ASSESSING GEOLOGIC ECOSYSTEM SERVICES IN THE BLACK HILLS OF SOUTH DAKOTA AND WYOMING: A PRELIMINARY APPROACH

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Introduction

The goals of this study are as follows:

- Explore different methods of cataloging geologic ecosystem services (CICES vs. Gray et al., 2013)
- Catalog geologic ecosystem services
- Assess the vulnerability of geodiversity elements and their associated geologic ecosystem services
- Assess the role of geodiversity in producing geologic ecosystem services

Figure 1: Proterozoic granite and metamorphic rocks of Mount Rushmore National Memorial

The CICES Categorization

- The U.N. Millennium Ecosystem Assessment (MA) was a groundbreaking work for the field of ecosystem services that grouped services into four categories: cultural, provisioning, regulating, and supporting
- The Common International Classification of Ecosystem Services (CICES) builds on the MA, and seeks to standardize the classification of ecosystem services (Haines-Young and Potschin, 2018)
- CICES is a hierarchical classification framework that increases in specificity and exclusivity as it moves from "Section" through to "Class" and "Class Type"
- Services are provided a four-number code which corresponds to a specific section, division, group, and class
  - The class type category is a textual category that allows for further distinction
- CICES V5.1 is the first version to include abiotic ecosystem services
  - Although there is overlap between the two, abiotic ecosystem services are distinct from geologic ecosystem services, as the latter excludes atmospheric and hydrologic processes

An example application of the CICES framework to the geologic ecosystem services identified in the Black Hills is as follows:

"Mineral matter" was a service identified in the Black Hills (see Table 1). Mineral matter collected in the Black Hills can be used for construction, jewelry, or bullion, and can be categorized as such:

Section: Provisioning (Abiotic)
Division: Non-aqueous natural abiotic ecosystem outputs
Group: Mineral substances used for nutrition, materials or energy
Class: Mineral substances used for material purposes
The resulting code for this service would be: 4.3.1.2

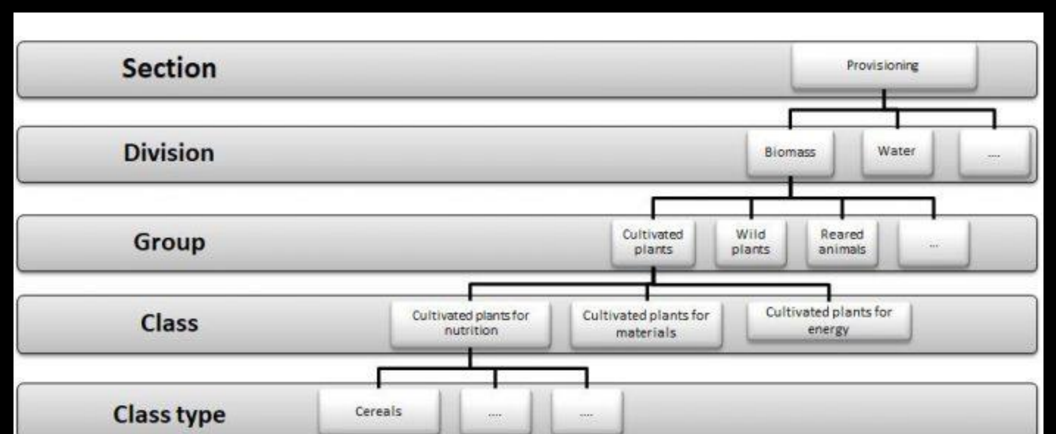

Figure 2: Hierarchical structure of CICES V5.1 from Haines-Young and Potschin, 2018.

