

social sciences

The Next 50 Years: Opportunities for Diversifying the Ecological Representation of the National Wilderness Preservation System within the Contiguous United States

Jocelyn L. Aycrigg, James Tricker, R. Travis Belote, Matthew S. Dietz, Lisa Duarte, and Gregory H. Aplet

The US National Wilderness Preservation System (NWPS) is the world's largest wilderness protection network, yet within the contiguous United States (CONUS) it does not encompass the diversity nor is it fully representative of ecological systems on federal lands. To potentially increase NWPS diversity and representation, we simulated adding potentially eligible lands within CONUS, in the following sequence, to assess changes in ecological systems: National Park Lands not currently designated wilderness; non-NWPS lands currently managed to not degrade wilderness character; USDA Forest Service Inventoried Roadless Areas; and Bureau of Land Management roadless lands. Inclusion of these categories would increase the NWPS area from 12.8 to 48.3% of federal lands, increase diversity by adding 46 ecological systems, and nearly triple the number of ecological systems on federal lands with >20% representation. Our analysis identifies opportunities to increase diversity and representation of ecological systems within the NWPS.

Keywords: National Wilderness Preservation System, protected areas, recommended wilderness, roadless areas, National Parks, United States, representation, diversity

Noss and Cooperrider (1994, p. 89) stated that a first principle of conservation planning is to “represent, in a system of protected areas, all native ecosystem types...across their natural range of variation.” Expanding the representation of ecological systems (i.e., native ecosystem types) within a protected area network (i.e.,

a network of lands having permanent protection from conversion of natural land cover and a mandated management plan to maintain a natural state; US Geological Survey Gap Analysis Program [USGS GAP] 2012) has three primary benefits. First, maximizing the diversity of ecological systems represented in protected areas will probably

protect greater numbers of species and their habitat. For example, Pouzols et al. (2014) showed that protected area expansion, if strategically implemented, could triple the average protection of vertebrate species ranges. Second, greater diversity of ecological systems represented in a protected area network may enhance the resilience of species and habitats to global changes (Shaffer and Stein 2000). Third, greater representation of ecological systems in areas protected from human-caused disturbance can serve as reference areas for comparison with more highly managed or human-impacted areas (Belote et al. 2016). Leopold (1949, p. 196) recognized the benefit of an ecologically representative protected area network by stating that “each biotic province needs its own land for comparative studies of used and unused land.”

The value of an ecologically representative system has long been recognized, even though few existing protected areas were es-

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tablished explicitly to protect representative examples of ecological systems. Over the last few decades, additions to the global protected area network have not commensurately increased ecological representation, but rather have maintained the bias toward high altitude and low productivity areas (Aycrigg et al. 2013, Watson et al. 2014). This is consistent with the lack of complete ecological system representation found within the protected area network of the United States and, more specifically, within the National Wilderness Preservation System (NWPS) (Aycrigg et al. 2013, Dietz et al. 2015). Over the past 50 years, the NWPS has protected numerous large unfragmented areas but has yet to achieve the full representation of ecological systems found on federal lands (Dietz et al. 2015).

In 1964, the US Congress established the most protective of protected area networks, the NWPS, to preserve “natural conditions” and “ecological, geological, or other features of scientific...value” (The Wilderness Act [WA] 1964, Section 2c). Examination of the ecological diversity and representation in the NWPS as a distinct protected area network is important for two reasons. First, the NWPS, which comprises 12.8% of the total federal lands, 13.6% of the protected area network, and approximately 2.6% of the contiguous United States (CONUS), is functionally and legally distinct from other protected areas within the United States because the system has a high level of protection and prohibits many human activities, such as road-building, logging, energy development (i.e., oil and gas drilling), off-road motor vehicles, developed tourism facilities, and permanent structures (WA 1964, Section 4c). Second, WA provides for the expansion of the NWPS in a systematic way (WA 1964, Section 3). For example, all four federal land management agencies (i.e., National Park Service [NPS], Bureau of Land Management [BLM], US Fish and Wildlife Service [FWS], and US Department of Agriculture Forest Service [USDA FS]) are legally required to evaluate the need for new wilderness areas during their land and resource management planning processes. In addition, roadless areas possessing wilderness characteristics, which are among potentially suitable federal lands, are eligible for wilderness designation.

Areas outside the NWPS, but with wilderness character, are becoming rare because of pressures from land-use changes, such as demands for energy development and urban

expansion surrounding these areas (Martinuzzi et al. 2015). Consequently, these areas are becoming a more important component of a comprehensive strategy to protect biodiversity. Even though there are many types of protected areas (on federal, state, local, and private lands) that contribute to biodiversity conservation throughout the United States, the NWPS serves a unique role and it could better conserve biodiversity if its resilience could be strengthened by identifying the most ecologically important areas to diversify its ecological representation on federal land.

Dietz et al. (2015) found that although the total area of the NWPS within CONUS has increased steadily over the last 50 years, the number of ecological systems represented in wilderness reached an asymptote approximately 30 years ago. The number of ecological systems represented was less than the total number of ecological systems that occur on federal land and therefore could potentially be included in the NWPS.

