CONTRIBUTION OF THE AMERICA'S RED ROCK WILDERNESS ACT TO CLIMATE CHANGE ADAPTATION AND MITIGATION EFFORTS

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Meeting the challenges of climate change

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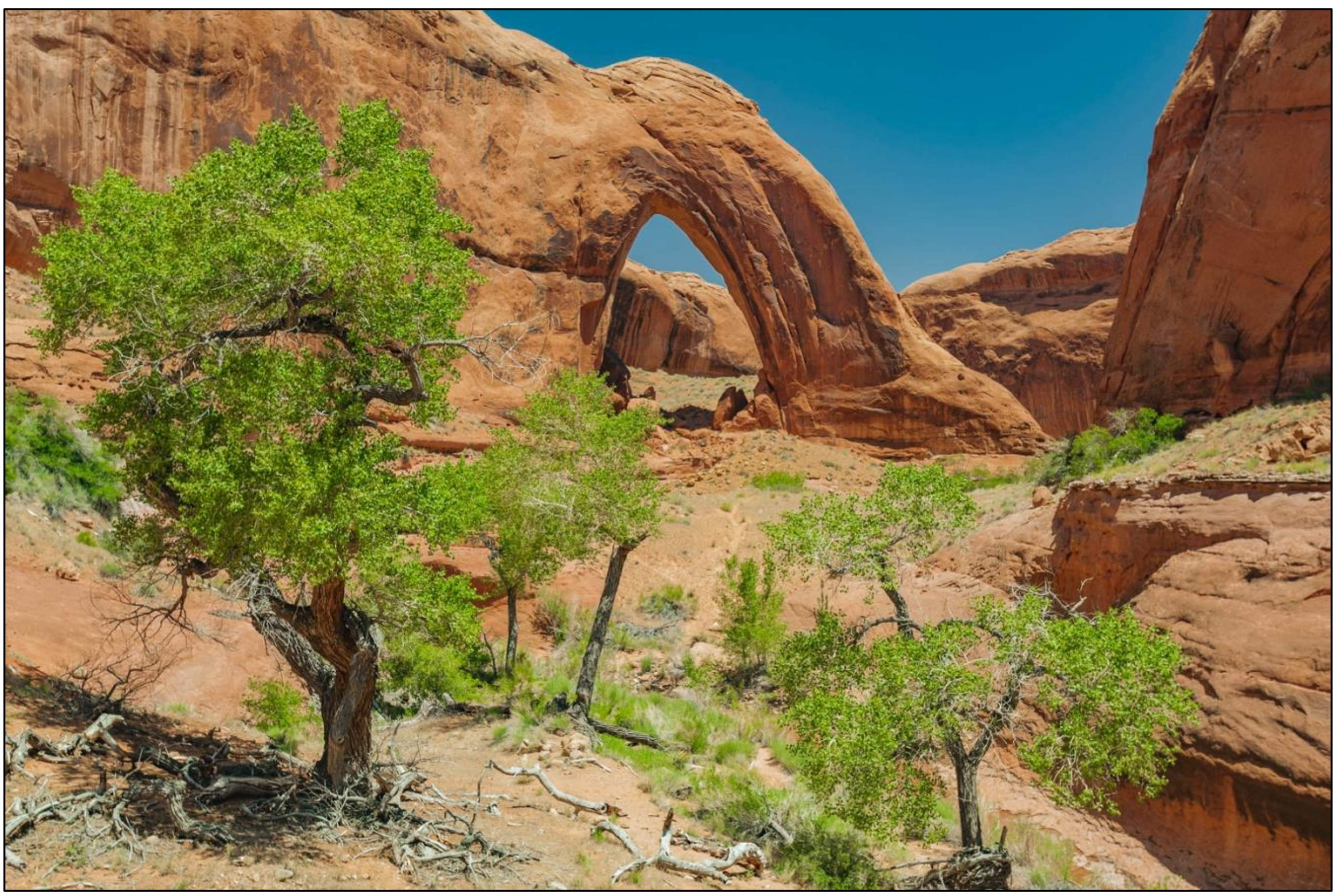
Executive Summary

The America's Red Rock Wilderness Act (ARRWA) would add around 9 million acres of Utah public lands to the National Wilderness Preservation System, including lands removed from Grand Staircase-Escalante and Bears Ears National Monuments.

Chapter 1 of this report describes ARRWA lands and major ecosystems and provides an overview of protections that passage of the ARRWA would provide to these lands. This chapter also summarizes projected climate change and related impacts for the study area.

The remainder of the report reviews the potential contribution that ARRWA lands could make to climate change efforts, focusing on benefits that fall within two main categories:

- **Climate change adaptation**, which refers to the ability of ecosystems to cope with and/or respond to the impacts of climate change; and
- **Climate change mitigation**, which refers to reducing the concentration of heat-trapping greenhouse gases in the atmosphere in order to limit increases in global temperature.



Broken Bow Arch, Grand Staircase-Escalante National Monument (Photo: © Jeff Foott).

Contribution of ARRWA lands to climate change adaptation efforts

Chapter 2 focuses primarily on whether and how permanent protection of ARRWA lands could enhance ecosystem adaptation to climate change through three major contributions: protection of potential climate refugia, increased landscape connectivity to facilitate species migration/dispersal and range shifts, and reduction of surface disturbances (e.g., fossil fuel development, livestock grazing, off-road vehicle [ORV] use) that exacerbate the impacts of climate change.

Key findings

- Wilderness designation of ARRWA lands would result in the permanent protection of areas likely to serve as important climate change refugia (i.e., areas that are buffered from exposure to rapid changes and climate extremes), which are largely unprotected at low elevations within this region. Climate change refugia facilitate the persistence of sensitive species, preventing the loss of genetic diversity to buy time for adaptation over longer time scales. They can also protect populations from extirpation following extreme events (e.g., severe drought or wildfires), by serving as sources for recolonization of the surrounding landscape.
- Protection of ARRWA lands would likely increase landscape connectivity in the region, as these lands includes large, unprotected areas of the western U.S. that have been identified in multiple studies as critical landscape corridors. Protected area networks that increase landscape connectivity are able to facilitate species movement, enhance gene flow, reduce the risk of extirpation in isolated populations, and increase access to suitable habitat patches that can act as "stepping stones" to support species' range shifts.
- Preventing surface disturbances on ARRWA lands would reduce disturbances that can exacerbate the impacts of climate change on species and ecosystems. Studies suggest that reducing surface disturbances that damage biological soil crusts and increase wind erosion can benefit Colorado River flows, which are significantly impacted by long-range transport of dust emissions from Utah soils that cause earlier snowmelt in downwind mountain ranges and associated decreases in annual flow volume of the Colorado River. Preventing vegetation loss and soil disturbances can also preserve the hydrological benefits provided by intact watersheds (e.g., flow regulation, erosion control, groundwater recharge, water filtration) and increase ecosystem resistance to establishment of exotic plants, both of which are critical to limit climate-driven losses in biodiversity and ecosystem functioning.

Off-road vehicle damage in the Behind the Rocks area near Moab (Photo: © Ray Bloxham).

Contribution of ARRWA lands to climate change mitigation efforts

Chapter 3 evaluates the potential contribution of ARRWA lands to climate mitigation efforts. We conducted two separate analyses to estimate a) the amount of oil, gas, and coal resources present on ARRWA lands and greenhouse gas emissions associated with those resources, and b) the amount of natural carbon that would be sequestered (i.e., captured) and stored on these lands by the end of the century, if they remained undisturbed.

Key findings

- Permanent protection of ARRWA lands would keep 14,956 million barrels of oil, 14,264 billion cubic feet of natural gas, and 9,136 million short tons of coal in the ground. This would prevent the release of greenhouse gases associated with the extraction and combustion of these resources, which are estimated to range from 14,364 to 34,870 million metric tons of carbon dioxide equivalent. This amount is comparable to 3.6 years of U.S. greenhouse gas emissions at 2018 levels, and would account for over 5.7% of the amount of carbon that could be released globally while still limiting warming to no more than 1.5°C rise.
- Modeling results suggest that ARRWA lands have the potential to sequester and store 271 million metric tons of organic carbon in plant biomass and soils by the end of the century. This represents an increase of 9.8% in organic carbon stocks compared with 1981–2010, largely due to climate-driven expansion of woody vegetation into areas currently dominated by grasses and forbs. Modeled organic carbon stocks from the past three decades account for 25% of the current total ecosystem carbon stocks on Utah federal lands, and 0.4% of total carbon stocks on all U.S. federal lands. Although incomplete scientific understanding makes accurate modeling of soil inorganic carbon stocks difficult, estimates based on a state-wide average suggest that carbon stocks on ARRWA lands may be double or triple that amount when soil inorganic carbon is included. However, reduction of surface disturbances is critical to prevent loss of vegetation, damage to biological soil crusts, and changes in soil properties, all of which can significantly reduce ecosystem capacity to sequester and store carbon on ARRWA lands.

Chapter 1. Introduction

San Rafael Swell (Photo: © Ray Bloxham).

The America's Red Rock Wilderness Act of 2017 (S. 948, 115th Congress) proposes protecting around 9 million acres of public lands managed by the Bureau of Land Management (BLM) in Utah. Passage of the ARRWA by Congress would permanently protect these lands under the Wilderness Act of 1964, which established the National Wilderness Preservation System and set formal standards for the designation and protection of wilderness areas by Congress. The Wilderness Act is intended to permanently preserve intact, high-quality ecosystems that retain wilderness characteristics, and is the strongest level of conservation protection available within the United States (*1*–*3*). Passage of the ARRWA would restore protections removed for wild areas within Grand Staircase-Escalante and Bears Ears National Monuments, while also protecting additional intact lands within unique areas such as Cedar Mesa, Grand Staircase, and Dirty Devil.

Wilderness designation of ARRWA lands would also contribute to the 30x30 conservation goal put forth by scientists (*4*), which calls for protecting at least 30% of all lands and oceans by 2030 in order to protect global biodiversity and ecosystem services, including those critical for climate mitigation. Within the U.S., a number of legislative measures (e.g., S. Res. 372 2019; H. Res. 835 2019) have been proposed that align with this goal at a national level (*5*). However, just 12% of the U.S. land area (293 million acres) has been permanently protected as of 2017 (*6*). In order to meet the 30x30 national conservation goal, an additional 438 million acres of land must be protected within the next 10 years. Wilderness designation of ARRWA lands would add 6.4 million acres to the current total, accounting for 1.5% of the remaining amount and doubling the current amount of permanently protected land in the state of Utah (*6*). An additional 2.6 million acres of Wilderness Study Area lands would also gain official wilderness designation, strengthening their protected status.

1.1. Overview of ARRWA lands

The proposed wilderness lands are distributed across large portions of the Colorado Plateau, Utah High Plateaus, and Great Basin ecoregions, with the largest proportion of ARRWA lands occurring in the Colorado Plateau of southeastern Utah (see Figure 1). Biological diversity is high in all of these regions, and they include many hotspots that collectively support hundreds of plants, birds, mammals, reptiles, amphibians, fish, and invertebrates (*7*–*11*). The harsh desert climate, diverse geologic history, and wide range of elevations within these regions have also contributed to the evolution of local adaptation within relatively isolated populations, resulting in the presence of many endemic species and unique biological communities (*7*–*11*).

