Environmental Conservation **26** (1): 53–58 © 1999 Foundation for Environmental Conservation

Using GIS to identify under-represented ecosystems in the National Wilderness Preservation System in the USA

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Date submitted: 20 April 1998 Date accepted: 4 December 1998

Summary

Wilderness designation continues to be a contentious effort and must be fully justified even in wealthy countries such as the USA. An important consideration in setting priorities for additional designations of Wilderness is to ensure that under-represented ecosystems are protected. The utility of Geographic Information Systems in performing this task is illustrated using data on ecoregions and areas in the National Wilderness Preservation System to determine the relative protection currently afforded to different ecoregions in the continental USA. We find that 23 of the 35 ecoregions have less than 1% of their land area protected as Wilderness, and 7 of the 35 have no land protected as Wilderness whatsoever. While much of the land with little protection is in areas dominated by private land ownership in the mid-west and southeast, a surprisingly large amount of land in the Intermountain states of Nevada and Utah, which is in public ownership, is substantially under-represented in the National Wilderness Preservation System as well. The implications of this analysis for wilderness allocation strategies are detailed. The technique illustrated in this paper is a useful aid in designing protected area strategies in countries throughout the world.

Keywords: ecoregions, federal lands, GIS, wilderness, wilderness study areas, conservation strategy

Introduction

Conservation of natural areas through land protection programmes has a long history in the USA, the most prominent is the National Park System established in 1916 (Forestra 1985, p. 301). Since that time, the concept of natural area conservation through designation of land has spread to dozens of countries. An even more preservation-oriented land protection programme was established more than 30 years ago in the USA with the Wilderness Act of 1964 (US Congress 1964). That Act designated 54 areas totalling just over 3.6 million ha to comprise the National Wilderness Preservation System (NWPS). Together with the Eastern States Wilderness Act (Hendee *et al*. 1990), the NWPS now protects more than 42 million ha in 630 areas and is managed by four Federal government agencies (Cole 1996). About half of this total is in Alaska, and about 20% is in the Pacific and Rocky Mountain regions of the USA, less than 5% is in the Northeast and Southeast USA.

While the total area protected is vast, much of the designated areas can be characterized in three ways: areas of high scenic value; areas that had little or no commodity value due to their alpine or desert characteristics; and areas in states with relatively receptive Congressional delegations such as California, compared to Utah and Nevada. Given that 42 million ha are protected, questions regarding 'how much area is enough' recur frequently in the debates over whether to designate qualified candidate areas not yet protected as wilderness. Clear priorities need to be set, but on what basis?

In recent years, policymakers have become more aware of the importance of preserving natural diversity in plants and animals and physical environments. Thus, while the factors implicit in the categories listed above continue to be important, the Wilderness Act and government agency evaluation criteria now include diversity of ecosystems represented in NWPS as a selection criteria (Hendee *et al*. 1990). The same dilemma of how much natural area to protect is being faced in newly-emerging nations of the former communist bloc and the newly democratic regime in South Africa (Wells 1996). The challenge of overcoming poverty in these countries also makes it critical that the conservation goal of protecting a diversity of ecosystem types be met without unnecessary redundancy.

While a standard policy analysis tool for such a problem is to compare benefits and costs in dollar terms, the full range of benefits of biodiversity are difficult to monetize. As such, Faith and Walker (1996*a*) propose a multi-criteria approach to evaluating the trade-offs between costs of protecting specific areas and their contribution to biodiversity. Costs to society take the form of opportunity costs of foregone development options and direct management costs. The gains in biodiversity can be measured in a variety of ways including the species richness of the candidate area, its vulnerability to loss or a combined measure of the two (Faith & Walker 1996*b*). Other measures include irreplaceability (Pressey *et al*. 1994) and genetic distinctiveness (Metrick & Weitzman 1998). Identifying and adding a collection of species that lack representation in existing protected areas, called GAP analysis (Kiester *et al*. 1996), is another key criterion. The Wilderness Act of 1964 also requires agencies to evaluate whether the candidate area provides outstanding oppor-

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tunities for primitive and unconfined recreation (US Congress 1964; USDI [US Department of Interior] Bureau of Land Management 1991).