Catalog of Geologic Ecosystem Services

MA Category	Geologic Ecosystem Service	Service Description	Contribution and benefits from geodiversity features and/or processes
Cultural	**Artistic Value**	The value that is derived from the landscape which serves as a source of inspiration for the artist.	Non-Use: The landscape character of the Black Hills inspires many forms of art, including painting, drawing, poetry, literature, and architecture.
	Education	The potential to learn from natural processes and ecosystems. This learning can take place in the classroom or outdoors.	Direct: The Black Hills region is characterized by lithologic diversity, complex structure, and geomorphological variance, making it an outstanding area to study from an earth sciences perspective.
			Indirect: Due to the geodiversity of the Black Hills, this region presents a unique study area from a biological perspective, considering the variety of flora and fauna within the Black Hills, and the difference between Black Hills flora and fauna and that of the surrounding Great Plains.
	Culturally Significant Sites	These are sites which may be important for their instillation of feelings of patriotism, spiritual connection, or represent historically significant locations.	Non-Use: The Black Hills region has been referred to as "the heart of everything that is" by local Native American tribes. There are also individual sites throughout the Black Hills which are of cultural importance. These sites include Mount Rushmore National Memorial, Devil's Tower National Monument, Wind Cave National Park, Bear Butte National Monument, and the Homestake Mine (which houses the Sanford Underground Research Facility).
Provisioning	**Mineral Matter**	Minerals benefit society in a variety of ways, due to differences in chemical composition, which influences hardness, coloration, and structure.	Direct: Mineral matter mined in the Black Hills can be used for construction (limestone for cement), ornamentation (precious gems in jewelry or dimension stones on buildings), or bullion (silver and gold for coinage).
	Water	Geology serves as the fabric for aquifers and controls the formation of surface water features. Soil qualities, subsurface geology, and topography influence the storage potential for surface water, while qualities such as chemical composition, porosity, and permeability influence an aquifer's storage and yield capability.	Direct: Outcrops of limestone in the Black Hills act as recharge zones for underground aquifers, which serve as significant sources of groundwater for western South Dakota. Geology also exerts a control on where surface water— rivers, lakes, and reservoirs— are found. Ground and surface water are used in many ways, such as municipal drinking water, water for plant irrigation, or industrial processes.
	Fiber	Fibrous material, such as wood, cotton, hemp, or grasses, used to construct clothing or utilities (e.g., baskets, ropes, roofing).	Indirect: Nutrients provided to the soil by weathered mineral matter.
Regulating	**Water Quality**	As water percolates through the subsurface, it interacts with the soil through physical and chemical processes, which alter the composition of the fluid.	Direct: Rock, surficial deposits, and soil act as natural filters which can remove particulate matter, organic waste, and other pollutants before it reaches groundwater.
			Indirect: Parent material heavily influences the type of soil that will form when a rock is weathered; furthermore, soil type controls the plant communities found in an area. Therefore, soils' control on plant communities influences the potential for groundwater to be remediated by biota.
	Climate	Topography exerts a control on temperature and precipitation in a region and explains the distribution of these climatic variables.	Direct: Rain-shadow effect on mountain ranges influences the formation of certain biomes, and thus determines what types of ecosystems form.
	Pollination	Rock outcrops and soil type vary in their suitability for habitat by burrowing.	Indirect: Organisms which act as pollinators for ecosystems often nest in burrows.
Supporting	**Soil Formation**	The weathering of parent material and the rate of soil formation is a significant factor in providing a medium for plant growth and underpins the delivery of many important ecosystem services.	Direct: Various ecosystem services depend on soil as a source of nutrients (e.g., food, fuel, fiber).
	Habitat	Geology provides the physical environment, which is altered to become a suitable habitat for flora and fauna. Furthermore, geomorphological processes influence habitat type and condition.	Direct: Determines the flora and fauna found in an area, which influences the presence and integrity of other ecosystem services.
	Burial and Storage	Geologic formations and landforms can present locations suitable to water storage or the burial or disposal of different kinds of waste.	Direct: Economic benefits posed by the accessibility and suitability of an area for a specified purpose.

Table 1: Selected geologic ecosystem services identified in the Black Hills. The table was constructed using the framework exhibited in Gray et al., 2013. This framework lists the ecosystem service category, the service itself, a description of the service, and a description of how geodiversity features/processes contribute to the service.

Preliminary Vulnerability Assessment

Figure 3: Devil's Tower National Monument, an Eocene trachyte intrusion

- Assessing the vulnerability of geodiversity features and geologic ecosystem services is crucial to ensuring they are sustainably managed
- Vulnerability of geodiversity features is described using two indexes: resistance to destruction, and the resilience of the feature to recover from damage (Brooks, 2013)
- Resistance of the features was informed based on the geology, and perceived desire to maintain feature integrity; resistance was ranked from "none" to "high"
- Resilience of geodiversity features was informed based on the time required to reform the feature; geomorphic features (e.g., floodplains = medium resilience) vs. rock features (e.g., granite needles = no resilience)
- Vulnerability of geologic ecosystem services was informed based on the scale at which the services operate, how the service is enjoyed, and the ability of the service to recover on a human timescales
  - Artistic value is a non-use service (vulnerability = low)
  - Mineral matter forms via geologic processes, taking thousands to millions of years (vulnerability = high)
  - The ability of geologic material to improve water quality is moderately at risk to human interference (vulnerability = medium)
  - Large-scale soil forming processes are not generally vulnerable; however, climate change may pose a threat to these processes (vulnerability = medium)

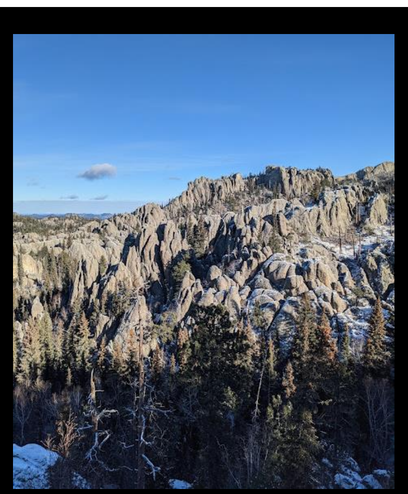

Figure 4: Weathered "needles" of Proterozoic granite, Black Hills National Forest

