, make restoration difficult. Location of development with respect to past disturbances also impacts the immediate, long term, and cumulative effects on wildlife habitat.

A guiding principle in decisions regarding siting of oil and gas infrastructure is that certain soils and topography that will be difficult or impossible to restore must be avoided, and locations for development should be chosen with a goal of minimizing new sources of fragmentation. Siting of EFS development within a ranch is also important to wildlife habitat and overall impact. Whenever possible, avoid duplication of roads or construction of new ones. If practical, align development along existing property boundaries since these areas have generally been previously disturbed by fence construction and boundary roads. In addition, develop-

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Restoration successes, such as this reseeded former pad site in Wilson County, are facilitated by careful site selection based on soils and topography.

ment of core areas within large blocks of native habitat should be discouraged.

Concerns about soils relate to the ability to reestablish desired native vegetation following disturbance, either from the natural seed bank or through seed-based restoration efforts. Extremely saline soils, alkaline soils, or areas with scant topsoil normally supporting sparse native vegetation can be very difficult to restore or will require exceptional rainfall conditions for successful restoration. This is especially true as one moves from east to west across the EFS because of decreasing annual rainfall.

Generally, course textured soils will have larger seed banks and show exceptional resiliency to disturbance. However, the loss of soil structure and organic matter when soils are disturbed can make revegetation difficult. Fine textured soils also have inherent restoration challenges, such as crusting, compaction, and susceptibility to invasion after disturbance by the most problematic exotic invasive grasses to control—Old World bluestems.

Areas with hills, deep drainages, or steep slopes also are difficult to restore to native vegetation. This is usually related to the water holding capacity of these sites. Slopes lose much of incoming rainfall to runoff and drainages may remain too wet for desired vegetation to establish after disturbance. Reseeding operations in both scenarios can be complicated. Frequently, seed can be washed away on slopes, and in areas occasionally or frequently inundated, seed rain via runoff can introduce large amounts of unwanted seeds, often of exotic invasive grasses, resulting in competition with seeded native vegetation.

The likelihood of restoration success should be a key factor considered when choosing sites that will be impacted by Eagle Ford disturbances. In general, look for areas with deep, neutral, medium to fine textured soils having little topography along the ranch boundaries. If sites exist that were farmed, had past mechanical brush work, or were historically planted to exotic grasses, then development there will have less impact than if development occurs in unaltered natural habitat. Selection of these areas also provides the potential to perform restoration that might have already been needed, but not possible prior to development. In almost all cases, advocating for development sites to be located in favorable areas for restoration, instead of more difficult to restore areas, will result in greater success of wildlife habitat restoration. In addition, it will lessen the financial burden of restoration for both the landowner and the operator.

Brush Clearing and Initial Vegetation Management

The method of removing existing vegetation can impact habitat attributes and restoration success. The first step before disturbance is initiated should be inventorying the site to establish baseline plant community characteristics. This will provide a much needed reference for eventual restoration goals.

Because most South Texas woody plants resprout readily from root crowns remaining in the soil, top removal alone generally is ineffective at removing brush from sites that will be developed and used for

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Removal of brush from sites being developed for energy infrastructure should take into account the later implications of brush resprouting from root crowns.

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How the soil is handled can have considerable implications for restoration success and later prevalence of exotic invasive grasses.

long-term energy production or transfer. Top removal, via shredding, mulching, or dozing may be sufficient for some activities where temporary brush removal is all that is desired for access, such as for seismic surveys or temporary water or flow line rights-of-way. However, for longer term removal, brush must be root plowed or grubbed to remove the crown of the woody plants, especially mesquite.

Oftentimes, because of the large amount of debris created by plowing or grubbing, some effort to rake, stack, and remove or burn woody debris is prudent. Mulching dense woody vegetation can result in thick mulch layers that act as a deterrent to later establishment of herbaceous vegetation. However, moderate amounts of mulch can be beneficial for moisture retention, seed establishment, and release of species previously shaded out under dense brush canopy. Knowledge of the brush density, duration of site use, and habitat needs of the property will aid in deciding which method is used to clear brush for energy sites. Such decisions will influence future brush density and composition. In general, manipulated brush stands in South Texas have less species diversity and are often subsequently denser if allowed to mature after disturbance.

