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Balancing Rare Species Conservation with Extractive Industries

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Abstract: The Colorado Plateau has abundant oil, gas, and alternative energy potential. This energy potential is scattered among a patchwork of land ownership, with private, tribal, and public lands being actively developed for energy extraction. Elements of biodiversity (e.g., listed and sensitive plant and animal species) are distributed among all land tenures, yet the laws protecting them can vary as a function of land tenure. It is imperative to understand the spatial distributions of threatened endangered, and sensitive species in relation to land tenure to preserve habitat and conserve species populations in areas undergoing energy development. We developed species distribution models and spatial conservation optimization frameworks to explore the interactions among land ownership, existing and potential energy extraction, and biodiversity. Four management scenarios were tested to quantify how different approaches to energy extraction may impact rare plant distributions. Results show that incorporating risk and land tenure in spatially optimized frameworks it is possible to facilitate the long-term viability of rare plant species. The scenarios developed here represent a different attitude towards the value of rare plants and the risk of energy development. Results gives insight into the financial consequences of rare species protection and quantifies the biodiversity costs of energy development across landscapes.

Keywords: rare plants; conservation planning; oil and gas; colorado plateau; energy development and potential

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1. Introduction

Oil and gas exploration and extraction are acknowledged threats to global biodiversity that often negatively impact species conservation [1,2]. The infrastructure associated with oil and gas development has been documented to increase habitat fragmentation while reducing habitat quality and availability [3–5]. While vagile species may relocate from areas of high energy development, evidence of decreased survivorship exists [6,7]. However, plant species are static in their ability to avoid ecological impacts, which raises significant interest in the relationship between plant species conservation and oil and gas development. With the high number of plant species qualifying for listed status under the Endangered Species Act, being considered of concern by Non-Governmental Organizations (NGOs) like NatureServe, and the increasing global demand for oil and gas resources [3], we question how these conflicting conservation and energy demand objectives may be mutually satisfied. This study explores the spatial and economic relationships among plant species of concern, oil and gas development, land ownership, and the potential of concurrently meeting conservation objectives between two conflicting values: continued energy exploration and development, and species habitat conservation.

This study focuses on the Colorado Plateau, a biodiverse and energy-rich ecoregion located in the Intermountain West of the United States [8]. Due to unique geologic and edaphic features, the Colorado Plateau boasts profuse oil and gas resources. Due to the same features, plant biodiversity hotspots occur but are severely limited in their distribution to small, discrete ranges [9–11]. As a result, many species are placed under federal and state management plans due to their rarity. In addition to limited range size, plants realize significant disturbance from anthropogenic activity that accompany oil and gas development. Two primary disturbances are unpaved road usage and dust dispersal. Unpaved road use has been linked to not only reducing available habitat for plant species, but creating barriers to dispersal, spreading exotic and harmful species, and increasing dust loads on plants that reduce growth and diminish reproductive potential [12,13]. In addition, previous studies have examined an abundance of coevolved plant and pollinator species in the Colorado Plateau [14,15]. Dust, noise, and turbulence that accompany oil and gas development affect the distribution and density of pollinators which result in indirect impacts to plant health [16,17].

Societal interests regarding biodiversity conservation and natural resource extraction are diverse and often conflicting. Whereas the prospect of maximizing oil and gas development and extraction while simultaneously conserving the total landscape of rare species is desirable, that outcome is simply not possible. However, solutions abound in spatial prioritization and conservation planning. Spatial conservation prioritization and planning is the science of systematically deciding where to implement certain actions regarding biodiversity conservation [18]. Here, we implement Marxan [19], the most widely used conservation planning software in the world, as a means of identifying spatial locations where conservation actions that protect plants are located, given a background of energy extraction. Marxan is a simulated annealing algorithm designed for solving complex conservation planning problems through systematically selecting area (often referred to as planning units) for conservation action [20,21]. This selection is derived from the defined proportion of a conservation target (i.e., conserving x% of a species habitat and range), a financial cost associated with the action for each unit, and a calculated probability of risk relating to the conservation action failing on a unit per unit basis [22]. It has been observed that conserving planning units that cover at least 30% of a species spatial distribution and habitat may sufficiently protect that species in the long-term [23]. Here, we seek to acquire the 30% threshold for a community of flowering plant species co-located in a region of high and ongoing energy development.

The interaction between humans and ecosystems is global, affecting not only singular species, but ecological communities. Therefore, exploration of these conflicts is not well served by single species approaches. To maximize our actions in plant conservation, we implement a multi-species-based approach in this study. While developing robust conservation scenarios for a single species remains a major endeavor, conservation biology has shifted from species representation within communities to communities within their environment [24]. Multi-species-level approaches to biological conservation are a major advance in most current single-species conservation and management practices [25]. Initiatives that establish species rarity as an indicator of conservation priority, a significant focus of this study, may be biased if they disregard important evolutionary and adaptive processes taking place in lower diversity communities [26]. Studies suggest that reductions in biodiversity result in a decreased stability in ecosystem function and productivity (Frankel et al. 1995). Therefore, rare flowering plant species of the Colorado Plateau, while differing in individual conservation categorization or listed status, are treated with the same conservation objectives in this study to maximize the ecological function of biodiversity.

2. Methods

To assess the conservation options in the Colorado Plateau, we use a combination of Species Distribution Modeling (SDM) and Spatial Conservation Prioritization (SCP). Using a variety of SDM algorithms, we constructed spatially explicit habitat suitability models for a group of 29 flowering plant species of concern. We also examined the distribution of current oil and gas infrastructure, oil and gas development potential, and land tenure associated with predicted plant habitat suitability. This framework also includes the financial cost tied to both well-head restoration and land ownership as a function of optimization. We developed 4 scenarios to identify spatially optimized locations with object functions that set targets for conservation action while minimizing energy development. This approach optimizes conservation of 29 flowering plant species by selecting the minimum number of planning units required to cover 30% of each species distribution and habitat at the lowest financial cost. By minimizing the amount of units selected for conservation action, we not only minimize financial cost but also reduce the selection of areas of high energy development and potential. This study provides not only general options for land managers in areas with extractive industries but identifies specific spatial zones for conservation action.

