Ecoregions as a level of ecological analysis

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Received 14 August 1996; received in revised form 11 October 1997; accepted 24 October 1997

Abstract

There have been many attempts to classify geographic areas into zones of similar characteristics. Recent focus has been on ecoregions. We examined how well the boundaries of the most commonly used ecoregion classifications for the US matched the boundaries of existing vegetation cover mapped at three levels of classification, fine, mid- and coarse scale. We analyzed ecoregions in Idaho, Oregon and Washington. The results were similar among the two ecoregion classifications. For both ecoregion delineations and all three vegetation classifications, the patterns of existing vegetation did not correspond well with the patterns of ecoregions. Most vegetation types had a small proportion of their total area in a given ecoregion. There was also no dominance by one or more vegetation types in any ecoregion and contrary to our hypothesis, the level of congruence of vegetation patterns with ecoregion boundaries decreased as the level of classification became more general. The implications of these findings on the use of ecoregions as a planning tool and in the development of land conservation efforts are discussed. Published by Elsevier Science Ltd.

1. Introduction

An understanding of the factors that determine where an ecological boundary is located and how it influences our understanding of ecological processes is a fundamental issue facing ecologists and land planners (Weins et al., 1985; Gosz, 1991). It is generally accepted that ecological zones should be hierarchical, with their size dependent upon the scale of study, and their boundaries based on semipermanent landscape components (Bailey et al., 1994). This basis allows recognition of an ecological unit regardless of present land use or successional status of the vegetation.

Systems classifying geographic areas into zones containing similar characteristics, so as to better understand their similarities and relationships, date back many decades. Early classifications were often based on topographical contrasts, such as the identification of the major physiographic provinces within the US by Powell (1895). Many of the fundamental principles he used were adopted by subsequent scientists in this field of study. Foremost among these was Nevin Fenneman who refined physiographic provinces in the US into regions and subregions, based primarily on structural geology and landform attributes (Fenneman, 1928, 1931). Atwood (1940) [mapped by Raisz (1954)] further refined these zones by incorporating human factors into the classification.

Other efforts to divide the earth’s surface into identifiable zones have been based on climate and vegetation. Herbertson (1905) mapped the world into 13 different natural area regions ranging from polar highlands to equatorial lowlands. Several other investigators have further refined this system over the years, both globally and for specific countries. Merriam (1898) defined zones of natural vegetation and agricultural crops based on climate, and Walter and Box (1976) presented a global plan for classifying ecosystems also based on climate. Potential natural vegetation (Kuchler, 1964) has also been used to classify the US into ecological provinces. Dice (1943) subdivided the North American continent into biotic provinces, areas characterized by “...peculiarities of vegetation type, ecology, climax, flora, fauna, climate, physiography, and soil”. Canadian resource managers have been among the leaders in developing frameworks for land classifications based on ecological criteria that include vegetation, soils, landform, and...

2. Ecoregions used in the analysis

In this paper we focus on land classification systems based on ecoregions. Ecoregions have been defined as geographic “...regions [that] generally exhibit similarities in the mosaic of environmental resources, ecosystems, and effects of humans..” (Omernik, 1995). They are relatively homogenous regions in terms of their ecological systems, organisms and environment. Bailey (1983) similarly defined ecoregions as “…geographic zones that represent geographical groups or associations of similarly functioning ecosystems.” Ecoregions “…therefore define broad areas where one can expect to find the same kinds of vegetation and soil associations on similar sites.”

Here we examine and compare ecoregions as defined by the two major proponents of the concept in the US, Robert Bailey and James Omernik. Both systems were developed to facilitate the planning of regional conservation strategies. We use the ecoregion classifications developed in map form at a scale of 1:7 500 000 for the US in 1976 (Bailey, 1996) and described by Bailey (1980) and modified and published as a map with accompanying manual by Bailey (1995). Methods used in delineating the regions are described in Bailey (1983, 1996). This map defines 52 ecoregion provinces for the US ranging in size from 11 900 km² to 751 000 km².

We use the 7 500 000 scale Level III ecoregion map of the US published with map supplement by Omernik in 1987 (Omernik, 1987) with the map slightly revised in 1995 (unpublished). To date, Omernik has not published a manual describing each of the ecoregions developed. This map defines 78 ecoregions, that range in size from 15 000 to 330 000 km².