Geodiversity of the Black Hills

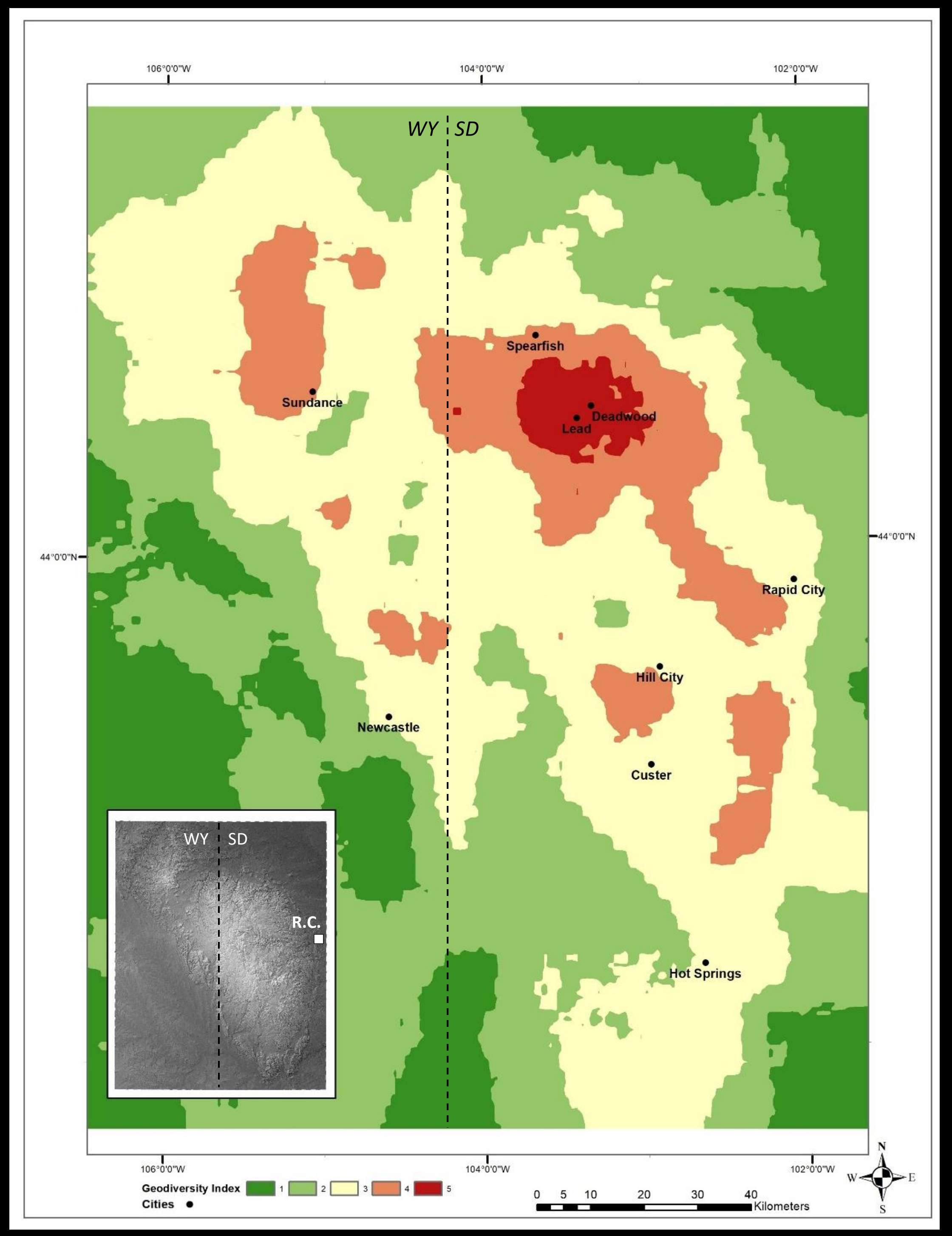

Figure 5: Geodiversity of the Black Hills. Values are ranked 1 (low) to 5 (high). Methodology adapted from Araujo and Pereira, 2018. This map considers the influence of lithology, pedology, geomorphology, and water resources.

- Geodiversity has arisen as the abiotic counterpart to biodiversity, and draws attention to the multiplicity of geologic structures, materials, and processes
- Understanding how geodiversity and geologic ecosystem services are spatially correlated can be used to inform the understanding of the relationship between these two metrics

References

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