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A national approach for mapping and quantifying habitat-based biodiversity metrics across multiple spatial scales

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ABSTRACT

Ecosystem services, i.e., services provided to humans from ecological systems have become a key issue of this century in resource management, conservation planning, and environmental decision analysis. Mapping and quantifying ecosystem services have become strategic national interests for integrating ecology with economics to help understand the effects of human policies and actions and their subsequent impacts on both ecosystem function and human well-being. Some aspects of biodiversity are valued by humans in varied ways, and thus are important to include in any assessment that seeks to identify and quantify the benefits of ecosystems to humans. Some biodiversity metrics clearly reflect ecosystem services (e.g., abundance and diversity of harvestable species), whereas others may reflect indirect and difficult to quantify relationships to services (e.g., relevance of species diversity to ecosystem resilience, cultural value of native species). Wildlife habitat has been modeled at broad spatial scales and can be used to map a number of biodiversity metrics. In the present study, we present an approach that (1) identifies mappable biodiversity metrics that are related to ecosystem services or other stakeholder concerns, (2) maps these metrics throughout a large multi-state region, and (3) compares the metric values obtained for selected watersheds within the regional context. The broader focus is to design a flexible approach for mapping metrics to produce a national-scale product. We map 20 biodiversity metrics reflecting ecosystem services or other aspects of biodiversity for all vertebrate species except fish. Metrics include species richness for all vertebrates, specific taxon groups, harvestable species (i.e., upland game, waterfowl, furbearers, small game, and big game), threatened and endangered species, and state-designated species of greatest conservation need, and also a metric for ecosystem (i.e., land cover) diversity. The project is being conducted at multiple scales in a phased approach, starting with place-based studies, then multi-state regional areas, culminating into a national-level atlas. As an example of this incremental approach, we provide results for the southwestern United States (i.e., states of Arizona, New Mexico, Nevada, Utah, and Colorado) and portions of two watersheds within this region: the San Pedro River (Arizona) and Rio Grande River (New Mexico). Geographic patterns differed considerably among metrics across the southwestern study area, but metric values for the two watershed study areas were generally greater than those for the southwestern region as a whole.

1. Introduction

The discussion for formal maintenance and conservation of biological diversity (biodiversity) was first organized in a cohesive fashion by the United Nations Environment Programme in 1992 at the Rio Earth Summit. A year following, 168 countries signed the Convention of Biological Diversity (CBD) to protect and ensure conservation and sustainable use of biodiversity. The CBD recognized that the Earth's biological resources are essential to human well-being and economic and social development and thus constitute a global asset of crucial value to both present and future

Abbreviations: BIP, Biodiversity Indicators Partnership; CBD, Convention of Biological Diversity; IPBES, Intergovernmental Science Policy Platform on Biodiversity and Ecosystem Services; GEO BON, Group on Earth Observatory Biodiversity Observation Network; MEA, Millennium Ecosystem Assessment; GAP, Gap Analysis Program; SGCN, Species of Greatest Conservation Need; ICLUS, Integrated Climate and Land Use Scenarios; IPCC, Intergovernmental Panel on Climate Change; SWReGAP, Southwest Regional Gap Analysis Project; T&E, threatened and endangered; TEEB, The Economics of Ecosystems and Biodiversity; UNEP-WCMC, United Nations Environment Programme World Conservation Monitoring Centre; US, United States.

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generations (Secretariat of the Convention on Biological Diversity, 2005). More recently the United Nations Secretary-General initiated and completed the Millennium Ecosystem Assessment to assess the consequences of ecosystem change for human well-being and the scientific basis for action needed to enhance the conservation and sustainable use of ecosystems. The assessment provided a reaffirmation that sustainable societies are dependent on the goods and services provided by ecosystems, including clean air and water, productive soils, and the production of food and fiber, and more importantly it propagated the ecosystem services paradigm upon which to assess and value biotic resources throughout the world (Millennium Ecosystem Assessment, 2005; Farber et al., 2006). Ecosystem services have been defined in a variety of ways; however, in the end they reflect the basic outputs of ecological function or process that directly or indirectly contribute to human well-being, economy, health, and a sense of security. The central premise of the ecosystem services framework is that all forms of life on earth (i.e., biodiversity) provide the core benefits that humans derive from their environment and thus are responsible for sustaining human culture throughout the world. Thus, while managing for biodiversity is not a substitute for identifying key ecosystem service providers, managing for biodiversity may be a workable way to achieve an acceptable balance among the sometimes competing demands for various ecosystem services (Duffy, 2009).

