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The importance of U.S. national forest roadless areas for vulnerable wildlife species

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ABSTRACT

Inventoried roadless areas (IRAs) in national forests in the contiguous United States (CONUS) are public lands that are ecologically intact and could be prime candidates for addition to the protected-area system, thereby contributing to the goal of protecting 30% of the Earth by 2030. Despite calls both to protect roadless areas and to downgrade them, we know surprisingly little about the importance of IRAs as habitat for vulnerable wildlife species. We assessed the importance of IRAs—in total and individually—as habitat for wildlife species of conservation concern (SCCs) and, for context, compared their habitat value to that of other national forest lands and CONUS lands in general. We also quantified how well the protected-area system would provide habitat for wildlife SCCs if all unprotected IRAs were added to it. Of the 537 wildlife SCCs in CONUS, 308 species (57%) have at least some suitable habitat in one or more IRAs. The median IRA contains suitable habitat for 10 wildlife SCCs, with a maximum of 62 wildlife SCCs. Despite their geographic and elevational clustering and predominance of a single biome type, IRAs provide a larger proportion of suitable habitat for multiple wildlife SCCs than non-IRA CONUS lands. The median number of wildlife SCCs' suitable habitat per 900-m^2 pixel is also slightly higher in IRAs than in most national forest wilderness areas, national monuments, and other currently protected areas. If all IRAs were added to the protected-area system in CONUS, there would be a substantial decrease (−38) in the number of wildlife SCCs that are currently considered "poorly represented" in protected areas. In this study we provide quantitative information about the importance of IRAs as habitat for vulnerable wildlife species so that stakeholders, agency staff, and lawmakers can make informed choices about where to invest limited resources for conservation.

1. Introduction

Conversion and degradation of natural landscapes and human-caused climate change are contributing to the sixth mass-extinction event on Earth (Ceballos et al., 2015). The contiguous United States (CONUS) is no exception to this crisis, where nearly one third of terrestrial vertebrate species are vulnerable to extinction or regional extirpation (Dietz et al., 2020). Terrestrial vertebrate species—colloquially known as "wildlife"—are well studied and can often serve as indicators of the overall health of ecosystems (Ceballos

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et al., 2020).

For vulnerable wildlife species, protected areas are a simple and foundational solution to the extinction crisis. Studies show that, worldwide, protected areas reduce the loss and degradation of natural habitats (Bruner et al., 2001; Naughton-Treves et al., 2005) and slow the rate of extinction of threatened species that occur within them (Butchart et al., 2012). The protected-area system in CONUS, while necessary to the viability of vulnerable wildlife species, is currently insufficient in size, representation of ecosystem and species diversity, and connectivity, i.e., relative lack of barriers to species' movements (Aycrigg et al., 2013; Jenkins et al., 2015; Belote et al., 2016). It currently stands at slightly over 7% of total land area (when Alaska and Hawai'i are included, about 12% is protected; Bertzky et al., 2012; UNEP-WCMC, 2021) and is heavily skewed toward the West and to alpine, boreal, desert, and subtropical-wetland ecosystems.

Scientists and policymakers have recently made appeals to protect 30% of the Earth's land area by 2030 ("30 ×30″; Haaland et al., 2021) as an interim step to protecting half of the Earth by 2050. The "half-earth" goal reflects a rough estimate of the amount of land needed—if distributed in the right manner—to ensure the long-term viability of plant and animal species that remain on the planet (Wilson, 2016; Dinerstein et al., 2019).

Historically, protected areas in the U.S.—such as national parks and wilderness areas—were often established through a combination of political expediency, attempts to avoid resource-use conflicts, and a public desire for primitive recreation, solitude, and outstanding natural scenery (Cordell et al., 2005). Only relatively recently has there been an appreciation for the contribution of protected areas to sustaining animal populations (Scott et al., 2001), with notable exceptions for protecting charismatic fauna (e.g., Porcupine caribou [*Rangifer tarandus granti* Allen]) and for the "production" of migratory waterfowl in National Wildlife Refuges. Still, even National Wildlife Refuges did not have a strong and singular wildlife conservation mission until the passage of the National Wildlife Refuge System Improvement Act in 1997 (Public Law 105–57). Because protected areas have not always been located in the best areas for biodiversity, much work has been done to assess the ecological values (e.g., ecological representation, biodiversity, and connectivity) of various areas for conservation (e.g., Belote et al., 2017) and how best to use tools or principles to prioritize them for protection (Belote et al., 2021).

There is a theoretical side to prioritizing areas for biodiversity conservation, and there is a practical side. Often they diverge. For example, land could be added systematically to the protected-area system solely in the order of its importance for conserving vulnerable species that are not well represented in the current reserve system (e.g., Pouzols et al., 2014). Practically, however, there are constraints to conservation actions, such as private-land rights, cost of land acquisition, development conflicts, political viability, ecological condition of the land, and degree—and therefore cost—of restoration or mitigation required. Often conservationists look for the "low-hanging fruit" that could most readily contribute to the size, connectivity, or representativeness of the protected-area system. Some characteristics of these areas are public ownership, relatively low value or high cost for extraction of natural resources or development, minimal conflict of uses, and high ecological intactness.

One type of land that exemplifies these characteristics are inventoried roadless areas on national forests (IRAs). IRAs are ecologically intact (USDA, 2001), federal, public lands in the national forest system of at least 2024 ha in the western U.S. and at least 405 ha in the eastern U.S. (they may be smaller if adjacent to roadless areas managed by other federal or state agencies) without open roads or major developments or structures. IRAs were inventoried as roadless by means of the U.S. Forest Service's (USFS) second Roadless Area Review and Evaluation in 1979 (43 Code of Federal Regulations § 19.3) and later made subject to the Roadless Area Conservation Rule of 2001 (36 Code of Federal Regulations § 294).

The Roadless Area Conservation Rule, which prohibits permanent roadbuilding and many types of commercial logging, is not considered to be as enduring as federal law would be, as any presidential administration can exempt roadless areas from the rule, rewrite regulations, or remove the rule entirely via a public review process. In addition, the Roadless Rule allows for broad, low-intensity use that may not be consistent with biodiversity conservation, such as off-road vehicle recreation and cattle grazing. For these reasons, the U.S. Geological Survey's Gap Analysis Project (GAP)—the official arbiter of America's terrestrial and marine protected areas—does not consider them to be "protected" in GAP status 1 or 2 (see GAP status definitions in *Data and Methods*). IRAs—which, in the absence of other overlaying conservation designations, are classified as GAP 3—can be elevated to "protected" status through such Congressional designations as Wilderness Areas, National Parks, or National Monuments. Currently there are 2481 IRAs that have not yet been protected as wilderness, parks, national monuments, or other conservation designations or otherwise achieved "protected" status through various means, such as overlapping state wildlife-protection designations. Typically, when IRAs are elevated to protected status, they are renamed with the label of the new designation, such as "wilderness," and are no longer referred to as "IRAs." Thus, all mentions hereafter to "IRAs" refer only to areas that are not currently protected in GAP status 1 or 2. These unprotected roadless areas total 15,948,918 ha—approximately 2% of the area of CONUS (778,971,743 ha)—and are the focus of this study.

As demonstrated by the recent efforts by the states of Utah and Alaska to seek exemptions from the Roadless Rule, these areas, because they lack durable Congressional protection, are under threat of degradation from logging, new road construction, development, and motor vehicles (Congressional Research Service Report R4, 4650, 2020) which are leading sources of human-caused fires, introduction of invasive species, fragmentation of habitat, and extraction of natural resources (Trombulak and Frissell, 2000). Roadless areas worldwide are important as refugia for biodiversity, as areas of high ecological integrity, and as bulwarks against the direct effects of roads and motor vehicles—such as habitat loss, noise disturbance, and roadkill—and indirect effects—such as habitat fragmentation, invasive species, and resource extraction (DellaSala and Strittholt, 2003; Selva et al., 2015). Roadless areas are especially valuable in supporting populations of animal species that require large areas free of human disturbance (Fahrig and Rytwinski, 2009; Torres et al., 2016). Across the globe, the proportion of threatened and extinct endemic animals is higher in countries with smaller roadless areas (Pouteau et al., 2021). IRAs in CONUS are largely ecologically intact: unroaded, unlogged, and undeveloped (USDA, 2001). They represent a vast amount of roadless, public land with known conservation values, such as delivering clean drinking water, capturing carbon, and buffering protected areas (Talty et al., 2020).