Optimal reserve design is more than just determining a cost-effective total acreage and identification of individual areas to be protected. The portfolio of areas must have a spatial distribution of areas sufficiently distant so that environmental stochasticity does not wipe out the entire population of a particular species, but close enough that remaining members of the population could recolonize these areas. This is often referred to as the SLOSS dilemma of 'single-large versus several small' (Baz & Garcia-Boyero 1996). Further, the areas must be large enough to ensure species persistence and maintenance of species diversity through the preservation of unrestrained ecological processes.

In the USA, Wilderness is one protected area designation for conserving selected portions of the natural landscape along with National Park and National Wildlife Refuge designations. However, Wilderness designation provides the strictest protection from development because it prohibits roads, logging, mechanized access and construction of permanent structures. Davis' (1989) analysis of Wilderness in the USA addresses preservation management, specifically the inclusion of representative samples of naturally occurring ecosystems in the NWPS.

Increasing the representation of ecosystems has been a criteria of the US Forest Service (USDA [US Department of Agriculture] Forest Service 1978) and Bureau of Land Management (USDI [US Department of Interior] Bureau of Land Management 1991) when recommending roadless areas for designation as Wilderness. Unfortunately, the agencies' recommendations have not benefited from a comprehensive, national analysis of ecosystem representation in existing Wilderness Areas of all four federal Wilderness management agencies. As a result, the agencies may be missing an opportunity to make strategic recommendations that fill important voids in ecosystem protection.

This paper represents the first comprehensive, national analysis of Wilderness representation of all four federal land management agencies in the Lower 48 states in the USA. Combining Geographic Information System (GIS) data from all four federal agencies and several non-governmental entities, we are able to identify ecosystems that are under-represented in the NWPS and should therefore be priorities for Wilderness preservation recommendations and designations. The paper also illustrates an approach which can be used by conservation agencies and groups worldwide as part of any systematic process of protected area design to conserve the full range of ecosystem diversity within their countries. The biodiversity contribution of different candidate protected areas can then be balanced against their costs and vulnerability using trade-off decision tools such as those of Faith and Walker (1996*a*).

Prior efforts to evaluate ecosystem representation in wilderness assessments

In USDA Forest Service's second Roadless Area Review and Evaluation (RARE II) in 1978, the agency decided to give preference to additions of areas that would increase the diversity of the NWPS (USDA [US Department Of Agriculture] Forest Service 1978). RARE II adopted the Bailey-Küchler ecosystem classification system which considers macroclimate (Bailey 1995) and potential natural vegetation (Küchler 1970). Since vegetation often defines habitat suitability for wildlife species, vegetation differences can be treated as an indicator for many wildlife communities as well (Davis 1989, p. 78). The USFS defines adequate representation of an ecosystem to include two or more distinct examples of at least 400 ha (Davis 1989, p. 78). In addition, the areas selected must epitomize that particular ecosystem.

As a result of RARE II and subsequent designations by Congress, some of the country's ecosystems were represented in the NWPS by 1989 (Davis 1989). The Bureau of Land Management (BLM) has also adopted the Bailey-Küchler system for its wilderness studies. Additions of BLM land have the potential to increase the diversity within the NWPS since BLM lands are ecologically distinct from the USFS.

The Davis (1989) analysis has not been updated. A project using GIS to prioritize target areas of currently unprotected species (i.e. gaps) has demonstrated the potential utility of such an analysis just for the State of Idaho (Kiester *et al.* 1996). Given that the last comprehensive analysis was nearly a decade old and did not reflect recent sizeable Wilderness designations, we undertook an updated analysis using Bailey's (1995) ecoregions at the province level and Federal agency Wilderness GIS data. The Bailey (1995) system of ecoregion classification uses three levels. Of these, *domains*, and within them *divisions*, are based largely on the large ecological climate zones. Each division is subdivided into climate subtypes, or *provinces*, on the basis of macro features of the vegetation. The subtypes correspond to major plant formations and are named accordingly. Mountain provinces exhibiting altitudinal zonation and having climatic regime of the adjacent lowlands are distinguished according to the character of the zonation by listing the altitudinal zones present. For the purposes of this paper we will use the terms province and ecoregion interchangeably. It should be noted that in the following analysis, the level of aggregation for our ecoregions influences the absolute number of ecological areas the analyst is trying to represent in any given protected area strategy. The more disaggregated the ecoregions, the more difficult it will be to represent adequately all of them in a protected area network of a given size. However, our relative measures such as percentages and ratios are less affected.