We extended the analysis of Dietz et al. (2015) to simulate the potential for increasing the diversity and representation of ecological systems by sequential and cumulative additions to the NWPS. We identified four spatially distinct and mutually exclusive land designation categories that could be included in the NWPS. First, we included National Park lands that are not designated as wilderness but are eligible for wilderness designation (WA 1964, Section 3c). We excluded portions of National Parks that were already designated wilderness, National Parks that were established principally for cultural resources or as scenic roadways, and

National Parks of <5,000 acres, which is, with some exceptions, the minimum size for wilderness areas (WA 1964, Section 2c). Second, we included congressionally or administratively recommended wilderness areas including USDA FS and BLM Wilderness Study Areas and areas recommended for wilderness by USDA FS, BLM, and FWS. These lands are currently managed so as not to degrade their wilderness character. This category excludes any areas that are within National Parks to keep it distinct from our first category (from here forward we refer to this category as “lands managed so as not to degrade their wilderness character”). Third, we included USDA FS Inventoried Roadless Areas (IRAs) that are not included in the second category. Fourth, we included BLM roadless areas that are not included in the second category. We chose these land designation categories and this sequence because they represent our estimate of the current level of protection already afforded these lands and the likelihood of securing sufficient public support for their addition to the NWPS under the process established by WA (1964). We wanted to compare our results to the results of Dietz et al. (2015); therefore, we used CONUS as the spatial extent for our analysis. Our objectives are to evaluate the change in ecological system diversity (i.e., how many ecological systems) and representation (i.e., what proportion of an ecological system) by simulating the addition of each of four land designation categories to the NWPS (Table 1). As in Dietz et al. (2015), we used 20% as a convenient threshold to measure representa-

Management and Policy Implications

Over 50 years ago, the Wilderness Act (1964) established a process for adding lands to the National Wilderness Preservation System (NWPS). If the goal of wilderness management and policy is to provide the best possible representation of ecological systems within the NWPS, then adding lands to the NWPS will be vital for preserving the diversity of species and habitats found throughout the contiguous United States. Adding lands to the NWPS will also provide the most robust wilderness protection network for adaptation to future land-use and climate change. We demonstrated which land designation categories among National Park lands not currently designated wilderness, non-NWPS lands currently managed to not degrade wilderness character, USDA Forest Service Inventoried Roadless Areas, and Bureau of Land Management roadless lands provide the greatest opportunities for diversifying and increasing representation of ecological systems. This information can inform future management and policy of the NWPS. All four land designation categories provide important opportunities for increasing ecological system representation. However, even if all land designation categories were added to the NWPS, 64 ecological systems on federal lands (12%) would remain unrepresented. There is, nonetheless, substantial opportunity to diversify the NWPS and increase levels of representation of ecological systems.

Table 1. Description and rationale for four land designation categories.

Land designation category	Description	Rationale
NWPS	All federal lands in CONUS that compose the NWPS, irrespective of agency (i.e., NPS, USDA FS, FWS, BLM), location, or size. We did not include wilderness areas designated on Dec. 19, 2014 under the National Defense Authorization Act.	These are the most up-to-date spatial data of the NWPS. They serve as the baseline for comparison in assessing the increase in diversity and representation of ecological systems as we added each land designation category.
National Park lands	All federal land units in CONUS administered by NPS that are >5,000 acres and are neither parkways nor classified as cultural sites. This excludes all National Park land units included in NWPS.	These are lands that already receive a high degree of protection, are managed for biological diversity, and are eligible to be designated as wilderness (>5,000 acres). Parkway are excluded because they are, by definition, roads and would not qualify as wilderness areas. Cultural sites are, for the most part, managed for their archaeological, historical, architectural, or other cultural resources and generally do not qualify as having wilderness characteristics (i.e., where the hand of man is substantially unnoticeable).
Lands currently managed so as not to degrade their wilderness character	All federal land units in CONUS administered by the USDA FS, BLM, and FWS that are designated as Wilderness Study Areas (WSAs) by the US Congress or federal agencies or that have been recommended as wilderness by the USDA FS, BLM, or FWS in land and resource management plans. This excludes any areas within National Parks.	These lands are all managed so as not to degrade their wilderness character and, therefore, already receive a high degree of protection. They are also the most likely areas, politically, to be added to the NWPS, as they have been recommended or studied as potential new wilderness areas.
USDA FS IRAs	All federal land units in CONUS administered by the USDA FS and recognized as “roadless” through the official inventory conducted during the promulgation of the Roadless Area Conservation Rule (RACR). ¹ This excludes all land units included in lands managed so as not to degrade their wilderness character.	These lands qualify as potential wilderness areas and are protected (through the RACR) from many human-caused stressors, such as road-building, commercial timber harvesting, mining, and oil and gas extraction. Their level of protection is not as great as that of lands currently managed so as not to degrade their wilderness character, but they are better protected than the remaining federal lands. This is the generally accepted “inventory” of USDA FS lands from which new wilderness areas are designated.
BLM roadless areas	All federal land units in CONUS administered by BLM and determined to be “roadless” through an inventory conducted by the Pew Research Center (Dickson et al. 2014). This excludes all land units included in lands managed so as not to degrade their wilderness character.	These lands qualify as potential wilderness areas (>5,000 acres), but do not receive the level of protection afforded to USDA FS IRAs.

We started with the NWPS and then in sequence added all National Park lands that have yet to be designated wilderness within the NPS; lands managed so as not to degrade their wilderness character and that have been studied by Congress or recommended by federal land management agencies, including the USDA FS, BLM, and FWS, for wilderness designation; the remaining USDA FS IRAs; and the remaining roadless lands managed by the BLM. The sequencing represents our estimate of the current level of protection already afforded these lands and also the likelihood of securing sufficient public support for their addition to the NWPS under the process established by WA (1964).

tion of an ecological system within the NWPS.