Despite the known values of and threats to IRAs and the conservation opportunity they afford, until now we had not known how valuable IRAs are for providing suitable habitat for vulnerable wildlife species in the contiguous U.S.; no one to our knowledge had investigated this question with fine-scale habitat data. A few regional studies of the relationship between wildlife species and roadless areas have been conducted (Chen and Roberts, 2008; Crist et al., 2005) as well as one national coarse-scale study which lacked data for several states and examined only *known occurrences* of species but not *suitable habitat* for those species (Loucks et al., 2003). Otherwise, the value of IRAs to vulnerable wildlife species had been largely unexplored. In addition, evaluation of IRAs is particularly important because they may be *relatively* easy to add to the protected-area system to bring us closer to a fundamental goal of 30 × 30—saving species—as there is a well-established process for the USFS to recommend IRAs for wilderness designation to the U.S. Congress (36 Code of Federal Regulations § 219.7 (c) (2) (v)). We must, however, assess *how much* IRAs could contribute to wildlife conservation, so stakeholders in turn can assess whether elevating their protection is worth the political, financial, or social capital needed to protect them. Should conservation biologists or decision-makers focus here or on other areas?

Because of the opposing demands to protect roadless areas and to downgrade them, there is a pressing need to assess the ecological values of these areas. Our goal in this study is not to address *all* the multiple values of IRAs or to attempt to prioritize their protection in relation to other lands, public or private; it is to provide an inventory of the habitat for wildlife species of conservation concern in IRAs so that scientists, national forest managers, and politicians can make better-informed decisions about which lands to place in the protected-area system—taking into account myriad other factors outside the scope of this study: threats, political opportunities, costs, and other ecological values such as connectivity, ecosystem representation, and carbon sequestration. Our goal here is to assess the importance of IRAs—in total and individually—as habitat for wildlife species of conservation concern (SCCs; *sensu* Dietz et al., 2020) and, for context, compare their habitat value to that of other national forest lands and U.S. lands in general. We also have quantified how well the protected-area system would provide habitat for wildlife SCCs if all unprotected IRAs were added to it.

Specifically, we answer the following questions:

1.1. Number of species

How many wildlife SCCs have suitable habitat in IRAs, and what is the distribution of habitat for SCCs among individual IRAs? How do these numbers vary by taxonomic class?

1.2. Proportion of IRAs as habitat

What proportion of all IRA land-area provides suitable habitat for wildlife SCCs? How does that proportion vary by taxonomic class?

1.3. Proportion of habitat in IRAs

What proportion of each wildlife SCC's total suitable-habitat area is found in IRAs? How does that proportion vary by taxonomic class?

1.4. Comparison to other lands

How does SCC (habitat) richness in IRAs compare to that in all USFS protected areas and all USFS unprotected, roaded areas? How does this comparison vary by taxonomic class?

1.5. Additional protection

How would the proportion of habitat protected for wildlife SCCs change if IRAs were added to the protected-area system? How does this proportion vary by taxonomic class?

2. Data and methods

We used the most recent version of the highest-resolution mapped data available (30-m × 30-m pixels = 900 m^2; Albers projection) for wildlife habitats in CONUS: U.S. Geological Survey (USGS) GAP species habitat maps (Gergely et al., 2019). These data represent a complete compilation of terrestrial vertebrate suitable-habitat models for CONUS (fine-scale wildlife habitat data are incomplete for Alaska and Hawai'i, so we excluded these states from the study), based on 2001 ground conditions (McKerrow et al., 2018). These models include all 1590 mammal, bird, amphibian, and reptile species found in CONUS during summer, winter, or year-round and 129 subspecies of terrestrial vertebrates that the GAP team determined had ranges that were spatially distinct and had unique habitat relationships that warranted a separate subspecies model (Gergely et al., 2019). These GAP habitat maps are derived from a deductive habitat suitability model—the Wildlife Habitat Relations Model—which uses remotely-sensed spatial information on habitat variables within a species' range (based on known occurrence points) to predict spatial occupancy of a species. The model predicts either presence or absence based on habitat characteristics, as opposed to a continuous-value probability of occurrence (see complete methodology in Gergely et al., 2019). The model represents, therefore, a best prediction of whether there is suitable habitat for a species or subspecies in each pixel, irrespective of whether it is currently occupied by the species or subspecies. Some areas that are deemed "suitable habitat" may not, at present, be occupied by the species in question. We defined "total suitable-habitat area" for each species by calculating the sum of every 900-m^2 pixel from these models.

We defined "species of conservation concern" (SCC) (*sensu* Dietz et al., 2020) as any terrestrial vertebrate species that meets one or more of the following criteria: 1) listed as threatened, endangered, or a candidate species under the U.S. Endangered Species Act (USFWS 2018); 2) classified by the International Union for Conservation of Nature (IUCN) as extinct in the wild, critically endangered, endangered, or vulnerable (IUCN, 2019); or 3) classified by NatureServe either globally, as an infraspecific-taxon, or nationally as possibly extinct, critically imperiled, imperiled, or vulnerable (NatureServe, 2019).

There are 1719 species and selected subspecies of terrestrial vertebrates in CONUS. We included all species and subspecies from the USGS GAP habitat list without making independent judgments about "lumping" or "splitting" species into subspecies or about whether species or subspecies could be considered "native" or "naturalized" to CONUS. Of these wildlife species, 537 (>31%) are species of conservation concern (Dietz et al., 2020).

PAD-US version 2.0 (USGS 2018), published on September 30, 2018, is a geodatabase of the national inventory of terrestrial and marine protected areas that are dedicated to the preservation of biodiversity and to other natural, recreational, and cultural uses, managed for these purposes through legal or other effective means. It is the most comprehensive and complete dataset for protected areas available in the U.S. The geodatabase includes geographic boundaries, land ownership, land management, management designation, parcel name, area, and protection category.

PAD-US classifies all lands into four categories with the following definitions: GAP 1—an area having permanent protection from conversion of natural land cover and a mandated management plan in operation to maintain a natural state within which disturbance events (of natural type, frequency, intensity, and legacy) are allowed to proceed without interference or are mimicked through management; GAP 2—an area having permanent protection from conversion of natural land cover and a mandated management plan in operation to maintain a primarily natural state, but which may receive uses or management practices that degrade the quality of existing natural communities, including suppression of natural disturbance; GAP 3—an area having permanent protection from conversion of natural land cover for the majority of the area, but subject to extractive uses of either a broad low-intensity type (for example, logging, off-highway vehicle recreation) or localized intense type (for example, mining); GAP 4—an area with no known public or private institutional mandates or legally recognized easements or deed restrictions held by the managing entity to prevent conversion of natural habitat types to anthropogenic habitat types.

We defined "inventoried roadless areas" (IRAs) in national forests as those areas that are classified by the USFS as falling under the Roadless Area Conservation Rule (RACR 2001) but not classified as "protected" as GAP 1 or GAP 2 in the Protected Area Database of the United States (PAD-US). Most IRAs are currently classified as GAP 3, with some exceptions in areas where state or other federal conservation areas (e.g., Wilderness Study Areas) overlap IRAs. We then eliminated areas smaller than 100 ha to ensure removal of small "slivers" that may occur with imprecisely overlaid spatial data sets.