Methods and data sources

GIS analysis was conducted using ESRI's various GIS software packages including Arc/Info®, Arc View®, and Atlas®. Ecoregion data was obtained in electronic form from Robert

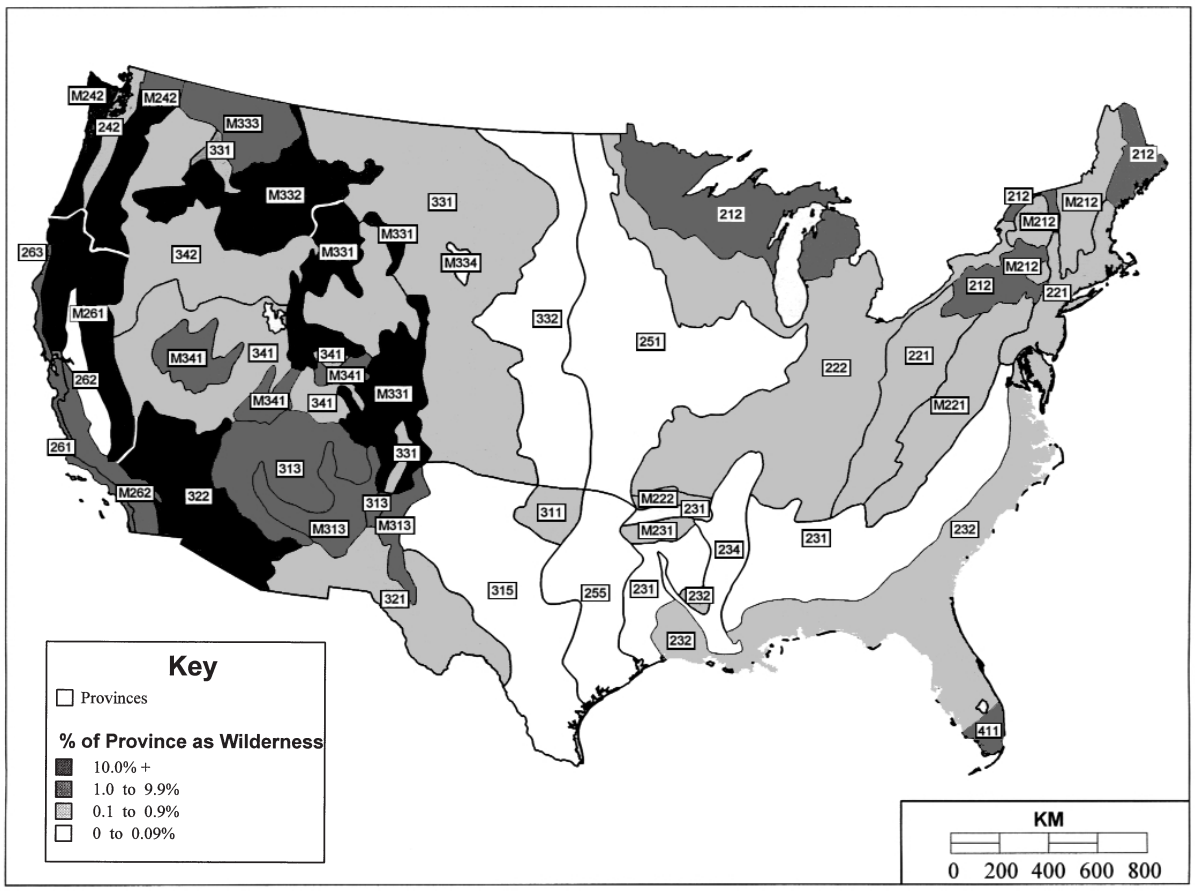

Figure 1 Relative protection of Provinces by Wilderness.