Methods

Data Description

We compiled spatial data layers for CONUS from different sources for the NWPS, National Parks, lands managed as wilderness, USDA FS IRAs, BLM roadless areas, and all remaining federal lands (Table 1). We obtained data for currently designated wilderness areas (i.e., NWPS) from the Wilderness Institute, College of Forestry and Conservation, University of Montana.² We obtained data for federal land, including National Park boundaries from the Protected Areas Database of the United States (PAD-US version 1.3) (USGS GAP 2012). PAD-US is a geodatabase that includes geographic boundaries, landownership, land management, management designation, parcel name, area, and protected status of federal, state, and voluntarily provided private protected areas. We obtained data for lands managed so as not to degrade their

wilderness character and USDA FS IRAs from an aggregation of data from the USDA FS, NPS, FWS, and BLM. Spatial data for the BLM roadless areas were provided by the Pew Charitable Trusts (Zachmann et al. 2014) and represent areas where no roads that have been improved and maintained by mechanical means exist (Dickson et al. 2014). We conducted a comprehensive review of the spatial data and corrected errors in attribute data (i.e., ownership and management classification) and spatial extent.

To quantify the diversity and representation of ecological systems in four land designation categories, we used the National GAP Land Cover data set of mapped and classified ecological systems, which is a compilation of USGS GAP land cover data from the Southwest, Southeast, Northwest, and California (USGS GAP 2011) and LANDFIRE land cover data for the Midwest and Northeast³ (see also Aycrigg et al. 2013, Dietz et al. 2015). Ecological systems are a land cover classification system that include natural and

seminal vegetation (e.g., Boreal Aspen-Birch Forest, North Pacific Montane Grassland). Resolution of the land cover data is 98 ft, and the minimum mapping unit is 2.5 acres (Aycrigg et al. 2013). Based on regional accuracy assessments and validations, higher accuracies are typically associated with forest and some shrub ecological systems than with rare and small patch ecological systems (e.g., wetlands) (Lowry et al. 2007, Davidson et al. 2013).

Of the 565 ecological systems and land-use classes within the National GAP Land Cover data set for CONUS, we evaluated the 554 that represented natural and semi-natural vegetation. We excluded eight land-use classes that were highly human modified (e.g., high-intensity developed, cultivated cropland) and three that were classified as open water, including fresh, brackish/salt, and aquaculture.