Soil Salvage and Handling

Restoration is difficult when topsoil and subsoil are mixed during EFS construction activities. Topsoil is one of the most valuable commodities in restoration. Topsoils are host to much of the biological activity influencing plant community health and vigor. Topsoils are also a significant reservoir of native seeds in the soil seed bank. Efforts to remove, store, and protect these resources generally entail removing the surface soil layers and piling them adjacent to the energy infrastructure such that they will not be impacted by oil and gas production activities or accidents such as spills.

In general, care should be taken in how soils are handled. The act of topsoil removal is a catastrophic physical disturbance that immediately impacts soil microbial communities. Natural depth gradients and spatial patterns in soil microbial communities that characterize undisturbed soil are destroyed. The process of stripping and stacking soil also tends to homogenize soil organic and nutrient contents. The development of soil microbial communities in stockpiled topsoil may be negatively impacted for at least two years post-disturbance and the top four inches of stockpiled topsoils will lack high amounts of the microbial groups that are present in intact soils. Thus, topsoil salvage piles will not maintain biological activity or seed banks for extreme durations.

Our research has shown that small topsoil salvage piles, vegetated with the same species of plants as will ultimately be restored to the site are superior to large, deep, and denuded piles. Efforts to establish desired vegetation on topsoil salvage piles through seeding are recommended as an interim restoration practice. Doing so maintains the desired condition of the stockpiled soil and ensures a viable and functional restoration resource at some point in the future.

If topsoils are appropriately salvaged, handled, and conditioned during storage, then adequate seed banks

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Desirable vegetation should be reseeded on topsoil salvage piles to maintain the biological activity of the soil for later use in restoration projects.

and soil resources can exist for natural revegetation of disturbed sites after reapplication of stored topsoil. A key consideration in this process is management during the topsoil storage period. Our results have shown that if soil from which stockpiles are created contains a viable seed bank of native species without exotic invasive grasses, and if stockpiles are not invaded by exotic grasses during their storage period, then their native seed bank can persist and be viable for several years following initial stockpile construction. However, if stock piles are invaded, then the resulting seed rain can dominate the stockpile seed bank. Similar results have been found in our pipeline restoration work. Thus, in most cases, ideal salvage and storage conditions are difficult to achieve. Reseeding is generally advisable in addition to application of stockpiled soil to be confident that desired revegetation outcomes will be achieved.

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Native plant diversity in the Eagle Ford Shale region can be lost with exotic grasses.

Exotic Invasive Grass Control

Invasion of exotic invasive grasses, such as Old World bluestems, Lehmann lovegrass, guineagrass, and buffelgrass, is an inevitable occurrence on most energy production sites in the EFS. These invasions generally start small with pioneering plants establishing from seed inadvertently brought to the site through vehicular traffic. In other instances, removal of the native plant community provides vacant niches and alters nutrient availability that facilitate establishment and growth of exotic invasive grasses. In either case, rapid intervention to kill these plants to prevent them from producing seed and populating the seed bank is prudent for future restoration. This is also the case for topsoil salvage piles. Exotic invasive grasses should not be allowed to vegetate stored topsoil stockpiles as growth of these plants will condition those soils for later growth of exotic grasses instead of native vegetation.

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Without efforts to control them, exotic invasive grasses such as buffelgrass will dominate many sites used for energy exploration in the Eagle Ford Shale.

For all EFS development in native habitat, monitoring for exotic grass establishment is recommended. Spot-spraying a broad spectrum herbicide such as glyphosate to eliminate these plants is prudent. Efforts must be continually employed for success, and at a minimum should be conducted quarterly. For cleared sites that are not presently being used for oil and gas activities, but have been disturbed, use of annual cover crops is helpful in providing competitive vegetation that will reduce the ability of exotic grasses to establish on the site. For winter, oats or wheat are suitable cover crops. For spring, summer, and autumn, annual grasses such as browntop millet, Texas panicum, or browntop signalgrass are ideal.

The use of seeds from locally-adapted native plants after disturbance to deter the establishment of exotic invasive grasses has merit as a management practice. In studies on former croplands in the Lower Rio Grande Valley, western South Texas, and South Texas Sand Sheet, we found that seeding a diverse mixture of native plants prohibited reinvasion and subsequent dominance by exotic invasive grasses (primarily ringed dichanthium and Bermudagrass) two years post-planting. Although not a panacea for exotic invasive grass control, this restoration strategy has merit for niche-filling and providing competition to exotic grasses. When combined with efforts to reduce seed banks and spot-treatments with herbicides, this strategy

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The use of cover crops planted in tandem with native seed mixes can help reduce the competitive advantage of exotic invasive grasses in the early stages of restoration.

can have considerable merit for providing diverse native vegetation beneficial to wildlife. We also have found that inclusion of warm season cover crops with a native seed mix can reduce future exotic grass biomass without impacting future native grass biomass.

