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ADAPTIVE MANAGEMENT AND QUAIL CONSERVATION ON RANGELANDS IN THE AMERICAN WEST

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ABSTRACT

Adaptive management has been and is being practiced with the goal of sustaining populations of wild quails on large areas of rangelands in the American West. Because the current land use practices throughout most of the eastern two-thirds of the United States largely do not promote early-successional vegetation communities, rangelands contain the largest remaining blocks of contiguous (unfragmented) habitat for the northern bobwhite (*Colinus virginianus*) and the other 5 species of quails found in the western states. Many wildlife professionals on both private and public rangelands are practicing a diverse array of quail habitat and population management actions that could be considered a form of adaptive management—an iterative process used to make decisions in the context of uncertainty. Though this "learning by doing" approach is not always formally labeled adaptive management, these wildlife professionals intuitively recognize the value of the process in sustaining populations of wild quails. We support our assertions about adaptive management with 4 case study examples of adaptive management projects that promote quail conservation—including quail hunting—on both private and public rangelands in the American West. By discussing these scenarios within an adaptive management framework, we hope to highlight current and future opportunities for adaptive management in quail conservation on rangelands and to discuss where adaptive management may be improved or no longer be appropriate.

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Adaptive management is a structured, iterative process used to make decisions about how to manage renewable natural resources in the context of uncertainty (Walters and Holling 1990). Though commonly thought of as trial and error, adaptive management is a definitive and structured process that assesses specific resource problems, identifies and carefully implements management options, collects data to evaluate outcomes, and adjusts management based on what was learned before repeating the process (Figure 1). When followed, the process of adaptive management can halt an endless cycle of trial and error, increasing knowledge and leading to more effective management. This common-sense approach of "learning by doing" is popular in natural resource management, though learning varies with the rigor of the approach (Figure 1) and is not appropriate for every resource problem (Figure 2).

Rangelands are areas where the native vegetation is predominantly grasses and grass-like plants and forbs (broad-leaved annual and perennial plants that have fleshy stems and produce seeds, many of which are eaten by quail). In many cases rangelands also contain extensive areas of shrubs or dispersed trees (Pellant et al. 2020). Not only are the greatest opportunities for quail conservation in America on rangelands, the most widespread opportunities for hunting wild quails today are on rangelands (Brennan and Hernández, in press). These quail hunting opportunities are predominantly on privately

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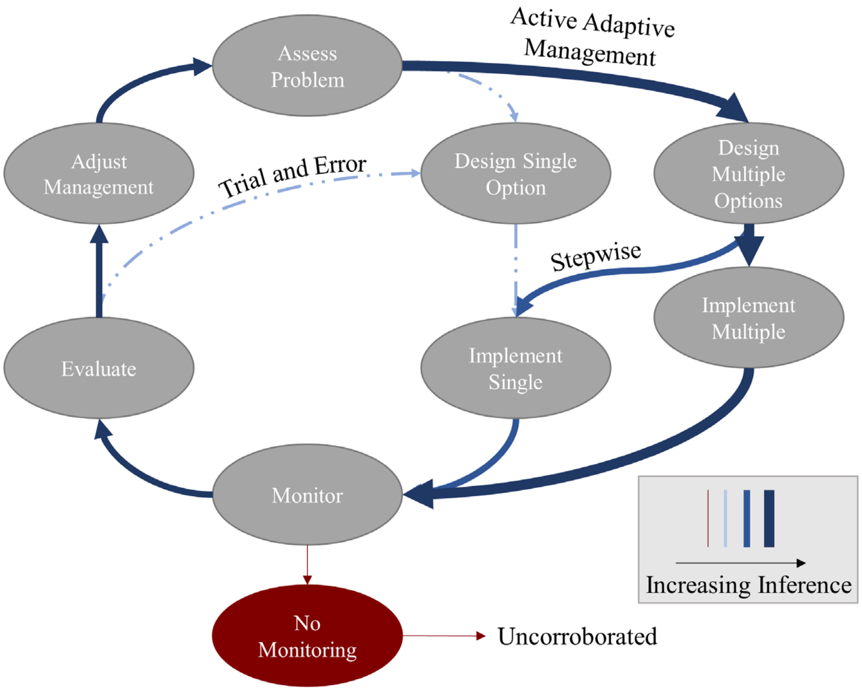

Fig. 1. Adaptive management is a structured, iterative process used to make decisions about how to manage natural resources when there is uncertainty. The potential for learning and inference improves as the approach becomes more robust, from little or none in uncorroborated learning to more through trial and error, even more in a stepwise approach, and finally maximizing learning and inference through active adaptive management (adapted from Allen et al. 2011).

owned rangelands, such as in Texas, USA and Oklahoma, USA, as well as on publicly owned rangelands managed by resource agencies across many states in the American West (defined here as the area of the conterminous United States west of the eastern borders of North Dakota, South Dakota, Nebraska, Kansas, Oklahoma, and Texas) and on some state agency wildlife management areas. Approximately two-thirds of rangelands in the contiguous 48 states are privately owned, with the remaining third in the public trust (USDA NRCS 2020). Rangelands make up about 30 percent of the land area, or roughly 312 million hectares, in the 48 states (Reeves and Mitchell 2011).

In temperate North America, rangelands support all 6 species of native quails with the American West serving as a stronghold for most quail populations (Sauer et al. 2013). In general, rangeland management typically involves ecological methods such as replacing large-scale disturbances through grazing or fires (i.e., pyric herbivory [Fuhlendorf et al. 2009]) or a combination thereof rather than agronomic methods such as cropping and silviculture. The disturbance elements of general livestock-based rangeland management are used—with certain modifications—for quail management. For example, modulating grazing pressure to maintain residual grass cover for nesting quail, and forbs that produce arthropod and seed foods, is an essential component of quail management for all species of quails on rangelands. Mechanical soil disturbance from disking or aeration (or both) is also a key quail habitat management tactic in many rangeland circumstances. Applications of prescribed fire are extremely important for maintaining quail habitat on rangelands. Restoration of native vegetation on disturbance corridors from oil and gas extraction activity, or on pastures with nonnative grasses, is also a key element of rangeland management applied to quail conservation.

Adaptive management for quail conservation on rangelands is often conducted by people who do not realize that they are practicing adaptive management or may know it by another name. This statement is not intended to be ironic. It simply means that adaptive management for quail conservation on rangelands of the American West is a phenomenon that is often underappreciated or overlooked, possibly because investigation of the life history of quail first began in the southeastern pine forests by Herbert Stoddard (1931) nearly a century ago. Following Stoddard, Walter Rosene (1969) focused on the life history and management of northern bobwhite (*Colinus virginianus*; hereafter, bobwhite) in the southeastern Coastal Plains and the pine forests that once supported legions of bobwhite coveys. Quail population research slowly marched west to cropland landscapes in the Midwest in the work of ecologists such as Errington (1945), and Roseberry and Klimstra (1984). The numerous references to bobwhites in the central and southeastern states by Leopold (1933) also cemented the concept where the forest and cropland landscape matrix still dominates a great deal of quail conservation thinking—especially for bobwhites—today.

