National Quail Symposium Proceedings

Volume 7 Article 55

2012

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IMPACTS OF INVASIVE, EXOTIC GRASSES ON QUAIL OF SOUTHWESTERN RANGELANDS: A DECADE OF PROGRESS?

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ABSTRACT

Exotic grass invasions are a serious concern for State and Federal agencies, non-government organizations, and private landowners engaged in quail conservation and management. Quail biologists recognized the potential negative impacts of exotic grass invasion on North American quail populations 2 decades ago. This issue was addressed in a review paper published in the Proceedings of the 5th National Quail Symposium in 2002. That paper reported the state of our knowledge on impacts of exotic grass invasions on 5 quail species inhabiting southwestern rangelands. Our objective is to update the progress of exotic grass-quail research on southwestern rangelands during the past decade by reviewing studies that provide specific results about the impacts of exotic grass invasions on southwestern quail populations. Results of studies that have quantified the impacts of exotic grass on quail habitat use are summarized and discussed along with studies that describe how exotic grasses impact important components of quail habitat such as diversity and abundance native herbaceous plants and arthropods. Management of exotic grasses is also discussed.

Citation: Kuvlesky Jr., W. P., L. A. Brennan, T. E. Fulbright, F. Hernández, S. J. DeMaso, J. P. Sands, R. M. Perez, and J. B. Hardin. 2012. Impacts of invasive, exotic grasses on quail of southwestern rangelands: a decade of progress? Proceedings of the National Quail Symposium 7:25–33.

Key words: exotic, fire, grass, herbicide, invasion, management, quail, range, southwest

INTRODUCTION

The status of quail populations on rangelands of the southwestern United States continues to be of concern to Federal, State, and private land natural resource managers, upland bird hunters, and bird watchers. Populations of the 6 native quail species in North America have not increased despite recognition that western quail species needed prompt attention from quail biologists during the

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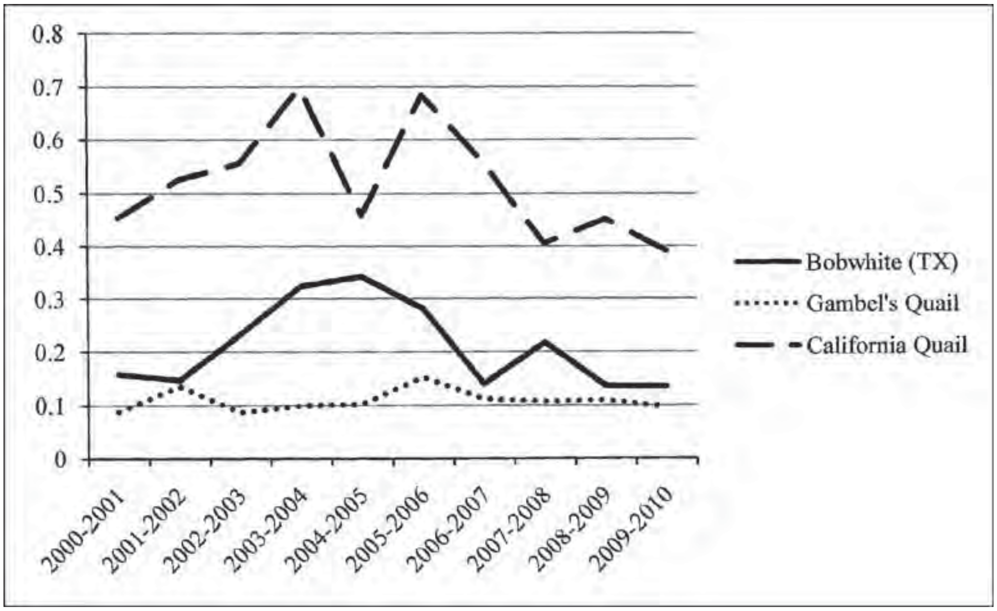

Fig. 1. National Audubon Society Christmas Bird Count population trends in number of birds per hour for northern bobwhites from Texas, and Gambel's and California quail from the United States between 2000 and 2010.