Site Preparation for Restoration

Restoration of native vegetation, either through seeding or applying salvaged topsoils, should only proceed after all energy production or construction activities are completed and infrastructure is removed, unless it is an interim vegetation establishment practice such as along roads or to maintain biological activity in stockpiled topsoils. In many cases, once mechanical operations cease, soil sampling for comparison to adjacent undisturbed sites is recommended. This evaluation will aid in assessing loss of organic matter, depletion of soil nutrients, or issues with salinity, pH, or other chemical characteristics of soils for restoration sites. Care should be taken to evaluate soil compaction, which is common on fine soil textured sites where large machinery or frequent traffic occurred. If soil compaction is a concern, ripping, cover cropping, or efforts to increase soil organic matter may be needed. As a final step in preparing a site for restoration, contouring the area to match the surrounding landscape often is needed, as is disking or cultivation to mechanically create a good seedbed. Broad spectrum herbicide application such as glyphosate can be effective in controlling unwanted vegetation that will compete with seeded native species or the native seeds in the soil seed bank.

If large amounts of exotic invasive grasses or other unwanted plants are present on the restoration site, control efforts should be conducted before attempting to reseed the site or before salvaged topsoil is redistributed at the site. In addition to controlling the existing plants, it is prudent to allow germination to occur to assess the amount of exotic invasive grasses remaining in the seed bank. If seed bank issues are apparent, repeated shallow cultivation after initial deep plowing or repeated glyphosate herbicide applications are recommended to eliminate these plants. At the time native seeds are planted or topsoil is redistributed, the less competition from unwanted plants, the better.

Seeding Considerations

When the goal is to restore native vegetation to a disturbed site, *use of locally-adapted native seed varieties is paramount to success*. Using seed resources originating from the same ecoregion as the planting site or one immediately adjacent to it **is a cardinal rule**. Use of these ecotypic seeds ensures long-term adaptation of the resulting plants to the conditions of the area, and importantly, these plants will function as part of the larger vegetation community of the region. The critical importance of this principle is clearly illustrated in one of our on-going projects studying frac pond restoration. A portion of the surface of a retired frac pond was composed only of the excavated subsoil used to create the berm surrounding the frac pond and another portion of the frac pond was covered with stockpiled topsoil. We seeded a mix of locally-adapted native grasses to both surfaces and found similar native grass plant densities in both surfaces one and two-years post-seeding.

© David Wester

Seeding techniques and the use of locally-adapted native seeds have been extensively tested in the Eagle Ford Shale.

Care should be taken when purchasing native seeds. Native plant seeds should be marketed and purchased based on the Pure Live Seed (PLS) basis. Seeds purchased should be accompanied by a purity analysis that provides information on any weed seed found in the seed lot, and regarding any other crop seed. If weed seeds or other crop seeds are found ask for a list of what these are, and beware that "other crop" contents can include unwanted exotic grasses.

For county level recommendations of seed mixes based on general soil type, an online tool for seed mix recommendations is available on the *Texas Native Seeds* Program website (https://www.ckwri.tamuk.edu/research-programs/texas-native-seeds-program-tns/native-seed-selection-tool). A list of adapted native seed varieties for each ecoregion impacted by EFS development and vendors of those seed sources is also given in Tables 2 and 3. Our research strongly indicates that native plants not on this list are unlikely to perform well for EFS restoration. Many of the recommended seed sources were developed by the *Texas Native Seeds* Program, or its precursor, the *South Texas Natives* Project. Other recommended seed selections were developed by the USDA Natural Resources Conservation Service Plant Materials Program. Most species released by these entities must be sold as Texas Department of Agriculture Certified Native Texas Germplasm, and production is regulated by licensing agreements to ensure seed quality and cleanliness. Seed of the same plant species as those recommended, but sold as Variety Not Stated (VNS) should be avoided, as quality or origin issues are inherent in most seed not identified by the vendor to the variety level.

Native seed mixes for restoration of EFS vegetation should be diverse and should reflect the native plant community composition in the surrounding region. However, diversity should not take priority over use of adapted plant species. Information on seed mix composition can be obtained from resources on plant community makeup of the area, such as the USDA Natural Resources Conservation Service's Ecological Site Descriptions or recommendations made available by the *Texas Native Seeds* Program. However, general guidance may fail to capture unique plant distributions. Pre-disturbance plant community inventories or sampling of native sites that are similar to the restoration site can be useful in deciding which native plant seeds to use in a particular project.