Each of the maps is hierarchical in terms of divisions. Bailey subdivides his map into increasingly detailed smaller geographic areas) of domain, division, province and section. Omernik (see Omernik, 1995) has subsequently aggregated his original map into three levels, I, II and III, also reflecting increasingly detailed subdivisions. We use the province level classification of Bailey and the Level III map of Omernik in our analysis as these provided the greatest detail in equivalent versions.

Different ways in which ecoregion boundaries can be developed are summarized in Bailey (1996). For the ecoregions used in this study, the two investigators used different methods to develop the ecoregion boundaries. As we interpret the process, Bailey based his province level ecoregions primarily on Kuchler’s (Kuchler, 1964) classification of potential natural vegetation in the US with the boundaries influenced by Koppen’s (Koppen, 1931) climatic classification as modified by Trewartha (1968). Kuchler (1964) classified 116 types of natural plant communities in the continental US defined as “the vegetation that would exist today if human being were removed from the scene and if the resulting plant succession were telescoped into a single moment.”

Omernik’s classification was also based on Kuchler’s (1964) vegetation map in conjunction with physiography (Hammond, 1970), land use pattern (Anderson, 1970), and soils (USDA, 1957). These measures are combined in a way that requires numerous subjective decisions on the relative importance of the different data layers. Because of this the results are often not repeatable (Host et al., 1996).

3. Objectives

The broad issue we raise in this paper is whether ecoregions provide a useful and appropriate tool for conservation planning. The specific question we ask is how well the boundaries of ecoregions, as proposed by either investigator approximate the extent of mapped vegetation cover types. We further examine the influence that the hierarchical level of vegetation classification has on the concurrence of the correspondence of vegetation types within the boundaries of ecoregions. We hypothesize that there should be ‘some’ congruence between ecoregions and mapped vegetation types, and that this congruence should increase as the level of vegetation classification becomes more general. We further hypothesize that the ecoregions as defined by either investigator should respond similarly to these tests. We recognize in proposing these hypotheses that the ecoregion boundaries were not explicitly based on maps of existing vegetation and that there are scale issues, i.e. the ecoregion boundaries are mapped at a geographic scale far more coarse than the maps of existing vegetation. Thus we would not expect complete correspondence. However, we also consider vegetation to be a good integrator of climate, soils and landform, and thus some correspondence would be expected.

We undertook these analyses not to criticize the ecoregion concept or the delineations of either investigator. Rather we did this because individual ecoregions have increasingly been used in the US as a basis for organizing and interpreting environmental data for inventory, monitoring, and research efforts (Gallant et al., 1995), and because we now have, for the first time, detailed regional-scale vegetation cover maps, available in digital format with which to test our assumptions.

4. Methods

We limited our analysis to the states of Idaho, Oregon and Washington. We used vegetation cover
maps developed for the respective states by the individual state programs of the GAP Analysis Program (GAP) (Scott et al., 1993). These maps were created by incorporating LANDSAT Thematic Mapper satellite imagery, aerial photography, existing maps and field reconnaissance (Scott et al., 1993) and compiled at scales ranging from 1:500 000 to 1:100 000 with a minimum mapping unit from 250 to 40 ha. The maps were digitized into a geographic information system (GIS) (ARC/INFO version, Environmental Systems Research Institute, Redlands California). Actual vegetation was classified into cover types based on subjective assessments of canopy dominance by one or more species. Because each state’s GAP program classified vegetation independently, many resulting individual cover types, although very similar in species composition were given a different title by each state (Davis et al., 1995). Therefore, the vegetation classification was subsequently standardized by aggregating similar state plant communities into new standardized multi-state types. Many individual state plant communities were distinct and were therefore not aggregated. Three hierarchical levels of classification were used in the analyses, a community or alliance level of classification (Level I), the most definitive, consisting of 118 types (Jennings, 1993); a dominant species classification (73 types) (Level II) developed by the authors from the Level I classification; and a formation level (18 types) (Level III) also developed by the authors and based on structural similarities and common growth forms.

We used the nine Bailey (1996) ecoregion provinces that fall either entirely or partly within the three-state area (Table 1). We excluded those ecoregions, such as the Wasatch and Unita Mountains that had only a small portion of their total area in the region.