Quail III (Robel 1993) and Quail V (Brennan 2002) symposia. The National Audubon Society's Christmas Bird Count (CBC) data from 2000 to 2010 (National Audubon Society 2010) indicate Gambel's (*Callipepla gambellii*), scaled (*C. squamata*), and Montezuma (*Cytronyx montezumae*) quail populations remained stable over the past decade (Figs. 1, 2). Montezuma quail numbers remain extremely low and Gambel's and scaled quail populations have trended downward over the past 3 years (2007–2010). The status of northern bobwhites (*Colinus virginianus*) (data restricted to Texas), mountain quail (*Oreortyx pictus*), and California quail (*C. californica*) are even more worrisome because CBC data indicate that populations continued to decline over the past decade.

There are myriad reasons for declines of native quail species in the southwestern U.S; however, habitat loss continues to be one of the primary concerns among quail biologists (Brennan 2002, Zornes 2009). Factors commonly observed that involve loss of quail habitat that are immediate and noticeable include urban and suburban development, livestock overuse of rangelands, and an increase in modern farming activities. The invasion of southwestern quail habitats by exotic plant species represents a more subtle and less immediate form of habitat loss that has been occurring for decades. This was

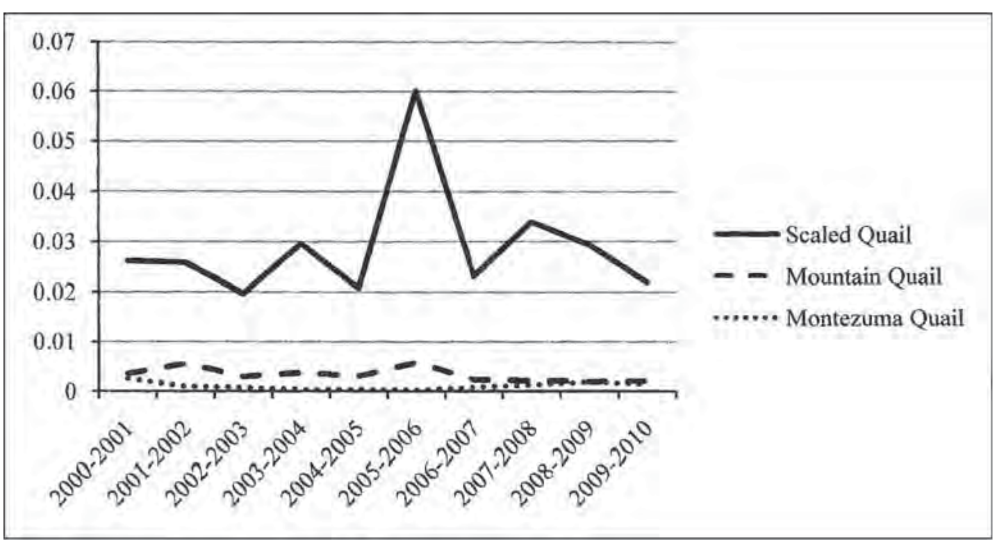

Fig. 2. National Audubon Society Christmas Bird Count population trends in number of birds per hour for scaled, mountain, and Montezuma quail from the United States between 2000 and 2010.

first detailed as a threat to quail populations by Engel-Wilson and Kuvlesky (2002) and Kuvlesky et al (2002). The potentially negative consequences that exotic grasses have on Gambel's, scaled, and Montezuma quail, and northern and masked bobwhites (*C. v. ridgwayi*) were reviewed by Kuvlesky et al. (2002) who noted the need for research on the quail/invasive exotic grass issue was desperately needed to better manage the potential threat to quail populations.

Our objective is to review research addressing the invasive exotic grass-quail issue that has been accomplished during the decade since Quail V. Most of the research that has been accomplished during the past 10 years has been on northern bobwhites, and that section is limited to bobwhites. We believe understanding how invasive exotic plants impact quail is important and this paper provides updated reviews of (1): how exotic grass invasions impact rangeland vegetation communities used by quail; (2): how exotic grass invasions impact arthropod communities, which are important quail food; (3) how exotic grass communities impact quail and (4): potential strategies to manage invasive exotic grasses to benefit rangeland quail populations.