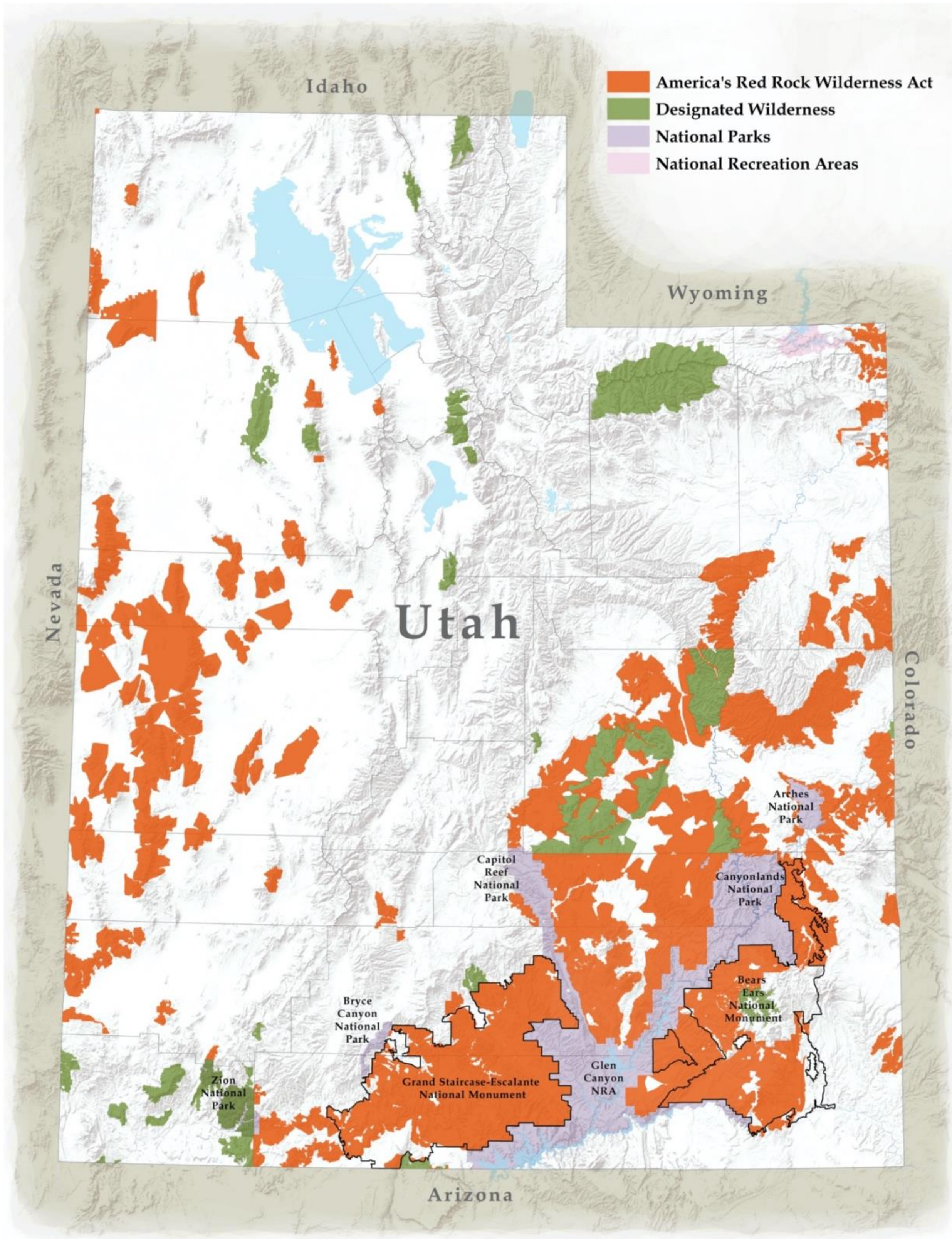


Figure 1. BLM lands proposed for wilderness protection under the ARRWA, as well as existing wilderness areas, national parks, and national recreation areas.

The region includes rugged mountains and red rock deserts featuring natural arches and bridges, steep cliffs and canyons, buttes, mesas, plateaus, and other landscape features that have been formed by erosion of soft sedimentary rocks over millions of years (*8*). The landscape is mostly cold desert characterized by extreme summer and winter temperatures (*8*). Deserts, grasslands, and shrublands are the dominant ecosystems at lower elevations, including saline shrublands dominated by native species (e.g., saltbrush [*Atriplex corrugate*]) that are tolerant of high salt concentrations within ancient lake beds (*7*, *8*, *12*). At slightly higher elevations, sagebrush steppe dominated by blackbrush (*Coleogyne ramosissima*) and/or big sagebrush (*Artemisia tridentata*) are common, as are pinyon pine (*Pinus edulis*) and Utah juniper (*Juniperus osteosperma*) woodlands (*8*, *12*). Island mountain ranges also include mountain shrub communities, stands of quaking aspen (*Populus tremuloides*), and montane and subalpine conifer forests (*8*). Major river networks include the Upper Colorado River, Green River, and Sevier River (*8*), and smaller streams and springs throughout the region provide critical habitat for plants and animals as well as corridors for wildlife movement (*7*, *8*). Unique ecosystems also occur around cliffs, canyons, talus slopes, and seeps/springs, as well as within alpine lakes and meadows at high elevations (*7*, *8*).

Dryland ecosystems often feature fragile biological soil crusts (hereafter referred to as biocrusts), which are slow-growing mats of cyanobacteria, lichens, mosses, and fungi that form on the soil surface and bind the particles together (*13*, *14*). The resulting matrix is highly resistant to erosion by wind and water (*13*, *14*). These crusts are highly responsive to moisture pulses that allow biological activity (*15*), and they play a critical role in arid ecosystems by stabilizing soils to prevent flash flooding and erosion, increasing water infiltration, supporting vegetation establishment and survival, and sequestering carbon (*13*, *16*–*19*).

Undisturbed biological soil crusts cover large portions of the Labyrinth Canyon area (Photo: © Ray Bloxham).

Current uses of ARRWA lands are wide-ranging, and include uses compatible with conservation such as hunting, horseback riding, hiking, and camping, as well as those that result in surface disturbances such as ORV use, oil and gas drilling, mining, and livestock grazing (*1*). Designation as wilderness would prohibit further development and resource extraction, including road construction and modification, construction of buildings and other man-made structures, new mining claims or mineral leases, logging or other commercial uses, and new reservoirs or powerlines (*1*, *2*, *20*). The Wilderness Act allows for some existing activities, including livestock grazing and preexisting mining claims and oil/gas leases (*20*). Hands-off management is presumed, as wilderness areas are intended to allow wildfire and other natural disturbance regimes to occur without human interference (*2*, *21*, *22*). However, management interventions are allowed for the control of fire, insects, and disease, particularly where previous degradation (e.g., fire suppression) has impacted normal ecosystem functioning or where not doing so would threaten endangered species or resources outside of the wilderness area (*2*, *20*, *23*). Other allowable uses of wilderness lands include non-mechanized recreational activities (e.g., hiking, fishing, hunting, backcountry camping), scientific study, and educational programs (*2*, *20*).

1.2. Projected climate impacts on ARRWA lands and associated ecosystems

Even remote wilderness areas with high ecological integrity are impacted by anthropogenic climate change (*24*), and the proposed wilderness lands are projected to experience rapid shifts in climate conditions and disturbance regimes over the coming century (see Table 1).

Table 1. Projected future changes in the primary climate stressors likely to impact ARRWA lands. Arrows represent the trend direction (e.g., increase, decrease, or shift towards earlier timing).

Climate Stressor	Trend Direction	Projected Future Changes
Air Temperature	▲	• 4.9–8.7°F (2.7–4.8°C) projected increase in average annual temperature in the southwest U.S. by 2100 (*25*)
Precipitation	▲ ▼	• Likely shift towards wetter winters and drier springs and summers (*26*), as well as increases in interannual precipitation variability (*27*) and the frequency of extreme precipitation events (*26*)
Snowpack & Snowmelt	▼ ◀	• Decreased proportion of precipitation falling as snow, significant reductions in snowpack, and earlier snowmelt (*28–32*)
Streamflow	▼ ◀	• 35–55% projected decline in annual streamflow by 2100 (*33*, *34*) • Shift towards earlier spring peak flows and reduced volume of peak flows due to changes in snowpack and snowmelt (*29*, *30*)
Drought	▲	• Increased risk of prolonged and/or severe drought (*35–37*), with a >70% chance of multi-decadal drought by 2100 (*35*, *36*)
Wildfire	▲	• Increased fire frequency over the coming century (*38*), including a significant increase in the frequency of very large fires (*39*)

1.2.1. Ecological implications of climate change

Climatic changes within the region may result in:

- Increased evapotranspiration rates, driving shifts toward higher aridity even in the absence of precipitation declines (*29*, *37*, *40*).
- Reduced plant productivity and increased mortality due to greater water stress (*41–45*).
- Changes in plant functional group dynamics, leading to shifts in community composition (e.g., increased relative dominance of shrubs and invasive annual grasses over native perennial grasses; *46–48*).
- Reductions in surface water availability and quality (*33*, *34*, *49–53*), with significant impacts for riparian vegetation (*54*, *55*) and aquatic communities (*52*).

- Increased risk of ecosystem type conversion (e.g., forests to shrubland or shrubland to non-native grassland) due to frequent and/or severe wildfires, particularly in drier areas and during periods of drought (*56*–*59*).
- Reduced habitat suitability and possible species range shifts towards northern latitudes and/or higher elevations (*60*, *61*), with likely loss of high-elevation montane habitat islands (*62*, *63*).
- Range contractions and/or local extirpation where species are unable to track suitable habitat (i.e., due to dispersal limitations or low landscape permeability; *64*).
- Loss of genetic diversity and species richness, particularly where species are already coping with habitat fragmentation and loss (*65*, *66*).
- Changes in carbon sequestration and storage due to reduced overall plant productivity (*45*), shifts in plant community composition (*67*), and altered soil community composition and activity (*45*, *68*–*73*).

Dryland ecosystems, such as Utah's San Rafael Desert, are likely to become increasingly arid (Photo: © Ray Bloxham).

1.2.2. Interactions between surface disturbances and climate change

The impacts of climate change can interact with existing threats to species and ecosystems, including surface disturbances such as livestock grazing, ORV use, mechanical vegetation treatments, oil and gas development, and road construction, among others. On ARRWA lands, some of the significant interactions that may occur include:

- Increased wind erosion and dust emissions in disturbed areas (*12*, *16*, *74–79*), which may be exacerbated by climate-driven increases in aridity and more frequent and/or severe droughts (*78*, *80–82*). Long-distance transport of dust emissions from disturbed Utah soils can drive earlier snowmelt in distant mountain ranges (*80*, *83*, *84*), which has been associated with earlier spring peak flows (by 3-6 weeks) and reduced annual flow volume (by 5-6%) within the Upper Colorado River Basin (*80*, *84*).

Dust storms are likely to be more common in the future (Photo: USGS).