Val Lehmann started working as a professional wildlife biologist for the King Ranch in South Texas during the 1940s. The nearly 4 decades it took to publish his landmark book

Fig. 2. This key can be used to determine whether adaptive management is an appropriate approach to decision-making in the context of management problem(s) (adapted from Williams et al. 2009).

(Lehmann 1984) was probably one factor responsible for the relative lack of appreciation for the ability of rangelands to sustain abundant populations of wild quail, and by extension, excellent opportunities for quail hunting, especially during years of relatively abundant rainfall.

Bobwhite populations are now essentially locally or regionally extinct in the croplands or forest lands of the southeastern and Midwest United States, which were once the core of the bobwhite's distribution (Chapman et al. 2020). These landscape changes have brought to light the important role of rangelands in bobwhite conservation, and with improved understanding of these systems, an increase in appreciation for these rangelands. A body of peer-reviewed scientific literature and books from major academic presses sharpened our understanding and appreciation of the importance of rangelands for quail. The first and second editions of "Beef, Brush and Bobwhites" (Guthery 1986, Hernández and Guthery 2012, respectively) and the book "Texas Quails: Ecology and Management" (Brennan 2007), along with the scores of peer-reviewed publications from university wildlife programs—especially in Oklahoma and Texas—have done a great deal to support the idea that rangelands are critically important to sustaining, and in many cases elevating, populations of wild quails.

Though in this introduction we have highlighted a plethora of advances in knowledge of rangeland management for bobwhites, fewer studies and literature sources exist for the 5 other species considered here. Because adaptive management helps to address uncertainty, it may be that the opportunity for future use of adaptive management is greatest for these less studied quail species (Figure 3). Moreover, rangelands are inherently heterogeneous and defined in part by stochastic processes (Fuhlendorf et al. 2001) over space and time, further emphasizing the benefits that adaptive management may present when managing quail under uncertainty. Given the pressure dynamics such as climate change will add to uncertainty in rangeland conditions (Brown and Thorpe 2008) in future decades, we argue that highlighting the adaptive

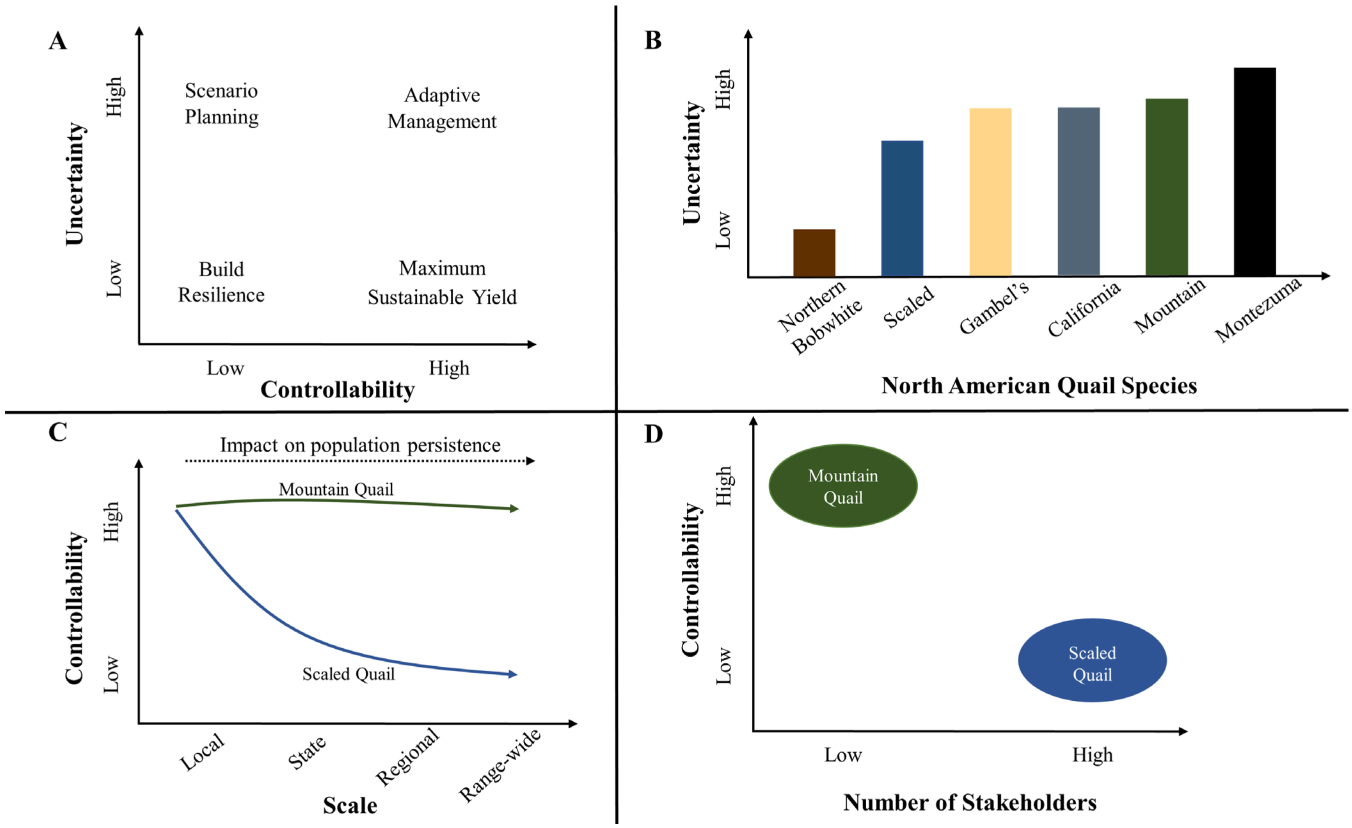

Fig. 3. Adaptive management is most useful when there are high levels of uncertainty in a system where management actions can be controlled (A, adapted from Peterson et al. 2003 and Allen et al. 2011). Uncertainty, or gaps in scientific knowledge, varies across different species of western quails, and therefore the potential utility of adaptive management varies as well. Where uncertainty is low (northern bobwhite), adaptive management may not be necessary (B). Controllability also varies across different species of western quails, largely depending on the scale of interest (C) and the number of stakeholders within each scale (D). Controllability may be highest at local scales where a single manager has authority, but may diminish at larger scales when it becomes necessary to coordinate across many decision-makers.

management process for North America quail conservation on western rangelands is critical, though perhaps not always feasible. It is our hope that by addressing these scenarios, future quail research and management will be designed to utilize adaptive management to reduce uncertainty and guide decision-making.

ADAPTIVE MANAGEMENT CASE STUDIES

We present 4 case studies of adaptive management approaches for quail conservation on rangelands: Joint Ventures, Habitat Management, Population Management, and Restoration Management. When taken together, the participants in these case studies represent a mix of stakeholders, government natural resource agencies, non-governmental organizations, and academia in some form or another. The application of adaptive management for quail conservation on rangelands is the common theme that connects these case studies.