EFFECTS OF INVASIVE PLANTS ON NATIVE RANGELAND COMMUNITIES

Invasive exotic plants are an unfortunate reality in the United States. Most introductions were made with the intention of improving food and fiber production or to improve aesthetics (ornamental plants). Most of the estimated 5,000 species of exotic plants that have become established in native ecosystems have significantly altered these ecosystems by displacing native plant species (Pimental et al. 2005). Displacement of native plant species by introduced plants often has a cascading negative impact on the invertebrate and vertebrate organisms that also co-inhabit the invaded ecosystems. Many exotic grasses from southern Africa, Mediterranean regions, and Eurasia were first introduced to the overgrazed rangelands of the southwest U.S. to stabilize soil surfaces and provide forage for cattle with the hope these introductions would improve the economics of livestock production. Certain introduced grasses have economically benefited livestock producers in specific locations, such as buffelgrass (*Pennisetum ciliare*) in southern Texas. Others have become costly weeds that are difficult for livestock producers to control (e.g., invasion of Old World bluestems in coastal bermudagrass [*Cynodon dactylon*] pastures).

The impact of these exotic grasses on ecosystem processes and dynamics at the time of introduction was not part of the discussion. For example, Pimental et al. (2005) estimated the cost associated with exotic plant invasions (e.g., loss of livestock forage, costs of herbicides) on pastures in the United States is 6 billion dollars; they also indicated that numerous threatened and endangered species that occur on pasturelands are at risk due to competition from invading exotic plants.

The impacts of exotic plant invasions continue to be a major concern for natural resource managers. This is because exotic plant invasion on millions of hectares of southwestern rangelands continues unabated today and may be getting worse. Gori and Enquist (2003), for example, estimated non-native grasslands comprise 22.6% of current U.S. grasslands in southeastern Arizona alone: Boer lovegrass (*Eragrostis chloromelas*) and Lehmann lovegrass (*E. lehmanniana*) are common and/or are the dominant grass species on > 556,560 ha. Additionally, cheatgrass (*Bromus tectorum*) has invaded 5 million ha in Utah and Idaho since it was introduced to North America, and has diminished the flora and fauna of the ecological communities it has invaded (Pimental et al. 2005).

Ingress of exotic plants into native plant communities is a continuing process, resulting in dominance of increasingly large tracts of land by more exotic plants. Bowers et al. (2006) examined trends of abundance of exotic plants on a Sonoran Desert site and found that between 1982 and 2005 the number of exotic species increased from 34 in 1982 to 44 in 2005. The percentage of casual, naturalized, and invasive categories of exotic plant species increased by 44, 40, and 15%, respectively. These findings led the authors to conclude the longer a species persists, the more likely it is to overcome barriers to naturalization and invasion; ultimately the proportion of exotic plant species on their Sonoran Desert study area will continue to increase over time. Unfortunately, little has been accomplished since 2002 to reduce exotic grass invasions and the detrimental impacts invasive exotic grasses have on native plant communities. These intentional and unintentional introductions of exotic grasses to southwestern rangelands continue to damage native plant communities.

Buffelgrass

Buffelgrass is one of the most damaging of exotic grasses to southwestern native plant communities. Buffelgrass is a native of South Africa that was introduced to Texas in the early part of the 20th century in an effort to improve forage production for cattle on native rangelands. It had become naturalized by the end of the 1950s over most of South Texas (Hanselka 1988). It has adapted so well to the rangelands of Texas that over 20 years ago Hanselka (1988) described buffelgrass as 'South Texas Wonder Grass.' It was the most important grass in South Texas from a cattleman's perspective because it was an adaptable and drought tolerant plant, and increased livestock carrying capacity almost threefold (Hanselka 1985). However, buffelgrass can pose significant problems for native plant communities once it is established and becomes the dominant plant species. For example, Flanders et al. (2006) found that native forb and grass diversity, and abundance in South Texas was significantly lower on sites dominated by buffelgrass, along with Lehmann lovegrass, than on sites dominated by native plants. Sands et al. (2009) studied the impacts of buffelgrass invasions on native herbaceous plant communities in the western Rio Grande Plains of Texas for 2 years and found that in plots with > 25% buffelgrass the native forb canopy was reduced by > 70%, native forb species richness was reduced by > 60%, and forb stem density was reduced by > 70% compared to plots with < 5% buffelgrass. Olsson et al. (2011) reported that portions of the Sonoran Desert invaded by buffelgrass were characterized by lower native perennial plant cover and species richness, and that cover and richness declined as time increased post-invasion indicating an ongoing transformation from a rich perennial shrub community to exotic plant community was occurring. Rogstad et al. (2009) indicated the biological diversity of the Sonoran Desert was threatened, in part, by the invasion of exotic grasses and indicated buffelgrass is particularly harmful because it readily suppresses annual and perennial plants, and forms dense stands in a desert that initially supported low densities of perennial grasses. Buffelgrass is a tenacious invader and supremely well adapted to rangelands from coastal southern Texas to the Sonoran Desert in southern California; it represents a significant threat to the biodiversity of millions of hectares of the southwestern U.S.