- Altered hydrology, reduced freshwater availability, and reduced water quality where surface disturbances degrade intact watersheds (*17*, *85–88*) or result in large water withdrawals and discharge of contaminated water (such as occurs during the extraction of tar sands; Rosa et al. 2017). Warmer, drier climate conditions and more frequent extreme precipitation events are likely to exacerbate the impacts of existing water stress on native plants and animals while also increasing pressure to develop remaining water resources for human use (*22*, *33*, *90*).
- Increased spread and establishment of invasive plants (*91*, *92*) that displace native plant species, alter ecosystem processes, and degrade critical wildlife habitat (*47*, *93*, *94*). The expansion of cheatgrass (*Bromus tectorum*), in particular, has increased wildfire frequency and annual area burned by enhancing fuel availability and continuity (*95*, *96*). Frequent fires, in turn, increase the cover of invasive grasses, creating a positive feedback loop that perpetuates altered fire regimes (*97*, *98*) that are associated with increased soil loss (*76*) and reduced habitat quality for wildlife (*99*, *100*). Warmer temperatures and increased drought are projected to enhance wildfire risk and contribute to the spread of invasive grasses over the coming century, further strengthening invasive grass-fire feedback loops (*47*, *101*).
- Anthropogenic surface disturbances that reduce carbon sequestration and storage due to vegetation loss, damage to biocrusts, increased erosion, and changes in soil properties. The removal of woody vegetation is generally associated with a net loss of stored carbon (*102*), due to both the removal of above-ground plant biomass (*67*, *103*, *104*) as well as changes in carbon cycling that reduce soil organic carbon (*105*, *106*). Disturbances also impact community composition and biogeochemical processes in fragile biocrusts (*15*, *70*, *107–109*), which fix carbon through photosynthetic activity (*15*, *110*, *111*) and play a critical role in the formation of underground stores of soil inorganic carbon (*112*, *113*).

Chapter 2: Contribution of ARRWA lands to ecosystem adaptation to climate change

Wilderness lands represent high-quality, intact ecosystems, and it is widely acknowledged that their protection is critical to preserve biodiversity and large-scale ecosystem processes that support functioning natural systems and human communities world-wide (*24*, *114–116*). Globally, intact wilderness areas are rapidly declining, with almost 10% of remaining areas having been lost over the last two decades (*115*). Thus, protection of remaining wilderness lands is becoming increasingly urgent in order to prevent the irreversible loss of critical benefits associated with these protected areas, including support of critical habitat and movement corridors for endemic and/or rare species, watershed protection, and carbon sequestration, among other benefits (*24*, *114–119*).

Desert bighorn sheep (Ovis canadensis nelsoni) in the White Canyon area (Photo: © Ray Bloxham).

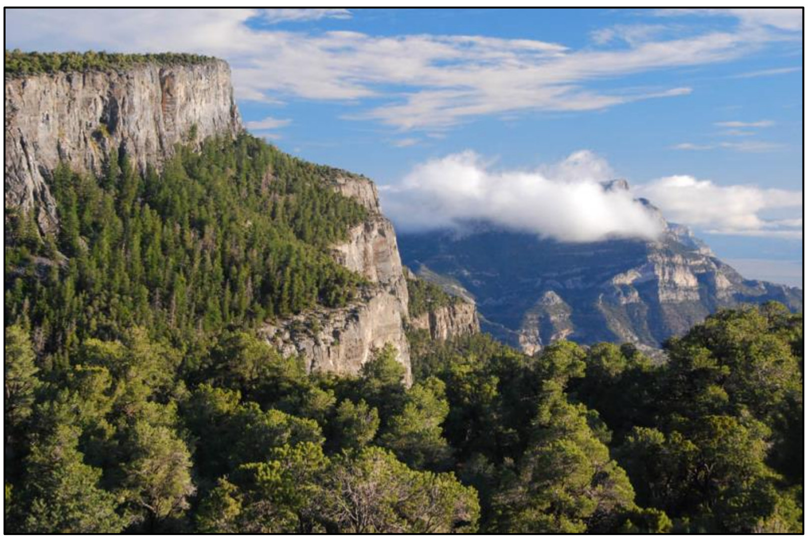
Despite the many benefits of wilderness areas, there are very few studies that have focused on quantifying the impacts of wilderness protection on plants, wildlife, or ecosystem functioning (*120*). One notable exception is a recent study by Marco et al. (*116*), which found that wilderness areas reduce species extinction risk by about half. They observed the most pronounced benefits in wilderness areas that host unique biological communities and/or represent the majority of remaining habitat for a given community (*116*), which suggests significant benefits for ARRWA lands given the presence of many biological hotspots and high levels of endemism found there (*7–11*). However, this study did not explicitly evaluate extinction risk in the context of climate change (*116*). Generally, it is assumed that ecologically-intact wilderness lands that have high connectivity and represent a wide range of environmental conditions are the most likely to support climate change adaptation within individual species, communities, and/or ecosystems (*24*, *118*, *121–123*). Multiple mapping efforts have noted that the Great Basin and Colorado Plateau regions of Utah, where ARRWA lands are concentrated, are of high conservation value due to their ecological integrity and connectivity (*3*, *118*, *124–126*), as well as their geophysical diversity (*127*) and the potential for increasing the diversity and representation of protected ecological systems (*117*, *118*).

Broadly speaking, protection of wilderness areas likely supports ecosystem adaptation to climate change by maintaining landscape-scale ecological processes and housing larger populations of sensitive species that increase the potential for local genetic adaptation (*24*, *128*) and are less vulnerable to extirpation compared to those in non-wilderness areas (*116*). This chapter outlines in more detail the primary ways that wilderness designation of ARRWA lands would likely support climate change adaptation through:

- Protection of potential climate change refugia;
- Increased landscape connectivity that facilitates species migration/dispersal and range shifts in response to changing conditions; and
- Reduced surface disturbances that interact with climate change, resulting in negative impacts to native species and ecosystem processes.

2.1. Protection of potential climate change refugia

The protection of climate change refugia is considered a key adaptation strategy within the scientific literature (*129*–*134*). Climate change refugia are areas of the landscape that are buffered from exposure to rapid changes and climate extremes, facilitating the persistence of sensitive species (*131*, *132*). Physical and biological characteristics that create climate change refugia include factors that decouple site conditions from regional climate, such as groundwater inputs (e.g., seeps/springs and spring-fed streams); strong climatic gradients (e.g., temperature inversions over valleys that create cold-air pools); topographic and geomorphic variability that creates a wide variety of potential microclimates (e.g., north-facing slopes); and plant communities that create their own microclimates or provide shade and increased humidity (e.g., late-successional forests; *131*, *133*, *135*–*137*). In general, temperature and moisture refugia are most likely to occur at higher elevations, in areas with higher levels of precipitation, where topographic and/or edaphic complexity is high, and at sites with permanent sources of surface water (*63*, *138*–*140*).



High-elevation areas, such as the Swasey Mountain in Utah's West Desert, may serve as climate refugia that support species range shifts (Photo: © Ray Bloxham).

Climate change refugia that preserve relict populations of species within their current range are known as *in situ* refugia, which prevent the loss of genetic diversity and buy time for adaptation over longer time scales (*132*). These are particularly critical for species that are unable to track changing climate conditions rapidly enough due to dispersal limitations or low landscape permeability (*63*). *In situ* refugia also protect populations from extirpation following extreme events such as severe drought or large, high-severity wildfires, allowing recolonization of the surrounding landscape following disturbance (*131*, *141*). By contrast, *ex situ* refugia refer to areas where organisms from nearby regions may find suitable conditions, and are sometimes referred to as "stepping stones" (*63*, *142*). *Ex situ* refugia have the potential to support range shifts, and are likely to be critical where conditions within *in situ* refugia may not be maintained over longer time scales (*131*, *132*, *142*).

Studies have found that the Colorado Plateau region has very high topographic complexity (*63*, *124*) and geophysical diversity (*127*), as well as generally lower climate change velocity (i.e., the rate of changes in climate conditions) compared to surrounding areas (*63*). This suggests that preserving intact ecosystems in this region is likely to result in the protection of climate refugia that can support the persistence of native species (*63*, *127*). A recent study found that 16–25% of potential refugia in North America (defined as locations with increasingly rare climate conditions) are already protected, despite them accounting for only 10% of the land area (*138*). This shows that protected areas in North America already include a disproportionate amount of potential refugia compared to the general landscape. However, refugia located at lower latitudes (<40 N) and lower elevations (<8,000 ft) were more likely to be unprotected; this includes the Central Basin and Range and Colorado Plateau ecoregions, where they estimate that 70–80% of potential refugia remain unprotected (*138*). Taken as a whole, these studies suggest that ARRWA lands are likely to contain a high proportion of refugia, making their protection critical to maintain the high biodiversity and unique communities found in the region.

Riparian areas, such as those along Utah's San Rafael River, are often associated with climate refugia (Photo: © Ray Bloxham).

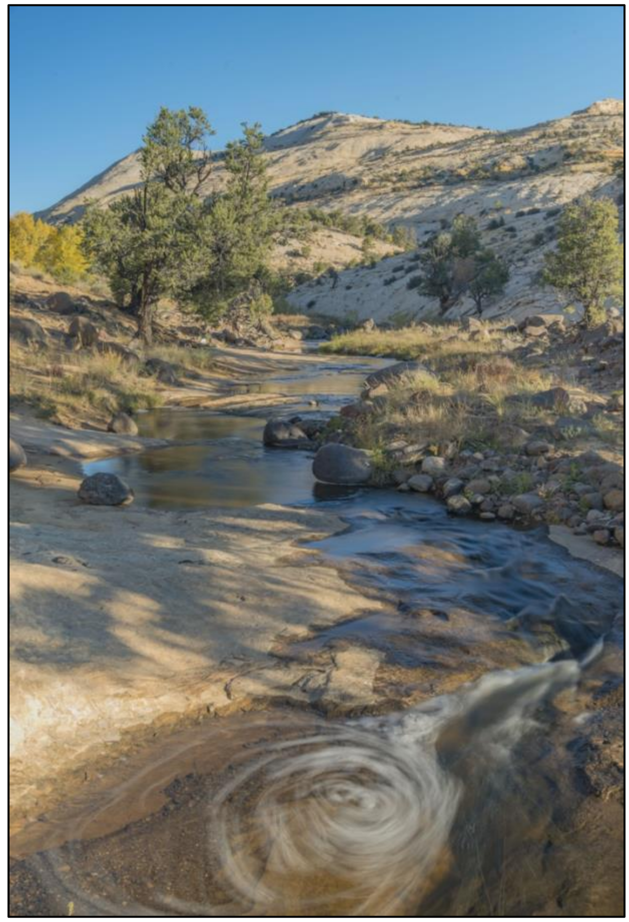
Key Findings

- **Wilderness designation of intact ecosystems within the Colorado Plateau region and surrounding areas would likely result in the permanent protection of important climate refugia.**
- **Climate refugia facilitate the persistence of native species, buying time for range shifts and/or genetic adaptation to changing conditions. Refugia also protect populations from extirpation following extreme events (e.g., severe drought or wildfire), allowing later recolonization.**

2.2. Increased connectivity to facilitate species migration/dispersal and range shifts

In order for plants and wildlife to cope with the impacts of rapid climate change, it is critical to expand protected area networks to include ecologically-intact landscapes that enhance connectivity among suitable habitat patches (*121*, *129*, *143*, *144*). Proposed ARRWA lands includes many large, unprotected areas that have been identified as having high conservation value due to their ability to maintain and/or enhance ecological connectivity among existing wilderness areas and national parks (*3*, *124*–*126*). Areas around San Rafael Swell and Canyonland National Park of the Colorado Plateau and

parts of the Great Basin in western Utah also represent higher-than-average vegetation community diversity and topographic complexity (*124*), further supporting their ability to protect biodiversity (*145*) and provide refugia for species with limited mobility or dispersal ability (*136*). Strong conservation protection of these lands is critical because they are also considered of high value for energy development (*126*, *146*, *147*), which fragments wildlife habitat and key migration corridors (*148*, *149*).
Maintaining connected landscapes increases species movement (*150*) and gene flow (*55*), reduces the risk of extirpation in isolated populations (*151*, *152*), and facilitates access to suitable habitat patches that can act as “stepping stones” to facilitate range shifts (*121*, *132*, *142*). For instance, Bothwell et al. (*55*) found that connected riparian networks increase genetic diversity of narrowleaf cottonwood (*Populus angustifolia*), a foundational riparian species in the western U.S. However, gene flow is likely to be threatened by climate change as more streams shift from perennial to intermittent flows. As such, Bothwell et al. (*55*) identified protection of dispersal corridors in the Colorado Plateau drylands as a high priority to maintain cottonwood populations in surrounding states. Studies evaluating the effectiveness of actions focused on increasing connectivity suggest that protecting natural corridors (i.e., those that already exist on the landscape) is more effective than constructing corridors (*150*) or improving habitat quality of unprotected areas (i.e., through the establishment of hedgerows, marginal field strips, or semi-natural forest patches; *153*).