Table 2. Locally-adapted native grass seed varieties recommended for use in Eagle Ford Shale restoration seeding projects by ecoregion and commercial vendor.

Native Seed Variety	Ecoregion[1]	Vendor[2]
Dilley Germplasm slender grama	RGP	B, DK
Atascosa Germplasm Texas grama	RGP, BLP	B, DK
Chaparral Germplasm hairy grama	RGP, POS, BLP	B, DK
South Texas Germplasm sideoats grama	RGP, BLP	DK
Haskell sideoats grama	BLP	B, DK, T
Mariah Germplasm hooded windmillgrass	RGP, POS	B, DK
Welder Germplasm shortspike windmillgrass	RGP, POS, BLP	B, DK, T
Hidalgo Germplasm 4-flower trichloris	RGP, POS, BLP	DK
Kinney Germplasm 2-flower trichloris	RGP	DK
Maverick Germplasm pink pappusgrass	RGP	B, DK
Webb Germplasm whiplash pappusgrass	RGP	DK
La Salle Germplasm Arizona cottontop	RGP, BLP	DK
Oso Germplasm Hall's panicum	RGP, POS, BLP	DK
Starr Germplasm longspike silver bluestem	RGP, POS, BLP	DK
Catarina Blend plains bristlegrass	RGP, POS, BLP	DK
Lavaca Germplasm Canada wildrye	RGP, POS, BLP	B, DK
Falfurrias Germplasm big sacaton	RGP	DK
Ramadero Germplasm spike lovegrass	RGP	DK
Saltalk alkali sacaton	RGP	B, DK, T
Nueces Germplasm sand dropseed	RGP, POS, BLP	DK
Duval Germplasm red lovegrass	RGP, POS, BLP	DK
Menard Germplasm purple threeawn	RGP, POS, BLP	B, DK
Guadalupe Germplasm white tridens	RGP, BLP	B, DK
Carrizo Blend little bluestem	RGP, POS	DK
OK Select Germplasm little bluestem	BLP	B
Wilson Germplasm Indiangrass	RGP, POS, BLP	DK
Lometa Indiangrass	BLP	B, DK, T
Kenedy Germplasm big bluestem	POS	DK
Earl big bluestem	BLP	B, DK, T
Alamo switchgrass	RGP, POS, BLP	B, DK, T
Van Horn green sprangletop	RGP, POS	B, DK, T
San Marcus eastern gamagrass	BLP	T

[1] RGP = Rio Grande Plains; POS = Post Oak Savannah; BLP = Blackland Prairie
[2] B = Bamert Seed Company; DK = Douglass W. King Seed Company; T = Turner Seed Company

The use of high quality, locally-adapted certified native seed is important to the success of restoration efforts.

After seeding, the use of erosion control blankets, mulches, or other moisture retaining substances can positively impact restoration outcomes. We have found greater retention of soil moisture, cooler daytime soil temperatures, and higher seedling density as a result of using erosion control blankets on EFS pipeline rights-of-way being restored.

Seeding Methods

General reseeding methods used in EFS restoration include drilling, broadcasting, and hydroseeding. Our research has indicated that each technique in combination with proper seedbed preparation and the use of adapted native seed varieties can be successful. In most instances, planting native seeds with a no-till seed drill and using multiple seed boxes that can handle the different types of seed will result in the most precise reseeding, as all seeds will be applied at proper planting depth on the target area. Additionally, the distribution and planting rate of seed and species in the mixture will be uniform across the site.

Broadcast seeding is generally more economical and can be just as effective as drill seeding if it is appropriately followed by cultipacking, light dragging, or some similar effort to ensure good seed-to-soil contact and coverage. Hydroseeding along with various mulches can be very effective in combination with adapted native seeds. Use of the technique is limited by cost, which can be extremely high.

Hydroseeding applications are generally only applicable to areas where revegetation is of critical importance such as steep slopes, federally regulated drainages, visual obstruction berms on pipeline rights-of-way, or dams of frac ponds. Hydroseeding to establish vegetation on and prevent erosion of topsoil piles is another common use of this planting technique.