Cooperative Joint Ventures

Joint Ventures are public-private partnership-based programs that deliver specific bird conservation objectives (Brennan et al. 2017:240). Joint Ventures were originally designed to implement national and international bird conservation plans for waterfowl (North American Waterfowl Management Plan 2004), and land birds (Rich et al. 2004), water birds, and shore birds (Brown et al. 2001, Kushlan et al. 2002) respectively. Joint Ventures are designed to "step down" large, continental-scale wildlife population goals and link them to regional or landscape habitat goals. Implementing these step-down plans then allows the cooperators in a Joint Venture to "roll up" these regional and landscape accomplishments to national and international planning groups (Giocomo et al. 2012).

Joint Ventures can be instrumental in working with partners who are management decision-makers. Within adaptive management, organizations such as Joint Ventures serve as "bridging organizations," facilitating communication and cooperation across stakeholders and even ecosystems (Allen et al. 2011). For example, state and federal agencies, non-governmental organizations, foundations, corporations, and university partners of the Oaks and Prairies Joint Venture cooperate and collaborate to build successful habitat delivery and enhancement initiatives such as the Grassland Restoration Incentive Program (GRIP 2013), which was then adopted by other Joint Ventures. DeMaso et al. (in press) provide extensive details about 5 Joint Ventures in Texas (Figure 4), which are briefly summarized in this case study. All 5 of these Joint Ventures use Strategic Habitat Conservation (Figure 5), which serves as an example of a type of adaptive management known as adaptive governance (Folke et al. 2005). In this example, joint-venture science and planning partners are building a vision and framework to achieve shared goals, while land management joint-venture collaborators are providing the management to achieve this vision. This approach allows adaptive management to move forward at larger ecological scales while providing support and cohesion to a diverse array of stakeholders who collectively learn, adjust, and manage a valued natural resource together for the benefit of all.

Cooperative partnerships are common in the wildlife conservation world. Joint Ventures represent a unique type of cooperative partnership because all partners invest significant resources in conservation activities, which means every member organization in a Joint Venture shares risks and costs but also receives rewards and credit if a specific initiative or project is successful. Sharing of resources and responsibilities is a critical component of the success of adaptive governance, as it promotes participation and encourages collaboration (Folke et al. 2005).

Three Texas Joint Ventures (Gulf Coast Joint Venture, Lower Mississippi Valley Joint Venture, and Playa Lakes Joint Venture) were established in the late 1980s to deliver habitat for breeding and wintering waterfowl. The development of continental plans for land birds, shore birds, and water birds, starting in 1990, resulted in the three Joint Ventures expanding the scope of the species being addressed and the addition of two more Joint Ventures by 2008 (Oaks and Prairies Joint Venture and the Rio Grande Joint Venture). While there are differences in operations, geographic scale, numbers of staff members, areas of conservation focus, management board structure, and membership, each of the 5 joint ventures has identified one or more species of quail for conservation planning and delivery.

In one project, the Gulf Coast Joint Venture spent a considerable sum (nearly $100,000) to identify bird species of conservation concern for this geographic region. The data from this project indicated that long-term (>40 years of counts) data could reliably estimate population trends of land birds that have high conservation priority such as brown-headed nuthatch (*Sitta pusilla*), northern bobwhite, Swainson's warbler (*Limnothlypis swainsonii*), and wood thrush (*Hylocichla mustelina*; Sands et al. 2017). Population trends for these and other species of high conservation concern were then linked to long-term changes in land cover across the Gulf Coast (Sands et al. 2018). Based on these findings, the Gulf Coast Joint Venture developed the Coastal Grassland Restoration Program (C-GRIP), which provided landowner subsidies as an incentive to implement the delivery of quail and land bird habitat conservation activities such as prescribed fire, brush management, and removal and reduction of nonnative invasive plants. At the time of this writing (February 2022), 4 of these Joint Ventures (Gulf Coast, Lower Mississippi Valley, Oaks and Prairies, and Rio Grande) have delivered nearly 83,000 hectares of improved or restored habitat for quail and grassland birds.

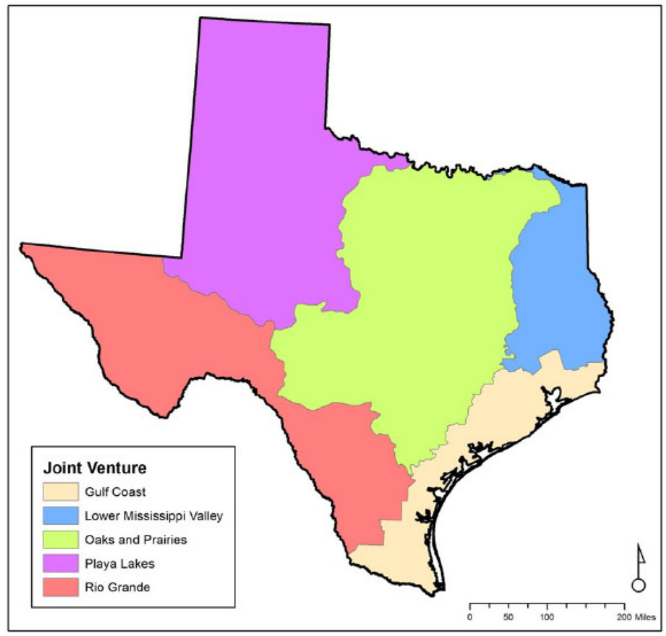

Fig. 4. Distribution of Joint Ventures across Texas, USA (Courtesy Mark Parr, Gulf Coast Joint Venture, U.S. Fish and Wildlife Service).

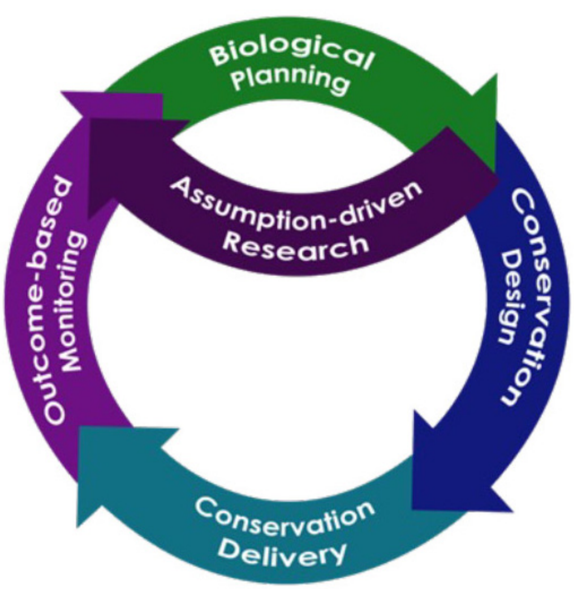

Fig. 5. Conceptual model of strategic habitat conservation (adaptive management) for delivering conservation. From DeMaso et al. (in press).