We used the GRID module of ARC/INFO which is raster based. Both ecoregion and vegetation data layers were converted from polygon to raster data. The cell size used in the analysis was 1 km². The actual vegetation layers were combined with each ecoregion classification. We assessed each ecoregion separately by calculating the proportion of total area of each cover type that occurred within a particular ecoregion. This was done for all three levels of classification. We also assessed whether one or more vegetation types dominated an ecoregion by calculating the proportion of each ecoregion occupied by each vegetation type. This was also done for all three levels of classification.

5. Results

To simplify interpretations of the proportion of the total area of each cover type that occurred within a particular ecoregion, the results were tabulated to show the number of types that had <20% and >80% of their total area in each ecoregion. These results for Bailey and Omernik ecoregions are shown in Tables 2 and 3. A typical pattern of the proportional occupancy by vegetation types in two separate ecoregions is shown in Figs. 1 and 2. The analysis of the proportion of each ecoregion occupied by each vegetation type was tabulated into two levels (<10% and >10% of each ecoregion) to simplify interpretation. The number of vegetation types that fell into these categories for Bailey and Omernik ecoregions are shown in Tables 4 and 5.

Over 59% of the total mapped occurrences of Level I vegetation cover types in the Bailey ecoregions occupied less than 20% of the ecoregion area. Just under 13% had >80% of their total area within a given ecoregion. This pattern was observed in all ecoregions except the
### Table 2
Number of vegetation types within three classification levels, with <20% and >80% of the total type area occurring in Bailey ecoregions.

<table>
<thead>
<tr>
<th>Ecoregion code</th>
<th>Level I classification Fine-scale vegetation</th>
<th>Level II classification Mid-scale vegetation</th>
<th>Level III classification Coarse-scale vegetation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td># Types</td>
<td>Number &lt;20%</td>
<td>Number &gt;80%</td>
</tr>
<tr>
<td>M242A</td>
<td>27</td>
<td>17</td>
<td>2</td>
</tr>
<tr>
<td>M242B</td>
<td>72</td>
<td>45</td>
<td>6</td>
</tr>
<tr>
<td>M261D</td>
<td>37</td>
<td>26</td>
<td>5</td>
</tr>
<tr>
<td>242A</td>
<td>25</td>
<td>14</td>
<td>1</td>
</tr>
<tr>
<td>M333B</td>
<td>35</td>
<td>20</td>
<td>0</td>
</tr>
<tr>
<td>M332A</td>
<td>62</td>
<td>38</td>
<td>3</td>
</tr>
<tr>
<td>242</td>
<td>70</td>
<td>22</td>
<td>30</td>
</tr>
<tr>
<td>M331D</td>
<td>14</td>
<td>12</td>
<td>0</td>
</tr>
<tr>
<td>331A</td>
<td>24</td>
<td>22</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>366</td>
<td>216</td>
<td>47</td>
</tr>
<tr>
<td>%</td>
<td>59</td>
<td>13</td>
<td></td>
</tr>
</tbody>
</table>

### Table 3
Number of vegetation types, within three classification levels, with <20% and >80% of the total area occurring in Omernik ecoregions.

<table>
<thead>
<tr>
<th>Ecoregion code</th>
<th>Level I classification Fine-scale vegetation</th>
<th>Level II classification Mid-scale vegetation</th>
<th>Level III classification Coarse-scale vegetation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td># Types</td>
<td>Number &lt;20%</td>
<td>Number &gt;80%</td>
</tr>
<tr>
<td>1</td>
<td>29</td>
<td>18</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>15</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>15</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>36</td>
<td>22</td>
<td>1</td>
</tr>
<tr>
<td>9</td>
<td>55</td>
<td>45</td>
<td>2</td>
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<tr>
<td>10</td>
<td>41</td>
<td>28</td>
<td>3</td>
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<tr>
<td>11</td>
<td>48</td>
<td>38</td>
<td>1</td>
</tr>
<tr>
<td>12</td>
<td>59</td>
<td>21</td>
<td>18</td>
</tr>
<tr>
<td>15</td>
<td>44</td>
<td>22</td>
<td>7</td>
</tr>
<tr>
<td>77</td>
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<td>1</td>
</tr>
<tr>
<td>78</td>
<td>21</td>
<td>14</td>
<td>3</td>
</tr>
<tr>
<td>Total</td>
<td>397</td>
<td>254</td>
<td>40</td>
</tr>
<tr>
<td>%</td>
<td>64</td>
<td>10</td>
<td></td>
</tr>
</tbody>
</table>

### Table 4
Number of vegetation types within three classification levels that occupy <10% and >10% of the area of each Bailey ecoregion.