2.1. Study Area

The Colorado Plateau is a high elevation, cold desert located in western North America's arid continental interior. The region has an area of approximately 182,000 km^2, spanning four degrees of latitude and four degrees of longitude from the Utah Wasatch mountains in the west (~111° W) to the Colorado Rockies in the east (~107° W), and from the Arizona/New Mexico Plateaus in the south (~36° N) to the Wyoming Basin in the North (~40° N). With a unique geologic history and rich diversity of soils, hot spots for plant species endemism and oil and gas potential occur throughout the Colorado Plateau [27,28]. The soils, however, are sensitive to disturbance and the patchwork of land tenure poses a challenge to comprehensive range-wide management of the unique biota across the Colorado Plateau. Land tenure consists of a patchwork of federal (63%), state (5%), tribal (14%), and private (17%) lands (Figure 1). Remaining land tenures, including lands owned by local governments and NGOs, account for <1%. For this study, land tenure is categorized by either public or private lands with tribal lands, local governments, and NGOs being classified as private.

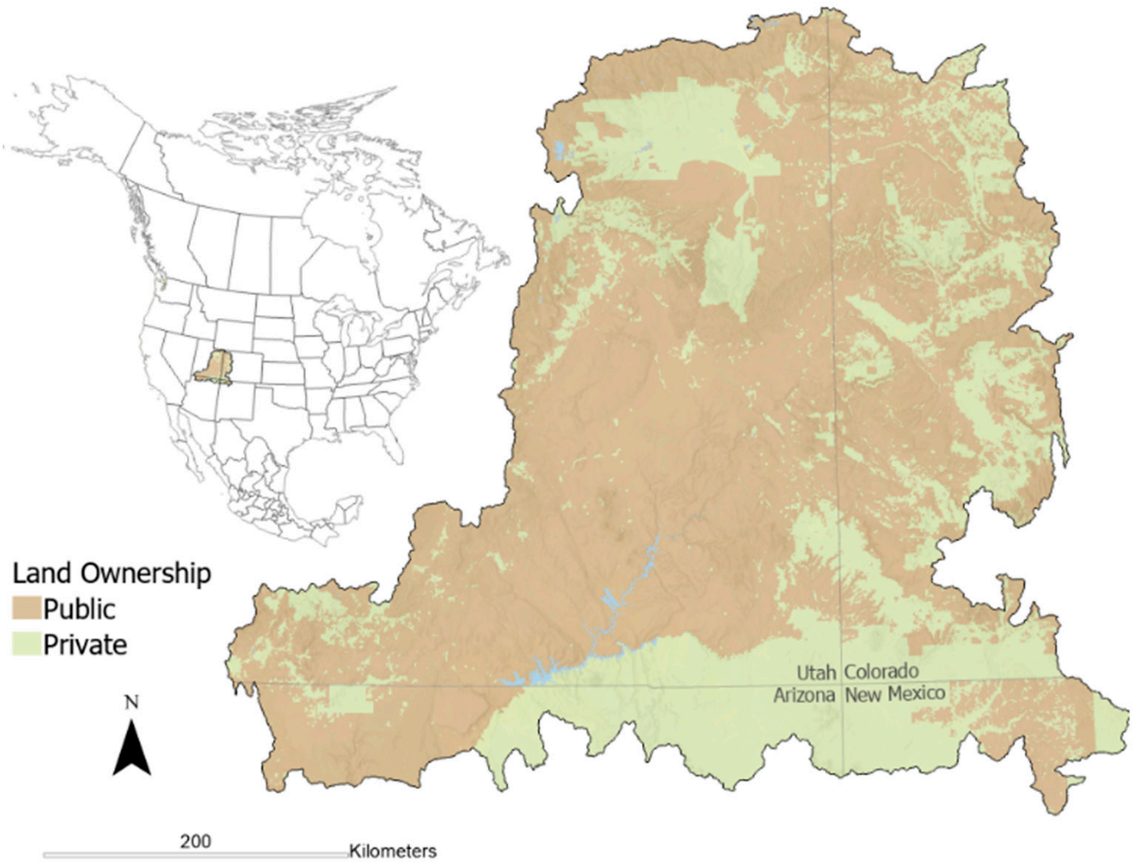

Figure 1. The Colorado Plateau and associated land tenures. Public ownership represents state and federal lands while private ownership represents local governments, NGOs, and tribal lands.

2.2. Rare Plants

Species of interest for conservation prioritization consisted of all flowering plant species within the Colorado Plateau boundaries that are categorized as G1-Critically Imperiled; G2-Imperiled; G3-Vulnerable; T1-Critically Imperiled Variety; and T2-Imperiled Variety under NatureServe (https://explorer.natureserve.org/ accessed 28 October 2022), an NGO and source for information on rare and endangered species in the Americas who uses a ranking system based on trends, rarity, and threats that contribute to the conservation status (extinction risk) of species. Species of interest also included those listed under the U.S. Fish and Wildlife Service's ESA as Threatened or Endangered (www.fws.gov/program/listing-and-classification accessed on 28 October 2022) and the International Union for Conservation of Nature (IUCN) Red List of Threatened Species (https://www.iucnredlist.org/ accessed on 28 October 2022). Meeting these criteria, 40 flowering plant species of concern occur in the Colorado Plateau. Eleven of these plant species were eliminated from this study due to limited data availability and quantity. The remaining 29 species are the focus of this study. These 29 species are distributed across the spatial extent of the Colorado Plateau and are found primarily in the state of Utah (Figure 2A). Several species are synonymous with other taxonomic designations (Table 1). Under NatureServe categorizations, 10 species are G-1 Critically Imperiled, 10 species as G-2 Imperiled, 3 as G-3 Vulnerable, 2 T-1 Critically Imperiled Variety, 3 as T-2 Imperiled Variety, and 1 Not listed under any categorization. Under ESA listing status, 6 species as Endangered (E), 7 species as Threatened (T), 3 species under review (U), 1 delisted species (D), and 12 species not listed (N). Under IUCN global conservation status, 3 species are Least Concern (LC), 2 species as Near Threatened (NT), 1 species as Critically Endangered (CR), and 23 species not listed (N). It is important to note that plant species listed under ESA are not directly afforded protection on private lands. Plant species occurrence spatially overlaps private and public and tribal land tenures, and the laws protecting them may vary as function of land tenure.