A riparian corridor in Grand Staircase-Escalante National Monument (Photo: © Jeff Foott).

In a long-term study of landscape corridors in South Carolina, Damschen et al. (*154*) found that corridors increased plant colonization and decreased extinction rates (by 5% and 2%, respectively) across plant species with diverse life histories, leading to steady increases in species richness over the course of the 18-year study. It is unlikely that protected area networks can fully prevent the regional extirpation of native species due to climate change (*121*, *153*), and significant shifts in community composition may still occur within individual protected areas due to the differential impacts of climate change on individual species (*121*). However, it is highly likely that protection of areas that significantly increase landscape connectivity and represent a range of environmental conditions will minimize loss of biodiversity at larger spatial scales (*118*, *121*, *126*, *155*, *156*).

Key Findings

- **The proposed ARRWA lands overlap with large, unprotected areas that have been identified as critical landscape corridors due to their potential for maintaining and/or enhancing ecological connectivity. Because many of these lands are also targeted for energy development, strong conservation protection is critical.**
- **Increased landscape connectivity facilitates species movement, which enhances gene flow, reduces the risk of extirpation in isolated populations, and increases access to suitable habitat patches that can act as "stepping stones" to support range shifts.**

2.3. Reduced surface disturbances that exacerbate climate change impacts

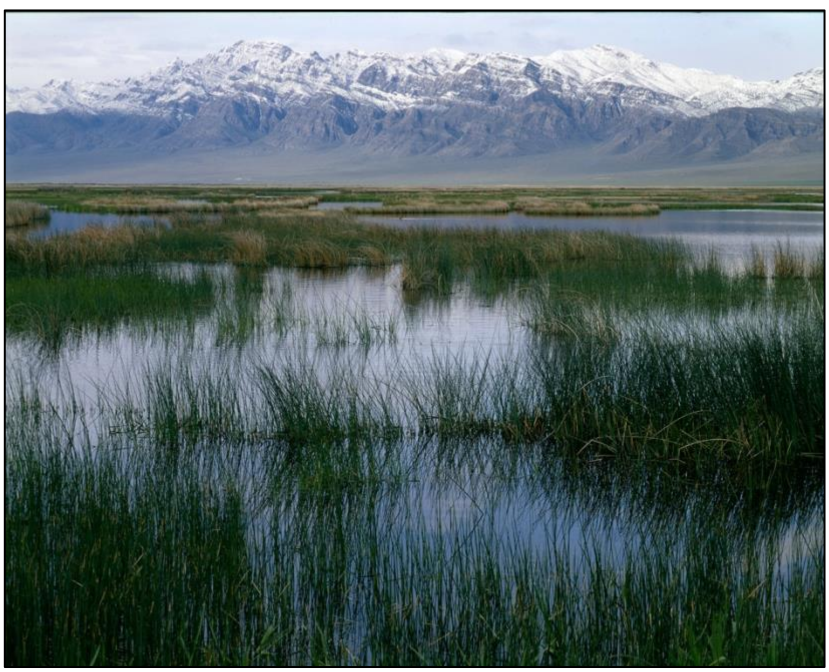
ARRWA lands proposed for wilderness protection are remote but highly valued for recreation, livestock grazing, extraction of abundant mineral and fossil fuel resources, and, increasingly, for renewable energy development such as utility-scale solar arrays (*1*, *146*, *147*, *157*, *158*). These land uses result in surface disturbances that degrade ecosystems through vegetation removal, soil compaction and erosion, damage to biocrusts, spread and establishment of invasive plants, hydrological changes, loss of habitat for rare plants and wildlife, and increased wildlife stress or direct mortality (*47*, *79*, *87*, *88*, *107*, *159*). Additionally, the biocrusts that stabilize soils and support plant establishment in much of the region are extremely fragile, making them vulnerable to damage even by very infrequent, low-intensity disturbances (*16*, *74–76*, *107*, *109*, *160*). Once disturbed, biocrusts can take decades or centuries to recover (*74*, *107*, *161*). These changes are generally associated with declines in ecosystem resilience (*47*, *87*), particularly in arid systems where low nutrient availability and dry growing conditions result in slow growth of plant communities (*162*, *163*). Increased temperatures and reduced moisture projected with climate change are likely to further slow ecosystem recovery (*70*, *79*), potentially allowing ecosystems to reach tipping points that result in abrupt and irreversible changes in functioning (*45*).

Dust and ORV tracks at Factory Butte in the San Rafael Swell (Photo: © Ray Bloxham).

Prevention or mitigation of surface disturbances is frequently cited as critical to support the ability of ecosystems to cope with and respond to the impacts of rapid climate change (*79*, *87*, *129*, *164*). Because the primary purpose of the Wilderness Act is to prevent human land uses and activity that degrade natural landscapes, wilderness designation represents a particularly effective tool to limit interactions between anthropogenic impacts and climate stressors in areas with intense pressure for development, resource extraction, or recreational use (*2*, *22*).

Multiple studies suggest that prevention of surface disturbances is critical to limit increases in the risk of dust emissions associated with warmer, drier climate conditions, particularly in dry and erodible soils (*12*, *77*, *79*, *165*). While conditions that promote wind erosion are present across much of the Colorado Plateau and Great Basin regions of Utah (*80*, *166–168*), southeastern Utah is at particularly high risk based on a combination of high aridity and fine saline soils associated with shale formations (*12*, *79*). Intact biocrusts enhance resistance to even very high wind speeds (*16*, *169*), and the presence of vegetation reduces the ability of wind to reach the soil surface (*170*). Where biocrusts are disturbed and vegetation loss increases the extent and connectivity of bare patches, wind erosion is significantly increased, particularly during periods of drought (*12*, *75*, *77*, *79*, *170*, *171*). A study near Moab, Utah found that surface disturbances such as ORV use and high concentrations of livestock were associated with substantially higher dust emissions compared to other land uses, with ORV use increasing erosion by almost 260 times the level observed at minimally disturbed sites (*12*). These results highlight the importance of preventing surface disturbances on ARRWA lands, where highly erodible soils are often stabilized by intact biocrusts.

Wilderness designation also represents an effective strategy to preserve the hydrological benefits provided by intact watersheds by preventing surface disturbances that negatively impact freshwater resources (*22*, *90*, *172*, *173*). Ecosystem hydrology, freshwater availability, and water quality are clearly linked to intact, undisturbed watersheds that provide benefits such as groundwater recharge, erosion and sediment control, moderation of overland runoff, water filtration/purification, and provision of high-quality plant and wildlife habitat (*90*, *172–176*). For instance, the use of ORVs on arid land compacts soils, significantly reducing water infiltration (*177*, *178*). Large undisturbed areas, such as wilderness, are also associated with aquatic systems that are more resilient to disturbances and can act as strongholds for rare and/or climate-sensitive species (*90*, *179*). These include native fish (*179*), which will increasingly depend on high-quality habitats as climate change impacts streamflow volume, water temperature, and dissolved oxygen levels (*50*, *52*).



Intact ecosystems, such as occur in the Fish Springs Range of Utah's West Desert, provide critical hydrological benefits (Photo: © Ray Bloxham).

Reducing surface disturbances by limiting human land uses and development also decreases opportunities for invasive plant seed dispersal and for colonization of disturbed soils, as well as the risk of human ignitions (*47*). For example, most exotic plants in Canyonlands National Park are limited to roadside verges and other areas with disturbed soils (e.g., around livestock water sources), and road improvement is associated with increases in exotic plant cover and species richness within adjacent habitats (*91*). This suggests that many species are less likely to spread in the absence of surface disturbances, and that even highly invasive species such as cheatgrass can be limited by preventing road construction and improvement (*91*). Within sagebrush ecosystems, limiting gaps between patches of vegetation and maintaining biological soil crusts have also been associated with increased resistance to exotic plant invasions (*180*). Although few studies have explicitly evaluated the impact of protected areas on invasive species, Gallardo et al. (*181*) found that, in Europe, remote protected areas with very low human density were more resistant to exotic plant invasions compared to those that were more recently designated and had higher levels of human activity. They also modeled the expansion of invasive plants under future climate conditions, and found that invasive species richness was projected to be significantly lower inside protected areas than outside of them (*181*). Taken as a whole, these studies suggest that protection of undisturbed habitats with low levels of human activity increases the resistance of ecosystems to invasive plants that are likely to accelerate climate-driven loss of biodiversity and ecosystem functioning (*47*).

Sagebrush surrounded by cheatgrass (Photo: Jennifer Cartwright/USFWS).

Key Findings

- **Preventing surface disturbances on ARRWA lands would likely limit the degree to which these disturbances exacerbate the impacts of climate change on species and ecosystem processes.**
- **Reducing surface disturbances that damage biocrusts and increase wind erosion can benefit Colorado River flows, which are significantly reduced by earlier mountain snowmelt caused by long-range transport of dust emissions from Utah soils.**
- **Preventing vegetation loss and soil disturbances preserves the hydrological benefits provided by intact watersheds and increases ecosystem resistance to invasion by exotic plants, both of which are critical to limit climate-driven losses in biodiversity and ecosystem functioning.**

Chapter 3: Contribution of ARRWA lands to climate change mitigation efforts

In order to meet any goal focused on climate change mitigation, it is necessary to drastically reduce greenhouse gas emissions from the production and use of fossil fuels while simultaneously increasing carbon sequestration (i.e., capture) and storage within plants and soils (*182*, *183*). The Paris Agreement sets a goal of limiting global surface warming to no more than 2.0°C above pre-industrial levels, and hopefully to 1.5°C (*184*), in order to avoid severe and irreversible impacts of climate change that increase exponentially with global temperature (*185*). The latest Intergovernmental Panel on Climate Change (IPCC) report states that, in order to have a 66% probability of limiting warming to 2.0°C, global emissions must decline 25% by 2030 (compared to 2010 levels) and reach net zero by 2070 (*185*). Accomplishing this goal would require the amount of carbon released into the atmosphere after 2018 to remain under 1,170 gigatons carbon (Gt CO_2; i.e., billion tons of carbon) from 2018 onwards, which is known as a "carbon budget". For comparison, global emissions would need to decline 45% by 2030 and reach net zero around 2050 to limit warming to 1.5°C, with a remaining carbon budget of 420 Gt CO_2 (*185*). However, the Intended Nationally Determined Contributions (INDCs) submitted by countries under the Paris Agreement are largely incompatible with the target warming limit of 1.5°C (*186*).

Natural gas development near Utah's White River (Photo: © Ray Bloxham).

Land preservation can play an important role in meeting climate mitigation targets by preventing the loss of carbon sequestration and storage following land-use conversion and surface disturbances (*187*, *188*). Similarly, multiple studies have highlighted the importance of careful, consistent calculation of potential lifecycle emissions in order to support management decisions that will prevent emissions from exceeding remaining carbon budgets (*189*–*192*). Although there are no studies that specifically examine the climate mitigation benefits of wilderness protection, the strength and permanence of land protection under the Wilderness Act mean that wilderness lands have high potential to prevent emissions associated with fossil fuel development while also enabling ecosystems to continue sequestering and storing carbon that would otherwise be contributing to climate change (see Box 1).

