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# The world's largest wilderness protection network after 50 years: An assessment of ecological system representation in the U.S. National Wilderness Preservation System

Matthew S. Dietz [a,*], R. Travis Belote [b], Gregory H. Aplet [c], Jocelyn L. Aycrigg [d]

[a] The Wilderness Society, 250 Montgomery St., Suite 210, San Francisco, CA 94104, USA
[b] The Wilderness Society, 503 W. Mendenhall St., Bozeman, MT 59715, USA
[c] The Wilderness Society, 1660 Wynkoop St., Suite 850, Denver, CO 80202, USA
[d] Dept. of Fish & Wildlife Sciences, Univ. of Idaho, 875 Perimeter Dr., Moscow, ID 83844, USA

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ABSTRACT

Protected areas, such as wilderness, form the foundation of most strategies to conserve biological diversity. However, the success of protected areas in achieving conservation goals depends partly on how well ecological diversity is represented in a network of designated lands. We examined how well the world's largest highly-protected conservation network—the U.S. National Wilderness Preservation System (NWPS)—currently represents ecological systems found on federal lands in the contiguous United States and how ecological system representation has accumulated over the 50-year tenure of the Wilderness Act (passed in 1964 and giving the U.S. Congress authority to establish wilderness areas). Although the total area of NWPS has risen fairly steadily since 1964, the diversity of ecological systems accumulated in wilderness areas (436 ecological systems) reached an asymptote 30 years ago that is well below the total pool of ecological systems available (553) on federal lands. Thus, NWPS currently underrepresents ecological system diversity. Additionally, only 113 ecological systems are represented at more than 20% of federal land area. As the designation of new wilderness areas becomes more difficult, it is important to increase the ecological representation of those areas to achieve greater protection of biological diversity. Over the next 50 years of the Wilderness Act, federal land-management agencies and the U.S. Congress could increase the ecological diversity of wilderness areas by prioritizing under-represented ecological systems in new wilderness legislation.


## 1. Introduction

Wilderness and other protected areas are the cornerstones of most regional, national, and international efforts to conserve biological diversity and sustain ecological processes of natural ecosystems (Bertzky et al., 2012). Protected areas are effective in reducing the loss, degradation, and fragmentation of natural habitats (Bruner et al., 2001; Naughton-Treves et al., 2005) and slowing the rate of extinction of threatened species that occur therein (Butchart et al., 2012). Recognizing the importance of protected areas for biodiversity conservation, the Convention on Biological Diversity (CBD) calls for at least 17% of the world's terrestrial areas to be conserved by 2020 (Woodley et al., 2012).

Protected areas can best achieve biodiversity goals if they are located in the right places—that is, they are representative of all ecosystems. The "representation" approach to conservation assumes that for protected areas to conserve genetic, species, and community diversity—as well as the structure, function, and evolutionary potential of natural systems—they must encompass the full variety of ecosystem types across their geographic range (Olson and Dinerstein, 1998; Margules and Pressey, 2000). Ecosystems are typically classified hierarchically by the principal vegetation communities that are found there. Protection of vegetation communities will help to protect the species that rely on them and the natural ecological processes that are characteristic of those communities (Rodrigues et al., 2004; Bunce et al., 2013). CBD has developed several indicators to evaluate the ecological representativeness of the global protected areas network, one of which is the percentage of ecosystem types (or vegetation communities) protected by 2020 (Woodley et al., 2012).

* Corresponding author. Tel.: +1 415 398 1482; fax: +1 415 398 1632.
*E-mail addresses:* matt_dietz@tws.org (M.S. Dietz), travis_belote@tws.org (R.T. Belote), greg_aplet@tws.org (G.H. Aplet), aycrigg@uidaho.edu (J.L. Aycrigg).

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As we commemorate the 50th anniversary of The Wilderness Act (signed into law on September 3, 1964), it is important to take inventory of the lands that have been designated as wilderness and evaluate how well the U.S. National Wilderness Preservation System (NWPS) represents the ecological diversity of America's publicly-owned federal lands—lands from which wilderness areas are exclusively designated. NWPS is a collection of federally-managed lands designated by Congress as 'wilderness areas'—"where the earth and its community are untrammeled by man, where man himself is a visitor who does not remain"—that are "protected and managed so as to preserve. . .natural conditions" (The Wilderness Act, 1964).

Why is it important to evaluate ecological diversity of the wilderness system in isolation from other protected areas in the U.S.? There are three principal reasons.