Bailey at the USDA Forest Service. Wilderness size and locations were collected from GIS coordinators in the US Forest Service, Bureau of Land Management and National Park Service. These data were provided to us via disks and downloaded from agency bulletin boards. Dean Tucker of the National Park Service provided access to a 1994 Wilderness size data set organized by the National Geographic Society (originally supplied by Russ Little of the National Geographic Society).

Data sets were provided from sources in one of three formats: Arc/Info® coverages, Arc® export files, or Atlas® GIS .agf files. After these formats were converted to common projections, analysis and display of the data were accomplished using Atlas® GIS. Statistics were calculated using a spreadsheet programme from the Atlas® files. The area estimates were compared with figures obtained independently of the GIS analysis and were found to be satisfactory (5%–10% difference). This was acceptable since the scale and accuracy in the GIS data available were highly variable from agency to agency and source to source. In several cases, tabular estimates of recent additions to the NWPS were directly added to update existing map coverages.

A statistical test of whether Wilderness acreage represents Provinces can be made using a χ^2 test of proportions. Adapting the resource selection models of Manly *et al.* (1993, pp. 42–3) we can test the null hypothesis that Wilderness Areas have been selected randomly with respect to Province. A random selection of Wilderness acreage would result in representation of Wilderness acres in proportion to the amount of land area in each Province. This χ^2 test involves comparing the population proportion of a given Province to the proportion of Province designated as Wilderness. The population proportions are used to form the expectation which is compared to actual proportions designated as Wilderness.

Results

Overall, 1.6% of the land areas in the Continental USA are protected as Wilderness. At the upper end, about 25.9% of the Everglades Province and 16.4% of the American Desert Province are Wilderness (with the latter high percentage occurring just recently with the recent California National Parks Wilderness legislation) (Table 1). High percentages of alpine provinces are also protected in the Cascades, Rocky Mountains, and Sierras. The top five provinces (just 15%) contain 75% of Wilderness, leaving the other 85% of provinces with 25% of USA Wilderness.

Some large provinces have essentially no Wilderness protection as 20 of the 60 provinces have zero or less than 1%

https://doi.org/10.1017/S0376892999000089 Published online by Cambridge University Press

Table 1 Comparison of Wilderness area (ha) by Province. Table figures do not add precisely due to rounding.