This chapter evaluates the potential climate mitigation benefit of wilderness protection for ARRWA lands, which are broadly focused within two general categories:

- Prevention of additional greenhouse gas emissions through reduced fossil fuel extraction and use; and

- Removal of existing atmospheric greenhouse gases through carbon sequestration and storage within plants and soil.

Box 1. Additionality, Permanence, and Leakage

In order for climate mitigation efforts to truly be effective, it is important to consider the concepts of additionality, permanence, and leakage:

- **Additionality** refers to emission reductions or carbon sequestration that is additional to what would occur at baseline levels (i.e., using benchmark practices and/or in the absence of a particular policy).
- **Permanence** refers to the endurance of mitigation benefits, which is critical given that carbon dioxide emissions can persist in the atmosphere for hundreds of years. Mitigation efforts that emphasize short-term gains at the expense of permanence may end up have significantly less benefit when considered at longer time scales.
- **Leakage** refers to off-site emissions that may reduce the apparent benefits of climate mitigation efforts (e.g., by concentrating human activities on adjacent lands).

3.1. Avoided greenhouse gas emissions from oil, gas, and coal kept in the ground

3.1.1. Background

Pumpjack at an oil well on Big Flat near Dead Horse Point State Park (Photo: © Neal Clark).

Nationally, a large proportion of energy production comes from public lands in the western U.S. (*193*), which are leased by federal agencies to private companies for oil, gas, and coal extraction and sale. While these leases offer a limited number of years for leaseholders to begin extraction (10 years for oil/gas or 20 years for coal), leases last indefinitely once production begins (*189*). Federal agencies are not required to track greenhouse gas emissions associated with fossil fuels on public lands, but studies suggest that they account for over 20% of national emissions (*193*, *194*) and up to 50% of all remaining U.S. fossil fuels (*189*). A recent report by The Wilderness Society (*191*) found that if lease sales on public lands continue at the same rate as they have during the past three years (Jan 2017–Jan 2020), lifecycle emissions associated with energy production on public lands and its end use consumption would be incompatible with the reductions required to avoid a 1.5°C rise in global temperature as set out by the IPCC (see *185*). Similarly, Mulvaney et al. (*189*) found that the extraction and consumption of remaining recoverable fossil fuels in the U.S. (both leased and unleased) would result in emissions of 492 Gt CO_2 – an amount that would surpass the entire global carbon budget for 1.5°C targets. Of these potential emissions, 91% were associated with unleased fossil fuel resources (*189*). These analyses and others (*182*, *190*, *192*) suggest that keeping oil, gas, and coal in the ground has the potential to significantly contribute to climate change mitigation efforts. Because the Wilderness Act permanently prohibits new lease sales and resource extraction (*20*), it is reasonable to assume that any fossil fuels underlying designated wilderness lands will remain there, preventing the release of greenhouse gases associated with the production and combustion of those fuels. However, there are no studies to date that specifically address the impact of wilderness protection on greenhouse gas emissions.

We estimated the amount of oil, gas, and coal that could be produced on unleased ARRWA lands, and then calculated the greenhouse gas emissions that would occur if all of those areas were leased and fully developed in the future. While it would not be possible to extract 100% of all fossil fuel resources on every acre (due to multiple use conflicts, economic constraints, and other factors), the results of this analysis represent an estimate of greenhouse gases that would be permanently sequestered under ARRWA lands if they were fully protected as wilderness areas.

3.1.2. Methods

Our analysis uses publicly-available information on fossil fuel resources and typical production within the region to estimate the total amount of fossil fuels that could be extracted from ARRWA lands, which included crude oil, natural gas (including coalbed methane), coal, oil shale, and tar sands.[1] For all fossil fuels, estimated extraction was calculated by determining the proportion of ARRWA lands that overlapped with resources within a specific geological formation (e.g., basin/play, coalfield). For crude oil, natural gas, and coal, this analysis includes only resources that are considered technically recoverable (i.e., could be extracted using current technologies) in areas that are not already under active oil, gas, or coal leases. Wherever possible, we improved the accuracy of the production estimates by including parameters that were location-specific (e.g., total production from representative oil and gas wells within the region) and/or that reflected the economic feasibility of energy development. Because it is not yet technically or economically feasible to extract oil shale and tar sands, the totals presented here are based on estimates of in-place resources (i.e., the entire fossil fuel resource in a geologic formation regardless of recoverability or economic viability).

Greenhouse gas emission factors are used to convert fossil fuel volumes into the amount of greenhouse gases emitted, and they account for downstream emissions that result from processing, transport/refinement, and combustion during end use. For this analysis, potential greenhouse gas emissions associated with crude oil, natural gas, and coal on ARRWA lands were calculated using standard emission factors for carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) published by the Environmental Protection Agency (*195*). Emissions are reported in units of carbon dioxide equivalent (CO_2e) based on 100-year global warming potential (a measure of how much heat a greenhouse gas traps in the atmosphere relative to carbon dioxide) for methane and nitrous oxide

[1] See Appendix A for a full description of the methods used in this analysis, including data sources, scenario parameters, and significant assumptions/sources of uncertainty.

published in the most recent IPCC Assessment Report (*196*).[2] For oil shale and tar sands, no standardized emission factors were available, so we estimated lifecycle greenhouse gas emissions using the Climate Pollution Calculator[3], an online tool created in conjunction with a report by Mulvaney et al. (*189*).

For crude oil and natural gas, direct emissions (sometimes called upstream emissions) from oil, gas, and coalbed methane wells were also included based on estimates from representative wells (*191*, *197*, *198*). However, we were unable to estimate direct emissions from active and abandoned coal mines, since there is no way to know how many mines would be placed in a given area. No information on direct emissions was available for oil shale or tar sands.

For all fossil fuels, we created three scenarios (low, reference, high) to account for a range of uncertainties associated with greenhouse gas estimates, including potential variability in production, transport/refinement, combustion, and climate-carbon feedback. Oil, natural gas, and coalbed methane scenarios were based on greenhouse gas emissions associated with low and high production compared to the reference scenario, using methodology from TWS (*191;* see Table B2 for resources calculated for all production scenarios). Scenarios for coal, oil shale, and tar sands were based on methodology from Mulvaney et al. (*189*), modified to reflect the availability of parcel-level data used to calculate overlap between fossil fuel deposits and ARRWA lands. This resulted in a single resource estimate, which was used as the reference scenario. For coal, the Climate Pollution Calculator was used to calculate low and high greenhouse gas emissions scenarios using the reference scenario as a baseline. Because production of oil shale and tar sands is not technically or economically feasible, these are included only in the high scenario (see Appendix A for explanation of scenarios for each fossil fuel).

It is important to note that this analysis represents an estimate of greenhouse gases associated with fossil fuels that will be permanently sequestered if these lands are protected under the ARRWA, but this study was unable to account for many factors that might prevent fossil fuel resources from being extracted and used even in the absence of wilderness protection. These factors include multiple use conflicts (e.g., the inability to extract oil and gas resources where a coal mine is placed), land use restrictions (e.g., the presence of cultural sites or protected species), and economic and technological constraints, among other factors. This study is also unable to account for market effects or substitution (i.e., increased development of fossil fuels in other areas) following permanent restrictions on ARRWA lands, which would result in leakage that reduces the net mitigation benefit of protection (e.g., *190*).

3.1.3. Findings

Currently unleased fossil fuels underlying ARRWA lands may include 14,956 million barrels of oil resources (MMBbl), which are comprised of 12,505 MMBbl from crude oil wells, 2,225 MMBbl from oil shale, and 226 MMBbl from tar sands deposits (see Table 2). Natural gas resources total 14,264 billion cubic feet of gas (Bcfg), which is estimated to include 11,939 Bcfg from gas wells and 2,325 Bcfg from coalbed methane wells. Finally, coal resources are estimated to be 9,136 million short tons (MMST), an

[2] See Table B1 in Appendix B for greenhouse gas emissions calculated using the 20-year GWP.

[3] https://www.biologicaldiversity.org/climatepollutioncalculator/ (accessed June 26, 2020)

amount that accounts for a large proportion (59%) of the estimated remaining recoverable coal resources within the state of Utah (*199*).

Table 2. Estimates of oil (MMBbl), gas (Bcfg), and coal (MMST) resources on ARRWA lands and associated lifecycle greenhouse gas emissions (million metric tons of carbon dioxide equivalent; MMt CO_2e) based on 100-year global warming potential under low, reference, and high scenarios.

		Greenhouse Gas Emissions (MMt CO_2e)		
Fossil Fuel Type	**Resources**	**Low**	**Reference**	**High**
Crude oil	12,505.0	845.7	5,453.7	8,165.2
Oil shale	2,224.9			775.5
Tar sands	225.6			77.3
Sum of oil resources *(MMBbl)*	14,955.5	845.7	5,453.7	9,018.0
Natural gas	11,938.7	105.7	681.6	1,006.9
Coalbed methane	2,325.0	36.1	160.7	224.0
Sum of gas resources *(Bcfg)*	14,263.7	141.8	842.3	1,230.9
Coal	9,136.0	13,376.2	17,769.1	24,621.3
Sum of coal resources *(MMST)*	9,136.0	13,376.2	17,769.1	24,621.3
TOTAL GREENHOUSE GAS EMISSIONS (MMt CO_2e)		**14,363.7**	**24,065.2**	**34,870.3**

The fossil fuels underlying ARRWA lands are associated with 24,065 MMt CO_2e potential greenhouse gas emissions in the reference scenario (range of 14,364 to 34,870 MMt CO_2e; see Table 2). Of these potential emissions, coal accounts for the largest proportion (~70%) and tar sands for the smallest (0.2%). Emissions per unit of area (a rough measure of energy-intensiveness) are highest for oil shale at 0.13 MMt CO_2e per acre, which is at least 7.5 times more intensive than for coal and over 1,400 times higher than for coalbed methane (see Table B1 for the calculated acreage of ARRWA lands used for each fossil fuel category). When accounting for the higher potency of short-lived pollutants such as methane by using a 20-year GWP, full development of all unleased fossil fuel resources underlying ARRWA lands could result in cumulative greenhouse gas emissions of 35,987 MMt CO_2e under the reference scenario (see Table B2).

The findings of the current analysis suggest that protection of ARRWA lands as wilderness areas has the potential to permanently sequester 24,065 MMt CO_2e (and up to 34,870 MMt CO_2e under the high scenario) by preventing the development of unleased fossil fuel resources. This is an amount equivalent to 3.6 years of greenhouse gas emissions for the entire U.S. at 2018 levels, which were 6,644 MMt CO_2e (*200*). If the entire amount of fossil fuels on ARRWA lands were extracted and used, it would account for 5.7% of the remaining carbon budget required to avoid a 1.5°C rise in global temperatures and 2.1% of the carbon budget required to prevent a 2.0°C increase (see *185*). Despite study limitations and the high uncertainty inherent in these estimates, the findings of this study illustrate the significant contribution that wilderness protection could have on climate mitigation by permanently preventing greenhouse gases associated with development of these fossil fuels from contributing to the remaining carbon budget.