Data Analysis

We sequentially combined four spatially distinct and mutually exclusive land

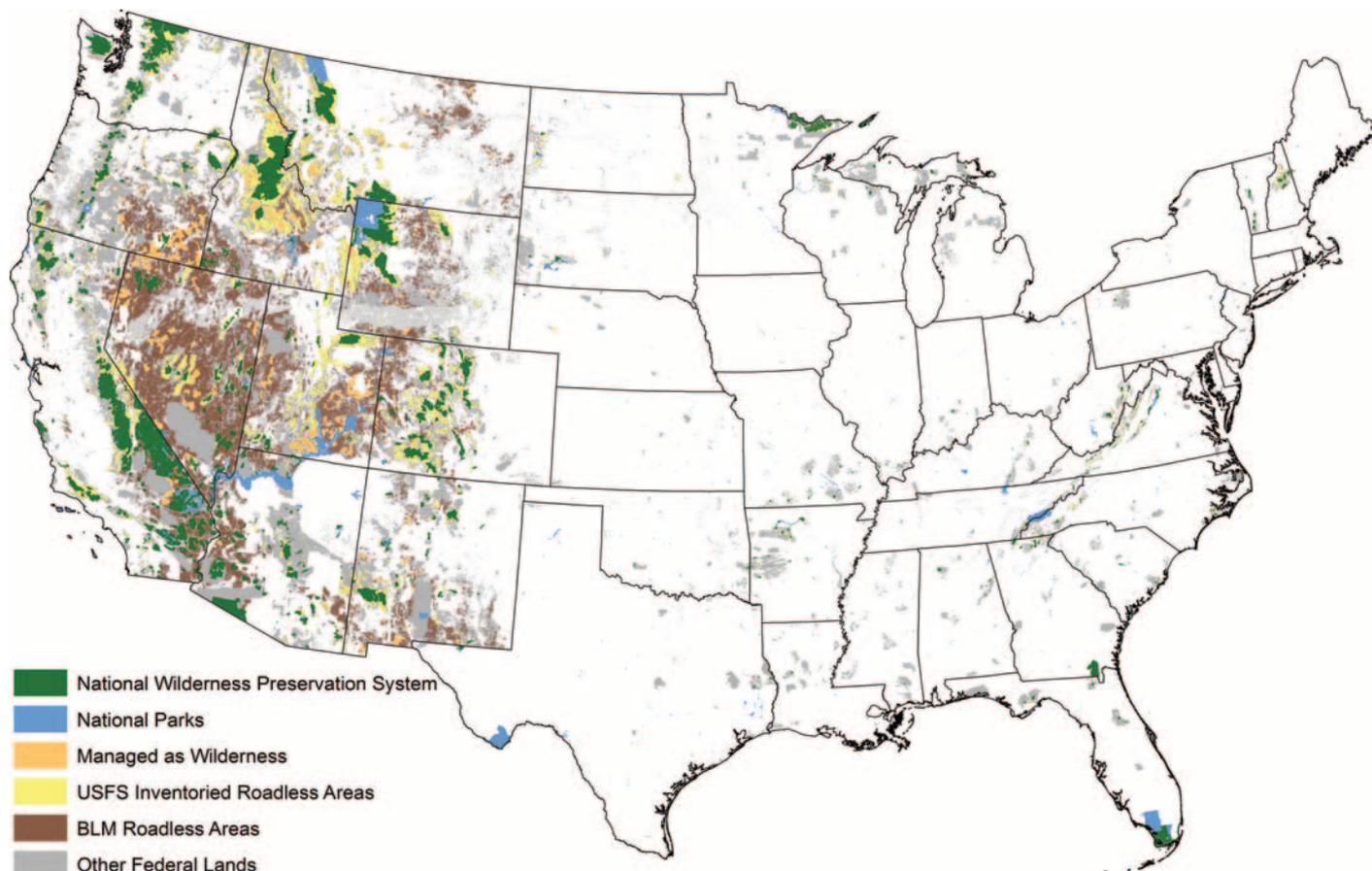


Figure 1. Map of land designation categories within CONUS, which are the following: NWPS; all National Park lands that have yet to be designated wilderness within the NPS; lands managed so as not to degrade their wilderness character and that have been studied by Congress or recommended by federal land management agencies, including the USDA FS, BLM, and FWS, for wilderness designation (shown on map as “Managed as Wilderness”); the remaining USDA FS IRAs; and the remaining BLM roadless lands. The remaining federal lands that are not included in any of the above categories are also shown. Each category is spatially separate from the others. See Table 1 for a description of each land designation category.

designation categories (Table 1) to obtain accurate area calculations. We converted these vector data to raster grid cells (i.e., 98×98 ft cells). All geographic information system (GIS) analysis was conducted using ArcGIS 10.2.2 (ESRI, Redlands, CA).

We combined the land designation categories with the National GAP Land Cover data set. To quantify the cumulative increase in ecological system diversity and representation with the simulated additions of each land designation category, we calculated the total number and area of each ecological system in the NWPS, of each land designation category, and across all federal lands. We calculated the representation of each ecological system as the percent area of each ecological system in the NWPS plus the area of each land designation category over the total area of each ecological system occurring on federal lands (i.e., $\text{representation} = [(\text{total acres of ecological system in NWPS} + \text{total acres of ecological system in each land designation$

$\text{category}) / (\text{total acres of ecological system on federal lands}) \times 100$). We binned these percentages into classes and following Dietz et al. (2015) used 20% representation as a convenient threshold to measure representation of an ecological system. We calculated these values with the sequential and individual addition of each land designation category to the NWPS. We summed the total number and unique number of ecological systems in the NWPS and each land designation category. Lastly, we calculated the absolute percent change with the addition of each land designation category to the NWPS (e.g., 5 percentage point change if representation increased from 10 to 15% with the addition of a land designation category) and the frequency of the percent change in representation for each ecological system (e.g., 5 ecological systems had a 5% percent change with the addition of the National Park lands).

Results

The NWPS consists of 51.6 million acres within CONUS (12.8% of federal lands in CONUS), National Park lands not designated as wilderness are 14.5 million acres (3.6%), lands managed so as not to degrade their wilderness character are 16.6 million acres (4.1%), USDA FS IRAs are 39.2 million acres (9.8%), and BLM roadless areas are 72.3 million acres (18.0%) (Figure 1). If all four land designation categories were added to the NWPS, the total area of the system would increase by 142.7 million acres and amount to 48.3% of all federal land area within CONUS.

The NWPS includes 444 ecological systems of which 113 have $>20\%$ representation. Expanding the NWPS into all four land designation categories resulted in 46 additional ecological systems or a 9% increase in the total diversity of ecological systems within the NWPS (Figure 2). Thirty-

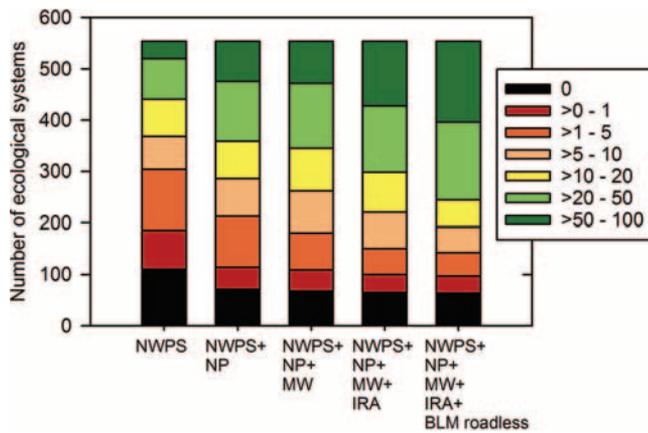


Figure 2. Number of ecological systems in the NWPS plus each cumulative land designation category shown by percent area of those ecological systems. The four land designation categories were all National Park lands (NP) that have yet to be designated wilderness within the NPS; lands managed so as not to degrade their wilderness character (MW) and that have been studied by Congress or recommended by federal land management agencies, including the USDA FS, BLM, and FWS for wilderness designation; the remaining USDA FS IRAs (IRA); and the remaining BLM roadless lands (BLM roadless). Each category is spatially separate from the others. See Table 1 for a description of each land designation category.

nine of the 46 additional ecological systems were included with the simulated addition of National Park lands. Sequentially adding all lands managed so as not to degrade their wilderness character, USDA FS IRAs, and BLM roadless areas only increased diversity by 7 ecological systems, but 82 more ecological systems had at least 20% of their federal land area designated as wilderness, which was the largest increase in area of all land designation categories (Figure 2). Designating the lands managed so as not to degrade their wilderness character would add 3 ecological systems, and 14 additional ecological systems had >20% representation in the NWPS (Figure 2).