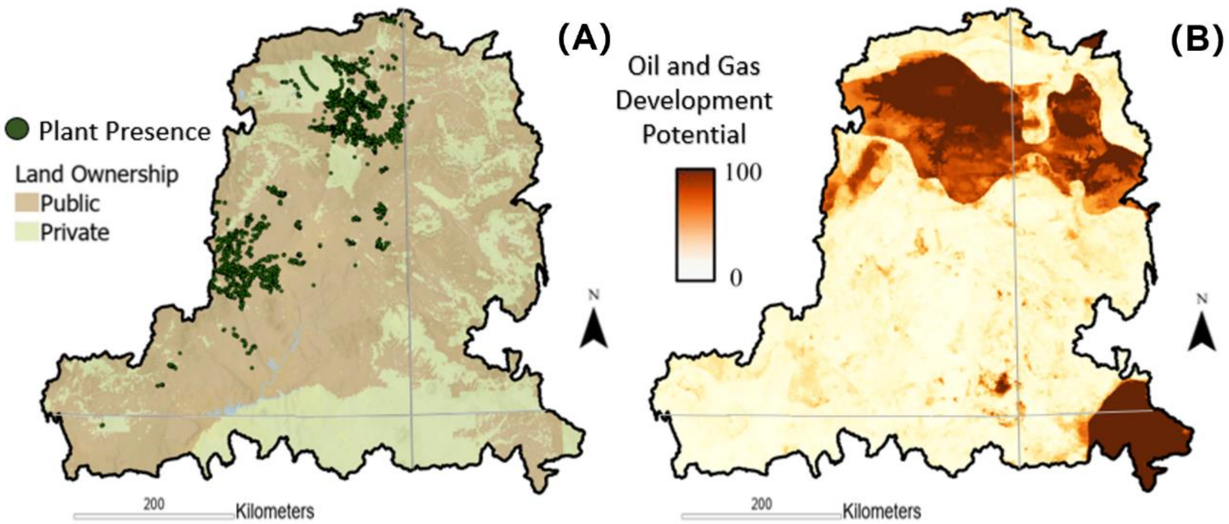

Figure 2. Spatial depictions of data in the Colorado Plateau. (**A**) Geographic locations of flowering plant occurrences distributed across private and public land tenures; (**B**) Oil and gas development potential probability model.

Table 1. Scientific and common name, code, and associated communities of the 29 flowering plant species of interest. Table is organized first by associated community then alphabetical order on scientific name. (=scientific name) and (=code) represent the alternative names and codes of synonymous trees.

Scientific Name	Common Name	Code [1]	NS [2]	ESA [3]	IUCN [4]
Aliciella caespitosa (A. Gray) J.M. Porter (=*Gilia caespitosa* A. Gray)	Rabbit Valley gilia	ALCA23 (=GICA8)	G2	N	N
Astragalus equisolensis Neese & S.L. Welsh (=*Astragalus desperatus* M.E. Jones var. *neeseae* Barneby)	Horseshoe milkvetch (=Elizabeth's milkvetch)	ASEQ (=ASDEN)	T2	N	N
Astragalus hamiltonii Ced. Porter (=*Astragalus lonchocarpus* Torr. var. *hamiltonii* (Ced. Porter) Isely)	Hamilton's milkvetch	ASHA3 (=ASLOH)	G1	N	N
Astragalus iselyi S.L. Welsh	Isely's milkvetch	ASIS	G1	U	N
Astragalus montii (=*Astragalus limnocharis* Barneby var. *montii* (S.L. Welsh) Isely)	Heliotrope milkvetch	ASMO11 (=ASLIM)	G3	T	N
Astragalus sabulosus M.E. Jones var. sabulosus	Cisco milkvetch	ASSAS	T2	U	N
Astragalus sabulosus M.E. Jones var. Vehiculus	Cisco milkvetch	ASSAV	T1	U	N
Cryptantha barnebyi I.M. Johnst.	Oilshale cryptantha	CRBA6	G2	N	N
Cryptantha grahamii I.M. Johnst.	Fragrant cryptantha	CRGR4	G2	N	N
Cycladenia humilis Benth. var. jonesii (Eastw.) S.L. Welsh (=*Cycladenia jonesii* Eastw.)	Jone's waxydogbane	CYHUJ (=CYJO2)	T2	T	N
Erigeron maguirei Cronquist (=*Erigeron maguirei* Cronquist var. *harrisonii* S.L. Welsh)	Maguire's fleabane	ERMA8 (=ERMAH)	G2	D	N
Eriogonum smithii (=*Eriogonum corymbosum* Benth. var. *smithii* (Reveal) S.L. Welsh)	Flat-top buckwheat	ERSM (=ERCOS2)	G1	N	N
Glaucocarpum suffrutescens (Rollins) Rollins (=*Schoenocrambe suffrutescens* (Rollins) S.L. Welsh & Chatterley (=*Thelypodium suffrutescens* Rollins) (=*Hesperidanthus suffrutescens* (Rollins) Al-Shehbaz)	Uinta Basin waxfruit (=Toad-flax cress)	GLSU (=SCSU2) (=THSU4)	G1	E	N
Lepidium barnebyanum Reveal (=*Lepidium montanum* Nutt. ssp. *Demissum* C.L. Hitchc.)	Barneby's pepperwood	LEBA (=LEMOD)	G1	E	N
Oreoxis trotteri S.L. Welsh & Goodrich (=*Cymopterus trotteri* (S.L. Welsh & Goodrich) Cronquist)	Trotter's alpineparsley	ORTR (=CYTR13)	G1	N	N
Pediocactus despainii S.L. Welsh & Goodrich	Despains's pincushion	PEDE17	G2	E	NT
Pediocactus winkleri K.D. Heil	Winkler's pincushion	PEWI2	G2	T	LC
Penstemon albifluvis England (=*Penstemon scariosus Pennell var. albifluvis (England) N.H. Holmgren)*	White River beardtongue	PEAL80 (=PESCA)	T1	N	N
Penstemon flowersii Neese & S.L. Welsh	Flowers' beardtongue	PEFL8	G1	N	N
Penstemon gibbensii Dorn	Gibbens' beardtongue	PEGI4	G1	N	N
Penstemon grahamii D.D. Keck	Uinta Basin beardtongue	PEGR6	G2	N	N
Phemeranthus thompsonii (N.D. Atwood & S.L. Welsh) (=*Talinum thompsonii* N.D. Atwood & S.L. Welsh)	Cedar Mountain fameflower	PHTH6 (=THAT)	N	N	N