First, the laws, regulations, management, and other circumstances surrounding the wilderness preservation system make it especially valuable for conservation of biological diversity. Wilderness has an exceptionally high level of protection from human-caused disturbance. Wilderness areas are free of many anthropogenic stressors, including road-building, logging, mining, oil and gas drilling, hydraulic fracturing, solar and wind energy development, agriculture, irrigation, fuel-powered tools, off-road motor-vehicles, snowmobiles, non-motorized mechanical transport, developed tourism facilities, and permanent structures (The Wilderness Act, 1964). Most other "protected" areas allow a greater degree of human use (e.g., gift shops, hotels, paved roads, and skating rinks in national parks), resource extraction (e.g., copper mining in national forests), or land conversion (e.g., cultivated cornfields in national wildlife refuges) that may negatively affect species that occur there. In recognition of their high degree of protection, the U.S. Geological Survey assigns wilderness areas a default GAP Status of 1—the highest rank (USGS, 2012). In addition, the International Union for Conservation of Nature (IUCN) classifies U.S. wilderness as category 1b—which, along with 1a, is the highest classification-level of protection (IUCN & UNEP, 2014). The primary objective of 1b areas (i.e., "wilderness areas") is "to protect the long-term ecological integrity of natural areas that are undisturbed by significant human activity, free of modern infrastructure, and where natural forces and processes predominate, so that current and future generations have the opportunity to experience such areas" (Dudley, 2008).

Although there are a few other types of protected areas in the U.S. that are classified as both GAP 1 and IUCN 1 (e.g., Research Natural Areas), they are generally small and often located inside of wilderness area boundaries. In contrast, wilderness areas, with minor exceptions such as islands, are a minimum of 2023 ha (5000 acres) each, and most are much larger (Wilderness Institute, 2014). The largest single wilderness unit in the contiguous U.S. (Death Valley Wilderness, California and Nevada) is more than 1.2 million ha. The large size of wilderness areas allows many of them to sustain large-scale natural processes (such as wildfire) and provide large, un-fragmented core areas which are essential for animal migrations, top-level predator–prey relationships, and habitat for wide-ranging, low-density animal species. The U.S. National Wilderness Preservation System is the largest national system of category-one protected lands in the world (IUCN & UNEP, 2014). Nearly 1 in 5 ha (18%) of all category-one protected areas and over one third (37%) of category-1b areas worldwide are in NWPS (IUCN & UNEP, 2014). Because NWPS is the world's largest category-one protected area system (IUCN & UNEP, 2014), the degree of ecological representation of these areas is globally important.

Second, the NWPS operates from the original law passed 50 years ago, which provides continual opportunities for expansion in a systematic way. Every U.S. Congress since 1964 has considered bills to designate additional areas to the system (Wilderness Institute, 2014), and all four federal land-management agencies are required by law to evaluate the need for new wilderness areas during their land and resource management planning processes. In contrast, there is no systematic, consistent, national-scale, legally-mandated process for creating new wildlife refuges, national parks, or national monuments.

Third, there exists an inventory of potentially suitable federal lands—roadless lands possessing wilderness characteristics—that are eligible for wilderness designation (The Wilderness Act, 1964). This type of standard process does not exist for other protected areas. Knowing which ecological systems are currently well-represented and which are under-represented in wilderness allows us to rank each potential new wilderness area based on how much it would increase ecological representation within the wilderness system. Representation analysis of the wilderness system, therefore, has real and practical applications for land managers and conservation organizations.

The wilderness system in the U.S. is uniquely managed, large, highly protected, and expandable in a systematic way. Therefore, there is great value in assessing ecological representation in the wilderness system by itself, in addition to assessing the entire protected area network.

We are building upon previous studies of ecological representation. Sixteen years ago, Loomis and Echohawk (1999) examined high-level vegetation communities' representation in wilderness designations—as a proportion of all lands, public and private—at the scale of Bailey's (1995) province-level ecoregional boundaries. Loomis' and Echohawk's study, in addition to being out of date, has two major limitations.

First, it examined representation of ecoregions at the province-level scale, which are too large to be helpful in prioritizing where to designate new wilderness areas (because those decisions are generally made at smaller scales, e.g., U.S. Congressional districts or national forests) and too broad to ensure that vegetation types which provide habitat for particular threatened, rare, or sensitive species are protected at a scale that is relevant to those species. Biological diversity is best associated with ecological system classification, rather than biomes or realms (Olson et al., 2001), which reflect large-scale patterns of climate and geography, but do not reflect species-level diversity. Second, their study examined ecological representation in wilderness only as a proportion of *all* lands in the U.S., which does little to help us understand how designating and managing *federal* lands will most efficiently and effectively increase under-represented vegetation classes. For example, knowing that tallgrass prairies are under-represented in NWPS does not help in prioritizing where to designate future wilderness areas, as virtually no wild tallgrass prairie lands are in federal public ownership, and private or state lands are not eligible for national wilderness designation.