Whereas the number of ecological systems represented in the NWPS increased only by a relatively small percentage, ecological systems with >20% representation nearly tripled from about 20 to 56% (or 113 to 309) of ecological systems (Figure 2). Eighty-two of these ecological systems were added with the National Park lands addition to the NWPS. Even though the other three land designation categories did not contribute substantially to diversity, their simulated addition would greatly increase representation of ecological systems to the >20% level, particularly in the West, where most of these lands occur. Other areas where the >20% level of representation would be reached with the addition of all four land

designation categories include the Appalachian Mountains, Florida peninsula, Texas, and northeastern United States (Figure 3A–E). Examining the addition of each land designation category sequentially, National Park lands would increase ecological system representation to the >20% level in southern California, southern Utah, the Appalachian Mountains, Texas, and the Florida peninsula (Figure 3B). Adding the lands managed so as not to degrade their wilderness character does little to increase the representation of ecological systems to >20%, but changes the representation of ecological systems from >1 to >5% throughout the western United States, particularly in Nevada, southern Oregon, southern Idaho, and Wyoming (Figure 3C). Adding USDA FS IRAs to the previous two land designation categories increases the representation of ecological systems to >50% in Idaho, western Montana, northwestern Wyoming, and Colorado (Figure 3D) and increases the representation of ecological systems in southern New Mexico, Missouri, and Arkansas to >10%. Addition of the BLM roadless areas to the NWPS changes most of the western United States to >20% representation with many ecological systems having >50% representation (Figure 3E). Overall, the representation of ecological systems increases the most in the western United States, where most federal land occurs.

Even if all four land designation categories were included in the NWPS, 64 (12%) unique ecological systems on federal lands would not occur in wilderness areas (Figure 2; Supplemental Table 1⁵). These include ecological systems with small ranges that occur in unique areas, such as the Mississippi River Riparian Forest (1,611 total acres in CONUS) and Texas Blackland Tallgrass Prairie (2,276 total acres in CONUS). Of the 64 unrepresented ecological systems, 84% of them have a total range size within CONUS of <10,000 acres (Supplemental Table 1). These unrepresented ecological systems mostly occur in the southeastern United States (Figure 3E).

If the land designation categories were added individually rather than sequentially to the NWPS, then the diversity of ecological systems would be greatest by adding National Park lands (Table 2). However, the greatest representation of ecological systems in the >20% group and the largest total area would be reached with the addition of BLM roadless areas. The result of adding all four land designation categories to the NWPS is the same whatever sequence of land designation categories is applied.

Overall, the percent change in representation with the addition of each land designation category increases the frequency of ecological system representation within the NWPS, but the frequency in the >20% group remains low (Figure 4). The percent change with the addition of National Park lands not yet designated as wilderness, USDA FS IRAs, and BLM roadless areas increases the frequency of ecological systems representation in the >20% group (Figure 4). Geographically, these percent changes occur where USDA FS lands occur in Colorado, Wyoming, Idaho, and Montana and where BLM lands occur in Nevada, Utah, Arizona, and New Mexico (Figure 5). Each incremental addition of a land designation category to the NWPS increases the number of ecological systems represented, but most often the percent representation is low, that is, mostly within the >0–1% representation group (Figures 4 and 5). The frequency of ecological systems with no change in their representation is greatest when the areas managed as wilderness and the BLM roadless areas are added to the NWPS (Figure 4). These ecological systems occur mostly in the eastern United States because no lands managed as wilderness or BLM roadless

⁵ Supplementary data are available with this article at <http://dx.doi.org/10.5849/jof.15-050>.