Table 1. *Cont.*

Scientific Name	Common Name	Code [1]	NS [2]	ESA [3]	IUCN [4]
Physaria tumulosa (=*Lesquerella rubicundula* Rollins) (=*Lesquerella hitchcockii Munz ssp. Rubicundula (Rollins) Maguire & A.H* (=*Lesquerella tumulosa* (Barneby) Reveal)	Kodachrome bladderpod (=Tum bladderpod)	PHTU (=LERU4) (=LEHIR) (=LETU)	G3	E	N
Schoenocrambe argillacea (S.L. Welsh & N.D. Atwood) (=*Thelypodiopsis argillacea* S.L. Welsh & N.D. Atwood)	Uinta Basin plainsmustard	SCAR5 (=THAR6)	G1	T	N
Sclerocactus brevispinus K.D. Heil & J.M. Porter (=*Sclerocactus whipplei* (Engelm. & J.M. Bigelow) Britton & Rose)	Pariette cactus	SCBR12 (=SCWI2)	G1	E	CR
Sclerocactus wetlandicus Hochstätter	Uinta Basin Hookless cactus	SCWE	G3	T	LC
Sclerocactus wrightiae L.D. Benson	Wright Fishhook cactus	SCWR	G2	E	NT
Spiranthes diluvialis (=*Spiranthes romanzoffiana Cham. var. diluvialis (Sheviak) S.L. Welsh*	Ute Ladies'-tresses	SPDI6 (SPROD)	G2	T	LC
Townsendia aprica S.L. Welsh & Reveal (=*Townsendia jonesii* (Beaman) Reveal var. *lutea* S.L. Welsh	Last Chance townsendia	TOAP (=TOJO)	G2	T	N

[1] Species codes are broadly recognized abbreviations for each species acquired from the United States Department of Agriculture (USDA) National Resources Conservation Service (NRCS) Plant Database (https://plants.usda.gov/ accessed on 28 October 2022). [2] Species status as indicated by NatureServe. [3] Species listing as indicated by the Endangered Species Act. [4] Species global conservation status as indicted by the International Union for Conservation of Nature Red List of Threatened Species.

2.3. Oil and Gas Development and Potential

The Intermountain West of the United States doubled oil and gas development between 1990 and 2007 [29], with global oil demand projected to increase by 50 percent between 2007 and 2030 [3]. Within the boundaries of the Colorado Plateau, energy development and potential are scattered among varying land ownership and are being actively developed for extraction on both public and private lands. The Colorado Plateau currently has approximately 63,000 active and 26,000 abandoned oil and gas well-pads [30] which are distributed throughout the entirety of the Colorado Plateau. Oil and gas wellheads, with an approximate lifespan of 30 years, have an estimated restoration cost that averages $24,000 USD [31]. With the reasonably short life cycle of oil and gas wellheads, regions like the Colorado Plateau are likely to have increased interactions between human activity and biodiversity through increased development. A spatially explicit model of oil and gas development potential for the Colorado Plateau [3] is used in this study to analyze the factor of risk in conservation planning (Figure 2B). The risk values associated with future development is model are assigned to each planning unit and represents the probability a planning unit may fail to protect the species it contains due to it being developed.

2.4. Species Distribution Modeling

Species distribution models (SDMs) of the 29-plant species constitute the spatial information by which the baseline conservation targets are defined. Five SDM classifiers were implemented to develop species-specific SDMs for the 29 plant species of interest. These models include: (1) a generalized linear model (GLM) with a logit link (logistic model) [32]; (2) maximum entropy [33,34]; (3) random forests [35,36]; (4) boosted regression trees [37,38], and (5) Bayesian additive regression trees [39,40].These five selected classifiers represent a range of statistical algorithms that are parametric and non-parametric in scope, and that are commonly applied to studies involving SDM. Model accuracies were examined by produced values for four model metrics: The Area Under Curve of the Receiver Operating Characteristic (AUC), Sensitivity, Specificity, and the True Skill Statistic (TSS). AUC values range from 0 to 1 and the higher the AUC value, the better predicting performance of that model. Sensitivity and specificity represent the model's ability to correctly predict suitable habitat and unsuitable habitat, respectively [41].

Models were fit with species-specific predictor variables, reduced in number from a common pool (Table S1). Because all data were collected from targeted sampling approaches [42] without underlying designs, selection of thresholds for model classification is problematic. Consequently, we implemented max kappa as the classification threshold [43] for each species-specific model. Model accuracy was assessed using the area under the curve (AUC) [44] and the true skill statistic (TSS) [45]. Individual SDMs were evaluated within an ensemble models context [46–48]. Ensemble models bolster defensibility of SDM applications as no single SDM is considered "correct". Procedurally, we stacked the five individual SDMs for each plant species and calculated a mean average, standard deviation (SD), and upper and lower range of likelihood for each modeled pixel. These outputs were converted to spatially explicit products representing the ensemble model prediction (mean) and variability (1 SD, range) of each plant species at a 1 km^2 spatial resolution.

The 29 species distribution ensemble models were then cropped to the Colorado Plateau's spatial extent. A grid of 1 km^2 planning units was overlaid on the landscape, and each planning unit was assigned a value that correlates with the number of species that have predicted distribution occupying that cell. The highest number of species distributions occupying a single cell was 10 while the lowest was 1. These values were then categorized in five classes: (I) 1–2 species; (II) 3-4 species; (III) 5-6 species; (IV) 7-8 species; and (V) 9-10 species (Figure 3). Oil and gas development potential, a probability model producing an output of values that range from 0 to 100, was overlaid on the 5 classes of species per cell to determine the probability of development risk among species density classifications. Current well-pads were also overlaid to determine amount in each species density classification.