One impediment that once precluded a nationwide ecological representation approach to wilderness designation and management in the contiguous 48 United States has recently been overcome with the availability of national-level, consistent, fine-scale data for vegetation communities, classified at multiple hierarchical levels (Aycrigg et al., 2013). The finest scale at which vegetation community data are available and consistent across the contiguous U.S. is at the level of "ecological system"—which is the term we use when referring to our analysis of ecological representation of vegetation communities. We examined, for the contiguous 48 United States (hereafter, simply, "United States"), which terrestrial ecological systems are represented in NWPS in relation to terrestrial ecological systems found on federal lands (Figs. S1 and S2). Specifically, we asked the following questions:

(1) For each ecological system in the United States, what percent of federal land area is in the wilderness system?

(2) What is the diversity of ecological systems currently in the wilderness system compared to the diversity of federal lands and to the diversity of all U.S. lands?
(3) How has total area and diversity of ecological systems in wilderness accumulated over the past 50 years?
(4) What is the relationship between rarity of ecological systems and how well they are represented in wilderness?

## 2. Materials and methods

To delineate ecological systems and their boundaries, we used U.S. Geological Survey Gap Analysis Program (GAP) national land-cover data version 2 (USGS, 2011), which provides seamless, detailed (30 m resolution; 1 ha minimum mapping unit) information on vegetation communities and land use patterns of the contiguous United States. GAP land-cover data combines data from previous GAP projects in the Southwest, Southeast, and Northwest United States, recently updated GAP California data, and data from the LANDFIRE project (for the Midwest and the Northeast). These national land-cover data were based on consistent satellite imagery (acquired between 1999 and 2001), digital elevation model derived datasets, and a common classification system to model natural and semi-natural vegetation. The land-cover data contain several nested hierarchical levels of vegetation community classifications which can be "cross-walked" to the six highest levels of the National Vegetation Classification System (NVCS, 2008)—the foundation of the most detailed, consistent map of vegetative associations available for the U.S.

We analyzed ecological representation in wilderness at the 6th level (the finest scale at which consistent, spatially-explicit GAP land-cover data are available) of the NVCS, which is hierarchically ordered as follows: 1. Class; 2. Subclass; 3. Formation; 4. Division; 5. Macrogroup; 6. Group (a.k.a. "Ecological System" in GAP terminology); 7. Alliance; and 8. Association.

We use the GAP terminology—"ecological system"—throughout this paper. The United States contains 576 ecological systems, 8 of which are highly-human-modified (we refer to them as "developed" in the main text): developed, high intensity; developed, medium intensity; developed, low intensity; developed, open space; cultivated cropland; pasture/hay; orchards, vineyards, and other high-structure agriculture; quarries, mines, gravel pits, and oil wells. Another 3 ecological systems are classified as "open water": fresh; brackish/salt; aquaculture. For all analyses, we focused only on the 565 non-developed, non-open-water classes of ecological systems.

We obtained spatial data on the boundaries of the National Wilderness Preservation System from wilderness.net (Wilderness Institute, 2014), which maintains the most up-to-date spatial data on wilderness areas. To map federal land area, we used the U.S. Protected Areas Database (PAD-US) version 1.3 (USGS, 2012), which is a geodatabase of the national inventory of terrestrial and marine protected areas that are dedicated to the preservation of biological diversity and to other natural, recreation, and cultural uses, managed for these purposes through legal or other effective means. The geodatabase includes geographic boundaries, land ownership, land management, management designation, parcel name, area, and protection category.

*Questions 1 and 2*: We overlaid wilderness and all federal lands with ecological systems in a Geographic Information System (ArcGIS 10.2) to calculate the total area of each ecological system within wilderness and federal lands. Because wilderness areas are designated exclusively from federal lands, we calculated "ecological system representation" in wilderness using Eq. (1).

$$\frac{\text{area of the ecological system in NWPS}}{\text{area of the ecological system on federal lands}} \times 100 \quad (1)$$

For example, when we say "boreal aspen-birch forest has 19% representation in wilderness", we mean that 19% of all *federal* land of that ecological system type is protected as wilderness in NWPS. After calculating ecological system representation, we mapped each ecological system according to its level of representation across all lands, federal and non-federal (Fig. 1A), and across federal lands only (Fig. 1B). We did the former because we believe it is interesting to know where well-represented and under-represented ecosystems exists across the entire U.S., regardless of whether they are on federal land, so that we are able to see broad patterns of geographic distribution of those ecosystem types. We also provide a map of ecosystem representation on federal lands only—to show how well ecosystems that occur on federal lands have been represented in the wilderness system and to isolate those areas that are eligible to be added to the wilderness system and which, if added, would increase ecological representation.

*Question 3*: We used the "specaccum" (i.e., species accumulation) function in the vegan package of R v. 3.0.2 (Oksanen et al., 2013; R Core Team, 2014) to calculate ecological system accumulation curves within wilderness since 1964. We investigated accumulation of new ecological systems in wilderness based on presence (i.e., an ecological system is accumulated if at least 1 ha of its area was represented in a wilderness area), as well as accumulation of ecological systems after achieving a 5% or 20% ecological system representation threshold. We chose those thresholds to evaluate "representation" over a wide range of values.