Additional Exotic Grasses

Invasions by other exotic grass species also negatively impact native vegetation communities. For example, Rogstad et al. (2009) indicated that red brome (*Bromus madritensis*) invasion posed a significant threat to the biodiversity of the Sonoran Desert because it gradually excluded native annual and perennial plants. Gabbard and Fowler (2007) examined the ecological amplitude of King Ranch bluestem (*Bothriochloa ischaemum*) on the Edwards Plateau of Texas and found this African exotic grass displayed little habitat preference because it was found in virtually every habitat type sampled. Moreover, in the plots where King Ranch bluestem was dominant, native plant species richness and diversity were lower than in plots with no King Ranch bluestem. Similarly, in another study conducted on the blackland prairies of central Texas, Wilsey et al. (2009) reported that herbaceous plant species diversity in exotic plant communities that included King Ranch bluestem and Johnsongrass (*Sorghum halepense*), decreased linearly with an increase in biomass produced by the exotic vegetation communities. Sands et al. (2009) found that Lehmann lovegrass contributed to the negative relationship between exotic grass cover, and total grass cover and the richness, coverage, and density of forbs on their South Texas study area. Thus, while buffelgrass is major exotic invader on rangelands throughout the southwestern U.S., numerous additional exotic grasses, including red brome, King Ranch bluestem, Johnsongrass, and Lehmann lovegrass pose additional threats to rangeland biodiversity over extensive areas.

Kuvlesky et al. (2002) suggested invasive exotic grasses negatively impact the rangeland communities they invade because they eventually become the dominant herbaceous species by replacing native plant species. Research conducted since 2002 confirms Kuvlesky et al. (2002) who suggested exotic grass invasions of rangeland quail habitat simplify native plant communities and reduce their value for quail. A reduction in important food plants via a decrease in forb species diversity reduces the value of any habitat for quail.

EFFECTS OF INVASIVE PLANTS ON ARTHROPOD COMMUNITIES

The impact of exotic grass invasions on arthropod communities vary. Rangelands in southeastern Arizona invaded by Lehmann lovegrass had an abundance of arthropods including Hymenoptera (ants, bees, wasps) and Hemiptera (true bugs) indicating these arthropods may not have been negatively impacted by exotic grass invasion (Litt and Steidl 2010). McIntyre and Thompson (2003) noted that in the southern High Plains of Texas, arthropod richness and abundance did not differ between Conservation Reserve Program (CRP) fields planted to weeping lovegrass (*E. curvula*) and Old World Bluestem (OWB) (*Bothriochloa ischaemum*) versus fields planted to a mix of native grass species.

Recent arthropod-exotic grass research indicates exotic grass invasions are detrimental to rangeland arthropod communities. Tallamy (2004) suspected that exotic plants negatively affect native phytophagous arthropods because native arthropods share no evolutionary history with exotic plants and, consequently, are unable to use exotic plants as a source of food. Most of the work published recently seems to support what Tallamy suspected. For instance, McIntyre and Thompson (2003) compared the abundance and diversity of arthropods between fields of weeping lovegrass, OWB, mixed native grasses with buffalograss (*Buchloe dactyloides*), mixed native grass without buffalograss, and native shortgrass prairie in the Texas Panhandle. Native prairie supported higher arthropod diversity and abundance than CRP fields, which was a reflection of differences in the structure and diversity of the vegetation between native prairie and CRP fields. Hickman et al. (2006) reported significantly less arthropod biomass in OWB fields compared to pastures with native herbaceous vegetation and attributed this to the general absence of forbs in OWB fields. Flanders et al. (2006) reported arthropod abundance on their South Texas study area was 60% greater on native grass sites than on sites dominated by buffelgrass and Lehmann lovegrass. Spiders, beetles, and ants were 42–83% more abundant on native grass sites and this was attributed to the greater niche diversity and abundance the native herbaceous vegetation provided arthropods.