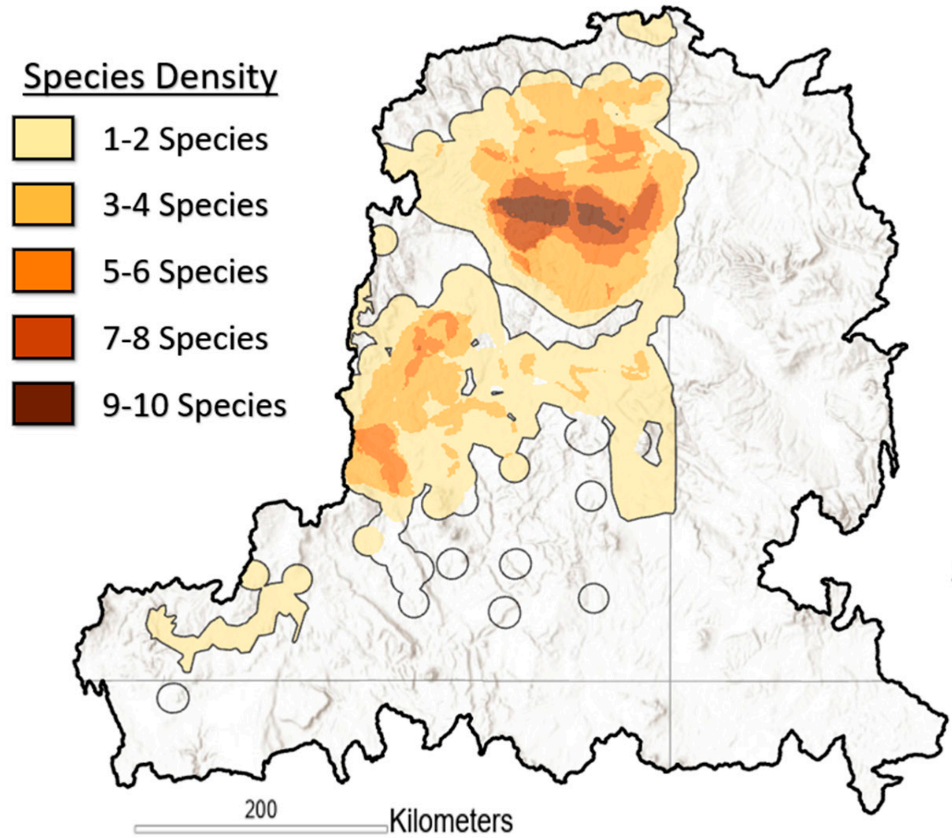

Figure 3. Species distribution modeling output density classifications derived from the number of individual species suitable habitat predicted in each cell.

2.5. Spatial Conservation Optimization

Our objective in applying the Marxan algorithm is to optimize the selection of planning units for the 29 species of interest. The underlying goals are to: (1) identify the least number of units suitable for flowering plant species conservation, and (2) do so at the lowest financial cost possible. The number of units selected is derived by the specified conservation target percentage, or, how much of each species distribution we would like to conserve. A 30% target is optimal in the long-term conservation of species [22,23,49], although targets 10–90% were applied to analyze other possibilities. The quantity of selected units for conservation action directly impacts current oil and gas activity, the potential oil and gas development, and the financial cost. The spatial extent of the units possible for selection covered the entirety of the 29 SDMs and consisted of 55,538 1 km^2 planning units. Each planning unit was parameterized with the probability of it containing each of the 29 plant species (the outputs from the SDM, 29 values per planning unit). The cost to either maintain public lands with no oil and gas infrastructure presence or to restore lands with currently occupied oil and gas infrastructure was the baseline deciding factor in unit selection.

The financial cost designated to each cell was dependent upon the number of oil and gas well-pads present in each cell. Cells that contained no oil and gas well presence were assigned a value of $1460, which is the value associated with public land maintenance [50]. While specific information on oil and gas production would be ideal, information on well pad development and production is largely considered proprietary by oil and gas business entities and specific information is consequently unavailable. Thus, we decided to evaluate the financial costs based on well-head restoration costs as a surrogate. Restoration drives the analysis of this study as restoring current and deprecated oil and gas infrastructure would provide the land needed for species habitat. Cells containing oil and gas well-pads were assigned the value of $24,500 multiplied to the number of well-pads occupying that cell. Analysis for each conservation objective (10% to 90%) was run 100 times with 10,000 iterations each. Analysis for conservation objective at 100% was not included as the values are fixed at upper limits containing all units or units on public lands only.

To better understand the consequences of prioritizing energy development and the conservation of rare plants, analyses were run under a set of different scenarios. Comparing these results provides insight into the financial consequences of plant species protection and quantifies biodiversity costs of energy development across landscapes. To inform future land management decisions regarding flowering plant conservation in the Colorado Plateau, we developed four scenarios (referred to as S1–S4) depicting a variety of conservation objectives and limiting real-world factors: (1) All planning units and land tenures occupying the Colorado Plateau ignoring the risk of future development (S1), (2) All planning units and land tenures occupying the Colorado Plateau accounting for risk of oil and gas development potential (S2), (3) All planning units occupying only public land tenures ignoring the risk of future development (S3), and (4) All planning units occupying only public land tenures accounting for risk of future development (S4). These scenarios function by reducing the overall number of possible planning units available for selection and introducing the potential risk of a unit failing to meet conservation objectives in the future. S1–S2 treat all units, regardless of ownership type, as equal while S3-S4 acknowledges that public land tenures may be more accessible to conservation action on public lands by completely withdrawing private lands from potential unit selection. This leads to S3–S4 scenarios being spatially restricted to public lands only (Figure 1). This frames the argument that conservation plans assigned to special status or listed species by federal and state governments are in theory, more easily protected on federal and state lands. The four scenarios therefore encompass financial costs, oil and gas development, oil and gas potential development, and land tenure (i.e., public and private lands).

Tribal lands are technically categorized as federal lands held in trust by the federal government. However, there is a complex relationship between the two entities [51]. The Endangered Species Act of 1973 (ESA), for example, differs in its application on tribal land versus non-tribal federal lands [52]. Secretarial Order #3206 (SO-3206) recognizes that, "Indian lands are not subject to the same controls as federal public lands" and that "tribes are appropriate governmental entities to manage their lands and tribal trust resources, and, as trustees, support tribal measures that preclude the need for conservation restrictions" [53]. For this reason, private and tribal lands, although technically separate in their dominion and classification often function similarly when it comes to endangered species management. Hence, we considered them operationally identical in our optimizations.