*Question 4*: We plotted and regressed the percent representation of each ecological system against the log of total area occurring on federal land to investigate whether commonness of ecological systems is related to their level of representation in wilderness. To map patterns of total area and representation simultaneously, we also classified ecological systems as "rare" (<100,000 ha on federal land) or "common" (>100,000 ha on federal land) and "well-represented" (>20% in NWPS) or "under-represented" (<20% in NWPS). We expected that common ecological systems on federal land are more likely than rare ecological systems to be well represented in NWPS. We mapped the results across all lands, federal and non-federal, and across federal lands only.

## 3. Results

The National Wilderness Preservation System (20,993,174 ha) encompasses 12.6% of federal land area and 2.6% of all land area (including inland water-bodies) in the U.S. Wilderness is designated on lands managed by the U.S. Forest Service (12,377,445 ha; 59% of all wilderness hectares), the National Park Service (4,098,734 ha; 20%), the Bureau of Land Management (BLM; 3,496,208 ha; 17%), and the U.S. Fish and Wildlife Service (789,706 ha; 4%). A comparatively small number of wilderness hectares are classified as "non-federal" lands, as these are private in-holdings that have not yet been acquired by the managing agencies. The proportion of each public land type designated as wilderness varies greatly: approximately 40% of national park lands are designated wilderness, 18% of national forest lands, 16% of national wildlife refuge lands, and 5% of BLM lands (Fig. S1).

In the 50 years of the Wilderness Act, 690 wilderness units have been designated, representing 436 ecological systems. In comparison, the U.S. contains 565 ecological systems (Fig. S2; Table S1), 553 of which are found on federal lands, leaving 117 ecological systems (21.2%) unrepresented in NWPS. Moreover, some ecological systems are only nominally represented in wilderness. Therefore, we calculated the number of ecological systems with more than 5% of federal land area in wilderness and more than 20% of federal