2.1. Number of species

We overlaid the suitable-habitat maps of each wildlife SCC with IRAs and tallied the number (total and by taxonomic class) of SCCs with habitat occurring in at least one IRA. We also tallied the number of wildlife SCCs with any amount of suitable habitat in each individual IRA. We ranked each IRA by the number of SCCs with habitat in it. For all wildlife SCCs, mammal SCCs, and bird SCCs, we binned richness into five classes based on 25th, median, 75th, and 95th percentiles of IRAs to map diversity of wildlife SCCs habitat for each IRA. Because amphibian and reptile SCCs' diversity was highly skewed, we created manual breaks for display but used the 99th percentile to map the most diverse tier of IRAs. We highlighted (in a list in the results section and in red in Fig. 1) the top 5% of IRAs in terms of richness for all wildlife SCCs, mammal SCCs, and bird SCCs and the top 1% for amphibian and reptile SCCs. All spatial analyses were conducted using ArcMap version 10.x, Python version 4.x, or R version 3.6.3.

2.2. Proportion of IRAs as habitat

From the overlays described above, we also calculated the proportion of all IRA land combined that is composed of habitat for at least one wildlife SCC. We also calculated the proportion of all IRA land combined that is composed of habitat for two wildlife SCCs, three SCCs, and so on. We compared these proportions to all other land in CONUS to evaluate whether IRAs disproportionately support habitat for wildlife SCCs.

2.3. Proportion of habitat in IRAs

We calculated the proportion of each wildlife SCC's total suitable habitat occurring within IRAs. This allowed us to evaluate which wildlife SCCs had the highest proportion of suitable habitat in IRAs, and thus are most dependent on IRAs for sustaining suitable occupied or potential habitat. We also identified which IRAs were particularly important for maintaining suitable habitat for which wildlife SCCs.

2.4. Comparison to other lands

In addition to calculating the total number of wildlife SCCs with habitat in each IRA (2.1), we also calculated the number of overlapping habitats for each 900-m^2 pixel within all IRAs. Specifically, we calculated the median, minimum, and maximum number of wildlife SCCs per 900-m^2 pixel for IRAs within USFS regions. We compared these values to median, minimum, and maximum number of species per 900 m^2 in existing USFS protected areas (PAs; i.e., *USFS lands* with GAP 1 or 2 status) and all other USFS lands not in IRAs or protected areas.

2.5. Additional protection

To evaluate how IRAs might improve representation of wildlife SCCs in the protected-area network (i.e., *all* lands with GAP 1 or 2 status), we first calculated the proportion of habitat for each wildlife SCC within existing PAs. We summed the proportion of habitat for each wildlife SCC within PAs with the proportion of habitat in IRAs. We then plotted histograms of the proportion of habitat in PAs and proportion of habitat in PAs + IRAs to display how adding IRAs to the PA system could change the representation of habitat for wildlife SCCs. We used 10% breaks for our histograms and counted species within bins to assess how adding IRAs to PAs would change representation of species, in total and by taxonomic class. We further classified wildlife SCCs with < 20% of their suitable habitat in PAs as "poorly represented", SCCs with 20–50% protected as "moderately represented", and SCCs with > 50% as "well represented" per Dietz et al. (2020). We counted species within these classes to assess broad trends in how adding IRAs to PAs could improve representation of habitat for wildlife SCCs.

3. Results

3.1. Number of species

Of the 537 wildlife SCCs in CONUS, 308 species (57%) have at least some suitable habitat in one or more IRAs. Moreover, every IRA contains habitat for at least two wildlife SCCs. The median IRA contains suitable habitat for 10 wildlife SCCs, with a maximum of 62 wildlife SCCs (in an IRA in southern Arizona). These distributions of wildlife SCCs in IRAs vary substantially by taxonomic class and by geographic region (Table 1 and Fig. 1).

The top 10 IRAs with suitable habitat for the largest number of wildlife SCCs are all in Arizona: Tumacacori (62 species), Pinaleno (60), Chiricahua (57), Oracle (56), Peloncillo (55), Santa Rita (55), Butterfly (54), Galiuro (53), Whetstone (52), and Middle Dragoon (51) Roadless Areas.

Much as biodiversity itself is unevenly distributed across CONUS, the numbers of wildlife SCCs with habitat in IRAs are unevenly distributed. Table 2 shows the number of IRAs by state in the top 5% of IRAs with respect to suitable habitat for the largest number of wildlife SCCs (range=62–23 species); the top 5% of IRAs with respect to suitable habitat for the largest number of mammal SCCs (range=23–12); the top 5% of IRAs with respect to suitable habitat for the largest number of bird SCCs (range=25–7); the top 1% of IRAs with respect to suitable habitat for the largest number of amphibian SCCs (range= 9–6); and the top 1% of IRAs with respect to suitable habitat for the largest number of reptile SCCs (range= 15–4) (in Fig. 1 the top 5% for mammals and birds and top 1% for amphibians and reptiles are mapped in red).

3.2. Proportion of IRAs as habitat

Nearly 99% of the total land-area of all IRAs contains suitable habitat for at least one wildlife SCC (15,754,341 of 15,948,918 ha), although much of that coverage is due to the availability of suitable habitat for mammals—predominantly bats. Approximately 98.7% (15,749,009 ha) of the total land area of all IRAs contains suitable habitat for at least one mammal SCC; 43% (6804,881 ha) for at least one bird SCC; 11% (1714,950 ha) for at least one amphibian SCC; and 4% (678,882 ha) for at least one reptile SCC.

Compared to non-IRA CONUS lands, IRAs provide a larger proportion of suitable habitat for wildlife SCCs for at least one species, two or more species, three or more species, etc., up to 7 species, after which the proportions of suitable habitat are roughly equal (Fig. 2). At its greatest difference, 81% of IRA land is suitable habitat for 5 or more wildlife SCCs, whereas only 56% of non-IRA land is suitable habitat for 5 or more wildlife SCCs (Fig. 2, dashed lines).

3.3. Proportion of habitat in IRAs

Of the 308 wildlife SCCs that are found in IRAs, there is wide variance in the proportion of each SCCs total suitable habitat that is in

Table 1
Wildlife species of conservation concern (SCCs) with suitable habitat in U.S. Forest Service inventoried roadless areas (IRAs). Totals are for all IRAs combined. Medians, minimums, and maximums are for individual IRAs.

SCCs	Total	Median/IRA	Minimum/IRA	Maximum/IRA
All Wildlife	308	10	2	62
Mammals	93	6	2	23
Birds	77	2	0	25
Amphibians	77	1	1	10
Reptiles	61	0	0	15