3. Results

3.1. Species Distribution Models

Twenty-nine flowering species distribution ensemble models were developed, and AUC values of the 29 plants ranged from 0.737 to 0.997 with a mean average of 0.931, which suggests a high average modeling prediction performance. Model sensitivity values ranged from 0.741 to 0.996 with an average value of 0.932 which specificity values ranged from 0.584 to 0.982 with a mean average of 0.843. TSS values, derived from Sensitivity+Specificity-1, ranged from 0.383 to 0.974 with a mean average of 0.781. Model metrics varied across all SDMs with values that suggest high predictive capability. We observed higher levels of predicted species richness (high overlap amongst predicted distributions) in the northern region of the Colorado Plateau (Figure 3). The spatial extent of density classifications generally became smaller as classification value increased from 1 to 10 species per unit cell, meaning there are fewer cells with a higher density of predicted species.

Classification values were distributed on both public and private and tribal lands but were overwhelmingly located on public lands. There was a slight increase of the spatial distribution of plant suitability on public lands as density classification values increase. Cells containing 7–10 species overlapped with the highest density of energy development potential while all cells with 9–10 species showed oil and gas development potential of >50%. Cells with 1–6 species had a greater range of energy potential probability values with a higher density of under 25%. Oil and gas well-pads were within the spatial extent of each density classification value with the highest amount in cells of 3–4 species. The number of well-pads decreases as species density classification values increase. These results suggest that there is varying overlap in the density of suitable species habitat and the overall occurrences of oil and gas development and potential. While SDM allows us to visually examine predicted suitable habitat of the 29 species of interest, the use of Marxan in this study will allow us to systematically optimize locations for conservation, which inversely optimizes locations for oil and gas development.

3.2. Spatial Conservation Optimization

Four SCP scenarios identified specific planning units for selection across a wide range of financial costs (Figure 4). Conservation targets ranged from 10% to 90% of each plants predicted spatial distribution. 100% of each species distribution was not included for scenarios as the financial cost is fixed, as the output involves no optimization and is just all the planning units occupied by any species. The number of selected units per conservation objective ranged from 2831 units to 42,814 units, always increasing as the conservation objective increases. As a higher conservation objective is desired, financial cost increases exponentially across all scenarios with values from $4.1 million USD to $394.4 million USD.

All scenarios have approximately the same financial cost for conservation objectives between 10% to 30%. S3 and S4 financial costs are highest through 40–90% objective targets. S1 and S2 calculated possibilities of unit selection from all 55,538 units, both on public and private and tribal land and cost less per objective targets 20–90% than S3 and S4. No species were missing from S1 and S2 throughout the entire range of conservation objectives. S3 and S4 cost approximately the same amounts per objective target of all percentages. These scenarios both calculated missing species (that the conservation objective could not be met given risk and available units) in objective targets 60–90% with a missing species in S4 at a conservation objective of 40%. S3 and S4 resulted in high financial cost and missing species due to selecting only public units and calculating risk of the unit failing from oil and gas development potential in S4 (Figure 4).