Adaptive Habitat Management

With around 4 million hectares of mostly contiguous vegetation on a landscape that grows millions of quail—when it rains—South Texas is the last great place when it comes to habitat for the bobwhite. An industry of fee-lease hunting, as well as private ownership, has emerged around upland game hunting in South Texas (Dodd et al. 2013). Howard (2007) was the first wildlife professional to document the logistics of running a South Texas quail hunting operation in an academic publication. A subsequent chapter by Howard and Rauch (in press) added to the concepts and examples in the original chapter by Howard (2007). The clear message to the readers of both of these chapters is that habitat management, in many different forms, is the backbone of running a successful South Texas quail hunting operation. Outside of quail hunting season, the bulk of employee hours are spent doing things like brush sculpting, strip-disking, prescribed burning, maintaining fencing to manage cattle, and so on.

Similar to the material in the recent book by Palmer and Sisson (2017), Howard and Rauch (in press) present a classic case study of intensive quail habitat management on private lands. Unlike our Joint Venture colleagues, the idea of adaptive management is not likely to be on the radar for wildlife professionals such as Rauch and Howard, nor their peers. They are focused more on ranch and pasture. These are highly practical wildlife professionals who seldom, if ever, get caught up with management activities that they think are not practical or simply will not work.

Understanding and dealing with plant succession is the key to successful quail habitat management in any environment. For instance, in the Piney Woods of the humid southeastern Coastal Plain, there is the need to reset the plant succession clock for "early" successional stages of vegetation using prescribed fire, selective uneven-aged forest harvest, and midstory brush and tree control. A short (≤ 3 years) return interval for prescribed fire is essential for maintaining grasses and forbs and keeping excessive woody cover under control in the humid southeastern Coastal Plains. In contrast to this short-return disturbance interval, in rangelands, the return intervals for various habitat management disturbances are much more dynamic than in the Coastal Plains. This is largely because there is a recurring pattern of extensive multiyear droughts that are punctuated by periods of relatively abundant rainfall across the rangelands of the American West.

By keeping track of covey flushes in a pasture, a manager can identify the areas in that pasture where quail were not flushed or seen (Figure 6A). After implementation of some patches of prescribed fire and a network of disked strips (Figure 6B), areas that were once void of bobwhites were subsequently used by them (Figure 6C; Howard and Rauch, in press). By implementing multiple types of management, monitoring quail responses, assessing results, and adjusting accordingly, an entire ranch may become usable space for bobwhites over time (Figure 7). The outcome is purposeful, adaptive habitat management (Larson et al. 2010, Hernández and Guthery 2012) that benefits bobwhites and many other species of grassland birds (Crosby et al. 2015). Moreover, the iterative process of identifying problems (low population or disproportionate use), applying management, monitoring responses, and assessing results reduces uncertainty in future management decision-making, resulting in the efficient use of resources and the more immediate realization of success. Though perhaps a less structured and simpler approach to adaptive management than that taken by Joint Ventures, adaptive management applied in this way is no less useful. In fact, it may be easier to use on private lands where controllability over the process is high as few decision-makers need to be engaged and those decision-makers have few barriers between them and implementing management and monitoring (Figure 3).

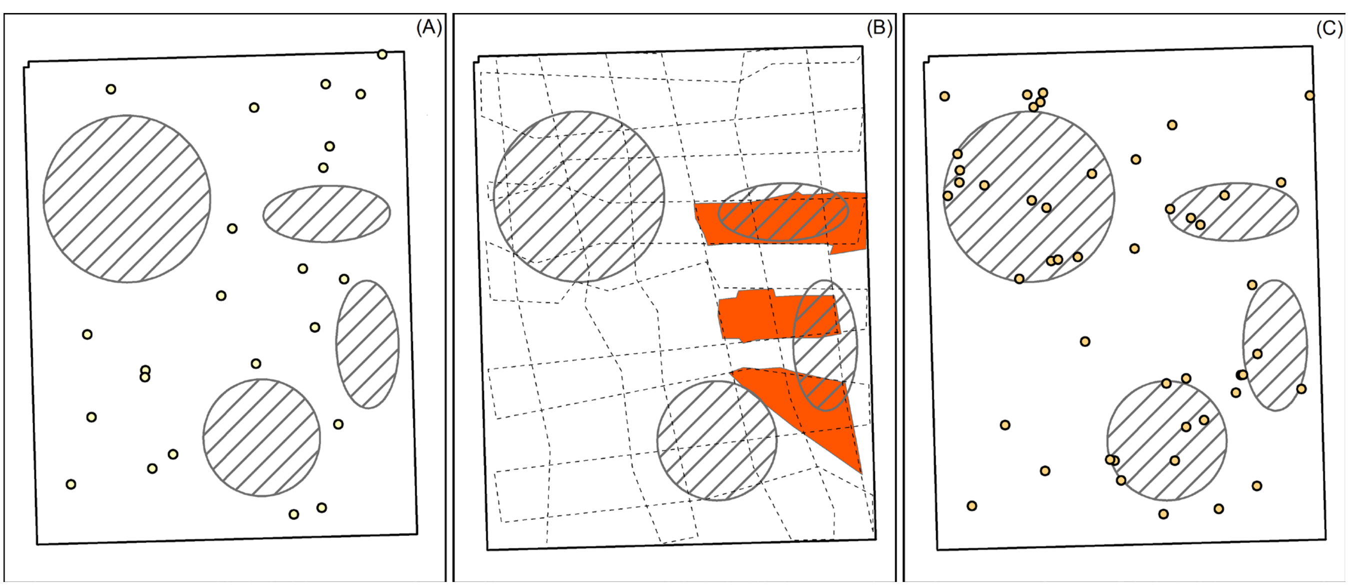

Fig. 6. Three panel maps of total coveys (yellow dots [A]), voids or areas where no coveys were found (diagonal lines within areas), management (prescribed fire [orange areas] and disk strips [dashed lines] [B]), and covey locations during the following year (orange dots [C]). Graphic by W. Rauch and H. Perotto-Baldivieso. From Howard and Rauch (in press).