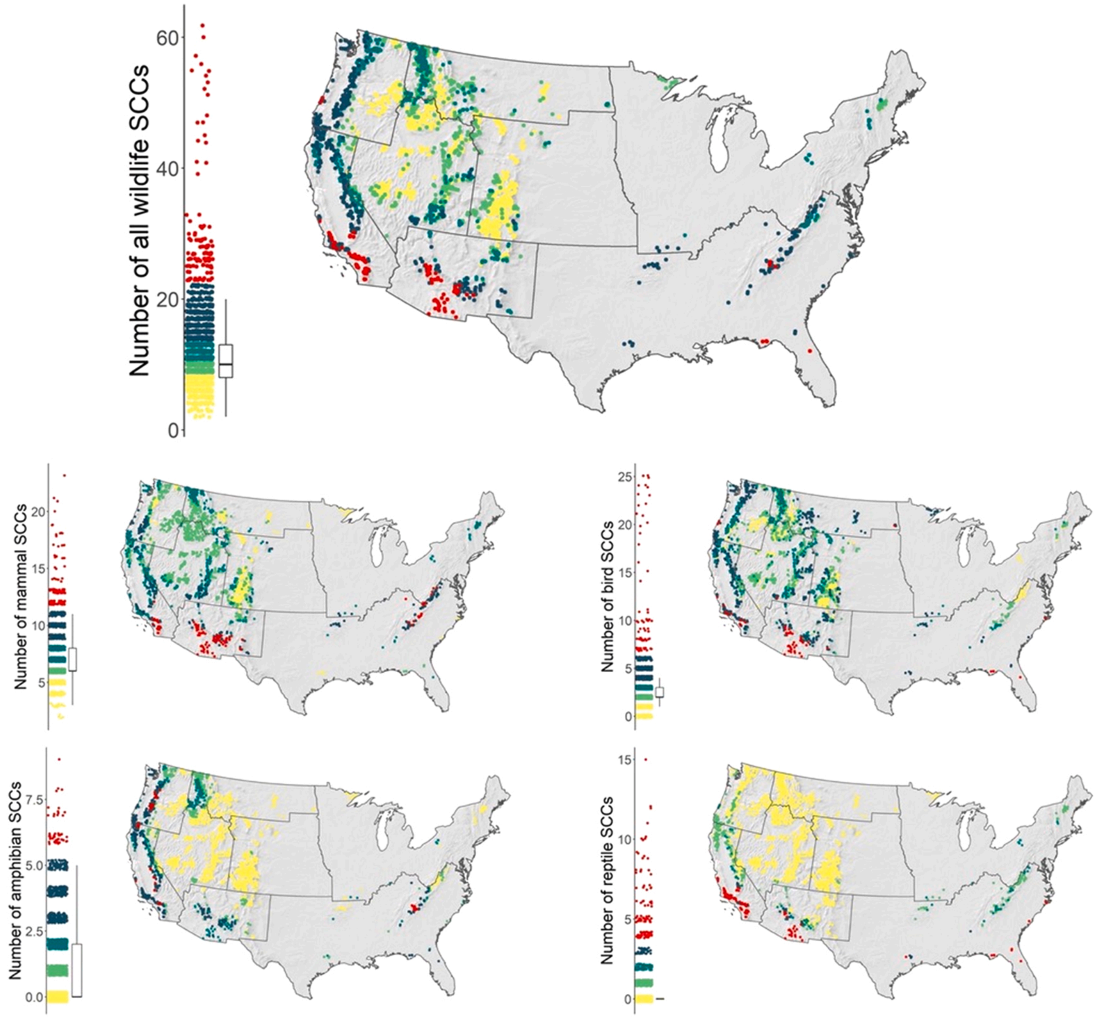

Fig. 1. Maps of the eight U.S. Forest Service (USFS) regions in the contiguous United States (CONUS), with points representing the geographic centers of each of 2481 inventoried roadless areas (IRAs), color-coded (legend on the left) by number of all wildlife species of conservation concern (SCCs)—and of the four taxonomic classes—that have suitable habitat within the IRA. Boxplots display medians and the first and third quartiles. The upper whisker extends from the third quartile to the largest value no further than 1.5 * IQR (inter-quartile range). The lower whisker extends from the first quartile to the smallest value at most 1.5 * IQR.

Table 2
The number of IRAs by state in the top 5% of IRAs with respect to suitable habitat for the largest number of wildlife SCCs (range=62–23 species); the top 5% of mammal SCCs (range=23–12); the top 5% of bird SCCs (range=25–7); the top 1% of amphibian SCCs (range= 9–6); and the top 1% of reptile SCCs (range= 15–4), respectively. Unequal totals between and among 5% and 1% categories are due to ties.

State	# of IRAS in Top 5% for Wildlife	Top 5% for Mammals	Top 5% for Birds	Top 1% for Amphibians	Top 1% for Reptiles
California	51	22	15	21	74
Arizona	44	52	34		24
Florida	4		4		6
Oregon	4		4	16	
New Mexico	2	22	3		
North Carolina	1	11	2	6	4
Virginia		11			
Georgia		1		5	
Kentucky		1			
Utah			1		
North Dakota			1		
Washington				2	
South Carolina					1
Texas					1

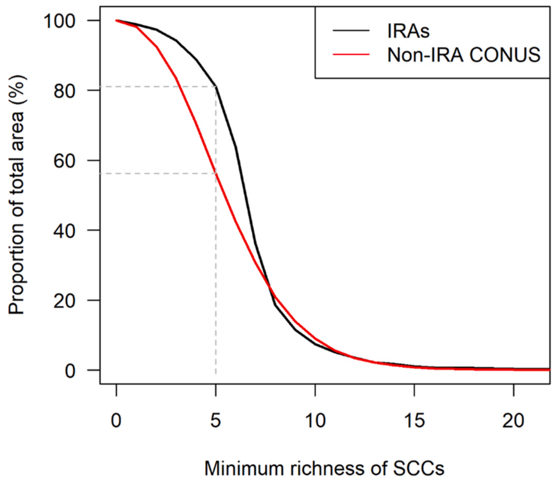

Fig. 2. Proportion of total suitable habitat in all USFS inventoried roadless areas (IRAs) and all non-IRA lands in the contiguous United States (Non-IRA CONUS) for minimum threshold numbers of wildlife species of conservation concern (SCCs). Compared to non-IRA CONUS lands, IRAs provide a larger proportion of suitable habitat for wildlife SCCs for at least one species, two or more species, three or more species, etc., up to 7 species, after which the proportions of suitable habitat are roughly equal. The dashed line indicates the greatest difference between IRAs and non-IRA lands. Data for 22–62 SCCs are not shown, as the proportion curves are virtually identical.

IRAs (Table 3). The maximum among all wildlife SCCs is over 50% of a species' total suitable habitat in IRAs. There are 8 wildlife SCCs with over 20% of their total suitable habitat in IRAs; 45 wildlife SCCs with over 10% of their total suitable habitat in IRAs; and 86 wildlife SCCs with over 5% of their total suitable habitat in IRAs. The median proportion of total suitable habitat that is in IRAs (for SCCs that are found in IRAs) is 1.45% across all classes, 2.19% for mammals, 0.39% for birds, 2.45% for amphibians, and 0.33% for reptiles (Table 3). When, however, SCCs are separated into "large-range" and "small-range," the small-range SCCs have substantially more than expected proportions of their total suitable habitat in IRAs. For species with a total range size under 1000,000 ha, it is 3.17%. For those species with a total range size under 100,000 ha, it is 5.00%.

The twenty highest proportions of total suitable habitat in IRAs across all classes of wildlife SCCs are composed of amphibians (9—all of which are salamanders), mammals (7), reptiles (3), and one bird species (Table 4). Eleven of those 20 species have those large proportions of total suitable habitat in 10 or fewer roadless areas (Table 4). In addition, 13 wildlife SCCs have greater than 10% of their total suitable habitat contained *in a single IRA* (as opposed to all IRAs combined).

3.4. Comparison to other lands

When compared across eight national forest regions, the median number of wildlife SCCs with suitable habitat per 900-m^2 pixel was largely similar between 1) IRAs 2) GAP 1 or 2 "protected" areas on national forests, and 3) non-IRA, roaded "unprotected" areas on national forests. The median IRA contained suitable habitat for more species than the median USFS protected area in five USFS regions, the same number of species in two regions, and fewer species in one region. The median IRA contained suitable habitat for the same number of species as unprotected non-IRA national forest lands in six USFS regions and fewer species in two regions. The medians, however, never differed by more than one or two species across the three categories. These differences varied slightly more by taxonomic class. For example, the median IRA in the southern region had habitat for eight mammal species, compared to seven in unprotected, non-IRA national forest lands, and five in national forest protected areas (Fig. 3).

3.5. Additional protection

If all IRAs were protected to the GAP status level of 1 or 2, the number of wildlife SCCs that are considered "poorly represented" (*sensu* Dietz et al., 2020) in the protected-area system would be reduced by 10.5% (from 362 [67.4% of SCCs] to 324 [60.3%]). The

Table 3
Proportion of each wildlife species of conservation concern's (SCCs) total suitable habitat in U.S. Forest Service inventoried roadless areas (IRAs) with suitable habitat.