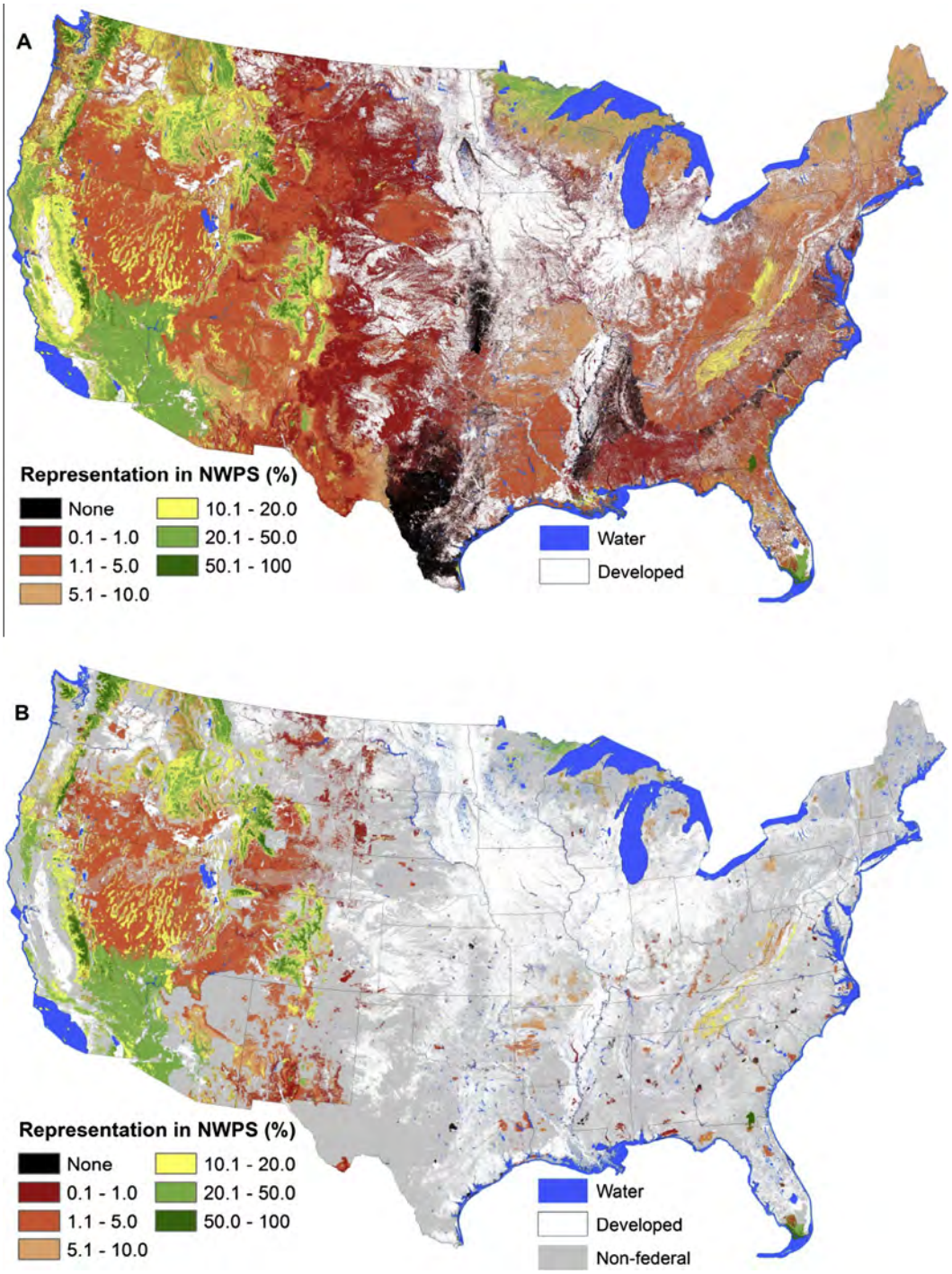


**Fig. 1.** The percent of federal land area in the National Wilderness Preservation System (NWPS) for each of 565 ecological systems (after removing developed land and open water) mapped across all federal and non-federal lands (A) and mapped across federal lands only (B).

land area in wilderness—to evaluate a wide range of representation thresholds. At the 5% and 20% representation thresholds, 244 and 113 ecological systems, respectively, occur in wilderness (Fig. S3). The proportion of area designated wilderness within each ecological system ranges from 0% to 100% of federal land area (Fig. 1A and B). Therefore, NWPS does not include the full richness of ecological systems available on federal land.

Total area within the U.S., on federal land, and in wilderness are characterized by a few common and widely distributed ecological systems, a pattern shown in the negative exponential distributions of rank abundance curves (Fig. 2). However, ecological systems in wilderness are more strongly dominated by a few ecological systems (slope of exponential decay function = −0.027, $R^2 = 0.95$) compared to ecological systems found on federal lands (slope = −0.020, $R^2 = 0.93$) and in the U.S. (slope = -0.017, $R^2 = 0.90$). Therefore, ecological system evenness in NWPS is lower compared to evenness of federal lands and of all U.S. lands.

Total area of NWPS has increased since 1964, albeit at a declining rate since 1995 (Fig. 3A). Half of the area currently in wilderness was accumulated by 1984, and 95% by 2006. New ecological systems represented in wilderness accumulated steeply for the first 20 years following passage of the Wilderness Act. However,

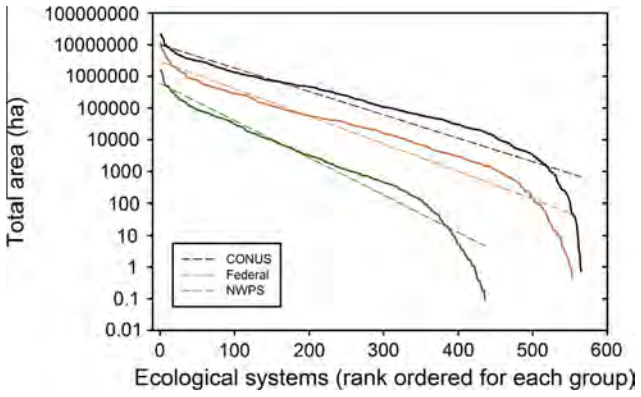


**Fig. 2.** Rank order abundance curves (i.e., "Whittaker" [1965] plots) of ecological system diversity within the contiguous United States (CONUS), on federal land, and within the National Wilderness Preservation System (NWPS). The slopes of the exponential decay functions (dashed lines) estimate differences in ecological system evenness. Total number of ecological systems for each group (U.S., federal, NWPS) represents total richness.