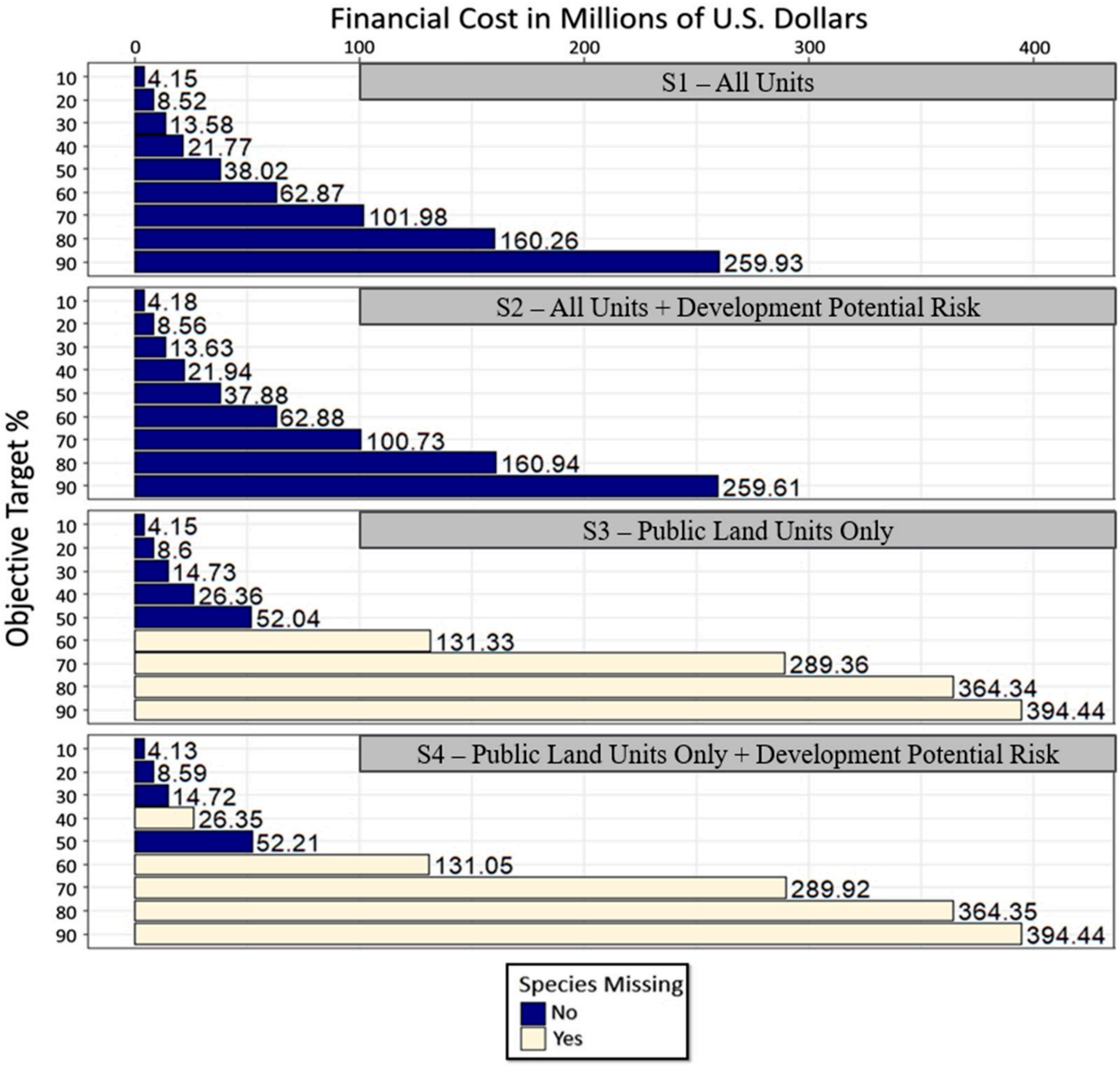

Figure 4. Marxan analysis results for financial cost distributions across conservation target percentages. Blue color depicts scenario runs that have reach conservation targets for all species; Tan color depicts scenario runs in which at least 1 species conservation target percentage is not obtainable due to risk, planning unit availability, and financial cost.

A 30% conservation target is suggested as an optimal outcome for each scenario, as it has become a general rule of thumb in the long-term conservation of terrestrial species and applied in several studies [22,23,49]. At 30% each scenario produces approximately the same financial cost regardless of whether the scenario encompasses all planning units of those on public lands only. S4 at 30% represents potentially the optimal scenario to select for plant conservation as it meets objective targets with no missing species, has a moderate price compared with other scenarios, accounts for oil and gas development potential in its unit selections, and selects units found solely on public lands. Additionally, S4 at a 30% conservation target selected units that had significantly less oil and gas well pads than those not selected (Table 2).

Table 2. Summary for the count of oil and gas well pads located within a range of cells for the selected scenario (S4–30% conservation target) and for units not selected.

Number of Well-Pads within	Number of Units–Selected	Number of Units–Not Selected
0	8815	38,640
1–3	422	5189
4–6	13	1174
6–9	5	604
10–15	-	421
15–20	-	121
21–30	-	87
>30	-	51

From spatially visible observations, S4 has selected units in wild and rough terrain that is unoccupied with oil and gas development (Figure 5A). Additionally, Planning units with current oil and gas infrastructure are examined to be excluded from selection in sections of the study area (Figure 5B). Due to the expansive range of both the plant species and oil and gas development, selecting locations that entirely exclude oil and gas development is not possible for a 30% target. Thus, units have been selected for conservation action that overlap or are spatially neighboring current well-pads and infrastructure (Figure 5C).

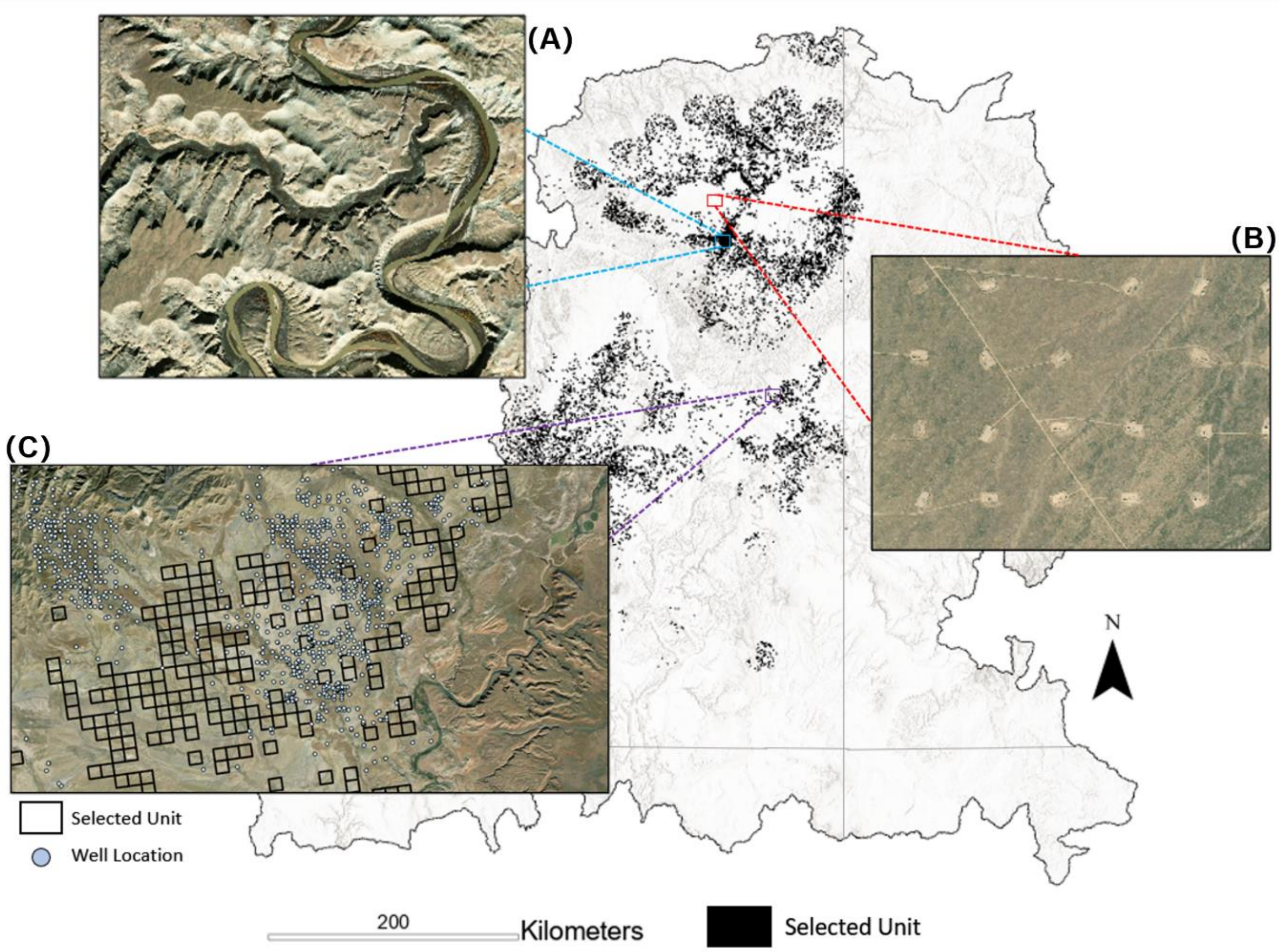

Figure 5. Selected solution of scenario 4 with a 30% conservation target with geographic locations of interest. (**A**) Satellite Imagery of an area of high planning unit selection depicting rough and wild landscapes; (**B**) Satellite imagery of an area of no planning unit selection depicting oil and gas infrastructure; (**C**) Satellite imagery of an area with high selection and oil and gas well-pads.