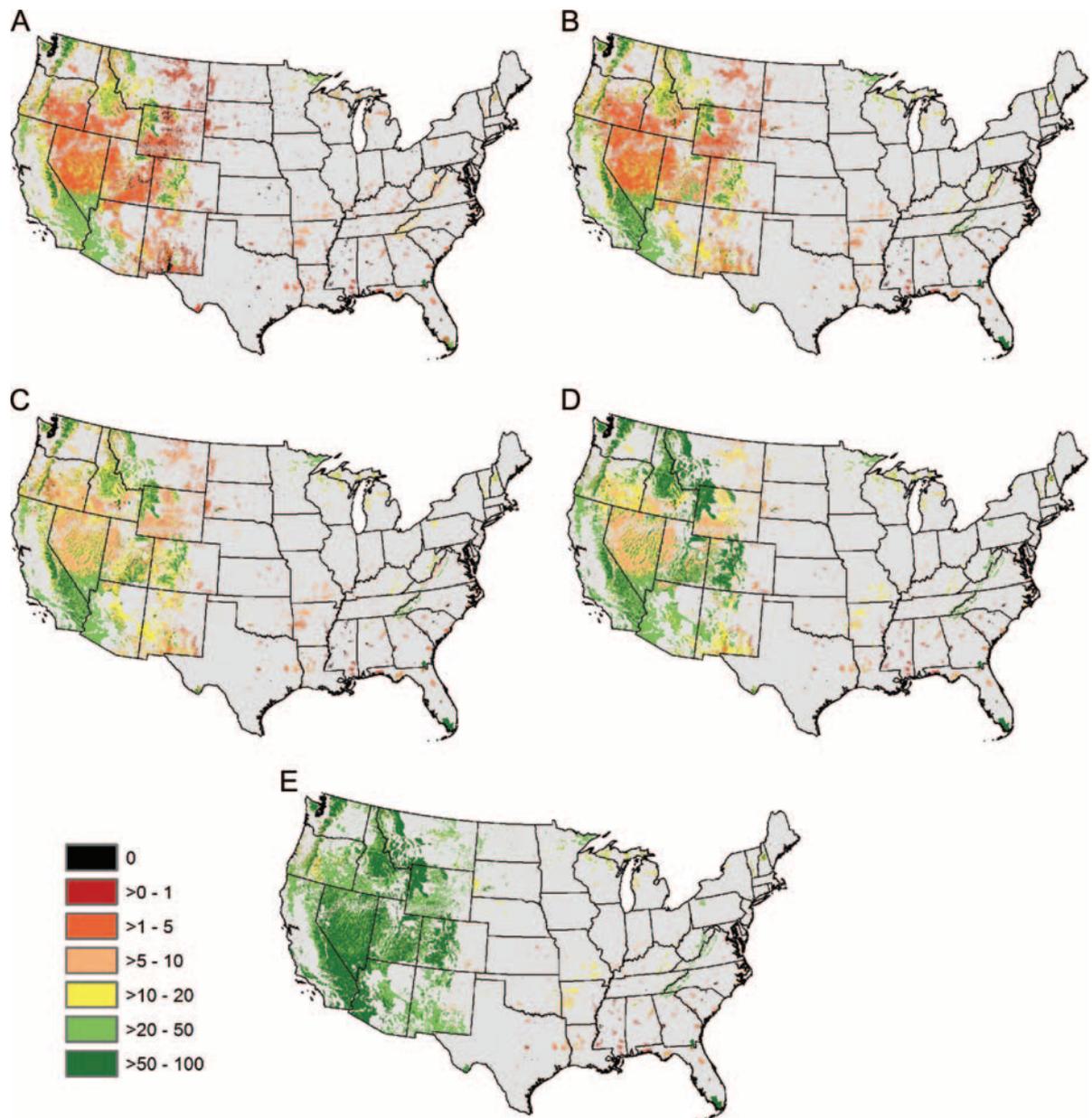


Figure 3. Percent area of ecological systems in the NWPS within CONUS plus each of four land designation categories by percentage group. A. NWPS. B. All National Park lands that have yet to be designated wilderness within the NPS. C. Lands managed so as not to degrade their wilderness character and that have been studied by Congress or recommended by federal land management agencies, including the USDA FS, BLM, and FWS for wilderness designation. D. The remaining USDA FS IRAs. E. The remaining BLM roadless lands. The percent area is based on the total area of each ecological system within the total area of federal lands, which includes the area in all of the above categories plus the federal land area not included in any of the above categories. Each category is spatially separate from the others. See Table 1 for a description of each land designation category.

areas occur in that area of CONUS (Figures 1 and 5C and D).

Discussion

Our intent was to simulate expansion of the NWPS onto lands eligible for wilderness designation and to evaluate opportunities for increasing the ecological system diversity and representation within the NWPS. Ay-crigg et al. (2013) showed that changing the management of multiple-use lands to focus

more on biodiversity conservation increased ecological system representation within the protected area network of the United States. Our results, focused on the NWPS, are similar because we showed that the diversity and representation of ecological systems can be increased within the NWPS with the addition of lands eligible for inclusion to the NWPS. Even though the NWPS is the world's largest wilderness protection network, many ecological systems are currently

underrepresented; therefore, identifying opportunities within CONUS to increase their representation is important for their conservation (Dietz et al. 2015). If all four land designation categories eligible for wilderness designation were included in the NWPS, 56% of all ecological systems occurring on federal land would have >20% representation in wilderness.

The sequence in which we cumulatively added four land designation categories influ-

Table 2. Accumulated area, total diversity, and representation of ecological systems in the NWPS plus each of four land designation categories that could be added to the NWPS.

Land designation category	Accumulated area (millions of acres)	Total diversity (no.)	Representation (no. by % area)						
			0	>0-1	>1-5	>5-10	>10-20	>20-50	>50-100
NWPS	51.6	444	110	76	118	64	73	79	34
NWPS + NP	66.2	483	71	43	99	73	73	117	78
NWPS + MW	68.2	449	105	65	96	76	85	91	36
NWPS + IRA	90.9	453	101	62	87	64	60	110	70
NWPS + BLM roadless	124.0	449	105	59	76	57	77	135	45
NWPS + NP + MW + IRA + BLM roadless	194.4	490	64	33	45	50	53	151	158

The four land designation categories are all National Park lands (NP) that have yet to be designated wilderness within the NPS, land managed so as not to degrade their wilderness character (MW) and that have been studied by Congress or recommended by federal land management agencies, including the USDA FS, BLM, and FWS for wilderness designation; the remaining USDA FS IRAs (IRA); the remaining BLM roadless lands (BLM roadless). Each category is spatially separate from the others. See Table 1 for a description of each land designation category.

