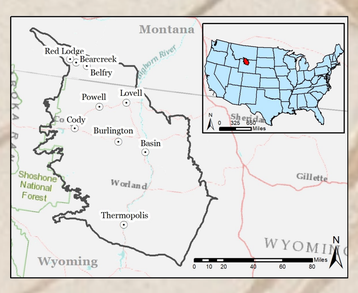
Digging for Dinosaurs:

Identifying Fossiliferous Areas in the Bighorn Basin

Introduction

The Bighorn Basin, located across Montana and Wyoming, is a geologic region that contains some of the richest fossil evidence in the world. With rocks as old as 2.5 billion years and almost every geologic time period accounted for, it is not surprising that geologists and paleontologists alike have realized the Basin's potential to reconstruct past environments and ecology. In particular, the Dinosauria—famous names like *Stegosaurus*, *Triceratops*, and *T. rex*—are well-represented and offer important insights into Earth's ancient history and responses to climate change.

Considering the Bighorn Basin is roughly the area of New Jersey, predetermining areas for dinosaur fossil excavations is essential to conserve both time and resources (Johnson & Clyde 2016). Traditionally, paleontologists have consulted geologic maps, performed extensive field surveys, or consulted satellite imagery to determine fossiliferous areas; however, these methods can be greatly improved with the use of GIS spatial analyses in advance (Emerson 2015).



This project seeks to identify the most suitable locations for future paleontological expeditions in the Bighorn Basin, with specific focus on the Mesozoic, the "age of the dinosaurs". Subsequent use of GIS within the study of paleontology will result in more productive field surveys and an increase in fossil discoveries, thereby improving both public and academic understandings of dinosaurs, prehistoric life, and deep time.

Methods

To identify fossiliferous areas, five suitability factors were extrapolated from peer-reviewed literature: geology elevation, land cover, location of existing fossil sites, and accessibility. Factors were given values of 1 (least suitable) through 4 (most suitable), with the exception of geology (0 or 1 to reflect correct rock age/type or not). Final scores for each factor were combined for an unweighted analysis. Factors were then assigned weights based on importance for fossil discovery and added again.

Suitability Score	Geology (Rock Type/Age)	Elevation	Land Cover	Accessibility (Transportation)	Proximity to Existing Fossil Sites
Weight	40%	30%	30%	5%	5%
1-Least Suitable	Igneous or Metamorphic; >Paleozoic, Paleozoic, or Cenozoic	1300-1500 m	Water, ice, snow, wetlands, developed land, cultivated crops	>3 miles	>15 miles
2	—	1100-1300 m	Forest	2-3 miles	10-15 miles
3	—	1500-1700 m	Pasture or barren	1-2 miles	5-10 miles
4-Most suitable	Sedimentary; Mesozoic	>1700 m	Grassland or shrubland	0-1 mile	<5 miles

The majority of data was obtained from the United States Geological Survey, with supplemental sources from MT State GIS, the WY Geospatial Hub, the Paleobiology Database, the National Land Cover Database, ArcGIS Hub, and Tufts GIS.