Simao et al. (2009) also reported reductions in plant species richness on plots planted with Japanese stiltgrass (*Microstegium vimineum*) as well as a 39% reduction in arthropod abundance and 19% reduction in species richness compared to control plots. Litt and Steidl (2010) quantified the effects of invasion of rangelands in southeastern Arizona by Lehmann lovegrass on arthropod assemblages and reported that richness of arthropod families, richness of morphospecies, and overall abundance of arthropods decreased as Lehmann lovegrass dominance of rangelands increased. Some arthropod families responded favorably to Lehmann lovegrass invasions, but most families responded negatively. This was attributed to a variety of factors that potentially made exotic grass-dominated areas inhospitable to arthropods including a reduction in vegetation patchiness and structural heterogeneity, altered microclimates, and reduced palatability of Lehmann lovegrass. Cord (2011) found areas dominated by native grasses on her South Texas study area had 32–55% more arthropods per sampling plot than areas dominated by the invasive grasses Kleberg bluestem (*Dicanthium annulatum*), which is an exotic plant, and tanglehead (*Heteropogon contortus*), which is a native plant with invasive characteristics. Cord (2011) also reported differences in specific arthropod Orders because native grass-dominated areas supported significantly more plant-feeding arthropods, spiders (Araneae), grasshoppers/crickets, and beetles than areas dominated by invasive grasses. She attributed the greater abundance of arthropods in native grasses to better arthropod habitat conditions because native grass communities had greater forb cover and higher plant species diversity than exotic-grass dominated areas.

Thus, some arthropod Orders do not appear to be impacted by exotic grass invasions of rangelands, but the simplification of the vegetation community via reduction in native forb and grass diversity clearly seems to reduce the number of habitat niches required by a variety of arthropods. This results in a simplified arthropod community inhabiting rangelands dominated by invasive exotic grasses. Arthropods are important part of quail diets and a reduction in arthropod diversity and abundance would likely be detrimental to quail populations inhabiting rangelands where exotic grass invasions have negatively impacted arthropod communities.

INVASIVE GRASSES AND QUAIL

Quail populations require food, cover, and useable space in sufficient quantities throughout the year to be self-sustaining. Kuvlesky et al. (2002) suggested exotic grass invasions of quail habitat should be a major conservation concern because these invasions have the potential to severely limit the essential food and cover resources quail require to survive. They also indicated that, in the absence of extensive exotic grass-quail research, they could not discount the possibility that exotic invasive grasses may benefit quail populations under certain conditions. The authors (2002) provided nothing more than educated guesses and speculation, which prompted them to challenge quail biologists to conduct research designed to specifically focus on the impacts of exotic grass invasions on quail populations, particularly on rangelands

The responses of quail to exotic grass invasions are not necessarily negative. Some recent quail-exotic grass studies have revealed that, depending on conditions, quail response to exotic grass invasions can be positive or neutral. For example, a case study on masked bobwhite recovery in southern Arizona and northern Sonora, Mexico concluded the presence of low to moderate infestations of buffelgrass and Lehmann lovegrass on rangelands occupied by masked bobwhites provided suitable habitat (Hernandez et al. 2006). Buffelgrass, under drought conditions, can be almost the only herbaceous cover available to masked bobwhites in Sonora (Kuvlesky et al. 2002). Sands (2007) reported that bobwhites on his western Rio Grande Plains study area in South Texas used buffelgrass as a nesting substrate, and Tjemeland (2007) also reported that bobwhites on his South Texas study area readily used buffelgrass-dominated fields for nesting and roosting. Doxon and Carroll (2007) examined arthropod and vegetation characteristics of several CRP fields in western Kansas relative to gamebird habitat suitability and found most fields, including those with an alfalfa component, and non-herbicide treated wheat fields had adequate arthropod-prey availability. These fields were deemed suitable habitat for ring-necked pheasant (*Phasianus colchicus*) and bobwhite chicks. Buelow (2009) evaluated the impacts of tanglehead on bobwhite habitat use in South Texas and reported bobwhites exhibited a neutral response to this native invasive plant as they nested in tanglehead stands, but did not select or avoid them. Moore (2010) found that guineagrass (*Urochloa maxima*) invasion did not reduce usable space for bobwhites on her South Texas study area. Bobwhites, at the macrohabitat scale, seemed to prefer guineagrass for loafing cover.