Following the Millennium Ecosystem Assessment, an Intergovernmental Science Policy Platform on Biodiversity and Ecosystem Services (IPBES) was formed to conduct periodic assessments of biodiversity and ecosystem services at global, regional, and sub-regional scales. The purpose is to address policy relevant questions, identify emerging issues and research gaps, and identify consistent tools and methodologies that can be operationalized on various scales, regardless of geography (IPBES, 2011). A key part of IPBES is a call for the development of scalable indicators and metrics that could provide thematic assessments and monitor status and trends of biodiversity and ecosystem services across multiple geographies at multiple scales. Other existing international biodiversity initiatives and recently created communities of practice, such as DIVERSITAS (Larigauderie et al., 2012), The Economics of Ecosystems and Biodiversity (TEEB, 2010), and Group on Earth Observatory Biodiversity Observation Network (GEO BON, 2010a,b) have engaged in similar calls for action.

Within the US, a national atlas (Atlas) of datasets that pertain to ecosystem services is currently under development by US Environmental Protection Agency, US Geological Survey, and other partner organizations. Communities and other decision-making bodies do not have adequate spatially explicit information to fully account for costs, benefits, and trade-offs of ecosystem services. The Atlas is being developed to help fill this information gap. This national effort will include measures of ecosystem services including clean air and water; water supply and timing; flood protection; climate stabilization; food, fiber, and fuels; and cultural, recreational, and esthetic amenities. The Atlas will also include metrics of biodiversity. Some biodiversity metrics clearly reflect ecosystem services (e.g., abundance and diversity of harvestable species, species richness for watchable wildlife). Other metrics, however, may reflect indirect and difficult to quantify relationships to services (e.g., relevance of species diversity to ecosystem resilience, cultural value of native species), that nevertheless have substantial stakeholder interest (e.g., abundance and diversity of threatened and endangered species; total species richness). The Atlas will be an online decision support tool that allows users to view and analyze the geographical distribution of the supply and demand for ecosystem services, and the geographic distribution of biodiversity metrics, as well as drivers of change. This paper addresses the biodiversity metrics.

Recent approaches to conservation planning have identified land acquisition and conservation for wildlife in response to the decline of biological diversity (Wilson and Peter, 1988; Wilson, 1992; Langner and Flather, 1994; Meffe and Carroll, 1994; Noss et al., 1995), including adaptive management (Ridder, 2008). Coupling biodiversity perspectives with geographical approaches to conservation planning has existed for many years (Burley, 1988; Goldman and Tallis, 2009). This concept was first applied to locating management areas for sensitive Hawaiian birds (Scott et al., 1986) and more recently has been developed broadly for biodiversity conservation purposes (i.e., US Geological Survey Gap Analysis Program) in the conterminous United States (Scott et al., 1993, 1996; Prior-Magee et al., 2007). Within the Gap Analysis Program (GAP), habitat suitability for terrestrial vertebrates is used to identify gaps in long-term maintenance of elements of biodiversity. The analysis is an approximation of the geographic distribution of natural diversity and the degree to which diverse areas are managed for their natural values to endure. The baseline datasets within GAP, particularly the individual species habitat models, are well-suited for use with the concept of ecosystem services and biodiversity because they are readily available, can be assembled in broad functional groups that represent ecosystem services or biodiversity metrics of concern, and they can be used at broad multiple scales.

Regional GAP efforts have progressed to the point that the current emphasis is to finalize national datasets and provide the ability to conduct analysis at local, regional, and national scales (Aycrigg et al., 2011). These efforts provide contemporary methods and data to evaluate the distribution of biotic elements and their conservation status in an ecoregional context without concern for political boundaries, and thus are now focused on providing policy-relevant tools and methodologies that can be easily assimilated into the environmental decision-making processes, regardless of scale or institutional responsibility (see Boykin et al., 2011).

The objectives of the ongoing project reported herein were: (1) to identify mappable biodiversity metrics that are related to ecosystem services (e.g., harvestable species representing recreation and subsistence value) or other stakeholder concerns; (2) to map terrestrial biodiversity metrics throughout the conterminous United States beginning with selected regions such as the southwest; and (3) to compare metric values obtained for selected areas of interest at various spatial scales, i.e., watersheds, regions, and the entire conterminous US. Herein, we illustrate progress to date by comparing values for 20 biodiversity metrics for three areas: the southwestern US (5 states) and two areas within this region.

2. Materials and methods

The three study areas were the southwestern US comprising the states of Arizona, Colorado, Nevada, New Mexico, and Utah, and portions of two watersheds within this region along the San Pedro River (Arizona) and the Rio Grande River (New Mexico; Fig. 1). The southwestern US was selected because the Southwest Regional Gap Analysis Project (SWReGAP; Prior-Magee et al., 2007) provided datasets for land cover and predicted suitable habitat models for 817 terrestrial vertebrate species for this region. The other two study areas were selected because they are known areas of high biodiversity and ecological importance (Simpson, 1964; USFWS, 1978; Finch and Tainter, 1995).

The southwestern US (hereafter, Southwest) study area represents approximately 20% of the conterminous United States, encompassing 1,389,000 km^2. SWReGAP mapped 125 land cover types within this region consisting of 109 ecological systems and 16 anthropogenic land cover types (Lowry et al., 2007b). Comer