4. Discussion

We begin by explicitly acknowledging that no solution meets 100% of both plant species conservation and energy extraction objectives. We achieved a solution (Scenario 4 at 30%) through prioritization that identified a set of spatially explicit outcomes. This solution included 9255 1 km^2 units that covered 30% of each plant species predicted distribution while accounting for oil and gas development risk, and while selecting units solely on public lands. While S1–S2 reached 30% coverage at lower costs, they include public and private lands (both S1 and S2) or do not include risk (S1). S4 achieves the same coverage but focuses on public lands only, given that ESA-listed plant species are not afforded protection private and tribal lands (Section 9, ESA) except where State law is in effect. This public lands solution achieves the target of 30% that has been suggested to provide significant value in species conservation over time [23].

Land tenure and oil and gas development potential play a significant role in shaping the selection of units, according to S4. While perhaps being more cost effective, S1–S3 solutions do not account for real-world limiting factors that shape decisions by combining land tenure and development potential risk. For biodiversity conservation planning in energy rich landscapes to be effective, it must explicitly examine human factors such as land tenure and future development probability to reduce conflict between nature and society [54,55]. It has been observed that complications regarding conservation efforts are often more prevalent on private and tribal lands than public lands [56]. Although options exist that provide incentives for private and tribal landowners to cooperate with species conservation policy (e.g., conservation easements, conservation banking) [57,58], they too often result in inefficient species conservation on private lands [59]. In addition to the discussion on public and private lands, the Endangered Species Act of 1973, Section 7 requires federal agencies to consult with the U.S. Fish and Wildlife Service (FWS) or National Oceanic and Atmospheric Administration (NOAA) to ensure that any proposed activity on public lands will not adversely modify or destroy critical habitat of a listed species [60]. By contrast, private lands (although under the same legal obligations of the ESA Section 7) may compromise habitat through incidental take permits that allow for land modification under a personal habitat conservation plan submitted by the property landowner [61]. Our scenario selection mitigates any potential conservation mishaps by removing unit selection on private lands all together. However, solely excluding private lands from conservation frameworks, although easier and ideal in theory, is not a panacea when confronting global conservation. In order to have effective biodiversity conservation in the current state of land ownership, efforts must be made to have public and private land entities work alongside each other [62]. Otherwise, financial costs will increase and the ability to fully conserve species habitat (i.e., conserving 100% of species habitat) will be unattainable. Including public and private and tribal land tenures in spatially optimized plans will allow us to honestly examine the needs and restrictions of effective conservation.

Our results do not suggest that conservation planning frameworks that incorporate financial cost, risk, and real-world limiting factor (i.e., land tenure) will ever produce a truly "perfect" scenario [63,64]. Spatial conservation prioritization provides opportunities for us to maximize outcomes among conflicting objectives to create a "best" scenario to our knowledge and modeling parameters, but we lack the ability to fully represent reality when examining the interactions among nature and society. As this uncertainty occurs in modeling and conservation planning in general, other limiting factors were found that may affect the outcomes of spatially optimized scenarios for rare plant species. A lack of data availability and sharing among agencies and political entities may restrict the number of species to examine defensibly, lack of data access was the primary reason 11 species were excluded from this study.

Studies that examine ecoregional study areas (i.e., the Colorado Plateau) often overlap societal and political boundaries. Ecoregional studies are intuitive to conservation planning as similar species of status and taxa occupy transcend political boundaries [65]. However, political governance often inhibits conservation efficacy in transboundary regions [66,67].

Rare species, like the 29 plants examined here, often have restrictions on their data availability and public sharing designated by state, regional, or federal organizations, which may negatively impact research that spatially covers political trans boundaries [68–70]. In addition to lawful restriction, there is surveyed reasoning as to why ecologists limit data sharing that ranges from insufficient data management, concerns for data misinterpretation, and jealousy [71].

Biodiversity occurrence databases and citizen science data collection allows for species occurrences to be publicly shared and examined, which may fill data gaps when data sharing is restricted among agencies [72,73]. Citizen science facilitates mass data collection that closes spatial gaps on global biodiversity occurrence data in seasons rather than years [43,74]. While success in citizen science is apparent, issues in widespread taxonomic misidentification have occurred with plant species as the rate of increase in global natural history collections outpaces the ability to process, evaluate and name species correctly. [75]. Likewise, there is an observed taxonomic bias and societal preference in citizen science data collection, which excludes species endemic to a single region [76] like the Colorado Plateau. In addition, species like our 29 rare plant species often have morphologically similar counterparts and may be very difficult to discriminate without electron microscopy or a determination based on geography [77]. The need for data availability and sharing among agencies of transboundary locations is apparent for the overall conservation of the worlds rare plant species.

Our research indicates that conservation in landscapes containing extractive industries is possible using restoration costs, and often the only solution as most financial variables related to extractive industry are proprietary. As the Marxan algorithm achieved 30% conservation of each species without significant encroachment into extractive areas, the conservation of rare flowering plants in the Colorado Plateau appears feasible. In addition, we highlight in this study that effective conservation may be achieved without the logistical hurdles associated with private and tribal lands. However, effective planning will require cooperation among diverse stakeholders with differing perspectives. To achieve similar results globally, it is anticipated that all land tenures may need to be mutually coordinated in conservation efforts.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/land11112012/s1, Table S1: Bioclimatic variable name, the commonly used abbreviation, and equation for the 19 bioclimatic variables used in this study. Code and publicly available data are available for download at http://www.hydroshare.org/resource/2e261339e6e44f67b6bf7ff85fa3fe48.

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