Recent research has documented positive responses of bobwhites to exotic grass invasions, but bobwhites may also respond negatively to exotic grass invasions depending on the circumstances. For example, Flanders et al. (2006) reported bobwhite abundance on native grass-dominated sites of their South Texas study area was twice as high compared to buffelgrass and/or Lehmann lovegrass-dominated sites. They attributed the greater abundance of bobwhites to the higher diversity and abundance of native herbaceous food-bearing species, and the more abundant and diverse arthropod prey present on the native-dominated sites. Sands (2007) found that bobwhites use stands of buffelgrass for nesting cover, but avoided buffelgrass after nesting. Avoidance of buffelgrass after nesting probably resulted because of the lower abundance of arthropods that occur in buffelgrass stands and because it impedes chick mobility making it poor brooding habitat. Sands (2007) added that he believed areas with extensive exotic grass cover reduced foraging habitat space for bobwhites. Buelow (2009) documented that bobwhites nested in tanglehead stands on his South Texas study area, but believed the invasions of this native grass ultimately provided poor brooding and foraging cover due to lack of food-producing forbs, increased litter depths, and lower amounts of bare ground.

MANAGEMENT OF EXOTIC GRASSES FOR QUAIL: IS IT POSSIBLE?

Ten years ago, scientists assumed exotic grass invasions of western rangelands posed a significant threat to quail populations (Kuvlesky et al. 2002). Subsequently, research has indicated that exotic grass invasions can represent a loss of quail habitat in the southwestern U.S. An important question is: can these invaded landscapes be managed to improve quail habitat; or can the rate of exotic grass invasion be sufficiently slowed to maintain existing quail habitat? The answer is probably yes. However, it is important to realize that complete eradication of invasive grasses is not possible for most exotic species of grass that are invading rangelands in the southwestern U.S. Either we do not know how to effectively manage invasions or we are in the early stages of research that is revealing how specific species might be managed. Success can probably be achieved in certain situations and for specific quail species. This will likely vary depending on the species of exotic grass targeted for management, the ecosystem being invaded, the extent of invasion, and past and current land management histories. We discuss several promising management techniques that have been developed to manage exotic grass invasions and strategies that will likely improve management of exotic grass invasions.

Management of Exotic Grasses

Managing exotic grass invasions in an effort to restore quail habitat on southwestern rangelands is possible but depends on the extent to which an ecosystem has been invaded, the extent of invasion on the area targeted for management and, most importantly, the exotic grass species targeted for management. Ecosystems in the early stages of invasion are generally easier to manage because exotic grasses can be removed when they first begin colonizing a site, allowing more options and techniques to be used. However, land managers must exercise continued vigilance to remove exotic grasses in the early stages of invasion. Invasive plants that have already become established in concert with native herbaceous species cannot realistically be managed by targeting individual plants. They must be managed by reducing exotic grass populations. Planning horizons must be implemented that schedule treatments over successive years to continuously combat recurring invasions. Managing exotic grass invasions where an exotic grass is the dominant species on a landscape scale that covers millions of hectares is often impractical and unrealistic because of the complex logistics and expense that would be required to achieve uncertain success. Application of specific herbicides and prescribed fire, along with manipulating soil chemistry and establishing potential competitors, have been demonstrated to effectively manage exotic grass invasions at least over the short term.