<table>
<thead>
<tr>
<th>Ecoregion code</th>
<th>Level I classification</th>
<th>Level II classification</th>
<th>Level III classification</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td># Types</td>
<td>Number types in &lt;10% area</td>
<td>Number types in &gt;10% area</td>
</tr>
<tr>
<td>M242A</td>
<td>27</td>
<td>24</td>
<td>3</td>
</tr>
<tr>
<td>M242B</td>
<td>72</td>
<td>70</td>
<td>2</td>
</tr>
<tr>
<td>M261D</td>
<td>37</td>
<td>35</td>
<td>2</td>
</tr>
<tr>
<td>242A</td>
<td>25</td>
<td>22</td>
<td>3</td>
</tr>
<tr>
<td>M333B</td>
<td>35</td>
<td>35</td>
<td>0</td>
</tr>
<tr>
<td>M332A</td>
<td>62</td>
<td>60</td>
<td>2</td>
</tr>
<tr>
<td>242</td>
<td>70</td>
<td>69</td>
<td>1</td>
</tr>
<tr>
<td>M331D</td>
<td>14</td>
<td>10</td>
<td>4</td>
</tr>
<tr>
<td>331A</td>
<td>24</td>
<td>23</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>366</td>
<td>348</td>
<td>18</td>
</tr>
<tr>
<td>%</td>
<td>95</td>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>
Intermountain Semi-desert area (242) where 43% of the types fell in the latter category and 31% of the vegetation types occupied less than 20% of the ecoregion area. Excluding this one ecoregion, only 5% of the mapped occurrences occupied more than 80% of the given ecoregions. This same pattern held true when the higher levels of classification were analyzed (62% and 10%, and 72% and 2% respectively at Level II and Level III).

In the Omernik ecoregions, almost 64% of the total mapped occurrences of vegetation types at Level I occupied less than 20% of the ecoregion area. Whereas 10% of the types had >80% of their total area within a given ecoregion. As with the above analysis, there was one exception, the Snake River Basin (12), where 31% of the types fell in the latter category and 36% of the vegetation types occupied less than 20% of the ecoregion area. This ecoregion is roughly equivalent to Bailey’s Intermountain Semi-desert ecoregion (Table 1). Excluding this ecoregion, only 6% of the mapped occurrences occupied more than 80% of the given ecoregion. Again, as with the above analysis, this same pattern held true when the higher levels of classification were analyzed (63% and 3%, and 81% and 7% respectively at Level II and Level III).

Over 95% of the total vegetation types mapped in the Bailey ecoregions at Level I occupied <10% of the area of the ecoregion. No types occupied more than 60% of the area of a given ecoregion. This pattern held for all ecoregions and for all levels of classification. Similarly, over 95% of the total vegetation types mapped in the Omernik ecoregions at Level I occupied <10% of the area of the ecoregion. No types occupied more than 55% of the area of a given ecoregion. This pattern again held for all ecoregions and for all levels of classification.

6. Discussion

The results of our analyses are remarkably similar for the two ecoregion classifications. This is surprising considering that the two classifications are by no means identical, and in the case of Great Plains Palouse (331A) and Columbia Plateau (10) or Middle Rocky Mountains (M333B) and Blue Mountains (11) they differ markedly in location. We calculated the proportion of a given vegetation type within an ecoregion to examine the fidelity between cover type and ecoregion boundary.
For both ecoregion delineations and for all three vegetation classifications, there was essentially no congruence. Most cover types had a small proportion of their total area in a given ecoregion (<20%), and as a result they occupied several different ecoregions. There was thus no support for the hypothesis that the boundaries of ecoregions would approximate the boundaries of the vegetation types.