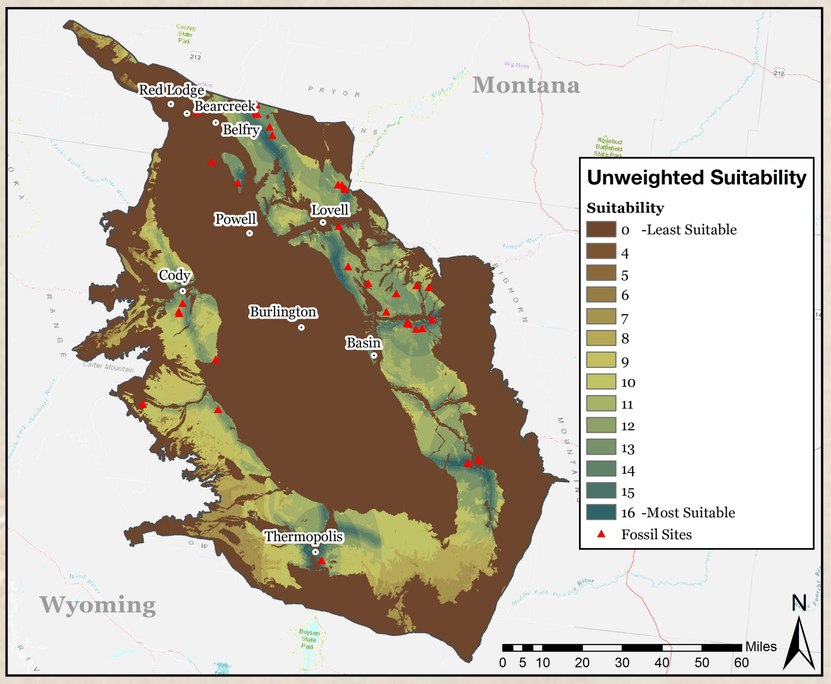
Suitability Analysis

Two final maps were created using the Map Algebra tool for raster data. Values for each cell (size of 200) were independently added from the five suitability maps shown below to output cells with values 0-16 (for the unweighted map, right) or 4-20 (for the weighted map, below).

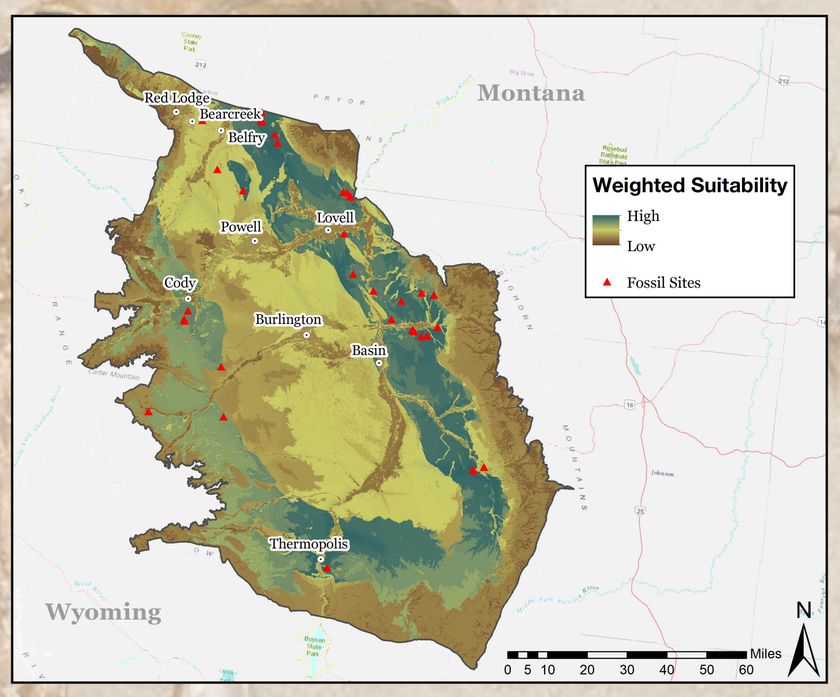
For the unweighted map, reclassification values for elevation, land cover, accessibility, and fossil sites were summed and then multiplied by the geology map values. As a result, any areas without sedimentary or Mesozoic rocks were given a value of zero. The map reveals the most suitable areas to be contained only within exposures of sedimentary, Mesozoic-aged rocks. Areas in the northeast, particularly in Montana and within the northeast region of Basin, have high suitability values and clustering of previous sites. In particular, locations near the city of Thermopolis, Wyoming and areas to the southeast have comparatively fewer sites but high suitability indices and could reflect possible starting points for future paleontological surveys.

To account for the fossil sites that are located outside of the sedimentary, Mesozoic-aged rock zones in the unweighted map, a weighted map was also generated. Weighted values for each of the five suitability factors are listed below. Geology was multiplied by 4 to reflect equal values across all factors. The potentiality of finding fossils across the eastern region of the Basin, particularly to the southeast and near Thermopolis, is again supported. The two fossil sites outside the sedimentary areas are found to be in intermediate suitability areas, perhaps small outcrops that are not accounted for, using the weighted map.