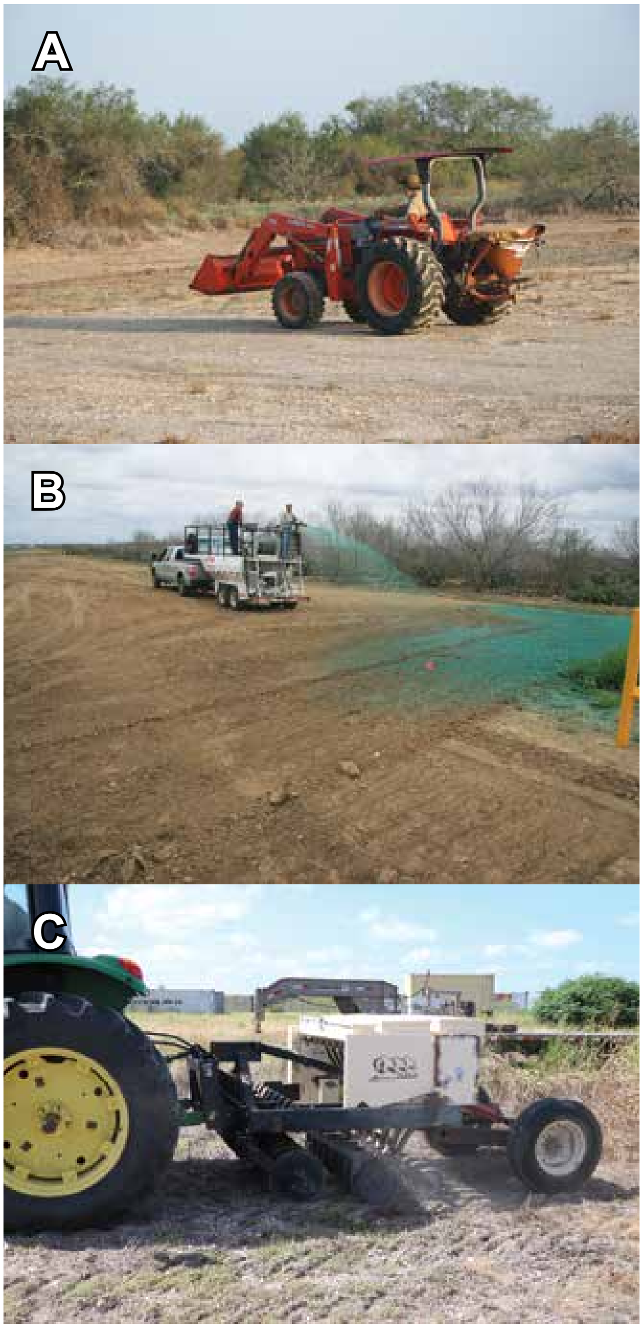
With any method of planting, care should be taken to calibrate the planting equipment to ensure recommended seed application rates are achieved. Planting more seed than recommended generally provides few long-term benefits, whereas planting too little seed can result in poor stands that compete poorly with weeds or exotic grasses. In addition, these poorly planted sites are prone to erosion.

The season in which seeding takes place is an important consideration for successful short-term establishment. In our research, late summer to autumn plantings (August 20–October 31) have superior emergence. This is influenced by September rainfall, shorter days, and cooler temperatures. Late winter to spring seedings (March–May 15) can produce excellent results; however, care should be taken to plant as early as possible in spring (at or just after danger of last frost) to avoid hot weather. If a site is to be reseeded outside of these time frames, use of a cover crop either alone or in combination with the native seed mix planted at the

Table 3. Locally-adapted native forb and legume seed varieties recommended for use in Eagle Ford Shale restoration by ecoregion and commercial vendor.

Native Seed Variety	Ecoregion[1]	Vendor[2]
Venado Germplasm awnless bushsunflower	RGP	DK
Goliad Germplasm orange zexmenia	RGP	DK
Zapata Germplasm Rio Grande clammyweed	RGP	DK
Ballii Germplasm prostrate bundleflower	RGP	DK
Sabine Illinois bundleflower	BLP	B, DK, T
Hondo Germplasm velvet bundleflower	RGP	B, DK
Rio Grande Germplasm prairie acacia	RGP	DK
Plains Germplasm prairie acacia	POS, BLP	B
Cuero Germplasm purple prairie clover	POS, BLP	DK
Aztec Maximilian sunflower	BLP	B, T
Eldorado Engelmann daisy	RGP, POS, BLP	B, T