Ecocode (Bailey 1995)	*Province*	*% of total USA lower-48 Wilderness*	*% of USA in Province*	*Wilderness to Province area ratio*	*Ratio over 1?*	*% Province as Wilderness*	*Wilderness (ha)*	*Total Province area (ha)*
322	American Semi-Desert and Desert Province	21.0%	2.9%	7.17	Yes	16.4%	3 722 261	22 759 679
M331	Southern Rocky Mountain Steppe – Open Woodland – Coniferous Forest –Alpine Meadow Province	17.4%	3.4%	5.10	Yes	11.6%	3 090 018	26 553 701
M332	Middle Rocky Mountain Steppe – Coniferous Forest – Alpine Meadow Province	13.7%	2.7%	5.04	Yes	11.5%	2 436 942	21 175 620
M261	Sierran Steppe – Mixed Forest – Coniferous Forest – Alpine Meadow Province	11.8%	2.3%	5.17	Yes	11.8%	2 090 199	17 704 974
M242	Cascade Mixed Forest – Coniferous Forest – Alpine Meadow Province	11.4%	1.8%	6.40	Yes	14.6%	2 024 273	13 857 883
411	Everglades Province	3.0%	0.3%	11.35	Yes	25.9%	525 847	2 029 530
M313	Arizona – New Mexico Mountains Semi-Desert – Open Woodland – Coniferous Forest – Alpine Meadow Province	2.9%	1.7%	1.75	Yes	4.0%	520 970	13 024 161
212	Laurentian Mixed Forest Province	2.8%	4.9%	0.57	No	1.3%	496 514	38 211 237
313	Colorado Plateau Semi-Desert Province	2.5%	2.5%	1.01	Yes	2.3%	451 580	19 539 076
M262	California Coastal Range Open Woodland – Shrub – Coniferous Forest – Meadow Province	2.5%	0.8%	3.00	Yes	6.9%	442 989	6 461 491
M333	Northern Rocky Mountain Forest – Steppe – Coniferous Forest – Alpine Meadow Province	2.3%	1.3%	1.84	Yes	4.2%	413 838	9 864 955
341	Intermountain Semi-Desert and Desert Province	1.4%	3.6%	0.39	No	0.9%	249 498	27 810 961
331	Great Plains – Palouse Dry Steppe Province	1.2%	9.7%	0.12	No	0.3%	214 461	75 401 755
232	Outer Coastal Plain Mixed Forest Province	1.2%	5.8%	0.21	No	0.5%	213 541	45 081 930
M341	Nevada – Utah Mountains – Semi-Desert – Coniferous Forest – Alpine Meadow Province	1.1%	1.5%	0.77	No	1.8%	199 142	11 310 160
321	Chihuahuan Semi-Desert Province	0.8%	2.8%	0.28	No	0.6%	143 385	22 099 730
342	Intermountain Semi-Desert Province	0.7%	5.3%	0.13	No	0.3%	123 232	41 263 960
M221	Central Appalachian Broadleaf Forest – Coniferous Forest – Meadow Province	0.6%	2.3%	0.26	No	0.6%	105 198	17 651 240
261	California Coastal Chaparral Forest and Shrub Province	0.5%	0.3%	1.35	Yes	3.1%	82 143	2 674 274
M212	Adirondack – New England Mixed Forest – Coniferous Forest – Alpine Meadow Province	0.3%	1.5%	0.23	No	0.5%	59 561	11 326 084
222	Eastern Broadleaf Forest (Continental) Province	0.2%	9.0%	0.02	No	0.1%	39 534	69 977 214
242	Pacific Lowland Mixed Forest Province	0.1%	0.5%	0.26	No	0.6%	23 269	3 858 641
315	Southwest Plateau and Plains Dry Steppe and Shrub Province	0.1%	5.4%	0.02	No	0.0%	16 113	41 736 523
221	Eastern Broadleaf Forest (Oceanic) Province	0.1%	3.5%	0.03	No	0.1%	15 706	27 070 111
263	California Coastal Steppe – Mixed Forest – Redwood Forest Province	0.1%	0.2%	0.52	No	1.2%	13 954	1 181 315
M222	Ozark Broadleaf Forest – Meadow Province	0.1%	0.2%	0.28	No	0.6%	10 672	1 659 337
231	Southeastern Mixed Forest Province	0.1%	6.4%	0.01	No	0.0%	10 665	50 038 817
M231	Ouachita Mixed Forest – Meadow Province	0.0%	0.3%	0.09	No	0.2%	4819	2 284 173
332	Great Plains Steppe Province	0.0%	4.5%	0.01	No	0.0%	4107	34 760 233
311	Great Plains Steppe and Shrub Province	0.0%	0.6%	0.03	No	0.1%	3442	4 553 752
234	Lower Mississippi Riverine Forest Province	0.0%	1.5%	0.01	No	0.0%	1668	11 477 710
251	Prairie Parkland (Temperate) Province	0.0%	7.3%	0.00	No	0.0%	0	56 570 391
255	Prairie Parkland (Subtropical) Province	0.0%	2.7%	0.00	No	0.0%	0	20 739 774
262	California Dry Steppe Province	0.0%	0.6%	0.00	No	0.0%	0	4 987 447
M334	Black Hills Coniferous Forest Province	0.0%	0.1%	0.00	No	0.0%	0	952 622
	Totals	100.0%	100.0%				17 749 539	777 650 460
	Median			0.26		2.3%		

protected as Wilderness (Figure 1). Plains and Southeastern mixed forest represent substantial portions of USA land areas with almost no Wilderness. However, many of these provinces are in areas with limited acreage of Federal lands, so the opportunities for Federal Wilderness designation may be limited. However, even in the states of Utah and Nevada, dominated by public land, the Intermountain Desert Provinces (Ecocodes 341 and 342) are largely unprotected as Wilderness, as evident by the light grey shading of these areas (Figure 1). This is particularly striking considering about 75% of the land is in Federal ownership in that region (Loomis 1993).