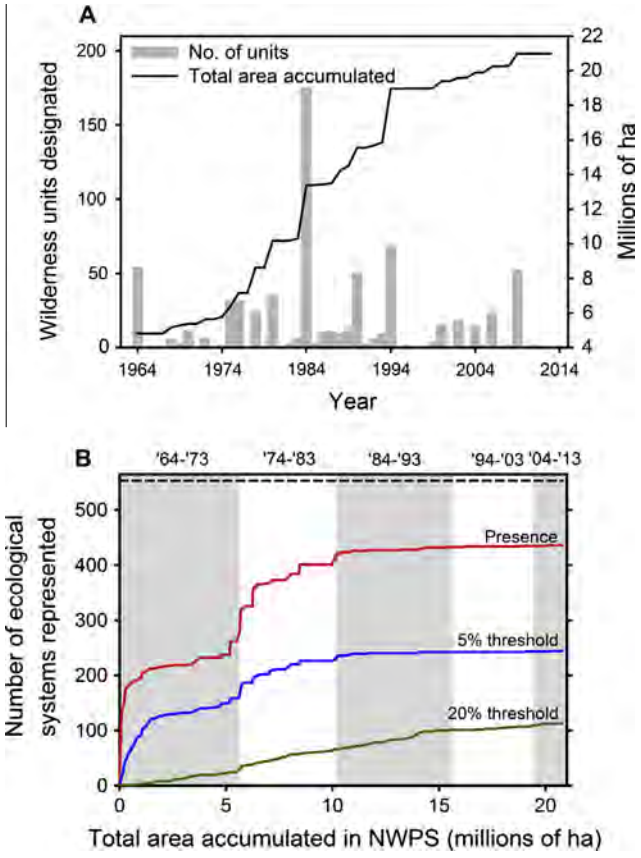


**Fig. 3.** Number of wilderness units and total area accumulated in the National Wilderness Preservation System (NWPS) over the 50-year tenure of the Wilderness Act (A). The number of unique ecological systems represented in NWPS as a function of total area accumulated (B). The red line indicates nominal presence of an ecological system in NWPS. The blue and green lines represent ecological systems with greater than 5% and 20%, respectively, of federal land in wilderness. The top of panel B represents the total number of ecological system in the United States, and the dashed line represents the total number of ecological systems on federal land. Decades starting with the 1964 passage of the Wilderness Act are shown as grey and white shading.

rate of accumulation of ecological systems in wilderness declined over the last 30 years. Specifically, half of the total ecological system richness currently represented in wilderness (as measured by both presence and the 5% representation threshold) was accumulated by the first year of the Wilderness Act (1964), and 95% of ecological system richness was accumulated by 1984 (Fig. 3B). Even at the 20% representation threshold, half of the total richness was accumulated by 1978, and 95% was accumulated by 1994. Growth in accumulated area in wilderness has greatly outpaced growth in total ecological system richness. In fact, in the past 15 years 2 million hectares were added to the wilderness system, but have resulted in the addition of only 1 new ecological system.

We found no relationship between the area of an ecological system occurring on federal land and the proportion of its federal land area represented in wilderness ($p = 0.93$; Fig. 4A). In other words, rare ecological systems on federal land are as likely to be represented in wilderness as common ecological systems.

## 4. Discussion

Our results clearly show that the National Wilderness Preservation System under-represents the full ecological system diversity occurring on federal lands. Neither the U.S. Congress nor federal land-management agencies have explicitly addressed the representation of ecological system diversity within NWPS, nor has there been any systematic conservation planning to achieve conservation goals of ecological representation (Margules and Pressey, 2000). U.S. wilderness areas have historically been designated through a mix of political will and public desire for recreation, solitude, and scenery, albeit with a growing recognition of their value in conserving ecological integrity (Cordell et al., 2005). Although ecological representation and conservation of biological diversity are not specifically addressed in the Wilderness Act, they have become important benefits of the system, as they have for all protected areas. This situation is not unique to wilderness. Few protected areas in the U.S. were established to conserve biological diversity. For example, the National Forest System's Organic Act, which provided the statutory basis for management of forest reserves, stated that the intention of the forest reservations is to "improve and protect the forest within the reservation,...securing favorable conditions of water flows, and to furnish a continuous supply of timber for the use and necessities of citizens of the United States" (Forest Service Organic Administration Act, 1897). National parks had a somewhat clearer mandate to conserve species, as the fundamental purpose of parks was "to conserve the scenery and natural and historic objects and the wild life therein and to provide for the enjoyment in the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations" (National Park Service Organic Act, 1916). Plant and animal species, however, were secondary concerns, as the Secretary of Interior was provided discretion for "the destruction of such animals and of such plant life as may be detrimental to the use of any of said parks" (National Park Service Organic Act, 1916). Perhaps more important than the original goals of protected areas is the degree of protection from stressors that they are afforded by law today. One reason why it is important to assess the ecological representation of wilderness areas in their own right is the high level of protection that occurs therein.

We do not, however, expect wilderness areas to provide for the protection of all biological diversity in the U.S. or even all the species found on federal lands. Other protected areas, in addition to wilderness, must contribute to achieving these goals. It is valuable, nevertheless, to assess the level of ecological representation in the wilderness system to understand how that representation may be increased to further protect biological diversity, for the wilderness system is unique and provides a type of protection from human stressors that other protected areas may not.