Unweighted Suitability for Fossiliferous Areas in the Bighorn Basin



Weighted Suitability for Fossiliferous Areas in the Bighorn Basin



Conclusion

The application of GIS to paleontology represents an underapplied yet powerful technique for future geological research. Targeting relatively unexplored areas (such as northeast of Thermopolis) in addition to areas of past productivity (between Lovell and Basin, Wyoming) shown by this analysis will not only improve future paleontological field work but also consequential public engagement and interest in the significance of dinosaurs, the natural sciences, and understanding our planet.

Future analyses should attempt to apply as many suitability factors as possible to narrow the search radius. Specifically, because not all fossil locations are reported due to the threat of fossil poaching, a more comprehensive compilation of known sites is needed. Information on depositional environment at the time of the animal's death, indicating fossilization potential, would also improve the present analysis.

References

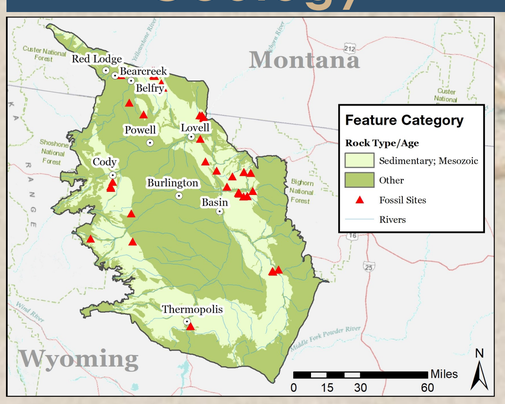
Emerson, Charles et al. "An Object Oriented Approach to Extracting Productive Fossil Localities from Remotely Sensed Imagery". *Remote Sens.* 7 (2015): 16555-16570.

Johnson, Kirk, and Will Clyde. "Hunting Lost Worlds in Wyoming's Bighorn Basin". Smithsonian Magazine, https://www.smithsonianmag.com/travel/hunting-lost-worlds-wyomings-bighorn-basin-180959338/ .

Oheim, Katheryn B. "Fossil site production using geographic information systems (GIS) and suitability analysis: The Two Medicine Formation, MT, a test case". *Paleogeography, Paleoclimatography, and Paleoecology* 251 (2007): 354-365.

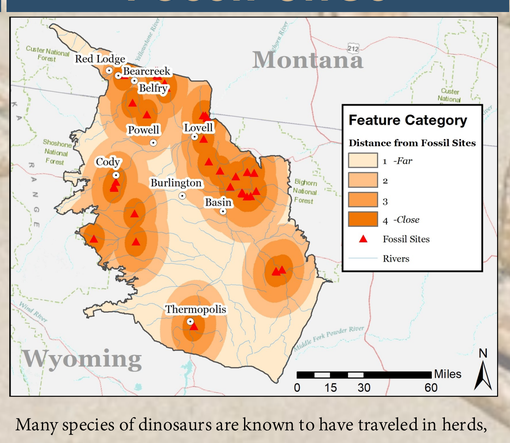
Ostrom, John H. "Were Some Dinosaurs Gregarious?" *Paleogeography, Paleoclimatography, and Paleoecology* 11 (1972): 287-301.

Geology



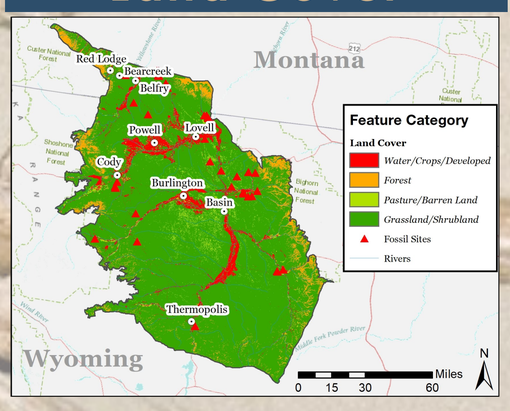
Fossilization will occur only if certain geological conditions are met. Suitable context for dinosaur fossils includes correct rock age (the Mesozoic, approximately 252-65 million years ago) and classification (sedimentary, which allows for rapid burial). After United States geology data was clipped to the Basin shapefile, correct rocks were selected from the geology layer and given a new attribute value of either 1 (sedimentary and Mesozoic) or 0 (other). The Polygon to Raster tool was then used to transform the map into a raster for later analysis. Because rock type is the key factor in determining locations of dinosaur fossils, it was given a weight of 0.4.