Herbicides.—Several studies have recently indicated herbicides can be used to reduce populations of specific exotic grass species if applied at appropriate rates and appropriate time of year when exotic plants are vulnerable. For example, Simmons et al. (2007) reported they reduced King Ranch bluestem abundance in the Texas Hill Country using glyphosate applied at 0.89 kg/ha during June and September. Tjemeland et al. (2008) found that tebuthiuron applied at 2.24 kg/ha during early fall after successive rainfall events induced new vegetative growth on their South Texas study area significantly reduced buffelgrass canopy cover, and increased native grass cover 2 years post-treatment. Steers and Allen (2010) applied the post-emergent, grass-specific herbicide Fusilade II at a rate of 15 ml/64 m^2 during 2 successive January treatments to desert shrubland in California following a fire and almost eliminated invasive grasses (*Bromus* spp. and *Schismus* spp.) while achieving native annual plant dominance and increased density of native perennial plants. Elseroad and Rudd (2011) reported aerially applying imazapic at a rate of 70 g ai/ha in October on northcentral Oregon grasslands significantly reduced cheatgrass frequencies for 3–4 years post-treatment, although they had limited success increasing native perennial species on treated areas.

The use of herbicides to manage other exotic grass species is often unsuccessful despite these reports of success because herbicides can have a negative impact on members of the native plant community. Rinella et al. (2009) reported aerial application of picloram at a rate of 1.1 kg/ha to a grassland in Montana resulted in increased abundance of targeted exotic herbaceous species because of the decrease in native herbaceous plant abundance that occurred. Mittelhauser et al. (2011) pretreated a blackland prairie site in Texas with glyphosate at a rate of 1.84 kg/ha and then aerially applied imazapic at 3 different rates (0.07, 0.092, 0.138 kg/ha) to reduce abundance of exotic bluestems and failed to have any significant impact on these invasive plants. Overall, it appears certain exotic grass species can be managed with particular herbicides under certain situations, particularly when their phenological status makes them vulnerable. However, it is also evident this will not work for all exotic grass species and or with other herbicides. Reducing the abundance of an exotic grass species should be the primary goal, but herbicides should not be used if they threaten the native plant community. Selectively reducing exotic grasses is desirable, but the issue is complicated as invading plants may share physiological and phenological characteristics with native species occupying the native ecosystem being invaded. Treatments may often pose a threat to the native plants that are targets of restoration (Simmons et al. 2007).

Prescribed Fire.—Fire, although it generally facilitates invasion, may be used to manage exotic grass invasions under certain conditions. Vermeire and Rinella (2009) discussed the use of fire to kill the seeds of Japanese brome (*Bromus japonicus*) and its potential for managing invasions of annual invasive grasses. Abella et al. (2009) reported that red brome live and dead cover averaged 9 to 10 times lower on burned areas than unburned areas 2 years following an intense wildfire in a desert shrubland on the outskirts of Las Vegas, Nevada. Red brome seed densities on the soil surface were 4 times lower on burned areas compared to unburned areas. Brooks (2002) reported that increased fire temperatures recorded under creosote (*Larrea tridentata*) plants in the Mojave Desert resulted in 4 years of reduced annual plant biomass and species diversity.

Perennial exotic grasses may also be vulnerable to fire under certain conditions. For example, Daehler and Goergen (2005) were able to restore a native Hawaiian grass to plots formerly occupied by buffelgrass by subjecting the plots to prescribed fire and low water supplementation for 4 years, suggesting buffelgrass plants can be suppressed via seed mortality as a result of burning under dry conditions. Ramierz-Yanez (2005) found that guineagrass populations were reduced when plants were subjected to intense prescribed fire followed by intensive cattle grazing. Native herbaceous species richness increased on burned areas 1 year post-fire. It appears there are opportunities to use prescribed fire to manage certain species of exotics if burning disrupts life cycles or otherwise occurs when species are vulnerable to fire. However, Brooks and Chambers (2011) indicated effective management of native perennial shrublands requires an understanding of their ecological resistance to invasion from exotic grass species and their resilience to fire. Further research to gain a thorough understanding of the ecological interaction among specific exotic grass species, fire, and native plant communities is needed.