Although preexisting active mining claims and oil/gas leases would not be subject to cancellation following protection of ARRWA lands, resource extraction on existing claims and leases may be hampered by additional mandates associated with the Wilderness Act including land-use restrictions, limited access, and surface restoration requirements (*201*). Negative publicity associated with fossil fuel extraction in and around wilderness areas can also contribute to lack of lease development (*201*), particularly as the public becomes increasingly aware of the importance of climate change mitigation. A recent survey of mining claims in four U.S. Forest Service wilderness areas within the Greater Yellowstone Ecosystem found that although 11 claims were still active by May 2017, none of these had ever resulted in mining (*202*). This suggests that wilderness protection may have indirect benefits on climate change mitigation by suppressing fossil fuel extraction on surrounding lands.

Coal Hollow Mine near Bryce Canyon National Park (Photo: © Ray Bloxham).

Key Findings

- **Because the Wilderness Act permanently prohibits new lease sales and resource extraction, it is reasonable to assume that wilderness designation will prevent the release of greenhouse gases associated with the production and combustion of any fossil fuel underlying those lands.**
- **Protection of ARRWA lands has the potential to permanently sequester between 14,364 and 34,870 million metric tons of carbon dioxide equivalent. This amount is comparable to 3.6 years of national greenhouse gas emissions at 2018 levels. If the entire amount was extracted and used, it would account for almost 5.7% of the global carbon budget required to avoid a 1.5°C rise in temperature worldwide.**

3.2. Carbon sequestration and storage

3.2.1. Background

Maximizing carbon sequestration (i.e., the rate at which carbon is removed from the atmosphere) and carbon storage (i.e., the amount and distribution of carbon stored) within plants and soil is a critical component of climate change mitigation (*24*, *123*, *182*, *183*, *187*, *203*). While highly productive ecosystems (e.g., tropical or temperate rainforests) are most often recognized as having high potential for climate mitigation (*5*, *203*, *204*), dryland ecosystems likely play an important role in global carbon sequestration because they cover about 47% of the global land area and can act as long-term carbon sinks under the right conditions (*205*, *206*). For instance, high biocrust cover in dryland soils supports the formation of caliche, which are crystals of calcium carbonate that result from reactions between desert biocrust fungi and the respiration of carbon dioxide from plant roots and microbes (*113*, *205*, *207*). The underground accumulation of caliche can result in significant amounts of inorganic carbon stored in the soil (*205*, *207*, *208*), representing an important global carbon sink (*209*, *210*).


Biological soil crusts (Photo: © Laura Welp).

Increased atmospheric carbon dioxide, warming temperatures, altered precipitation patterns, and climate-driven changes in disturbance regimes are likely to impact organic and inorganic carbon sequestration and storage in dryland ecosystems (*45*, *67*, *72*, *73*, *206*, *210*–*213*). Anthropogenic surface disturbances also have a significant impact on these processes due to vegetation loss, reduced microbial activity, and physical damage to soils and desert biocrusts (*15*, *17*, *109*, *112*, *113*, *205*). Together, climate-driven changes and anthropogenic disturbances are likely to impact carbon sequestration rates and stored carbon in dryland ecosystems. For instance, trampling of biocrusts may accelerate shifts in biocrust community composition associated with warmer temperatures, resulting in greater dominance of early-successional biocrust communities with lower carbon sequestration rates compared to late-successional mosses and lichens (*70*). Increases in drought-related mortality and increased spread of invasive grasses are also expected to drive more frequent and/or larger wildfires in the study region (*47*), resulting in the release of stored carbon (*214*). Although the impacts of climate change are ubiquitous even in remote areas, protection of wilderness areas would likely support their carbon sequestration and storage potential by preventing degradation from human disturbances.

This chapter first presents modeling results used to estimate ecosystem carbon stocks on ARRWA lands under recent historical (1981–2010) and late-century (2069–2099) climate conditions under a high-emissions scenario (RCP 8.5). This is followed by a discussion of the role that minimizing surface disturbances will need to play in preventing loss of vegetation, damage to biocrusts, and changes in soil properties that can significantly reduce ecosystem capacity to sequester and store carbon on ARRWA lands.

3.2.2. Methods

The MC2 is a dynamic global vegetation model (DGVM) that simulates changes in vegetation and associated changes in ecosystem organic carbon stocks (i.e., plant biomass and soil organic carbon [SOC]) under historical and future conditions, which include projections of climate change and human land use (*212*, *215*, *216*). MC2 simulates potential vegetation types based on lifeforms rather than species (e.g., evergreen and deciduous needleleaf and broadleaf trees and shrubs; C3 and C4 herbaceous plants such as grasses, forbs, and sedges). Changes in potential vegetation are determined at annual time steps, and the model considers climate conditions (e.g., temperature, precipitation, evapotranspiration) and atmospheric CO_2 as well as wildfire and competition for soil moisture and nutrients. MC2 simulates the interactions among these factors by modeling primary productivity, decomposition, soil respiration, and nutrient release over time to determine the amount of carbon stored within plant and soil carbon pools. For the purposes of this study, fire suppression was included as a relevant factor but human land use was not because proposed wilderness areas have not, by definition, experienced significant degradation or land-use conversion.

Model inputs include soil characteristics, atmospheric CO_2 concentrations, and monthly climate data for minimum and maximum temperature, precipitation, and vapor pressure at a 2.5 arc-minute (~4 km) spatial resolution. Climate data for the historical period (1980-2010) was derived from Daly et al. (*217*). Climate projections for the late-century time period (2069–2099) were represented by three global climate models (CanESM2, GFDL-ESM2M, IPSL-CM5A-MR) from the Climate Model Intercomparison Project Phase 5 (CMIP5; see Table 3), which were run for Representative Concentration Pathway (RCP) 8.5. The three climate models were selected from a larger set of 20 that were statistically downscaled using the MACA algorithm (*218*). They were chosen for this project because they capture 50% of the range for projections of change in temperature and 100% of the range for precipitation projections for the state of Utah (see Figure 2).[4]

Table 3. Climate models used as inputs to MC2 for this study, using a late-century time period (2069–2099) and a high-emissions scenario (RCP 8.5).

Model Name	Temp.	Precip.	Source
CanESM2	*Hot*	*Wet*	Canadian Centre for Climate Modelling and Analysis
GFDL-ESM2M	*Warm*	*Dry*	NOAA Geophysical Fluid Dynamics Laboratory
IPSL-CM5A-MR	*Hot*	*Dry*	Institut Pierre-Simon Laplace

[4] Projection ranges used were from the Scatterplot Visualization of Future Projections online tool on the MACA website, accessed on June 26, 2020 at https://climate.northwestknowledge.net/MACA/vis_scatterplot.php.

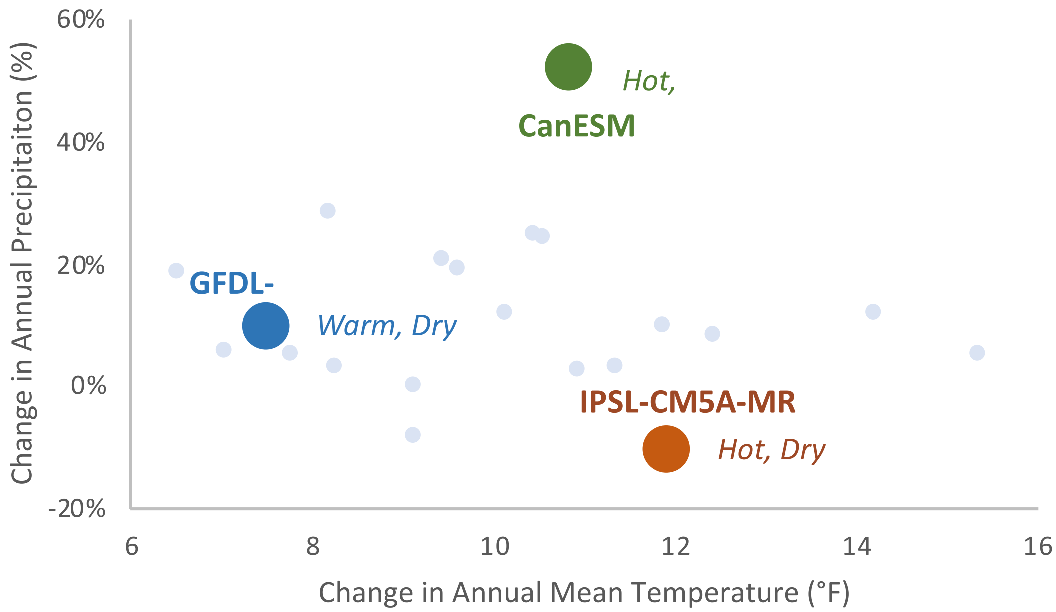


Figure 2. Comparison of change in annual mean temperature (°F) and annual precipitation (%) for the state of Utah across the three climate models used in this study. Light blue dots represent the 17 MACA-downscaled models not selected for this study.

3.2.3. Findings

For the historical time period (1981–2010), organic carbon stocks on ARRWA lands were 246,713,713 metric tons of carbon (Mt C), at an average of 27.3 Mt C/acre (see Table 4). By the end of the century, mean organic carbon stocks across all three emission scenarios are projected to be 271,005,695 Mt C, at an average of 30.0 Mt C/acre (see Figure 3). This change represents a 9.8% increase in carbon stocks by the end of the century, which is driven by modeled expansion of woody vegetation into areas currently dominated by herbaceous plants. Among the three climate models used for this study, the increase is most pronounced in the wettest future scenario (+11.4%) with less significant increases occurring in the hot/dry scenario (+7.8%), which represents a moderate decline in total annual precipitation.

Table 4. Total ecosystem carbon (Mt C), average carbon per acre, and change from historical carbon stocks for ARRWA lands under recent historical (1981–2010) and late-century (2069–2099) climate conditions using three climate models (CanESM2, GFDL-ESM2M, IPSL-CM5A-MR) and a high-emissions scenario (RCP 8.5).

Scenario	Total Ecosystem Carbon (Mt C)	Average Carbon (Mt C) per Acre	Change From Historical (%)
Historical	246,713,713	27.3	N/A
CanESM2 *(Hot, Wet)*	274,744,739	30.4	+11.4%
GFDL-ESM2M *(Warm, Dry)*	272,384,830	30.1	+10.4%
IPSL-CM5A-MR *(Hot, Dry)*	265,887,517	29.4	+7.8%
Model Average	**271,005,695**	**30.0**	**+9.8%**