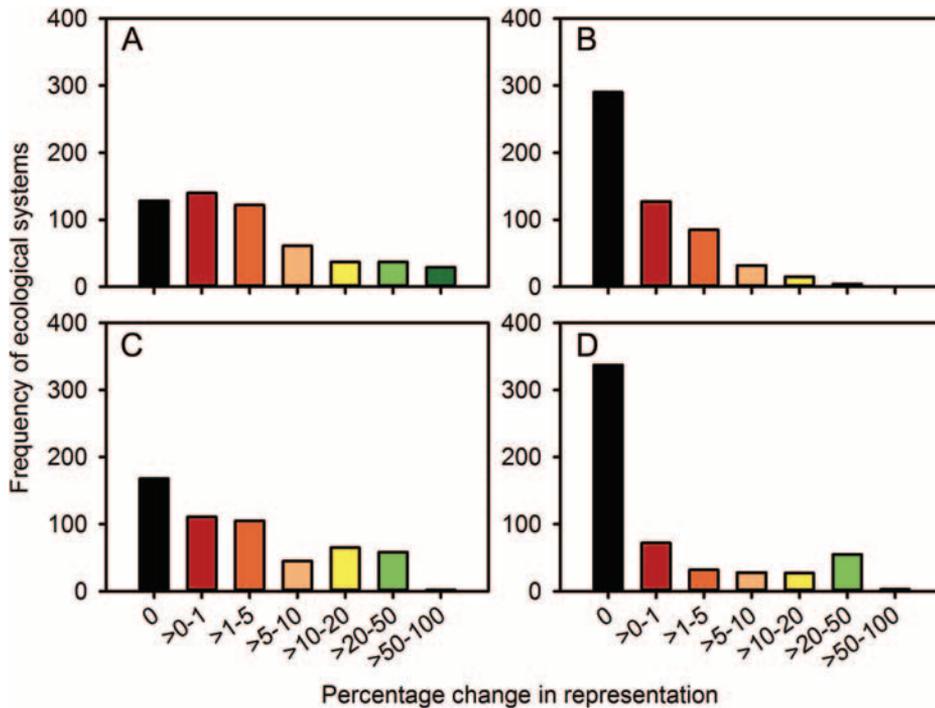


Figure 4. The frequency of percent change in representation of ecological systems with the addition of each land designation category. A. Percent change from the NWPS to NWPS plus all National Park lands (NP) that have yet to be designated wilderness within the NPS. B. Percent change from NWPS plus NP to NWPS plus NP plus lands managed so as not to degrade their wilderness character (MW). C. Percent change from NWPS plus NP plus MW to NWPS plus NP plus MW plus the remaining USDA FS IRAs (IRA). D. Percent change from NWPS plus NP plus MW plus IRAs to all land designation categories (i.e., NWPS plus NP plus MW plus IRAs plus the remaining BLM roadless lands). For example, the frequency of ecological system representation within the >1-5% group with the addition of NP lands to NWPS lands is 122 (A). Each category is spatially separate from the others. See Table 1 for a description of each land designation category.

enced how representation of individual ecological systems changed within the NWPS. We first evaluated National Park lands that have yet to be designated as wilderness but are managed for their wilderness character, which increased the total number of ecological systems represented in the NWPS by 39 (Figure 2). The added ecological systems occurred in areas with no or few existing wilderness areas nearby, such as Big Bend Na-

tional Park in western Texas and Great Smoky Mountains National Park on the border between Tennessee and North Carolina (Figure 1). We chose our sequence of adding land designation categories to the NWPS because it prioritized the least politically controversial categories and therefore the likelihood of securing sufficient public support for their addition. If we had simulated the addition of BLM roadless areas first

rather than the National Park lands, then the diversity would have been lower, but the representation of ecological systems overall and in the >20% group would have been greater (Table 2). There are 24 possible sequences for adding the four land designation categories; however, the final outcome of the NWPS including 48.3% of all federal lands would not be changed.

Expanding the area of the NWPS has benefits beyond increasing the diversity and representation of ecological systems. For example, increasing the area of the NWPS could increase the size of individual wilderness areas, which could help conserve current ecological processes (e.g., uninterrupted natural disturbance regimes and plant and animal dispersal) (Groves 2003) by minimizing habitat fragmentation. In addition, Jenkins and Joppa (2009) found that worldwide protection is very uneven, and many biomes have <10% of their area formally protected. Uneven representation within the current NWPS could be reduced by adding land eligible for wilderness designation, which could minimize habitat fragmentation and thereby preserve ecological processes (Dickson et al. 2014, Dietz et al. 2015). Adding all 4 land designation categories to the NWPS could reduce habitat fragmentation for 309 ecological systems (more than half of the total number of ecological systems on federal land within CONUS) by increasing their representation to >20% across all federal lands. The largest increases in >20% representation occurred when National Park lands not yet designated as wilderness, USDA FS IRAs, and BLM roadless areas were included in the NWPS (Figure 2). The location of these land designation categories contributed to increasing the equitability in representation because the National Park lands occurred in the eastern United States, where few current NWPS

