This Preprint has been reviewed through PCI Paleontology

It is a revised version of the preprint stored at the following link: https://doi.org/10.31233/osf.io/fy43t

The Morrison Formation Sauropod Consensus: A freely accessible online spreadsheet of collected sauropod specimens, their housing institutions, contents, references, localities, and other potentially useful information

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Abstract

The Morrison Formation has been explored for dinosaurs for more than 150 years, often specifically for large sauropod skeletons curators wanted to mount as attractions in their museum exhibits around the world. Several long-term campaigns to the Jurassic West of the United States produced hundreds of specimens, ranging from isolated, fragmentary bones to nearly complete skeletons of these enormous herbivorous animals. Given the sheer number of specimens, keeping track of what is housed in which institution is paramount to study variability, taxonomy, and consequently geographic and temporal distribution of the various species and genera recognized from the Morrison Formation. In an attempt to facilitate these studies, we have compiled an online spreadsheet intended to combine all the available information on sauropod specimens from collection databases, published literature, and personal observations. These include lists of contents of the specimens, in what institution the material is housed, references mentioning, describing, figuring, providing measurements and/or 3D scans, locality data and stratigraphy, as well as other potentially useful data for research purposes. The spreadsheet is openly accessible, but editing is currently restricted to the authors of this study, in order to ensure high-quality data curation to keep the file as useful as possible.

Introduction

The Morrison Formation is one of the best-known Mesozoic terrestrial ecosystems, with thousands of vertebrate, invertebrate, and plant specimens recovered over more than 150 years of paleontological exploration (Gee et al., in press; Tschopp et al., in press; Chure et al., 2006; Foster, 2007; Whitlock et al., 2018). It therefore provides a unique study case where we can address questions regarding ecosystem structure and functioning. This study case is particularly interesting because of its surprisingly high diversity of megaherbivores, with potentially more than 20 species of sauropod dinosaurs, living alongside smaller, but still large herbivorous ornithischians, as well as other, small-sized herbivores (dinosaurs, but not only; Tschopp et al., in press, 2015; Whitlock et al., 2018). Studies concerning distribution of species through space and time of Morrison Formation deposition are both hampered and facilitated by the fact that specimens have been excavated or acquired by numerous institutions from around the world. This facilitates studies through easier access to specimens for researchers that are not in North America (one does not necessarily have to travel to the USA to study Morrison Formation sauropods, as there is often material housed in some institution close-by; Fig. 1). However, it also hampers study, because it is difficult to keep track of which specimen is housed where, and what institution may hold those specimens that would be paramount to study first-hand for a particular research question. First-hand study of material in collections is crucial for the understanding of morphological details, as well as the scoring of specimens into phylogenetic matrices, because small features on the bones, broken edges, or bilaterally asymmetric characters can often not be detected or identified in figures (Tschopp et al., 2018), but may be useful for phylogenetic inference (Tschopp and Upchurch, 2019) or functional morphology studies. Many institutions do have most of their collections searchable online, but rarely are there online resources that let you one to search multiple databases simultaneously. Although considerable efforts to facilitate and standardize these searches are now underway in most institutions, we are still far from simple online searches for that particular specimen one needs for his or her research. The Morrison Formation sauropod consensus is an attempt to facilitate such a search. It has been compiled over the past 10 years. Given the continued exploration, preparation, and study of material from the Morrison Formation, this spreadsheet will never be complete – however, with the combined efforts of several sauropod specialists working on the Morrison Formation, this curated spreadsheet will be a useful tool for future research on these enigmatic and popular animals. We hope that it might also inspire other efforts to compile and publish similar spreadsheets for different taxa, geological units, and geographic regions.

Methods

The spreadsheet has evolved over the last 10 years to include a number of columns with data that proved useful for selecting specimens for particular analyses and planning collection visits. It is available at the following link: https://docs.google.com/spreadsheets/d/1OazMLgm6rZe7SaNP3YexbqS9Vo-FsqFyFoJktcr2H8Q/edit?usp=sharing. The spreadsheet is open for anyone to view, comment, download, print, and copy the entire document or parts of it. The columns are: taxonomic identification, specimen number, contents, references (with subcategories for who only mentioned it, and who provided description, figures, measurements, or 3D scans), information on ontogeny, locality, stratigraphy, current repository, and any other potentially useful information. Below, we will explain in more detail what these columns contain and how they are organized.

Taxonomy

Taxonomic identification of the specimens is of course the first information that researchers generally look for. Here, we usually follow the latest taxonomic assessment based on a detailed study, where these exist. In many cases, particularly in incomplete fossils, there has never been a detailed, published scientific assessment of their taxonomy, in which case the identifications are based on the respective institutions' catalog entries. In other cases, taxonomy has changed over time. These changes are generally not recorded in this column, but in the column “further info” (see below).