As a result of the first analysis we looked at the proportion of an ecoregion occupied by given vegetation types. This would tell us if one or more vegetation types dominated an ecoregion and thus might provide a meaningful definition to its boundaries. This was not the case in either ecoregion system or at any level of vegetation classification. The results, again remarkably consistent among the two ecoregion classifications, showed virtually all mapped vegetation types occupied <10% of a given ecoregion, and no one type or types dominated any ecoregion. In almost all cases where a high proportion of a vegetation type fell within a particular ecoregion, it still occupied a small proportion of the total area of the ecoregion. For example, eight types had 100% of their total area within Omernik’s Snake River ecoregion (12), but together they occupied only 8% of the area of the ecoregion. Similarly, 13 types had >95% of their area in Bailey’s Intermountain Semi-desert ecoregion (242), but they cumulatively occupied only 4% of the area.

Our results show that the patterns of existing vegetation mapped at varying levels of resolution do not correspond to the boundaries of the ecoregions we analyzed. We cannot extrapolate beyond the ecoregions of the north-west. Both ecoregion delineations were based, at least in part, on potential vegetation mapped by Kuchler (1964) not existing vegetation as we mapped it. Kuchler’s map is at a scale of 1:7500000, comparable to the ecoregion maps but much coarser than our existing vegetation maps. We do not believe at this stage, however, that the lack of congruence can be solely attributed to scale differences. Kuchler’s map is also quite detailed in the three-state region we studied, identifying 17 different types of potential vegetation. This compares favorably with the number of types mapped at our formation level. We intend in the future to compare our map of existing vegetation with that of Kuchler. However, that was not the object of this paper.

In reviewing this paper, Bailey (pers. comm.) commented that meaningful comparisons of vegetation differences across ecoregions can only be made if atypical vegetation types are eliminated from the analysis. We agree and do not consider any of the vegetation types used in this analysis to be atypical (Jennings, 1993). He further commented that the low correspondence between vegetation and ecoregion boundaries may be that the criteria used to classify the vegetation types were applied uniformly over the area without considering compensating factors, e.g. soil conditions may modify the apparent effects of climate. In fact, the criteria used to classify GAP vegetation maps are based largely on the interpretation of digital imagery and aerial photos, but also incorporated elements such as elevation, slope, and aspect which should, in part, take into account compensatory factors. We further recognize that one of the factors used in Omernik’s ecoregion designation was land-use pattern and that this could influence the degree of congruence between ecoregion and vegetation boundaries. However, this was not a heavily weighted criterion and we also excluded existing agricultural lands from our analyses.

We hypothesized that the level of congruence of vegetation patterns with individual ecoregions would increase as the level of vegetation classification became more general. We found the opposite. The proportion of the total types within a given ecoregion was the lowest at the highest level of classification (Level III). In fact at this level of classification, most of the types were, on the average, found in each ecoregion (76% for Bailey, 75% for Omernik). Conversely, at Level I, 34% and 31% respectively of the types were, on the average, found in each ecoregion.

We had expected our analyses to show a different picture and were surprised at the results. We do not argue that ecoregion boundaries should be exactly coincident with boundaries of vegetation cover types. However, since vegetation plays a dominant role in influencing occupancy by vertebrate and invertebrate species (Edwards et al., 1996) some congruence is desirable if ecoregions are to be used as a conservation planning tool.

7. Implications for conservation programmes

The issue we raised was whether the ecoregion scale of analysis is both useful and appropriate. We fully recognize that the matter of utility is contingent on the question being asked. The ecoregion has been used as a primary level of classification in examining where to site new national parks (Wright et al., 1994) and where to designate additional wilderness areas (Merrill et al., 1995) in Idaho. Likewise the Nature Conservancy, a private non-profit land conservation organization in the US has proposed the use of Bailey’s (1995) province level ecoregions as a guide for its land acquisition and conservation programs (Williamson, 1996). The results presented here may raise some questions over the utility of this approach and in fact have caused the senior author (R. Gerald Wright) to rethink recommendations made in an earlier paper that “The ecoregion is the most appropriate unit of spatial analysis... to define gaps in the protection of biological resources...”. (Wright et al., 1994, p. 212). In fact, based
on the results presented here, ecoregions may not be the most appropriate level of stratification for developing land protection plans, as least in the north-western states.

Acknowledgements

This work was supported by the GAP Analysis Program of the US National Biological Service. J. Michael Scott, Mike Jennings, Robert A. Bailey, and three anonymous reviewers provided thoughtful reviews and helpful suggestions on earlier versions of the manuscript.

References