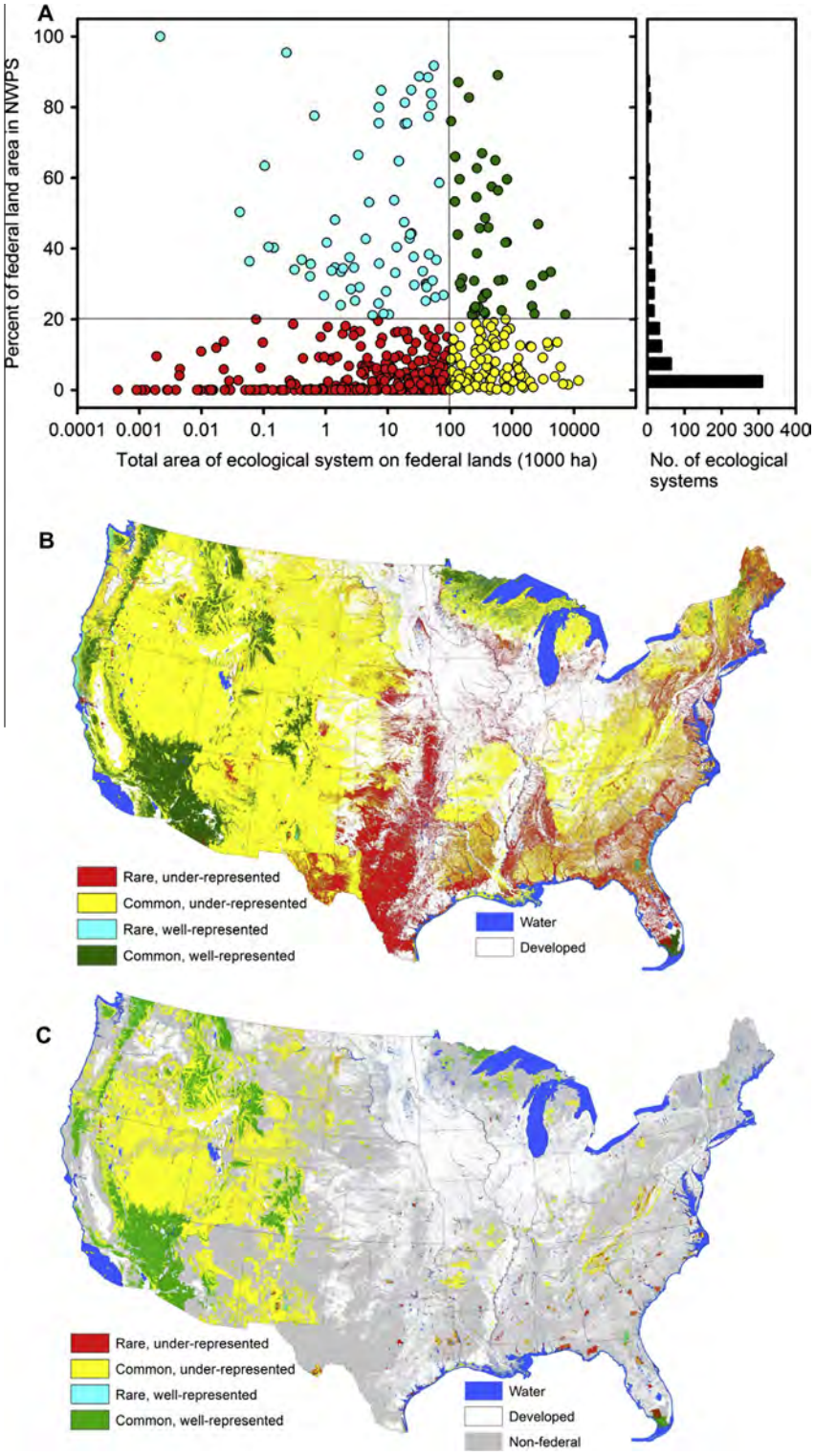


**Fig. 4.** The relationship between the area of ecological systems occurring on federal land and the proportion of federal land area represented in the National Wilderness Preservation System (NWPS) and our classification of ecological systems as "rare" or "common" and "well-represented" or "under-represented" (A). The histogram on the right shows the number of ecological systems in 20 bins of percent federal land area in NWPS. This classification is mapped for all non-developed, terrestrial ecological systems across all federal and non-federal lands (B) and mapped across federal lands only (C). Note: one example of a rare, well-represented ecological system is the Okefenokee Swamp on the Florida-Georgia border.

Wilderness areas are arguably the most important areas in the United States in which to achieve ecological system representation. Due to their strict rules of use and protection (Dawson and Hendee, 2009), wilderness areas have been increasingly recognized for their importance in conserving biological diversity and fundamental physical and biological processes, including large-scale disturbance regimes (Hobbs et al., 2010). Moreover, a network of connected wilderness and other protected areas that represent the

full expression of nature's diverse ecological systems can also serve as "untreated control units" for experimental treatments on other lands where novel methods of restoration and management will be increasingly implemented to mitigate the impacts of climate change and other human-caused stressors (Magness et al., 2011).