SCCs	Median %	Minimum %	Maximum %
All Wildlife	1.45	0.000002	50.61
Mammals	2.19	0.00002	39.05
Birds	0.39	0.00008	14.95
Amphibians	2.45	0.00003	50.61
Reptiles	0.33	0.00020	18.60

Table 4
The twenty highest proportions of total suitable habitat found in U.S. Forest Service inventoried roadless areas (% in IRAs) for all classes of wildlife species of conservation concern (SCCs). The total number of IRAs with habitat for each SCC is shown in the final column.

Common Name	Binomial	% in IRAs	# of IRAs
Relictual Slender Salamander	*Batrachoseps relictus*	50.61	2
Mt. Pinos Lodgepole Chipmunk	*Tamias speciosus*	39.05	4
Kern Canyon Slender Salamander	*Batrachoseps simatus*	36.66	3
Woodland Caribou	*Rangifer tarandus*	35.04	20
San Gabriel Mts. Slender Salamander	*Batrachoseps gabrieli*	27.29	11
Idaho Giant Salamander	*Dicamptodon aterrimus*	26.68	128
White-eared Pocket Mouse	*Perognathus alticolus*	23.29	5
Mexican Fox Squirrel	*Sciurus nayaritensis*	20.67	9
Scott Bar Salamander	*Plethodon asupak*	19.39	9
Ridge-nosed Rattlesnake	*Crotalus willardi*	18.60	15
Arizona Shrew	*Sorex arizonae*	18.48	7
Siskiyou Mountains Salamander	*Plethodon stormi*	18.27	14
Twin-spotted Rattlesnake	*Crotalus pricei*	17.47	19
Coeur d'Alene Salamander	*Plethodon idahoensis*	16.55	185
Mt. Graham Red Squirrel	*Tamiasciurus hudsonicus*	16.31	1
Brown Bear	*Ursus arctos*	16.17	215
Cheoah Bald Salamander	*Plethodon cheoah*	15.54	2
Kern Plateau Salamander	*Batrachoseps robustus*	15.27	10
Arizona Woodpecker	*Picoides arizonae*	14.95	18
Striped Plateau Lizard	*Sceloporus virgatus*	14.82	2

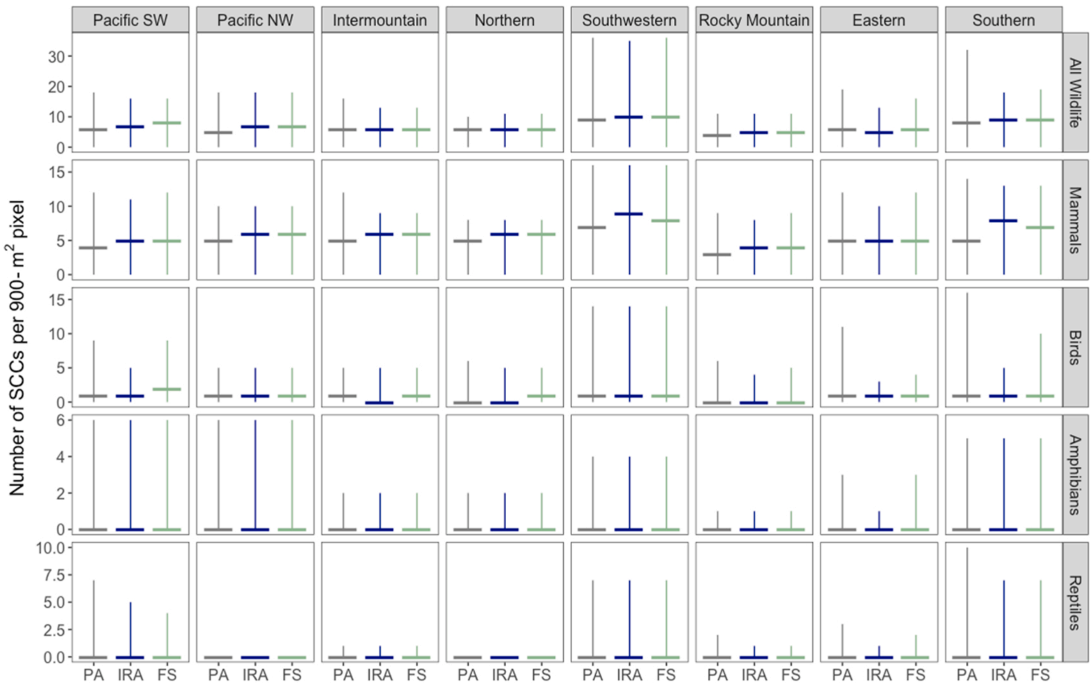

Fig. 3. The median (horizontal bars) and range (vertical bars) of the number of wildlife species of conservation concern (SCCs) per 900-m^2 pixel in U.S. Forest Service (USFS) GAP 1 or 2 "protected areas" (PA), USFS inventoried roadless areas (IRA) [all classified as "unprotected areas"], and USFS roaded, "unprotected areas" (FS) in the contiguous United States. The data are reported by USFS region and by taxonomic class.

number of wildlife SCCs considered "moderately represented" in the protected-area system would increase by 24.8% (from 113 [21.0%] to 141 [26.3%]), and the number of wildlife SCCs considered "well represented" in the protected-area system would increase by 16.1% (from 62 [11.5%] to 72 [13.4%]). In total, 38 wildlife SCCs would be elevated out of the "poorly represented" category in this conservation scenario. The results vary by taxonomic class, but the pattern is similar across mammals, birds, amphibians, and reptiles (Fig. 4).

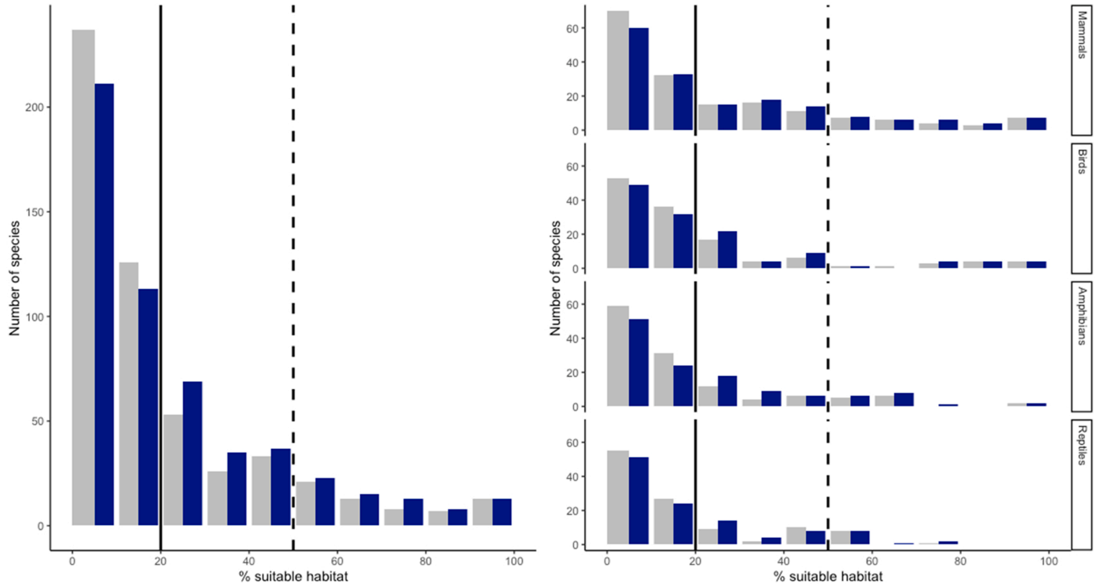

Fig. 4. How well the current protected-area system (grey bars) is capturing habitat for wildlife species of conservation concern (SCCs) and how that would change (blue bars) if all U.S. Forest Service inventoried roadless areas (IRAs) were protected. Distributions of SCCs—in total (left) and by taxonomic class (right)—according to the proportion, in deciles, of their total suitable habitat that is (or would be) protected in GAP 1 or 2 areas in the contiguous United States (CONUS). Species to the right of the dashed line are "well represented" in protected areas (50% or more). Species to the right of the solid line are at least "moderately represented" in protected areas (20% or more). Species to the left of the solid line are "poorly represented" in protected areas (<20%) [*after* (Dietz et al., 2020)].