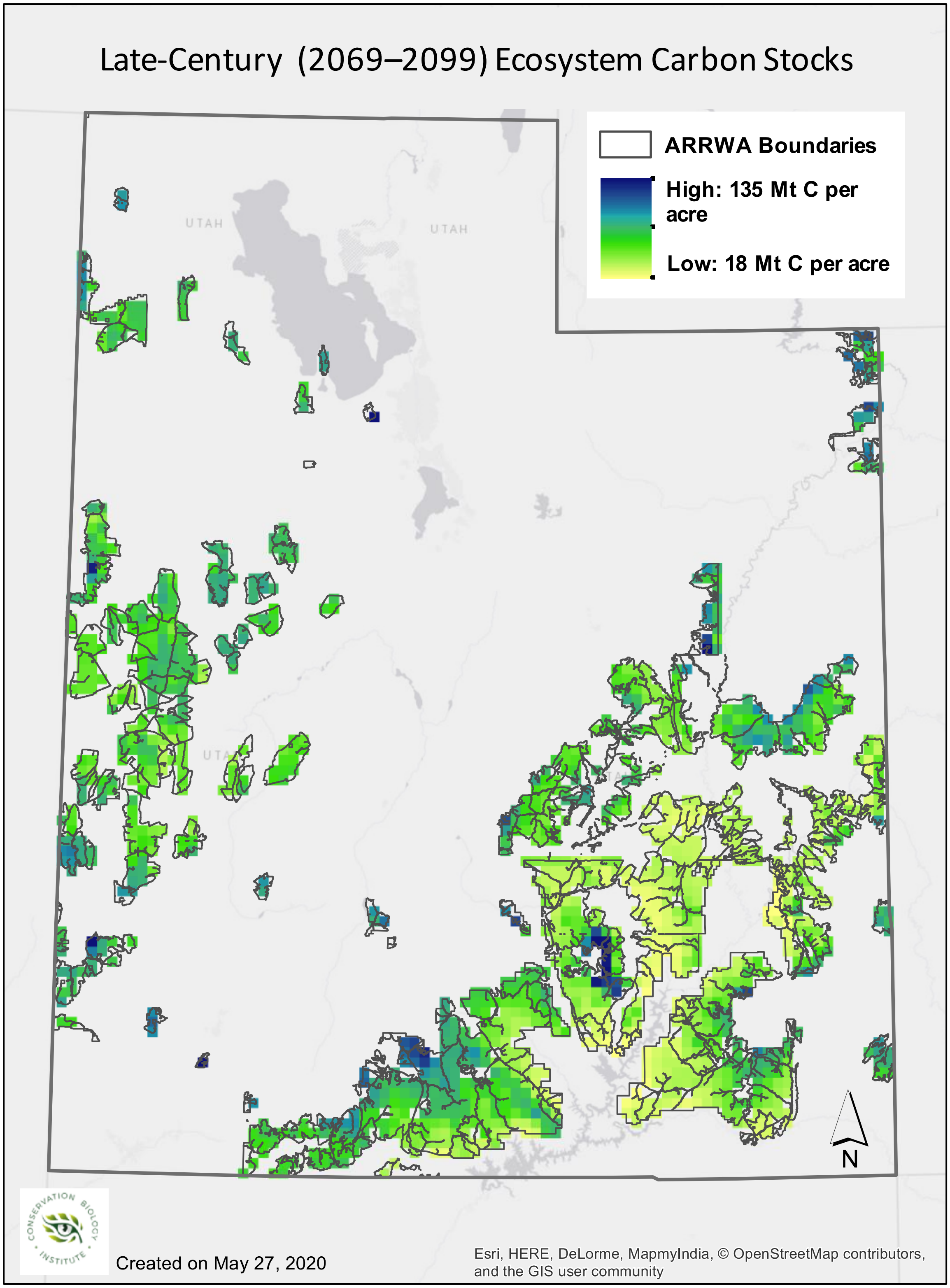


Figure 3. Late century (2069–2099) ecosystem carbon stocks (in Mt C/acre), using the average of three climate models (CanESM2, GFDL-ESM2M, IPSL-CM5A-LR) run under a high-emissions scenario (RCP 8.5).

Within ARRWA lands, average regional carbon per acre under future climate conditions is highest in the Uinta Basin in the northeast corner of the state (38.3 Mt C/acre). Other areas that represent relatively high carbon density include the Book Cliffs (33.8 Mt C/acre) and Great Basin (32.9 Mt C/acre) regions. These three regions are also projected to experience the most significant increases from historical carbon stocks (19.5% increase for the Great Basin, 16.4% for the Uinta Basin, 16.2% for Book Cliffs). By contrast, average carbon density is lowest in areas around Canyonlands National Park (23.7 Mt C/acre) and Glen Canyon (24.0 Mt C/acre). The smallest change in carbon density is for the San Rafael Swell region (3.4%), although areas around Canyonlands National Park and the Henry Mountains also have relatively small increases compared to other areas (4.2% and 4.7%, respectively).

Dragon Canyon in Utah's Book Cliffs (Photo: © Ray Bloxham).

The results of this study are consistent with the MC2 results of Bachelet et al. (2015, 2018), as well as other studies that suggest increased carbon sequestration is likely to occur as a result of expanding pinyon-juniper woodlands and type conversion of native grassland to shrubland (*67*, *103*, *104*, *219*). It is important to note that this increase was captured by the model as a result of climate changes, and so are not considered a direct benefit of ARRWA. However, the ARRWA may play a role in preventing the spread of invasive grasses, which were not included in the model but are known to exacerbate climate-driven increases in fire frequency and extent that can reduce carbon stocks (*214*). Other factors not considered within this model include pest outbreaks or extreme events, which can be associated with decreases in stored carbon (*211*, *215*), and the presence of soil inorganic carbon (SIC) stocks. The latter is likely to account for a significant amount of stored carbon on ARRWA lands, given that SIC is the predominant form of soil carbon within many dryland ecosystems (*205*, *209*). However, SIC is generally not represented within carbon modeling efforts because it is still relatively poorly studied in comparison to SOC.

There is little information available on SIC distribution that would enable an estimate of SIC stocks on ARRWA lands. Studies in hot desert ecosystems found that SIC stocks were typically 30,500 grams per square meter (g C m^{-2}; *208*) and can accumulate at a rate of 0.12–0.42 g C m^{-2} per year (Schlesinger 1985, Marion et al. 2008 cited in (*220*). Guo et al. (*209*) found that the mean SIC within the upper 2 meters (6.6 ft.) of Utah soils was 18,000 grams per square meter (range of 9,200–28,600 g C m^{-2}). Based on this state-wide average value and using a calculated soil area of 9,017,886 acres (*221*), estimated SIC on ARRWA lands could account for 656.9 million metric tons of carbon (MMt C). Even using the low end of the range, ARRWA lands could hold 335.7 MMt C, which is significantly higher than the modeled carbon stocks for plants and SOC.

Overall, the results of this analysis suggest that ARRWA lands have the potential to sequester and store up to 271,005,695 Mt C from plant biomass and SOC by the end of the century, and may hold more than double or triple that amount when SIC is included. This represents an increase of 9.8% in carbon stocks compared with 1981–2010, largely due to climate-driven expansion of woody vegetation into areas currently dominated by grasses and forbs. To put this into context, the current organic carbon stocks on ARRWA lands represent 25% of the average total ecosystem carbon stocks on Utah federal lands from 2005 to 2014, and 0.4% of carbon stocks on all federal lands in the U.S. (*194*).

3.2.4. Surface disturbances and carbon sequestration/storage

While the above analysis provides an estimate of the potential for carbon sequestration and storage on ARRWA lands, it assumes that these processes are not impacted by human activities and land-use change that reduce ecosystem capacity to sequester and store carbon. This occurs directly through the removal of above-ground plant biomass that captures and stores carbon (*67*, *103*, *104*), as well as indirectly through changes in soil carbon cycling or physical damage and loss of soil biocrusts that impacts organic and inorganic carbon stocks (*113*, *219*, *222*). Surface disturbances that may be associated with carbon sequestration and storage declines in southwestern U.S. dryland ecosystems include livestock grazing, ORV use, road construction, energy development, and mechanical vegetation treatments (*102*, *103*, *105*, *113*, *207*, *223*).

Vegetation cover is higher in undisturbed areas than those that have been grazed or cleared, which maximizes carbon stored within above- and below-ground plant biomass (i.e., leaves, stems, roots) (*102*, *224*). Pinyon-juniper woodlands and shrublands are the major contributors to above-ground carbon storage in arid and semi-arid ecosystems (*103*, *105*, *224*, *225*), and many studies have suggested that expansion of woody vegetation under future climate conditions is likely to be associated with increased carbon sequestration in dry areas (*67*, *104*, *212*, *215*, *219*). However, these areas are often targeted for mechanical vegetation treatments (e.g., mastication, chaining) due to a concern that increased fuel loads will enhance the risk of high-severity fires that release stored carbon (*102*, *226*). Studies in arid and semi-arid forests and woodlands suggest that although these treatments may accomplish other management objectives, they often do not result in lower net loss of carbon stocks because the treatments themselves remove significant amounts of carbon at the landscape scale (*226*, *227*). Soil disturbances associated with mechanical vegetation treatments can also result in the expansion of cheatgrass and other invasive herbaceous plants (*102*), which play a role in reducing carbon stocks by increasing fire frequency and extent (*214*).

Mechanical removal of pinyon and juniper trees in Utah (Photo: © TWIG Media Lab).

In addition to changes in carbon stocks due to the direct loss of above- and below-ground biomass, surface disturbances have significant impacts on SOC (*222*, *223*, *228*, *229*). Ungrazed sites in southern

Utah have been associated with SOC pools 60–100% larger than those on grazed sites, likely due to higher organic matter inputs (associated with greater vegetative cover) and lower rates of soil erosion (*222*, *229*). In a study of semi-arid shrublands in Australia, Daryanto et al. (*223*)found that areas protected from grazing and shrub removal had significantly more SOC compared to areas disturbed by one or both of those factors. Preventing soil disturbances and supporting year-round plant cover through the Conservation Reserve Program in the Southern High Plains Region of Texas has also been found to increase soil microbial activity, resulting in greater soil carbon stocks (*106*).

Surface disturbances are strongly associated with changes in community composition and biogeochemical processes in desert biocrusts (*15*, *70*, *107–109*), which cover a significant proportion of ARRWA lands. Undisturbed biocrusts are dominated by late-successional moss and lichen communities (*70*), which have significantly higher rates of carbon sequestration compared to early-successional crusts (*73*, *108*, *207*). Undisturbed, late-successional biocrusts also lose significantly less carbon through leaching (*230*). Swanson (*113*) found that carbon loss from SIC pools was lowest in areas of the Colorado Desert (California) where soils and vegetation cover remained undisturbed.

Biological soil crusts play a critical role in carbon sequestration (Photo: Neal Herbert/NPS).

Overall, intact ecosystems sequester and store more carbon than those that are disturbed, making the protection of these areas a critical step in meeting near-term carbon sequestration goals (*122*, *123*, *182*, *183*, *203*, *204*). While there are many studies that specifically evaluate the carbon benefits of protected areas, they are focused on forested lands (*231*) and are not directly applicable to ARRWA lands dominated by arid systems with sparse vegetation. However, the clear negative impact of surface disturbances on both organic and inorganic carbon pools suggests that protection under the Wilderness Act would maximize potential carbon sequestration and storage in the dryland ecosystems that characterize ARRWA lands by preventing declines in plant biomass and intact biocrusts as well as altering carbon cycling processes.

Key Findings

- **ARRWA lands have the potential to sequester and store 271 million metric tons of carbon plant biomass and soil organic carbon by the end of the century, which represents a 9.8% increase in carbon stocks compared to the last 30 years.**
- **Permanent protection of intact dryland ecosystems is critical because surface disturbances can severely limit carbon sequestration and storage due to vegetation loss, damage to biocrusts, and changes in soil properties that impact carbon cycling due to their ability to maximize carbon sequestration and storage.**

Appendix A. Technical appendix for fossil fuel analysis

Estimates of crude oil, natural gas, and coalbed methane well production and associated greenhouse gases was done using the methodology from a recent report by TWS (*191*). For coal, oil shale, and tar sands, the methodology of Mulvaney et al. (*189*) was adapted as necessary. All spatial data was processed and analyzed using QGIS 3.10.1 (*232*). Because ARRWA lands are not contiguous or uniformly distributed, we were limited by the availability of parcel-level spatial data that would allow us to determine where ARRWA lands overlapped fossil fuel resources (see Table A1 for data sources).

Table A1. Data sources used for fossil fuel and greenhouse gas analysis.