Specimen Number

Other than taxonomy, specimen numbers should generally remain the same, as long as the institution does not change. Even if a specimen has been traded or sold to another institution, the original collection numbers are usually preserved with the specimens, and new catalog numbers could be added in the new institution. One such case is the holotype specimen of the diplodocid *Galeamopus hayi*, which was collected by the Carnegie Museum crew in 1902 and 1903, cataloged as CM 662, later traded to the Cleveland Museum of Natural History, where it got the number CMNH 10670, and again sold to the Houston Museum of Nature and Science, where it is currently mounted and cataloged as HMNS 175 (Tschopp et al., in press; McIntosh, 1981). We attempted to have every specimen in the list with its current, most recent catalog number, so in the case of the holotype of *G. hayi*, we used HMNS 175. The older specimen numbers are mentioned under “further info” (see below). There are also cases, where specimens got were renumbered while remaining in the same institution (e.g., the holotype scapulacoracoid of the diplodocid *Supersaurus*; Jensen 1985; Curtice & Stadtman 2001; Lovelace et al. 2007); we also recorded the old specimen numbers in the column “further info” here.

Contents

The contents of a specimen list the single individual bones preserved. This appears to be fairly straight forward, but complete information is not always available from collection databases, which sometimes only list “partial forelimb”, or “nearly complete specimen”. For some of these, we were able to add information after personally visiting collections and seeing the specimens first-hand. In most cases, however, we just had to copycopied the information from the collection databases. Hence, if somebody would need all the metacarpals from Morrison Formation sauropods for a particular study, specimens that preserve “forelimbs”, or a “manus” instead of “metacarpals” specifically would have to be searched for as well.

References

We intend to list every study that mentioned a particular specimen, be it in the text, in a figure, in a table, as an operational taxonomic unit in a phylogenetic matrix, or as comparative material. We then subdivide this information in the subcategories of references actually describing (parts of) the specimen, figuring it, providing measurements, and we mention references that produced 3D models of elements of the specimen.

Ontogeny

Body size and ontogenetic stage can be interesting traits to understand ecological and evolutionary aspects, such as community structure, age segregation, and body size evolution. Being such an important factor, it deserves its own column. We note general size (where reported from collection databases or publications), as well as assessments of Histological Ontogenetic Stages (HOS; see Klein and Sander, 2008), and other subdivisions proposed in the literature (e.g., H-MOS; Woodruff et al., 2017).

Further info

Comments, or information not covered in other columns, are mentioned here. These can include changes in taxonomic interpretation, old specimen numbers, the presence of tooth traces, if the specimen is a type, information on the preservation of the bone, association with other specimens, and other potentially useful information for research.

Locality

Locality information is obviously crucial for studies of temporal and spatial ranges of species and genera. However, ~~not in all cases~~ locality data ~~is~~ are not publicly available~~,~~ in all cases for a variety of reasons, including protection from fossil poaching (e.g., in the case of the *Suuwassea* type locality and the northern-most occurrence of *Camarasaurus*; Harris and Dodson, 2004; Woodruff and Foster, 2017). Therefore, we do not provide exact GPS data here, and only include the names of the quarries and localities if these are already published. Qualified researchers can generally access more precise locality data (based on locality name) from the repositing institutions.

Stratigraphy

The stratigraphy of the Morrison Formation is extremely complex, and changes considerably throughout its enormous geographical extent. Thus, geological members such as the Brushy Basin Member are not recognized throughout the entire formation, and long-distance correlations are very difficult (e.g., (Tschopp et al., in press; Trujillo, 2006; Maidment et al., 2017). Here, we note identified geological members where reported, exact ages if known, and attribution to the Systems Tracts reported by Maidment et al. (2017). In absence of other stratigraphic data, we aim to include position relative to formation and/or member boundaries, if available.

Current Repository

Not much explanation is needed for the column listing the current repository. However, it is interesting to note that some of the specimen numbers do not correspond to the current repository because some institutions have traded or given away specimens in the past, and new specimen numbers from the current repositories are unknown to us. In some cases, specimens have also been split, with parts being sent to one institution, and other parts to another, or kept in the original institution (e.g., CM 662, now HMNS 175, see above; and some specimens from Bone Cabin Quarry given away or traded by the American Museum of Natural History).

Work in Progress

As mentioned above, ongoing excavation and study of these specimens makes it impossible that a list like this will ever be completed. Not just this, but having it assembled over a long time span, and combining information from several databases and researchers, data standardization is an issue, which is being tackled over time. For instance, in the contents column, bones are sometimes abbreviated, the side of the element is mentioned before or after the element, and some entries are in all capitals. Also, having added some of the columns over time (in particular the subcategories of the references for the descriptions, figures, etc., and the ontogeny and stratigraphy columns), some of the information that belongs into these newer columns might still be hidden in other columns (stratigraphic information was initially recorded in the locality or further info columns, for example). Nonetheless, we think that the currently available information in the spreadsheet is highly useful for exploratory analyses to find particular bones, specimens from a particular geographic area or stratigraphic level, or potentially juvenile individuals, as well as any reference that might mention them.