[1] RGP = Rio Grande Plains; POS = Post Oak Savannah; BLP = Blackland Prairie
[2] B = Bamert Seed Company; DK = Douglass W. King Seed Company; T = Turner Seed Company



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Methods and implements used for reseeding in the Eagle Ford Shale include (A) broadcasting using a broadcast seeder, (B) hydromulching using a hydroseeder, and (C) drilling using a no-till seed drill. Research has been conducted to compare the effectiveness of each seeding method in various restoration applications. Results have indicated that each technique can provide excellent results if site preparation is adequate and the appropriate locally-adapted native plants are seeded. Hydromulching is cost prohibitive for large sites, but can be effective for erodible or steep sites. Broadcast seeding is the cheapest seeding method, but must be followed by additional actions such as packing, rolling, or dragging. Drill seeding is typically the most efficient seeding method in terms of speed of application, but can be difficult to use because of the cost and availability of appropriate drills.

same time is recommended. Oats in winter or browntop millet in summer planted at ¼ their pure stand rates work well over most of the EFS.

Post-restoration Management

The immediate period after planting native seed or distributing salvaged soil seed banks can provide a critical window for management that will influence the success of the restoration effort. Often, after the first rainfall on a newly restored site the remaining exotic grass seed or competitive weeds will immediately germinate. Typically, these plants emerge much faster than planted native seeds; thus, a window for broad-scale intervention using herbicide controls may exist. Care should be taken that none of the native seeds planted have emerged at the time of herbicide application.

After establishment, and indefinitely thereafter, spot treating unwanted exotic invasive grasses or other unwanted plants is the best course of action. Shredding can be considered on sites where a dense or very tall canopy of annual broadleaf weeds is limiting growth of planted seedlings. In other cases, rope-wicks can be used to apply herbicide to faster growing but unwanted species such as Johnsongrass or annual sunflower, both of which are common on EFS restoration sites in the eastern portion of the play.

Greater efforts to manage brush may also be needed on or adjacent to restored EFS sites. Our research has indicated that brush densities tend to be higher on sites that were used for oil and gas production in South Texas. Causative factors likely include altered hydrology, soil disturbance, and use of these sites as loafing areas by cattle resulting in deposition of seeds in manure piles, along with reductions in competitive herbaceous cover.

Livestock grazing should be deferred from the pastures containing restoration sites. If this is not possible, then restoration sites may be protected by temporary fencing until planted vegetation establishes, matures, and produces seed. If restoration sites are relatively small and fencing is impractical, or in the case of pipeline rights-of-way where adequate forage resources exist throughout the pasture, then successful establishment can be accomplished with cattle present. From our research, we have found that while some reductions in establishment of highly palatable native species can be expected, there are benefits from moderately grazing newly restored sites. Often, cattle will focus their grazing on faster growing exotic grasses or palatable weeds such as annual sunflower.

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Restoration of native habitats to benefit wildlife will be of long-term importance to the sustainability of the unique natural resources found in South Texas.

In some respects, rainfall's boom or bust nature over much of the EFS means that when adequate rains for establishment of reseeded native vegetation occur, copious forage throughout the landscape often dilutes the impacts of grazers on small restoration sites. During marginal rainfall periods, livestock impacts on restoration sites in the early stages of establishment will be more troublesome. For establishment of highly palatable native forbs such as awnless bushsunflower and orange zexmenia or legumes such as prairie acacia or bundleflower, fencing to limit white-tailed deer use until plants are well established can be prudent. In cases where energy production sites are high-fenced to limit deer use, it is recommended to leave the fencing in place until after restoration is achieved.

SUMMARY

Restoration in the EFS will impact wildlife and their habitats in a large portion of South Texas for years to come. One of our major program goals at the Caesar Kleberg Wildlife Research Institute is the development of restoration techniques based on sound science and grounded in practical application that will provide landowners and the oil and gas industry with techniques that will be successful in mitigating disturbance impacts of energy exploration on wildlife. Because our research is based on science, the principles and practices that we have developed can be replicated and tried in other oil and gas plays throughout the nation and the world.

We are thankful to the donors, landowners, and industry partners who have enabled us to work on this important issue. South Texas is a special place for wildlife and conservation, and our efforts to bring greater focus on the challenges and opportunities provided by the EFS play will help to ensure that our native landscapes will be rich, diverse, and productive for generations to come.

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Successful restoration of former energy sites in South Texas will ensure the provision of quality habitat for wildlife.

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Impacts of Eagle Ford Shale development are clear on the South Texas landscape.

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