Crude Oil/Natural Gas Resources	
Current oil and gas leases	Utah BLM 2020 (*233*)
Basin and play boundaries	EIA 2016 (*234*), EIA 2019 (*235*)
Well spacing and EUR for representative wells	EIA 2020 (*236*)
Standard emission factors and GWP	EPA 2020 (*195*), Myhre et al. 2013 (*196*)
Direct per-well emissions	TWS 2020 (*191*), Kleinfelder 2013 (*198*)
Coalbed Methane Resources	
Coal leases	Utah AGRC 2017 (*237*)
Basin and play boundaries	EIA 2007 (*238*)
Well spacing and EUR for representative wells	EIA 2020 (*236*)
Adjustment for direct emissions	Glancy 2013 (*197*)
Coal Resources	
Coalfield boundaries and 4-foot seams	Utah AGRC 2017 (*239*), M. Vanden Berg
Recoverable resources by coalfield	Utah Geological Survey 2020 (*199*)
Utah coal consumption by sector	EIA 2019 (*240*)
Sector-specific emissions factors and GWP	EPA 2020 (*195*), Myhre et al. 2013 (*196*)
Oil Shale Resources	
In-place resources by township	USGS Oil Shale Assessment Team 2010 (*241*)
Constraints on recoverable resources	Vanden Berg 2008 (*242*)
Emissions web calculator	Climate Pollution Calculator[5]
Tar Sands Resources	
Uinta Basin tar sand deposits	USGS 2002 (*243*)
In-place resources for major deposits	Schamel 2009 (*244*)
Emission web calculator	Climate Pollution Calculator[5]

[5] https://www.biologicaldiversity.org/climatepollutioncalculator/ (accessed June 26, 2020)

This analysis attempts to estimate the amount of fossil fuel resources that underlie ARRWA lands in order to determine the amount of greenhouse gas emissions that would be associated with the extraction and combustion of those fuels. Because it is impossible to account for all of the complex, interacting factors that influence whether fossil fuel resources are developed, we do not attempt to account for potential competition among different fuel types (e.g., co-occurring fossil fuel deposits). However, we have utilized location-specific parameters and constraints related to technical/economic feasibility whenever possible in order to increase the accuracy of these estimates and avoid unnecessary overestimation of recoverable resources. Additional sources of uncertainty associated with greenhouse gas emissions from fossil fuels includes method of extraction (efficiency), methane leakage rates, method of well/mine abandonment, transport distance, and end-use product, among others (*189*, *194*).

Because the Wilderness Act allows existing leases to be honored, we used the simple assumption that all active oil, gas, and coal leases on ARRWA lands would be fully developed and so excluded these from the acreage used to estimate fossil fuel resources. Similarly, we assumed that all unleased resources could be leased at some point in the future, as "no leasing stipulations" and other limitations based on current policies and land uses could be altered or eliminated. Spatial data representing current leases in Utah was obtained from the Utah Bureau of Land Management for oil and gas (*233*) and from the Utah Automated Geographic Reference Center (AGRC) for coal (*237*).

A.1. Crude oil and natural gas (including coalbed methane)

We used basin and/or play-specific assumptions of average well densities and estimated ultimate recovery (EUR) per representative well (*236*) to estimate production separately for oil/gas and coalbed methane wells. Spatial data and maps showing sedimentary basins (*234*), tight oil and shale gas plays (*235*), and coalbed methane fields (*238*) were used to determine the geographic distribution of production assumptions applied to ARRWA lands. The Great Basin region was excluded from our analysis because there is currently little oil and gas development in this region and so there are no corresponding EIA assumptions. However, undiscovered oil and gas resources have been reported by the USGS National Oil and Gas Assessment (*245–247*), and so it is possible that production could expand into this region in the future depending on technical and economic feasibility.

For crude oil and natural gas, lifecycle greenhouse gas emissions were calculated following the same method as the TWS report (*191*). The standard emission factors provided by the EPA (*195*) together with 100-year global warming potential (GWP) from Myhre et al. (*196*) were utilized for indirect (downstream) emissions. Direct emissions from oil and gas wells were added to this total using the average values for Utah calculated by TWS (*191*). Direct emission factors were based on estimates for representative horizontal wells in the region from the Kleinfelder report produced for the BLM (*198*), as well as BLM lease sale Environmental Assessments or similar documents.

For coalbed methane, which was not evaluated in the TWS report (*191*), the same direct and indirect emission factors were used as for natural gas. However, the direct emissions were adjusted by +36% based on Glancy (*197*), which found that emissions from coalbed methane wells in the U.S. were 36% higher than those of conventional gas wells.

For oil, gas, and coalbed methane wells, we used the TWS (*191*) methodology to simulate low, reference, and high development scenarios to account for uncertainties associated with production and market conditions that drive greenhouse gas estimates. The reference scenario uses average regional well spacing and per-well EUR assumptions based on the 2020 Annual Energy Outlook (*236*). The high scenario adjusts the EUR upwards by 50% to simulate significant increases in domestic production, which is consistent with the AEO 2020 High Oil and Gas Resource and Technology Case (*236*). By contrast, the low scenario uses a conservative assumption of one well drilled per square mile (640 acres).

A.2. Coal

In order to estimate coal resources underlying ARRWA lands, we utilized estimates of remaining recoverable coal resources in Utah as of 2019 (*199*) and calculated the proportion of resources within each coalfield that overlapped with ARRWA lands. Spatial data representing 4-foot coal seams obtained from the Utah AGRC (*239*) were intersected with the Utah coalfields shapefile used by the Utah Geological Survey reports (obtained directly from M. Vanden Berg). We assigned recoverable resources only to areas designated as coal seams at least 4 feet thick (one of the constraints used to calculate recoverable resources by the Utah Geological Survey [*199*]), and assumed even distribution of recoverable resources within those seams.

Indirect (downstream) greenhouse gas emissions were calculated using sector-specific emission factors from the EPA (*195*), which were based on coal consumption data rather than coal rank in order to be consistent with previous studies (*189*, *194*). Consumption data for coal originating in Utah was obtained from the 2018 Annual Coal Distribution Report published by the EIA (*240*), and calculations determined that 80% of Utah coal was utilized by the electric power sector while 20% was utilized by industrial plants. Thus, 80% of ARRWA coal resources was assigned to the coal emission factor for the electric power sector, while 20% was assigned to the emission factor for the industrial sector (*195*). As for crude oil and natural gas, we combined the standard EPA emission factors with the most recent estimates of 100-year GWP (*196*). Because there is no way to determine the number of coal mines that would likely be needed to extract all coal from ARRWA lands, direct emissions were not included in our calculations. However, they likely represent a significant source of greenhouse gasses, particularly methane; the exact amount depends on many factors including type of mine, methane leakage rate, and eventual method of abandonment (*194*).

The reference scenario for coal uses sector-specific EPA emission factors (*195*) to directly calculate greenhouse gas emissions for the estimated coal resources on ARRWA lands. The low and high scenarios represent 75% and 139% of the reference scenario, respectively. To determine these proportions, we entered our estimate of ARRWA coal resources into the Climate Pollution Calculator online tool and determined the proportion of the median scenario represented by the low and high scenarios within that tool. This allowed us to roughly estimate the range based on uncertainties considered in the Mulvaney et al. report (*189*), which covered the entire United States, while still using a reference scenario based on Utah-specific sector emissions.

A.3. Oil shale

Oil shale resources underlying ARRWA lands were estimated based on in-place resources because production of oil shale is not yet technically or economically viable. We were unable to access spatial data associated with BLM's 2013 Final Oil Shale and Tar Sands Programmatic EIS and Record of Decision, and so we calculated distribution of in-place resources using shapefiles produced for a report by the USGS Oil Shale Assessment Team (*241*). However, additional factors that would likely limit the amount of recoverable resources were used to refine the USGS estimates. Specifically, we used maps in Vanden Berg (*242*) to visually estimate areas where oil shale resources were at least 5 feet thick, under 3,000 feet of cover, and would likely yield at least 25 gallons of shale oil per ton of rock. After eliminating areas that did not meet those additional constraints, we calculated the proportion of ARRWA lands that overlapped with oil shale resources by township as assessed by the USGS Oil Shale Assessment Team (*241*).

The Climate Pollution Calculator was used to calculate greenhouse gas emissions based on the median scenario presented in that tool. Because commercial production of oil shale resources is not technically or economically feasible, oil shale emissions are only included in the high scenario for this report.

A.4. Tar sands

There was relatively little information available for tar sands compared to other fossil fuel types included in this project, and, as mentioned above, we were unable to access spatial data associated with BLM's 2013 Final Oil Shale and Tar Sands Programmatic EIS and Record of Decision. As for oil shale, estimates are based on in-place resources because there are currently no economically viable methods of tar sand extraction in the U.S., so it is unknown whether large-scale extraction will take place in the future.

We estimated the distribution of in-place tar sands resources using shapefiles for Uinta Basin deposits (*243*), which were overlaid with ARRWA lands to determine the number of overlapping acres per major deposit. In-place resources for each deposit were based on total or per-acre estimates (*244*), and a percentage of these resources were assigned to ARRWA lands depending on the amount of overlap. Because no additional information about the spatial distribution of resources was available, a uniform distribution of in-place resources was assumed across the entire area of the deposit. Similarly, tar sand deposits outside of the Uinta Basin were excluded from this estimate because no shapefiles that included those were available. However, the Uinta Basin accounts for the vast majority of tar sand resources within the state, and amounts outside of that are likely negligible (*244*).

The Climate Pollution Calculator was used to calculate greenhouse gas emissions based on the median scenario presented in that tool. Because commercial production of tar sands resources is not technically or economically feasible, tar sands emissions are only included in the high scenario for this report.

Appendix B. Supplemental tables for fossil fuel analysis

Table B1. Lifecycle greenhouse gas emissions (MMt CO_2e) of fossil fuel resources on ARRWA lands based on 100- and 20-year global warming potential (GWP) under low, reference, and high scenarios. For oil shale and tar sands, 20-year GWP could not be calculated because no standard EPA emissions factors were available for these resources. As a result, 100-year GWP is used for both columns.

	Greenhouse Gas Emissions (MMt CO_2e) 100-year GWP			Greenhouse Gas Emissions (MMt CO_2e) 20-year GWP		
Fossil Fuel Type	**Low**	**Reference**	**High**	**Low**	**Reference**	**High**
Crude oil	845.7	5,453.7	8,165.2	847.4	5,464.8	8,181.7
Oil shale			775.5			775.5
Tar sands			77.3			77.3
Sum of oil	845.7	5,453.7	9,018.0	847.4	5,464.8	9,034.6
Natural gas	105.7	681.6	1,006.9	105.8	682.2	1,007.9
Coalbed methane	36.1	160.7	224.0	36.1	160.8	224.2
Sum of gas	141.8	842.3	1,230.9	141.9	843.1	1,232.1
Coal	13,376.2	17,769.1	24,621.3	22,341.5	29,678.7	41,123.4
Sum of coal	13,376.2	17,769.1	24,621.3	22,341.5	29,678.7	41,123.4
TOTAL	**14,363.7**	**24,065.2**	**34,870.3**	**23,330.8**	**35,986.5**	**51,390.1**

Table B2. Estimates of crude oil (MMBbl), natural gas (Bcfg), and coalbed methane (Bcfg) resources on ARRWA lands under low, reference, and high production scenarios.

		Fossil Fuel Resources		
Fossil Fuel Type	**Area (acres)**	**Low**	**Reference**	**High**
Crude oil	2,848,608	1,939.0	12,505.0	18,757.4
Natural gas	2,848,608	1,851.2	11,938.7	17,908.0
Coalbed methane	1,671,264	522.3	2,325.0	3,487.5

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