4. Conclusions and discussion

In light of calls both to protect roadless areas and to downgrade them (see Weber, 2019), there is an urgent need to assess the values of these areas to know what we would be conserving or losing. Area-based targets to protect land are insufficient without knowing biodiversity values, such as habitat for wildlife SCCs, and practical matters, such as conservation opportunity. Here we have attempted to give some context for the practical side of public lands conservation while providing a quantitative assessment of the suitable habitat for wildlife SCCs that IRAs could provide.

A surprising number of wildlife SCCs—well over half—have suitable habitat in IRAs even though IRAs cover only 2% of CONUS and are composed predominately of forested biome types and lack substantial representation of deserts, grasslands, savannas, and wetlands (Talty et al., 2020). Moreover, IRAs tend to be clustered geographically in forests in the Sierra Nevada, Cascade, Rocky, and Appalachian Mountains and are, on average, at higher elevation than the surrounding roaded lands (DeVelice and Martin, 2001). Yet, IRAs compare favorably to the rest of CONUS lands. Despite their geographic and elevational clustering and predominance of a single biome type, IRAs provide a larger proportion of suitable habitat for multiple wildlife SCCs than non-IRA CONUS lands (see Fig. 2). IRAs are distributed in such as fashion that they capture much of the biodiversity of the wildlife SCC "hotspots" across CONUS (mapped in Dietz et al., 2020). The high diversity of wildlife SCCs in Texas is one of the most notable exceptions, the state having few federal lands and very few IRAs.

Without exception, every IRA provides habitat for at least two wildlife SCCs, and the median IRA has habitat for 10 wildlife SCCs. In addition, almost all the *land-area* of IRAs (~99%) is habitat for at least one wildlife SCC, which is at least partially explained by the widespread geographic distributions of several bat SCCs. IRAs are important to terrestrial vertebrates of conservation concern across taxa: of the 308 wildlife SCCs with habitat in IRAs, 30% are mammals, 25% are birds, 25% are amphibians, and 20% are reptiles.

As shown in Fig. 1, the top 5% most habitat-diverse IRAs for all wildlife SCCS are found in southern California and Arizona, with a small number of high-diversity IRAs in Florida, Oregon, New Mexico, and North Carolina. For mammal SCCs, the top 5% of high-diversity IRAs includes Arizona, California, and New Mexico in the top tier, followed by North Carolina and Virginia with 11 high-diversity IRAs each, and Georgia and Kentucky with one high-diversity IRA each. For bird SCCs, again, Arizona and California top the high-diversity-IRA list (top 5%), with smaller numbers of high-diversity IRAs in the states of Florida, Oregon, New Mexico, North Carolina, North Dakota, and Utah. High-diversity IRAs for amphibian SCCs (top 1%) are found in the Sierra-Cascades (of CA, OR, and WA) and in the southern Appalachian Mountains (of NC and GA). High-diversity IRAs for reptile SCCs (top 1%) are limited to the far-southern regions of Southern California and Arizona (the great majority) and in Florida, North Carolina, South Carolina, and Texas.

Many wildlife SCCs depend disproportionately on IRAs for their habitat needs. Eighty-six wildlife SCCs have over 5% of their *total suitable habitat* in IRAs. This means that 16% of all 537 wildlife species of conservation concern in CONUS would have *at least* 1/20th (and oftentimes much more) of their habitat preserved as refuges and potentially source populations if IRAs were added to America's protected-area network. Eight wildlife SCCs are extremely dependent on IRAs for occupied or potential habitat, having greater than

20% of their total suitable habitat therein. Notably, four of these species are salamanders with small ranges.

IRAs also compare well against protected areas and unprotected, roaded areas in national forests. The median number of wildlife SCCs' suitable habitat per 900-m^2 pixel is slightly higher in IRAs than in most national forest wilderness areas, national monuments, and other currently protected areas. It is slightly lower in IRAs than in national forest roaded areas in two of eight regions, but in six regions, the habitat value of IRAs is the same as unprotected, roaded areas despite being generally at higher elevations. The obvious conservation advantage of IRAs over roaded national forest land, however, is their relative ecological intactness, absence of most conflicting uses, and adjacency to existing protected areas. A third of all IRAs are adjacent to an existing wilderness or national park, and two-thirds are within 1 km of one (Talty et al., 2020). Ideally, areas added to the existing reserve system should contribute to protecting species that are vulnerable to extinction or regional extirpation. If all IRAs were added to the protected-area system in CONUS, there would be a substantial decrease (−38) in the number of wildlife SCCs that are currently considered "poorly represented" in protected areas. Note, however, that these classification bins are convenient markers and that moving from one bin to another may be a small numerical advance.

IRAs could be prime candidates for protection, as they are publicly owned, ecologically healthy, and resilient. Protecting them is largely a matter of law or policy and would require no cost for acquisition and minimal or no cost for restoration. Given their high habitat value for wildlife SCCs and their ecological intactness, it may make practical sense to advocate for their protection as a relatively easy and cost-efficient step toward the goal of protecting 30% of U.S. lands by 2030.

There are several ways in which IRAs could be elevated to "protected" status (GAP 1 or 2) from their current "unprotected" status (GAP 3). As part of periodically revising national forest plans, regulations under the National Forest Management Act (36 Code of Federal Regulations 219) require that Forest Supervisors make recommendations to Congress for roadless areas to be designated as "wilderness." During this process all IRAs must be evaluated for wilderness characteristics, including their value to conserving plant and animal diversity. Congress may also directly pass laws to designate any or all roadless public lands as wilderness or national monuments, for example, irrespective of the national forests' wilderness recommendation processes. In addition, in recognition of the importance of IRAs, members of the U.S. Congress recently introduced the Roadless Area Conservation Act of 2021 (House Resolution 279), which would permanently protect all IRAs from roadbuilding, commercial logging, and other ecologically harmful activities.

Because IRAs are in administrative purgatory—not deemed "protected areas," yet subject to *some* protections under the Roadless Rule—they may be especially susceptible to the widespread downgrading, downsizing, and degazettement of conservation areas that have occurred recently in the U.S. and throughout the world (Golden Kroner et al., 2019). Indeed, the loss of wild areas around the globe far outpaces their protection, largely due to new roadbuilding and associated natural-resource extraction (Watson et al., 2016). Although "roadless" areas make up 80% of the Earth's land, more than half of them are remarkably small at under 1 km^2, and only 7% are larger than 100 km^2 (Ibisch et al., 2016). Large roadless areas are increasingly rare worldwide, particularly in Europe, India, Japan, and the contiguous United States (Ibisch et al., 2016; Watts et al., 2007).

Many ecologists have called for protecting the last of the wild, including roadless areas, to halt the disappearance of the Earth's few intact ecosystems, especially where they are rarest (Watson et al., 2018; Selva et al., 2011). Scientists in Europe, for example, have recommended that roadless areas be integrated into biodiversity conservation networks as a way to minimize conflicts while expanding protected areas to achieve the goals of the European Union's 2020 Biodiversity Strategy (Psaralexi et al., 2017). And in an interesting coincidence, there have been calls for a "European Roadless Rule" that would legally protect at least 2% of European land as road-free area (Kati et al., 2020).