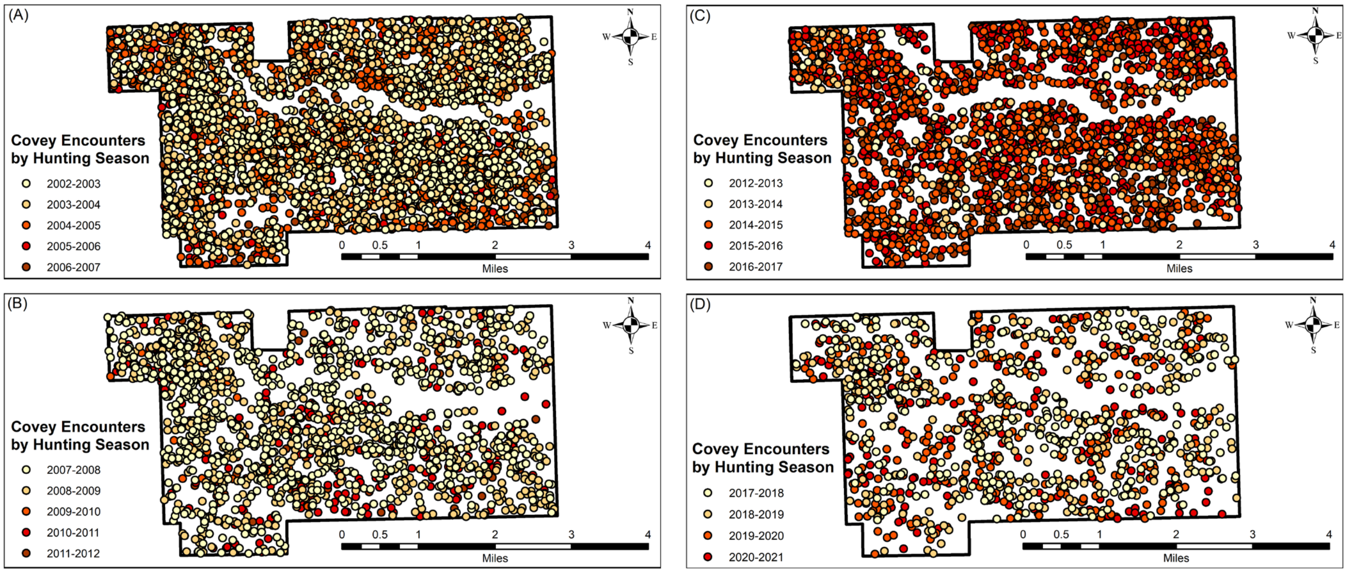

Fig. 7. Moving windows of quail covey locations on Elizita Ranch from the 2002–2003 through 2020–2021 hunting seasons. Graphic by W. Rauch and H. Perotto-Baldivieso. From Howard and Rauch (in press).

Adaptive Population Management

Adaptive Population Management can be considered in the context of adaptive harvest regulations and policies. The central concept of a successful Adaptive Population Management effort is to "adapt" the particular timing of species-specific hunting (season) and harvest (bag limit) based on a meaningful estimate of density (animals per unit area) on or before the opening of an annual hunting season. While the basic concept of tailoring or prescribing an annual harvest according to the level of abundance of a game species is theoretically a great idea, applications of wildlife harvest prescriptions are fraught with uncertainty (Connelly et al. 2020). For example, uncertainty about population dynamics and how these dynamics are structured, has caused a great deal of debate about how wildlife harvests and the timing of wildlife harvests (Dahlgren et al. 2021) should be managed. Furthermore, the uncertainty of whether hunting is additive or compensatory, and the uncertainty of density dependence on both annual production and overwinter survival are central to all upland game birds, including the bobwhite (DeMaso et al. 2013). Tomeček et al. (2015) concluded that species such as quail are characterized by limited dispersal and therefore are at risk for localized overharvest. However, before we discuss how many birds we can take, we first must have an idea of how many birds are present on a given area at the beginning of the hunting season.

How many bobwhites do I have?—On South Texas rangelands, helicopters are a platform for implementing distance sampling to estimate bobwhite population density (Smith et al., this volume; Montalvo et al., in press). This allows managers to fly surveys that use the number of coveys flushed along transects during the fall (November or early December) to estimate population density and set the annual harvest quota for a pasture or even an entire ranch. By knowing how many bobwhites are present in a given area and multiplying the number of birds by the size of the area, we then have an estimate (with a lower and upper 95% confidence interval). For example a 1,000-hectare pasture that has 1 bobwhite/hectare has approximately 1,000 bobwhites total ± the 95% confidence interval around the mean estimate of density. The smaller the confidence interval, the more confident we are of our mean estimate of density. When the spatial locations of coveys are collected during the course of flying along the transects, the density estimates can be used to create a density surface model map for the area surveyed (Figure 8).

How many bobwhites can I harvest?—Hunters are a fundamental component of bobwhite conservation (Brennan

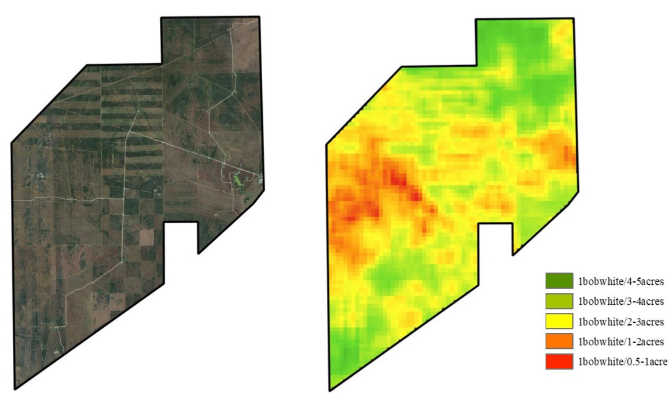

Fig. 8. Theoretical density (birds/unit area) map output from density surface model (at right) compared to aerial view of survey area. From Montalvo et al. (in press).

2015). The bobwhite is one of the most studied wild species of bird in the world, so a great deal of information is available on the metrics of its demography, such as survival, and annual productivity in nest success and egg production in relation to a large range of environmental factors such as temperature and rainfall (Guthery 2002). To understand what levels of annual bobwhite harvest may be sustainable, Sands (2010) and Sands and Tri (in press) summarized a great deal of bobwhite demographic data. These results were based on a series of simulation models that provided annual bobwhite population dynamics similar to what has been observed in South Texas (Figure 9). As a central part of this modeling effort, Sands (2010) implemented a set of simulation scenarios with 1) no harvest, 2) 10% harvest, 3) 20% harvest, 4) 30% harvest, and 5) 40% harvest. Adaptive management requires the use of models to predict the impacts of a management action and allows for the testing and refinement of multiple hypotheses simultaneously. Robust models, in this example, allowed researchers to explore the potential outcomes of different harvest scenarios and enabled them to make a more informed decision about which hunting effort scenario they should test. The model identified scenario 2, with a 20% harvest rate, to have the greatest mean annual yield of bobwhites.

Beginning in the 2018–2019 quail hunting season, Woodard et al. (this volume) began testing the 20% harvest recommendation developed by Sands (2010; Figure 9) on a 6,000-hectare hunted ranch and a comparable nonhunted ranch (4,800 hectares) approximately 16 km from the hunted ranch. Prior to the beginning of quail hunting season, Woodard et al. (this volume) used helicopters to fly transects to collect data to derive density estimates, and a subsequent 20% harvest prescription that included estimates of crippling loss. Based on data from 3 quail hunting seasons, they recommend using the lower 95% confidence interval (rather than the mean) of a bobwhite density estimate for calculating harvest prescriptions. Despite this controlled experimental study, uncertainty in adaptive quail population and harvest management will persist, particularly as quail face a changing environment and other stressors. Adaptive harvest management may continue to provide valuable structure to reducing uncertainty in harvest decisions.

Adaptive Population Restoration Management: Mountain Quail in Eastern Oregon

Sometime prior to the 1980s, the mountain quail (*Oreortyx pictus*) experienced regional and localized extinctions across large parts of the western Great Basin and lower Snake River watershed in Idaho, USA, Oregon, USA, and Washington, USA (Brennan 1990, 1994). The most likely reason behind these local extinctions was the deterioration of creekside-riparian vegetation caused by cattle grazing. In the arid rangelands of the Great Basin, creekside-riparian vegetation provides important habitat for nesting and food-producing for mountain quail, as well as loafing, roosting, and escape cover. These corridors of vegetation also provide pathways for mountain quail to disperse from relatively high-elevation nesting areas to lower valleys during the winter to avoid snow and cold. Additionally, dams along the lower Snake River, especially the Brownlee Reservoir impoundment, inundated large areas of low-elevation wintering habitat for mountain quail.