Native Seeding.—Managing exotic grasses in a manner that effectively reduces their populations is the first objective of restoring a native plant community. What should be done when dispersing exotic seeds threaten managed areas or when an exotic grass has thoroughly dominated an area for so long that native plants have long been suppressed? Salo (2004) suggested opportunities for red brome management exist immediately following drought because red brome does not establish a seed bank; thus, persistence in the Sonoran and Mojave deserts depends on uniform seed germination during cool moist winters. Populations are decimated when drought occurs, due to a lack of seed production. Native herbaceous plants use these winter drought opportunities to re-establish during subsequent wet periods in spring and summer on areas formerly dominated by red brome (Salo 2004). These established natives provide competitors that compete with red brome seedlings that later attempt to colonize these areas. Corbin and D'Antonio (2004) conducted an experiment on the coastal prairie of California providing evidence that established native perennials limit exotic annual grass invasions by limiting the availability of space and light.

Seeding native herbaceous plant species after winter drought may help suppress future red brome invasion in invaded areas and other areas invaded by exotic grasses where native seed banks are depleted. McLaughlin and Bowers (2007) studied the effects of exotic grasses on soil seed banks on a grassland study site of southeastern Arizona following a wildfire. They found the soil seed bank on their burned plots contained only exotic grass seed, prompting them to conclude that even when exotic grass management is successful, restoration of native grassland will require reseeding of native herbaceous plants. Abella et al. (2007) were able to restore native herbaceous vegetation on a burned site by carefully selecting a native seed mixture from plants that had a history of being productive on their Sonoran Desert study site. Similarly, Mittelhauser et al. (2011) improved densities of 4 warm season native grass species they established via post-treatment herbicide seeding on blackland prairie invaded by exotic bluestem.

Policy.—Effective management of exotic grass invasions can probably be accomplished most effectively by initiating a policy whereby experts from multiple disciplines relevant to invasive plants science and management have an opportunity to collaborate in an effort to develop coordinated management strategies. Rogstad et al. (2009) recommended the formation of an interagency invasive species team that would provide leadership including coordinating information, identify and pursue funding opportunities, developing treatment options, and rehabilitation prior to, during, and after fires.

MANAGEMENT IMPLICATIONS

A few research projects focused on the exotic grass-quail issue have been completed on Texas rangelands since Quail V. This research has revealed that invading exotic grasses, such as buffelgrass and Lehman lovegrass, probably negatively impact quail populations because bobwhite abundance is lower on areas dominated by exotic grasses compared to areas dominated by native grasses and forbs. However, in situations where an important habitat component is limited, some exotic grasses can supplement the limiting component making habitat conditions suitable for bobwhites. Overall, the reduction in native plant and arthropod species diversity and abundance that generally follows exotic grass invasions reduces habitat quality for not only bobwhites but other quail species that inhabit southwestern rangelands.

Recent research has revealed that certain exotic grasses can be managed with specific herbicides, prescribed fire, and using native plant seedings to serve as competitors. Thus, it may be possible to restore quail habitat on southwestern rangelands by exploiting the vulnerabilities of exotic grass species. However, exotic grass management requires repeated treatments for an extended period. Thus, an organized and comprehensive plan that establishes clear objectives and prioritizes management actions should be developed prior to implementing active management.

Concerns about the role exotic grass invasions are having on western quail species are legitimate because exotic grass invasions likely contribute to one of the primary reasons quail populations have been declining, i.e., habitat loss. Results of the research that has been accomplished since Quail V clearly indicate that exotic grass invasions of South Texas rangelands are impacting bobwhite populations and their habitat but these impacts are not always negative. Scaled, Gambel's, Montezuma, California, and mountain quail may be responding to exotic grass invasions of their habitats in a similar manner, but this remains speculation until research focusing on each of these western quail species is completed.

ACKNOWLEDGMENTS

We thank M. E. Tewes and D. G. Hewitt and 2 anonymous reviewers for providing helpful comments and constructive criticism during the review process. We are also grateful to C. E. Braun for his efforts to improve this manuscript. We also thank the Caesar Kleberg Foundation for Wildlife Ecology for supporting this effort. This is publication number 13-106 of the Caesar Kleberg Wildlife Research Institute.

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