The Global Deal for Nature calls for formal protection of 30% of the Earth by 2030 (Dinerstein et al., 2019). It is not, however, solely an area-based plan; there are specific metrics for achieving biodiversity goals, including protecting rare and threatened species and increasing ecosystem representation in protected areas. Previous studies in the U.S. have examined how adding IRAs to the protected-area system could improve ecosystem representation in the contiguous U.S. (Aycrigg et al., 2016) or regionally (Crist et al., 2005). But no previous studies have used fine-scale modelled suitable habitat data to assess the potential value of IRAs to wildlife SCCs across CONUS. A case study in Alabama assessed the correlation between roadless volume and species richness and found that the number of herpetofaunal and plant species increased with increasing roadless volume (Chen and Roberts, 2008). And nearly 20 years ago, a study was conducted to assess the overlap between known occurrences of vulnerable species—at the scale of 7.5-min. quadrangles (up to 17,900-ha areas)—and IRAs (Loucks et al., 2003). This study lacked data for Washington, Idaho, and Montana; did not consider suitable habitat (only *known* occurrences); combined plants, fish, and wildlife; and was at a resolution several orders of magnitude coarser than ours. Nonetheless, the analysis found that 77% of roadless areas had the potential to conserve threatened, endangered, or imperiled plant and animal species. They concluded that "IRAs belonging to the U.S. Forest Service are one of the most important biotic areas in the nation, and that their status as roadless areas could have lasting and far-reaching effects for biodiversity conservation" (Loucks et al., 2003).

This analysis is a first step in evaluating an important conservation value of IRAs—their suitability and current use as habitat for wildlife SCCs. This study is not, by itself, an effort to place IRAs in a prioritization hierarchy. Nor is it an argument for designating protected areas on public lands over private land conservation; restoration, preservation, and acquisition of private land are essential to biodiversity conservation (Kamal et al., 2015). This study provides quantitative data for one of the most important research questions of the movement to protect 30% of the Earth by 2030: how do we prevent extinction and regional extirpation of vulnerable species? We have placed this analysis in the context of the tradeoffs between the value of land as habitat for SCCs and the political, social, and fiscal viability of conservation. Future research will need to take into account other factors such as complementarity—efficiently representing species among sites (Moilanen, 2007)—and changing climatic conditions (Lawler et al., 2020).

Clearly IRAs are strong candidates for protection when considering such factors as public ownership, low human-footprint, high ecological intactness, few conflicting (current) uses, little restoration required, and low cost of "acquisition." Perhaps surprisingly, IRAs also are strong candidates for protection based on their importance to wildlife SCCs. IRAs represent well the habitat needs across taxonomic classes of wildlife SCCs. Given that 57% of wildlife SCCs have suitable habitat in IRAs, it is notable that the range of representation among terrestrial vertebrate classes is narrow (54.4% of all mammal SCCs have suitable habitat in IRAs; 59.7% of bird SCCs; 61.6% of amphibian SCCs; and 54.5% of reptile SCCs). There are no striking patterns of underrepresentation by class. There are, however, notable characteristics of species that are not found in IRAs: SCCs with small ranges in mostly private-land states such as Texas (e.g., Austin blind salamander [*Eurycea waterlooensis*]), island species (e.g., San Clemente Island fox [*Urocyon littoralis*]), coastal species (e.g., roseate tern [*Sterna dougallii*]), and species found in ecosystem types not generally associated with IRAs (e.g., American crocodile [*Crocodylus acutus*]). As a result, building an effective reserve system of protected areas, buffer zones, and corridors will rely on many strategies, including protective designation of public lands, restoration of industrial timber lands and ranchlands, re-conversion of croplands, purchase of conservation easements, and fee-title purchase of ecologically intact private lands.

Some strategies will be expensive or politically challenging but may well be worth the effort if their contribution to biodiversity is disproportionately large. Some strategies will be inexpensive or particularly palatable to the public but may not be worth the effort if they have relatively little to contribute to plant and animal conservation. Here we have provided quantitative information about the importance of IRAs to vulnerable wildlife species so that stakeholders, agency staff, and lawmakers can make informed choices about where to invest limited resources for conservation.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

Aycrigg, J.L., Davidson, A., Svancara, L.K., Gergely, K.J., McKerrow, A., Scott, J.M., 2013. Representation of ecological systems within the protected areas network of the continental United States. PLoS One 8, e54689.

Aycrigg, J.L., Tricker, J., Belote, R.T., Dietz, M.S., Duarte, L., Aplet, G.H., 2016. The next 50 years: opportunities for diversifying the ecological representation of the National Wilderness Preservation System of the contiguous United States. J. For. 114 (3), 396–404.

Belote, R.T., Dietz, M.S., McRae, B.H., Theobald, D.M., McClure, M.L., Irwin, G.H., McKinley, P.S., Gage, J.A., Aplet, G.H., 2016. Identifying corridors among large protected areas in the United States. PLoS One 11, e0154223.

Belote, R.T., Dietz, M.S., Jenkins, C.N., McKinley, P.S., Irwin, G.H., Fullman, T.J., Leppi, J.C., Aplet, G.H., 2017. Wild, connected, and diverse: building a more resilient system of protected areas. Ecol. Appl. 27 (4), 1050–1056. https://doi.org/10.1002/eap.1527.

Belote, R.T., Barnett, K., Dietz, M.S., Burkle, L., Jenkins, C.N., Dreiss, L., Aycrigg, J.L., Aplet, G.H., 2021. Options for prioritizing sites for biodiversity conservation: implications for "30 by 30″. Biol. Conserv. 264, 109378.

Bertzky, B., C. Corrigan, J. Kemsey, S. Kenney, C. Ravilious, C. Besançon, N.D. Burgess. 2012. Protected Planet Report 2012.

Bruner, A.G., Gullison, R.E., Rice, R.E., da Fonseca, G.A.B., 2001. Effectiveness of parks in protecting tropical biodiversity. Science 291, 125–128. https://doi.org/10.1126/science.291.5501.125.

Butchart, S.H.M., Scharlemann, J.P.W., Evans, M.I., Quader, S., Aricò, S., Arinaitwe, J., Balman, M., Bennun, L.A., Bertzky, B., Besançon, C., Boucher, T.M., Brooks, T.M., Burfield, I.J., Burgess, N.D., Chan, S., Clay, R.P., Crosby, M.J., Davidson, N.C., De Silva, N., Devenish, C., Dutson, G.C.L., Fernández, D.F.D., Fishpool, L.D.C., Fitzgerald, C., Foster, M., Heath, M.F., Hockings, M., Hoffmann, M., Knox, D., Larsen, F.W., Lamoreux, J.F., Loucks, C., May, I., Millett, J., Molloy, D., Morling, P., Parr, M., Ricketts, T.H., Seddon, N., Skolnik, B., Stuart, S.N., Upgren, A., Woodley, S., 2012. Protecting important sites for biodiversity contributes to meeting global conservation targets. PLoS One 7, e32529. https://doi.org/10.1371/journal.pone.0032529.

Ceballos, G., Ehrlich, P.R., Barnosky, A.D., García, A., Pringle, R.M., Palmer, T.M., 2015. Accelerated modern human-induced species losses: entering the sixth mass extinction. Sci. Adv. 1, 9–13.

Ceballos, G., Ehrlich, P.R., Raven, P.H., 2020. Vertebrates on the brink as indicators of biological annihilation and the sixth mass extinction. Proc. Natl. Acad. Sci. 117 (24), 13596–13602. https://doi.org/10.1073/pnas.1922686117.

Chen, X., Roberts, K.A., 2008. Roadless areas and biodiversity: a case study in Alabama, USA. Biodivers. Conserv. 17, 2013–2022.

Congressional Research Service Report R46504, 2020. Forest Service Inventoried Roadless Areas (IRAs), by Anne A. Riddle and Adam Vann.

Cordell, H.K., Murphy, D., Riitters, K., Harvard III, J.E., 2005. The Multiple Values of Wilderness: The Natural Ecological Value of Wilderness (Ch. 11). Venture Publishing, Inc., State College, PA.

Crist, M.R., Wilmer, B., Aplet, G.H., 2005. Assessing the value of roadless areas in a conservation reserve strategy: biodiversity and landscape connectivity in the Northern Rockies. J. Appl. Ecol. 42, 181–191.

DellaSala, D.A., J. Strittholt. 2003. Scientific basis for roadless area conservation. Report prepared by the World Wildlife Fund and Conservation Biology Institute.