This is the first study to assess the wilderness system at the ecological system level, including a comparison of ecological diversity to federal lands and all U.S. lands, an assessment of accumulation of representation over time, and an investigation of the relationship between rarity of ecological system and protection in wilderness.

A recent study (Aycrigg et al., 2013) evaluated representation of finer-scale ecological systems in the comprehensive "protected areas" network of the contiguous United States—including, but not limited to, wilderness areas—at the national and ecoregional scales. Protected areas throughout the world are classified by the IUCN by their primary management objectives, with categories 1a and 1b having the most natural conditions and the lowest degree of environmental modification (Dudley, 2008). Areas outside of category one, however, may be managed for multiple uses, including extraction of natural resources, concentrated recreation and tourism, facilities development, and conversion of natural habitat types to anthropogenic types. Representation of ecological system types in these areas may not provide the protection needed to be considered true biodiversity reserves. Therefore, we are expanding upon this work so that managers and conservation biologists can understand how best to increase ecological representation within the wilderness system itself. Fully representing ecological diversity in NWPS and other protected areas has not been achieved, partially because the assessment conducted here has only recently been possible with the availability of high-resolution, universal coverage of spatial data linked to a national ecological system classification (Aycrigg et al., 2013).

The opportunity to designate additional wilderness areas is substantial and real. In contrast, designation of new large-landscape national parks has slowed in recent decades and has no explicit means of growth through federal land-use planning. New national monument proclamations by the executive branch, although relatively common, do not consistently meet the management standards of strict ecological reserves. The Wilderness Act provides a means for the U.S. Congress to continually designate additional wilderness areas from federal public lands—primarily in un-roaded and sparsely-roaded areas. The diversity of ecological systems in NWPS, therefore, can increase if efforts are made to prioritize designations by ecological criteria. As shown in Fig. 4B and C, many common ecological systems remain under-represented in NWPS, providing ample opportunity to increase ecological diversity. Alpine, high montane, and boreal forest vegetation communities are well-represented in wilderness, as are low-elevation "warm" semi-desert areas with sparse vegetation (Table 1). The relatively rare wet-tropical ecological systems are also well-represented, largely due to the abundance of south Florida wilderness. Temperate forests, temperate and boreal grasslands and shrublands, and semi-desert scrub and grasslands (especially in "cool" deserts) are under-represented in wilderness, yet many millions of hectares of these subclasses are found on federal land.

Human population growth and subsequent pressure for development and extraction of natural resources will make wilderness areas increasingly vital to conserve biological diversity. If we intend to take advantage of the highly-protective nature of wilderness areas to conserve biological diversity, future recommendations for additions to the system should strongly consider how under-represented ecological systems could be prioritized in new wilderness bills. As the designation of new protected areas becomes increasingly difficult, it is important to achieve maximum ecological system diversity for every new area designated.

**Table 1**
Ecological subclasses of the National Vegetation Classification System (all open water and modified land combined into "other subclasses"), the proportion of federal land in the National Wilderness Preservation System (NWPS) for each subclass, the area of each subclass in wilderness, and the area of each subclass on all federal land [hectares are derived from spatial data].

| National Vegetation Classification System (NVCS) Subclass | % in NWPS | Hectares in NWPS | Hectares on federal land |
|---|---|---|---|
| Cool Semi-Desert Scrub & Grassland | 2.9 | 1,222,726 | 42,730,449 |
| Tropical Dry Forest | 3.8 | 1169 | 30,421 |
| Other Subclasses (Open water, modified land, etc.) | 6.5 | 611,951 | 9,397,380 |
| Temperate & Boreal Shrubland & Grassland | 10.4 | 1,489,897 | 14,346,766 |
| Temperate Forest | 14.8 | 10,050,644 | 67,817,892 |
| Warm Semi-Desert Scrub & Grassland | 16.0 | 3,068,431 | 19,211,918 |
| Mediterranean, Temperate & Boreal Nonvascular & Sparse Vegetation | 16.9 | 148,663 | 882,226 |
| Mediterranean Scrub & Grassland | 21.4 | 280,892 | 1,314,014 |
| Boreal Forest | 25.9 | 375,721 | 1,450,366 |
| Semi-Desert Nonvascular & Sparse Vascular Vegetation | 27.0 | 1,751,589 | 6,486,099 |
| Barren | 40.8 | 41,822 | 102,498 |
| Tropical Shrubland, Grassland & Savanna | 44.6 | 146,223 | 327,938 |
| Tropical Moist Forest | 45.1 | 123,752 | 274,565 |
| Temperate & Boreal Alpine Vegetation | 61.5 | 784,834 | 1,276,312 |
| Polar & High Montane Nonvascular & Sparse Vegetation | 72.9 | 892,641 | 1,224,276 |
| All NVCS Subclasses | 12.6 | 20,990,955 | 166,873,120 |

## 5. Role of the funding sources

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## Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.biocon.2015.02.024.

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