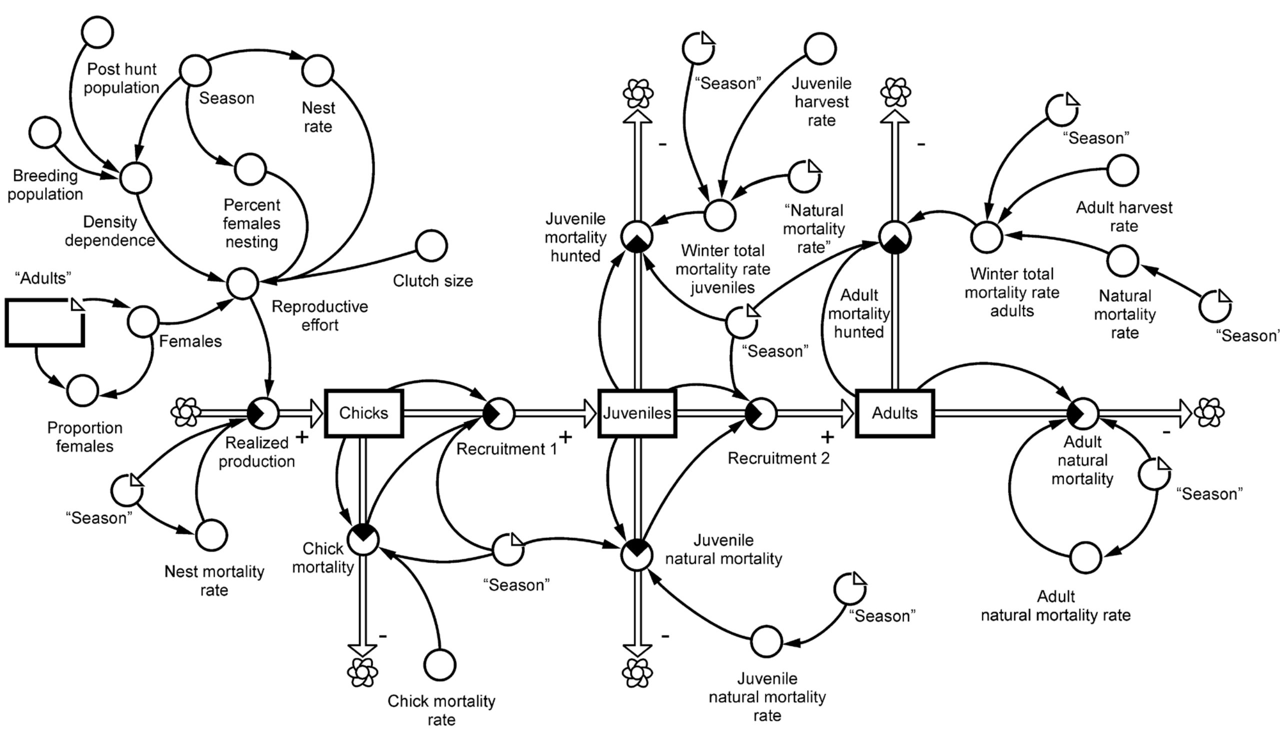

Fig. 9. Stochastic simulation model structure and parameters used to test the potential effects of different annual harvest rates on a bobwhite population in South Texas, USA. From Sands (2010).

Beginning in the late 1980s and through much of the 1990s, state wildlife agencies in Idaho, Oregon, Washington, and Nevada, USA and federal resource agencies, along with academia and stakeholder groups, worked to develop potential population restoration tactics aimed at the strategy of recovering mountain quail where they were once found in parts of the western Great Basin and the lower Snake River watershed. A key tactic of the mountain quail population restoration strategy in Oregon was to capture wild birds from the Coast Range in southwestern Oregon, where they are relatively abundant, and translocate them to places east of the Cascade Mountains where creekside-riparian vegetation was recovering from overgrazing. Mountain quail capture-relocation efforts in Oregon began in 1999 and continued through 2017 (Oregon Department of Fish and Wildlife n.d.:Table 1).

Data from radio-marked mountain quail that were captured in western Oregon and relocated to eastern Oregon from 2001 to 2010 were summarized by Budeau and Hiller (2012). Of the 1,430 translocated mountain quail, 800 were radio-marked to monitor nesting success and population persistence. The reproductive efforts of the relocated mountain quail were comparable to wild mountain quail (Pope and Crawford 2004, Budeau and Hiller 2012:354). Additionally, during subsequent years after these initial releases mountain quail that were not radio-marked were often seen in places near relocation sites, indicating that the relocated birds apparently reproduced successfully (Dave Budeau, Oregon Department of Wildlife and Fisheries, retired, personal communication).

The mountain quail relocation project in Oregon is considered to be a "remarkably successful" upland game bird population restoration project (Mikal Cline, Oregon Department of Fish and Wildlife, personal communication). Of course, not all of the specific, localized translocation efforts were successful. However, mountain quail were reestablished across sufficient areas of eastern Oregon (Figure 10), and were detected with sufficient regularity both by biologists and in reports from reputable birders that the geographic scope of mountain quail hunting was expanded from 8 to 16 counties in eastern Oregon by 2018, 1 year after restoration efforts ceased. By 2020, a 2-bird bag limit was authorized for mountain quail hunters throughout Oregon.

Adaptive management was a key to the success of the mountain quail translocation project in Oregon. Considerable efforts were made by Oregon Department of Fish and Wildlife biologists to identify release sites with vegetation that could provide mountain quail habitat. Subsequently, release sites in eastern Oregon were selected based on their similarity to