DeVelice, R.L., Martin, J.R., 2001. Assessing the extent to which roadless areas complement the conservation of biological diversity. Ecol. Appl. 11 (4), 1008–1018.

Dietz, M.S., Belote, R.T., Gage, J., Hahn, B.A., 2020. An assessment of vulnerable wildlife, their habitats, and protected areas in the contiguous United States. Biol. Conserv. 248, 108646.

Dinerstein, E., Vynne, C., Sala, E., Joshi, A.R., Fernando, S., Lovejoy, T.E., Mayorga, J., Olson, D., Asner, G.P., Baillie, J.E.M., Burgess, N.D., Burkart, K., Noss, R.F., Zhang, Y.P., Baccini, A., Birch, T., Hahn, N., Joppa, L.N., Wikramanayake, E., 2019. A global deal for nature: guiding principles, milestones, and targets. Sci. Adv. 5, eaaw2869.

Fahrig, L., Rytwinski, T., 2009. Effects of roads on animal abundance: an empirical review and synthesis. Ecol. Soc. 14, 1.

Gergely, K.J., K.G. Boykin, A.J. McKerrow, M.J. Rubino, N.M. Tarr, S.G. Williams. 2019. Gap Analysis Project (GAP) Terrestrial Vertebrate Species Richness Maps for the Conterminous U.S.: U.S. Geological Survey Scientific Investigations Report 2019–5034. https://doi.org/10.3133/sir20195034.

Golden Kroner, R.E., Qin, S., Cook, C.N., Krithivasan, R., Pack, S.M., Bonilla, O.D., Mascia, M.B., 2019. The uncertain future of protected lands and waters. Science 364 (6443), 881–886.

Haaland, D., Vilsack, T.J., Raimondo, G.M., Mallory, B., 2021. Conserving and restoring America the Beautiful: a preliminary report to the National Climate Task Force. Response Exec. Order 14008.

Ibisch, P.L., Hoffmann, M.T., Kreft, S., Pe'er, G., Kati, V., Biber-Freudenberger, L., DellaSala, D.A., Vale, M.M., Hobson, P.R., Selva, N., 2016. A global map of roadless areas and their conservation status. Science 354 (6318), 1423–1427.

International Union for Conservation of Nature, 2019. The IUCN Red List of Threatened Species. Version 2019–1 [WWW Document]. URL ⟨http://www.iucnredlist.org/⟩ (Accessed 3.21.19).
Jenkins, C.N., Van Houtan, K.S., Pimm, S.L., Sexton, J.O., 2015. US protected lands mismatch biodiversity priorities. Proc. Natl. Acad. Sci. USA 112, 5081–5086.
Kamal, S., Grodzinska-Jurczak, M., Brown, G., 2015. Conservation on private land: a review of global strategies with a proposed classification system. J. Environ. Plan. Manag. 58 (4), 576–597.
Kati, V., Kassara, C., Psaralexi, M., Tzortzakaki, O., Petridou, M., Galani, A., Hoffman, M.K., 2020. Conservation policy under a roadless perspective: minimizing fragmentation in Greece. Biol. Conserv. 252, 108828.
Lawler, J.J., Rinnan, D.S., Michalak, J.L., Withey, J.C., Randels, C.R., Possingham, H.P., 2020. Planning for climate change through additions to a national protected area network: implications for cost and configuration. Philos. Trans. R. Soc. B 375, 20190117.
Loucks, C., Brown, N., Loucks, A., Cesareo, K., 2003. USDA Forest Service roadless areas: potential biodiversity conservation reserves. Conserv. Ecol. 7 (2), 5.
McKerrow, A.J., Tarr, N.M., Rubino, M.J., Williams, S.G., 2018. Patterns of species richness hotspots and estimates of their protection are sensitive to spatial resolution. Divers. Distrib. 24, 1464–1477. https://doi.org/10.1111/ddi.12779.
Moilanen, A., 2007. Landscape Zonation, benefit functions and target-based planning: unifying reserve selection strategies. Biol. Conserv. 134, 571–579.
Naughton-Treves, L., Holland, M.B., Brandon, K., 2005. The role of protected areas in conserving biodiversity and sustaining local livelihoods. Annu. Rev. Environ. Resour. 30, 219–252.
NatureServe, 2019. NatureServe Web Service. [WWW Document]. URL ⟨http://services.natureserve.org/⟩ (Accessed 3.21.19).
Pouteau, R., Brunel, C., Dawson, W., Essl, F., Kreft, H., Lenzner, B., Meyer, C., Pergl, J., Pysek, P., Seebens, H., Weigelt, P., Winter, M., van Kleunen, M., 2021. Environmental and socioeconomic correlates of extinction risk in endemic species. Divers. Distrib. 00, 1–12.
Pouzols, F.M., Toivonen, T., Di Minin, E., Kukkala, A.S., Kullberg, P., Kuustera, J., Lehtomaki, J., Tenkanen, H., Verburg, P.H., Moilanen, A., 2014. Global protected area expansion is compromised by projected land-use and parochialism. Nature 516 (7531), 383–386. https://doi.org/10.1038/nature14032.
Psaralexi, M.K., Votsi, N.P., Selva, N., Mazaris, A.D., Pantis, J.D., 2017. Importance of roadless areas for the European conservation network. Front. Ecol. Evol. 5, 2.
Selva, N., Kreft, S., Kati, V., Schluck, M., Jonsson, B., Mihok, B., Okarma, H., Ibisch, P.L., 2011. Roadless and low-traffic areas as conservation targets in Europe. Environ. Manag. 48, 865–877.
Selva, N., Switalski, A., Kreft, S., Ibisch, P.L., 2015. Why keep areas road-free? The importance of roadless areas. In: van der Ree, R., Grilo, C., Smith, D. (Eds.), Ecology of Roads: A Practitioner's Guide to Impacts and Mitigation. John Wiley & Sons, Oxford.
Scott, J.M., Davis, F.W., McGhie, R.G., Wright, R.G., Groves, C., Estes, J., 2001. Nature reserves: do they capture the full range of America's biological diversity? Ecol. Appl. 11 (4), 999–1007.
Talty, M.J., Lacroix, K.M., Aplet, G.H., Belote, R.T., 2020. Conservation value of national forest roadless areas. Conserv. Sci. Pract. 2, e288 https://doi.org/10.1111/csp2.288.
Torres, A., Jaeger, J.A., Alonso, J.C., 2016. Assessing large-scale wildlife responses to human infrasctructure development. Proc. Natl. Acad. Sci. 113, 8472–8477.
Trombulak, S.C., Frissell, C.A., 2000. Review of ecological effects of roads on terrestrial and aquatic communities. Conserv. Biol. 14, 18–30.
UNEP-WCMC, 2021. Protected Area Profile for United States of America from the World Database of Protected Areas, April 2021. Available at: ⟨www.protectedplanet.net⟩.
USDA, Forest Service, 2001. Forest Service roadless area conservation: final environmental impact statement.
Watson, J.E.M., Shanahan, D.F., Di Marco, M., Allan, J., Laurance, W.F., Sanderson, E.W., Mackey, B., Venter, O., 2016. Catastrophic declines in wilderness areas undermine global environment targets. Curr. Biol. 26, 2929–2934.
Watson, J.E.M., Venter, O., Lee, J., Jones, K.R., Robinson, J.G., Possingham, H.P., Allan, J.R., 2018. Protect the last of the wild. Nature 563, 27–30.
Watts, R.D., Compton, R.W., McCammon, J.H., Rich, C.L., Wright, S.M., Owens, T., Ouren, D.S., 2007. Roadless space of the coterminous United States. Science 316, 736–738.
Weber, L. 2019. Roadless rule rollback would threaten Utah's at-risk plants and animals. In High Country News. ⟨https://www.hcn.org/articles/utah-biodiversity-thrives-in-utahs-roadless-areas-rollback-threatens-at-risk⟩.
Wilson, E.O., 2016. Half-Earth: Our Planet's Fight for Life. Liveright Publishing, London, UK.