Fossil Sites



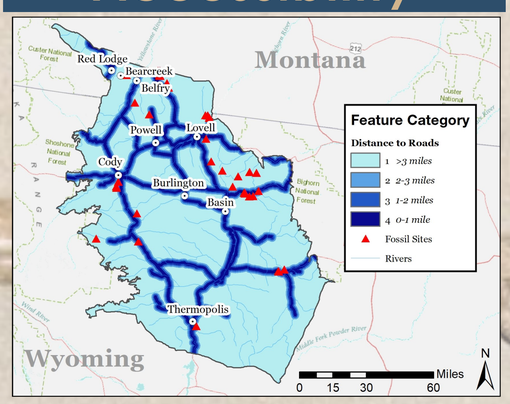
Many species of dinosaurs are known to have traveled in herds, so geological outcrops can expose the bones of many individuals at a time (Ostrom 1972). Therefore, previous dinosaur fossil sites were also considered potential indicators for future discoveries. Fossil localities in the United States were clipped to the study area using the Basin shapefile. Euclidean distance analyses were then performed, and resulting values were reclassified. A value of 4 indicates close distances to sites (roughly a <5 mile radius), and 1 indicates far distances (>15 miles). Because the radius is large and past sites are by no means a definitive criteria for more fossil material, known fossil locality was given a weight of 0.05.

Land Cover



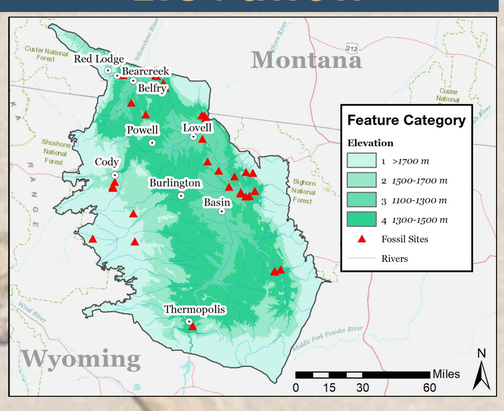
Land cover serves as a measure of both fossil potential and the reasonability of field expeditions. Rasters from the National Land Cover Database were clipped using the Basin input shapefile. Resulting land features were assigned values of 1-4; herbaceous grassland and shrubland received the highest values due to the probability of these areas being undeveloped, spacious, and possessing an abundance of sedimentary rocks. Areas with water, developed land, cultivated crops, or wetlands were given the lowest values because the likelihood of fossil discovery in regions with human disturbance or bodies of water is relatively low to none. Land cover is highly predictive of environments required for fossilization; its weighted value was determined to be 0.3.

Accessibility



General accessibility was defined as the distance of potential areas to roads. Transportation data from Montana and Wyoming GIS were clipped to the Basin shapefile and spatially analyzed using the Euclidean distance function. Classifications were roughly derived from the values in Oheim (2007). Increments of one mile were used to designate values of 1 to 4, with 4 being within one mile of transportation and 1 being farther than three miles. A limitation of this factor is that only major roads are represented despite minor and dirt roads often being used to access fossil sites. Therefore, accessibility was given a weight of only 0.05.

Elevation



Elevation is also an essential determinant of fossil suitability, as models can reveal the critical levels at which rock outcrops are exposed. Raster files based on 1x1 degree grids from the USGS National Elevation Dataset were mosaiced together and clipped to the Basin shapefile. Referencing Oheim (2007)'s analysis of the Two Medicine Formation, another Mesozoic area of study, elevation levels were reassigned with 1300-1500 m (4) as the most suitable, followed by 1100-1300 m (3), 1500-1700 m (2), and >1700 m (1). Similar to land data and geology, elevation estimates can narrow the area of study based on key exposure heights, so its weighted value was 0.3.

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Projection: USA Contiguous Albers Equal Area Conic USGS Version

Data Sources: USGS, MT State GIS, WY Geospatial Hub, the Paleobiology Database, ArcGIS Hub, Tufts GIS, and the National Land Cover Database

Photo Sources: The National Park Service, the Bighorn Basin Paleontological Institute, Tufts University, and Discover Magazine

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