This lack of proportional representation is empirically verified by the results of the χ^2 test for random selection of Wilderness Areas with respect to Province. Following Manly *et al*. (1993, pp. 42–3), the calculated χ^2 rejects the null hypothesis of random selection ($p < 0.01$).

Policy discussion

To provide some policy perspective on under-representation, we calculate the ratio of Wilderness to Province area. A ratio of one means that the province has equal percentages of the NWPS and continental USA land area implying representation proportional to area of occurrence. For example in the case of Province M331, a ratio of 5.1 (Table 1) means that this province has five times as much representation in the NWPS as it has in the land area in the continental USA. Thus this province is well represented in the NWPS. Conversely, Province 341, Intermountain Desert represents 3.6% of the USA land area but only 1.4% of the NWPS (Table 1). Thus, this Province has a ratio of 0.39 indicating it is under-represented in the NWPS and under-protected. Addition of another 1000 ha of Wilderness would be more important in Province 341 than in M331, in terms of the contribution to protecting diversity of landscapes. Of course as noted by Faith and Walker (1996*a*), the net benefits of the relative gain would depend on the opportunity costs of land in the two Provinces.

The Bureau of Land Management (BLM) has 10.52 million ha of lands technically suitable for Wilderness. However, BLM recommended about one-third of this area or 3.8 million ha as Wilderness. About 2.5 million of these hectares are in the Intermountain and Rocky Mountain regions and 1.3 million are in the Pacific Coast region. The addition of the BLM lands in the Intermountain Region would improve the ecological representation in the NWPS because a majority of it is high desert, an ecosystem that is currently under-represented in the System (Table 1, Fig. 1).

In relative terms, the greatest extent of protection is in the western mountains and southwestern deserts, and the lowest proportion in the high prairie and southern forests (Table 1). In the mid-west, additional representation of Wilderness may be possible via the establishment of state wilderness programmes. States such as Missouri have a Wilderness programme and if other states adopted such programmes, ecosystem representation could be improved in areas with few Federal lands.

Conclusion

While federal agencies have embraced GIS as a tool and expressed desires to protect ecosystems, they have not connected the two at the national level. Each agency performs its own analysis, on its own areas, with minimal attention to cross-agency interactions (Loomis 1993). We found that most of the agencies did not even have all of their own agency area data in a consistent GIS format to be displayed, let alone have access to GIS data on adjoining federal agencies. Given the political resistance to additional designations of Wilderness, it is imperative that the agencies, conservation groups and professional societies prioritize areas for protection. Integration of federal agency data on Wilderness is critical for linking Wilderness Study Area recommendations to a conservation policy designed to protect a representative mix of ecosystems. The data and analysis presented in this paper illustrate the utility of this GIS based approach systematically to identify ecosystems under-represented in the National Wilderness Preservation System. This research should spur greater coordinated federal land management agency effort under the heretofore weak cooperation shown by agencies belonging to the Federal Geographic Data Committee. In the meantime, our maps and tabular data should help federal agencies, conservation groups and professional societies focus their efforts on the protection of under-represented ecosystems in the National Wilderness Preservation System in the USA.

Acknowledgements

Geographic Information Specialists Jack Johnson of the BLM in Arizona, Dave Mensing of New Mexico BLM, Kim Foiles of USFS Region 1, and Dave Prevendel of USFS Region 4 were helpful in providing access to their areas' wilderness maps. In addition, Dean Tucker, National Park Service (NPS) provided much data and assistance, including a 1994 data set organized by the National Geographic Society (supplied by Russ Little of the Society). Ken Bonnetti was helpful in the literature review on ecosystem representation. Andy Seidl, Colorado State University, provided valuable suggestions for improving the clarity of the paper. We appreciate the numerous technical clarifications of Robert Bailey, USDA Forest Service. This paper has benefited from numerous suggestions by two anonymous reviewers.

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