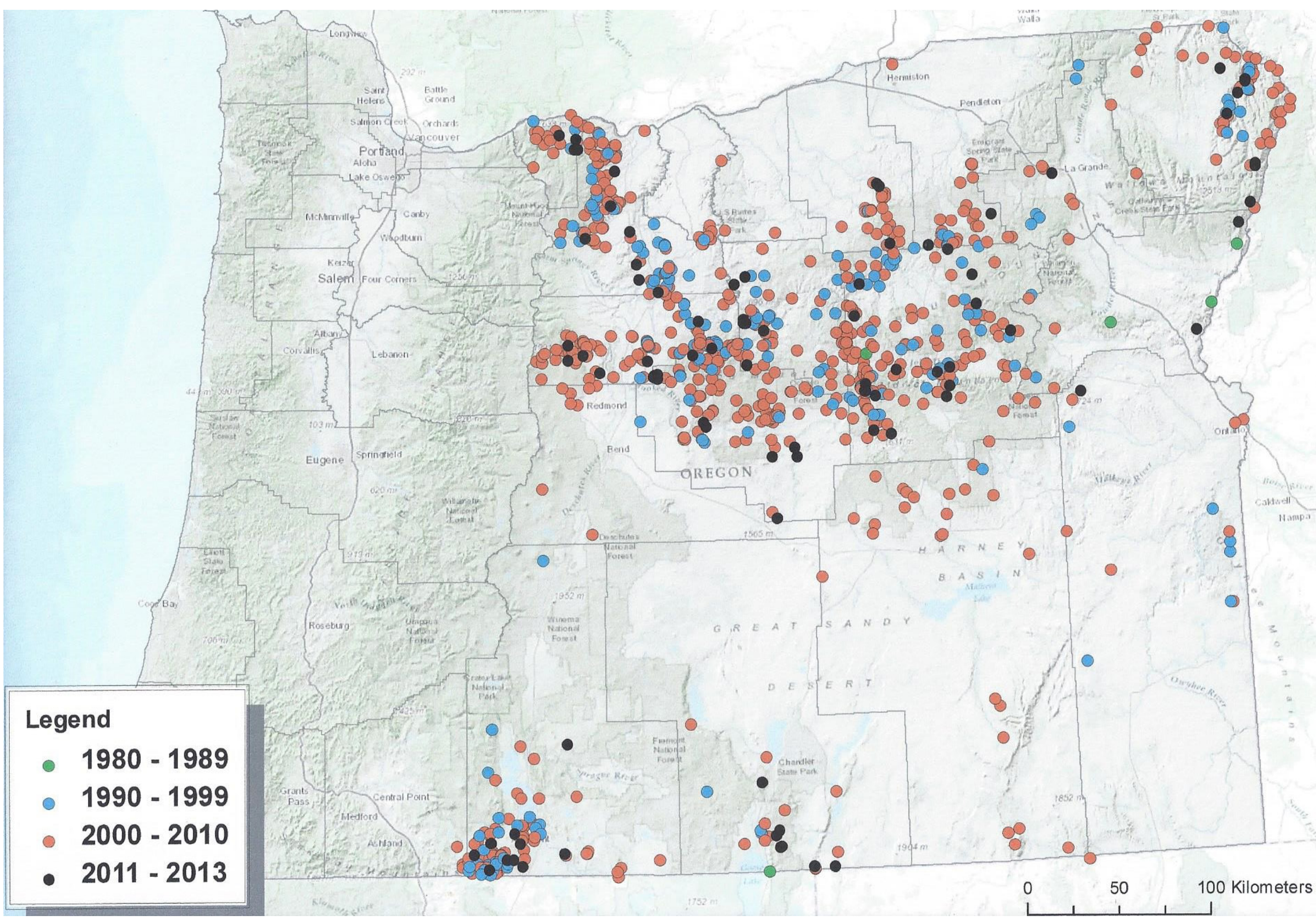

Fig. 10. Distribution of mountain quail sightings in eastern Oregon, USA, from 1980 to 2013. From Oregon Department of Fish and Wildlife.

release sites that were previously successful. This approach is an example of successful adaptive management for quail population restoration. The responsible use of state, federal, and private funds was required to make these restoration efforts successful (Mikal Cline, Oregon Department of Fish and Wildlife, personal communication).

The initial efforts to monitor the mountain quail response to relocations were based on radio-marked birds (Budeau and Hiller 2012). Since then, Oregon Department of Fish and Wildlife biologists have been monitoring the persistence of mountain quail in the translocation areas by collection of wings of hunter-harvested birds and citizen science platforms such as eBird. This story represents a contemporary case study that documents an expansion of quail hunting opportunities across nearly two-thirds of a western U.S. state, which is unique and remarkable (see the Oregon Department of Fish and Wildlife website https://www.dfw.state.or.us/resources/hunting/upland_bird/projects/mtn-quail.asp for more information).

In our experience, the mountain quail is, without a doubt, the most challenging of the 6 North American quails to hunt. Their secretive nature and preference for dense brushy vegetation that is often located in steep mountainous topography means that harvesting even 1 or 2 mountain quail in a day is a trophy-level achievement. This is in contrast to places such as South Texas, where it is possible to find and flush 30 coveys of bobwhites in a day (Valley Nature Films 2020) and easily fill a 15 bird/person/day bag limit. Nevertheless, the fact that quail hunters can now encounter and harvest mountain quail across a vast region of a western state where it was absent just a few decades ago is a testament to the importance of adaptive management for quail conservation on rangelands in the American West.

FUTURE DIRECTIONS: INTEGRATION OF TECHNOLOGY

Integration of technologies is and will continue to be a critical element towards successful implementation of adaptive management for quail populations in western rangelands. Given the highly dynamic nature of conditions and resources that exist in these systems, technological advances will help managers and scientists integrate spatio-temporal data into the adaptive management cycle to produce rapid assessments of management practices at extents that were likely not possible in the past. This is not to say that practitioners have not integrated technology into adaptive management strategies for quail on western rangelands in the past. The case studies presented earlier in this paper are a testament to this point. In this context, we aim to highlight new opportunities to provide a foundation for incorporating these data into already existing adaptive management frameworks.

Unmanned Aerial Systems

The relatively recent availability of low-cost unmanned aerial systems (UASs; or drones) has facilitated an entirely new avenue for monitoring important elements of quail management across a potentially wide range of spatial scales (Gillan et al. 2020). Rangeland inventory and monitoring data that are critical to understanding range conditions and resource availability for quail populations have historically been a labor-intensive exercise focused on sampling small portions of rangelands across a landscape to infer the health and conditions of the rangelands within the extent of management interest (Allen et al. 2017). Given the link between abiotic conditions, rangeland vegetation conditions, and quail population fluctuations, this traditional approach to rangeland inventory and analysis has been a critical tool for evaluating how quail populations respond to the interaction between environmental conditions and active management (e.g., prescribed fire, stocking rates) in rangelands. As techniques and operational workflows towards implementing UASs in rangeland monitoring continue to develop (DiMaggio et al. 2020, Gillam et al. 2020), it is clear that these tools will be a critical next step in adaptive approaches for range and habitat management (Rango et al. 2006). Given the plethora of sensors that have been developed to be fitted onto UASs to collect data, practitioners are capable of collecting data beyond just vegetation structure and composition (Pilliod et al. 2022). Thermal sensors allow observers to monitor thermal refuge (a critical component of quail habitat in rangelands [Tanner et al. 2017*a*]) and more recently potentially determine covey distributions through thermal signatures (Z. Pearson, Caesar Kleberg Wildlife Research Institute, Texas A&M University-Kingsville, personal communication). Moreover, novel adaptation of these sensors allows observers to quantify important but complex elements of rangelands such as foodscapes (Olsoy et al. 2020) or predator escape cover (Olsoy et al. 2015). With this continual need to integrate UAS technology into habitat monitoring at temporal and spatial scales not previously possible, the opportunity for managers to be formally trained in these techniques is also increasing rapidly. Online courses now exist at relatively low cost to obtain a Federal Aviation Administration (FAA) drone pilot license, while online tutorials and workshops continue to be provided so that integration of this technology becomes more obtainable for those interested.