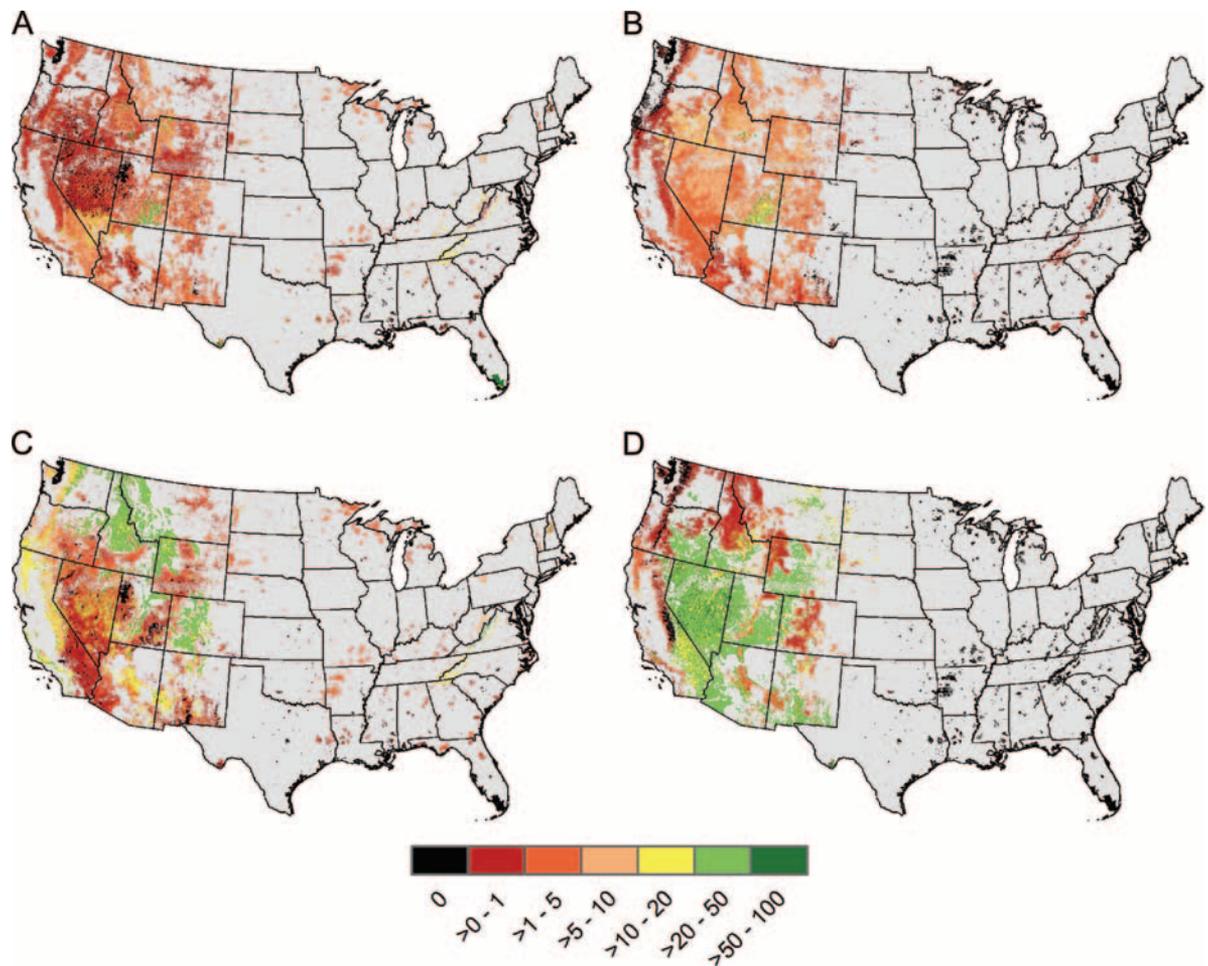


Figure 5. Percent area change of each ecological system with the cumulative addition of each land designation category to the NWPS. **A.** Addition of all National Park lands that have yet to be designated wilderness within the NPS. **B.** Cumulative addition of lands managed so as not to degrade their wilderness character that have been studied by Congress or recommended by federal land management agencies, including the USDA FS, BLM, and FWS, for wilderness designation. **C.** Cumulative addition of the remaining USDA FS IRAs. **D.** Cumulative addition of the remaining BLM roadless lands. Each category is spatially separate from the others. See Table 1 for a description of each land designation category.

lands exist, and the addition of USDA FS IRAs and BLM roadless areas expanded representation of ecological systems into highly diverse vegetation communities in the western United States (Figure 3) (Dickson et al. 2014). Expanding the NWPS into the remaining roadless areas, particularly in the western United States, presents a conservation opportunity that could preserve ecological processes and biodiversity (Dickson et al. 2014).

Currently, the NWPS has a high level of protection from direct human-caused disturbance, such as road-building, logging, and energy development, but even wilderness areas could be influenced indirectly, in the future, by threats outside their boundaries (Martinuzzi et al. 2015). Geldmann et al. (2013) found that compared with unprotected areas, protected areas experience lower rates of habitat loss; however, in areas

where external threats were high, protected areas were losing habitat within their boundaries. Using future scenarios of land-use change, Martinuzzi et al. (2015) found that urban expansion around protected areas, including wilderness areas, will continue to be a major threat, and many protected areas will lose their surrounding natural vegetation. USDA FS lands were projected to undergo the greatest changes in the surrounding land-use across future scenarios, whereas National Parks and the NWPS had the greatest land-use changes in the eastern United States, the West Coast, and parts of the Interior West (Martinuzzi et al. 2015). Expanding the NWPS to 48.3% of all federal land area within CONUS would increase the size of existing protected areas and buffer existing wilderness areas from both current and future threats outside their boundaries. We show that expanding the

NWPS into BLM roadless areas could potentially reduce the impacts of future land-use change throughout Nevada and Utah (Figure 5D). Land-use change will probably continue to threaten the integrity of protected areas; therefore, the opportunity to add four land designation categories either individually or combined to the NWPS is vital for reducing the direct and indirect influences of land-use changes.

Ecological systems occurring in southeastern United States will remain underrepresented or unrepresented even if all four land designation categories were included in the NWPS. Federal lands are scattered throughout the southeastern United States (Figure 3), but full representation of all ecological systems will require expanding the NWPS beyond federal lands that are eligible for wilderness designation. Both Aycrigg et al. (2013) and Jenkins et al. (2015) iden-

tified the southeastern United States as a priority area for conservation because species and ecological systems were underrepresented within the protected area network and suggested engaging both public and private conservation partners to increase representation.

Rapid land-use and environmental changes influenced by climate change make wilderness areas more valuable than ever as a baseline for evaluating change. Currently, the NWPS protects unique and irreplaceable ecological systems in places that can serve as baseline reference areas to measure the effects of climate change and bring together different federal agencies to manage these ecological systems. Even though, based on policy, many of the simulated additions to the NWPS are already managed as wilderness, the addition of approximately 142 million acres across CONUS could strengthen the resilience of the NWPS against future land-use and climate change impacts. Expanding the representation of ecological systems in wilderness may offer important benefits both as a conservation strategy in its own right and as an important scientific control for assessing future land-use changes (Dietz et al. 2015, Belote et al. 2016).

Endnotes

1. For more information, see www.fs.usda.gov/roadmain/roadless/2001roadlessrule.
2. For more information, see www.wilderness.net.
3. For more information, see www.landfire.gov.

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