However, challenges in integrating drone technology into adaptive management strategies for quail may exist depending on the spatial extent of the management area. Though quail populations on public lands (i.e., Bureau of Land Management [BLM] lands) or those that exist on large private ranches (i.e., South Texas [> 25,000 hectares]) may have a large enough spatial extent to implement adaptive management strategies at a population level, many lands are managed at a much smaller extent (i.e., the section level, or 259 hectares). In these situations, monitoring of conditions to provide information for adaptive management beyond the extent of the individual landowner's property may be hindered by access to adjacent lands that have direct implications for the success or failure of targeted management strategies and how data are implemented in the adaptive management cycle.

Publicly Accessible Remote Sensed Datasets

The average farm size in Oklahoma during 2020 was estimated at 180 hectares (USDA 2020). However, bobwhite covey home ranges in Oklahoma have been shown to range from 12 to 270 hectares and spring dispersal areas can range from 13 to 906 hectares (Carroll et al. 2017). These data show that bobwhites are responding to conditions and processes at a spatial extent that goes well beyond the average farm size in Oklahoma. This phenomenon clearly illustrates the need for integrating technology for data collection at a much larger scale than the average farm in Oklahoma, or practically any other state as well. With this in mind, access to new central repositories of satellite-derived or remotely sensed data across a wide range and scale of landscape conditions is providing practitioners with unprecedented ways to incorporate data about broad conditions at multiple temporal scales into adaptive management programs for quail (Oschner et al. 2019, Pilliod et al. 2022).

The recent release of the Rangeland Analysis Platform (https://rangelands.app) provides users with annual estimates of fractional cover of vegetation at a 30-m resolution across all rangelands in the United States (Allred et al. 2021). The tool also implements data on ecological resilience (Uden et al. 2019) to provide temporally and spatially dynamic data to help inform users on how management strategies are influencing vegetation dynamics and state-transitions. The Climate Engine (http://climateengine.org/) also provides users with access to global climatic conditions and vegetation data within and across years that can be integrated into the adaptive management framework to account for interactions between climate patterns, rangeland health, and management strategies. Another tools, Grass-Cast (https://grasscast.unl.edu/), provide users with predictions at a 10-km grain for above-normal, near-normal, or below-normal vegetation growth through integration of historical weather and vegetation growth data along with seasonal precipitation forecasts (Peck and Durham 2018). Such predictive data could help managers integrate flexible stocking densities and rates (Peck et al. 2019) to help buffer the variability in resources for quail that often occurs on western rangelands. Moreover, data for predicted soil moisture conditions are becoming available for western rangelands within portions of the distributions of bobwhite and scaled quail (*Callipepla squamata*) (http://soilmoisture.okstate.edu/; Ochsner et al. 2019). Such data could be integrated into assessments of range conditions or success of treatments such as herbicide applications. Here, we provide just a small number of the plethora of publicly available datasets that are available to be implemented in adaptive management strategies for quail management in western rangelands.

There Is an App for That!

One avenue of technology that can be used to bolster success of adaptive management strategies for quail management is the use of smartphone applications (apps) and citizen science programs (Teacher et al. 2013). More commonly, these 2 elements are seamlessly integrated to increase the opportunities and value that these programs may provide in the form of data for management strategies. Broadly, citizen science apps like eBird facilitate access to spatial and temporal presence data of avian species that are furnished solely through activities of citizen scientists (Sullivan et al. 2009). Recently, these data have been used to produce annual estimates of relative abundance (Fink et al. 2020), which may provide a broader view of quail population fluctuations that could be compared to local data from site-specific relative abundance monitoring efforts associated with management areas. As apps continue to become more accessible to a diverse use-base, species-specific or taxon-specific apps are becoming more common. For instance, the Gamebird Brood Observation app developed by Oklahoma State University facilitates documenting observations of gamebird broods by users to help record obervations of changes in reproduction and spatio-temporal trends in brood space use. Such an app could function as a central repository for managers interested in integrating these data into management plans intended to promote quail reproduction. Undoubtedly, the number of smartphone apps developed for quail management objectives will continue to grow, with obvious implications for adaptive management such as monitoring hunting pressure or measuring vegetation structural and compositional components related to management applications at local, regional, and rangewide scales.

Overcoming the Problem of Scale

One of the interesting aspects of adaptive management for quail conservation on rangelands is that the problem of scale works in both positive and negative ways. In a positive context, the scale of opportunities for sustaining wild and huntable populations of quails on rangelands far exceeds similar opportunities in most of the southeastern and midwestern parts of the United States, as mentioned at the beginning of this paper. In the case studies presented in this paper, positive outcomes for quail conservation projects ranged from tens of thousands of hectares (Joint Venture, Habitat Management, and Population Management Case Studies) to many thousands of square kilometers (Mountain Quail Case Study). A lesson here is that adaptive management for quail conservation can be successful on moderately large to very large scales, given that the relevant stakeholders and decision-makers can be brought together. From a negative viewpoint, the inexorable maw of urbanization and impermeable surfaces across large areas of the rangeland landscape represents a widespread and pernicious threat to virtually all rangeland quail conservation efforts. Fortunately, there are still vast areas of rangelands in the American West that support wild quail populations and the opportunity to hunt them. An inventory that compiles a reliable estimate of how many square kilometers of rangeland support wild quail populations would be a useful and interesting metric, especially if taken at 5- to 10-year intervals.

Uncertainty in a Changing Climate

Quail populations and climate and weather patterns are indisputably linked (Lusk et al. 2001, Hernández and Guthery 2012, Tanner et al. 2017*b*). A major challenge facing managers in future decades will be the uncertainty caused by rapidly changing climate patterns. For example, at the time of this writing, much of the southwestern United States within the distribution of multiple western quail species is under a megadrought—the driest period since the year 800 (Williams et al. 2022).

Drought severity, drought longevity, and increased temperatures due to climate change pose significant threats to all temperate North American quail species over future decades (Tanner et al. 2017*b*). Integrating climate scenarios into targeted management efforts and within an adaptive management framework will be a major path forward in ensuring resilience of natural resources (Peterson et al. 1997, Tompkins and Adger 2004) and subsequently quail populations under novel conditions. It is of paramount importance to understand that vulnerability will increase for some current "population strongholds" maintained under past and current climatic conditions (e.g., bobwhite in the panhandle of Oklahoma [Tanner et al. 2017*b*]), and addressing uncertainty related to climate change effects on meta-population dynamics will be critical for successful resource allocation and targeted management. There will undoubtedly be varying levels of uncertainty and disparate levels of severity to the species-specific responses to changing climate patterns (Tanner et al. 2017*b*), with both winners (Gambel's quail [*Callipepla gambelii*]) and losers (Montezuma quail [*Cyrtonyx montezumae*]) based on geographic distributions, evolutionary traits, and behavioral adaptations. Ignoring the uncertainty that changing climate patterns present to quail populations in the form of both direct (population dynamics) and indirect (increased rangeland variability) pressures will leave adaptive management strategies falling short of their goals for quail on western rangelands.

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