How to Contribute

Currently, only the authors of this paper have access to edit the spreadsheet. It is our goal to keep this spreadsheet up-to-date in perpetuity, independent of any potential personal difficulties of any of us authors. The addition of other paleontologists as spreadsheet editors is therefore very welcome, so that the work load and responsibility can be divided among many contributors. Therefore, qualified researchers who would like to contribute ~~in~~ to curating the spreadsheet are welcome to contact any of us authors, and can be easily added as spreadsheet editors. Alternatively, comments are allowed for anybody viewing the spreadsheet, so that potential minor edits, corrections, and additions can be proposed via comments as well. If this alternative method is used, we encourage the researchers publishing the comment to identify themselves so the reliability of the suggested changes and additions can be assessed.

Future steps

A future, very useful step would be to add links to the mentioned references. At this time, references are only mentioned as in-text references, with no added bibliography. Many of these papers are well-known among people working on Morrison Formation sauropods, but for students or other researchers entering the field, finding them may be difficult. Adding links to the thousands of mentioned references, however, will be extremely time-consuming, and has therefore been postponed. In an attempt to facilitate the search for references online, we started a freely accessible subcollection within the group "Dinosauria" on the free reference manager Zotero. The subcollection is called MorrisonSauropodDatabase, and can be seen when viewing the Group Library at the following link: https://www.zotero.org/groups/85528/dinosauria/items/collectionKey/V77A3XC4. It does not include a large number of references yet, but most of the others should be accessible in the main group "Dinosauria". Generally, however, a search for the specimen number on Google Scholar, restricted to the year of the particular publication, should find the reference.

Moving to an institutional instead of a commercial server will be a priority as well. We are currently exploring options. Any future move will be communicated in the spreadsheet itself, and through an update on the original preprint on PaleorXiv.

Discussion and Conclusion

In order to provide a more complete picture of the information currently available, we conducted some quick and basic data exploration. In its current state, the spreadsheet lists 3346 specimens housed in more than 60 institutions on six continents (Fig. 1). ~~About~~ Around 290 specimens have associated information on ontogeny. Approximately half ~~has~~ have associated locality data, but this number likely increases considerably in the near future, because the locality column was added only recently, and a lot of information still has to be moved into this column. The same accounts for the currently 930 entries in the stratigraphy column, where much of this information is still contained in other columns, or has yet to be extracted from collection databases and published literature. Numbers of specimens per institution or locality can be calculated too, but this would be somewhat misleading, because some sites produced largely disarticulated material or have not been documented in enough detail to reconstruct specimen association. These collections had to be cataloged giving different numbers to every single bone, which obviously inflates specimen numbers compared to partial or complete skeletons. In any case, this short data exploration shows that thousands of sauropod specimens from the Morrison Formation are available for study around the world and indicates the potential of such a spreadsheet for planning and conducting future research projects.

Acknowledgments

The authors want to express their deep appreciation for all the curators and collection managers, as well as their volunteers, who are working hard to digitize collection data and making them publicly accessible. There would be too many to mention personally, and some people might be forgotten, so it is easier to just provide a general, big Thank You. The main institutions providing information and access to specimens are the Beneski Museum at Amherst College (Amherst, Massachusetts, USA), the American Museum of Natural History (New York, USA), Academy of Natural Sciences (Philadelphia, Pennsylvania, USA), the Museum of Paleontology of the Brigham Young University (Provo, Utah, USA), Carnegie Museum of Natural Histoy (Pittsburgh, Pennsylvania, USA), Cincinnati Museum Center (Cincinnati, Ohio, USA), Cleveland Museum of Natural History (Cleveland, Ohio, USA), Dinosaur National Monument (Vernal, Utah, USA), Dallas Museum of Natural History (Dallas, Texas, USA), Denver Museum of Nature and Science (Denver, Colorado, USA), Field Museum of Natural History (Chicago, Illinois, USA), Houston Museum of Nature and Science (Houston, Texas, USA), Museum für Naturkunde (Berlin, Germany), Kansas University, Department of Vertebrate Paleontology (Lawrence, Kansas, USA), Los Angeles County Museum (Los Angeles, California, USA), Museum of the Rockies (Bozeman, Montana, USA), Museum of Western Colorado (Grand Junction, Colorado, USA), Natural History Museum (London, UK), New Mexico Museum of Natural History (Albuquerque, New Mexico, USA), Sam Noble Oklahoma Museum of Natural History (Oklahoma City, Oklahoma, USA), Smithsonian Institution, National Museum of Natural History (Washington DC, USA), South Dakota School of Mines (Rapid City, South Dakota, USA), Sauriermuseum Aathal (Aathal, Switzerland), Royal Tyrrell Museum (Drumheller, Alberta, Canada), Utah Museum of Natural History (Salt Lake City, Utah, USA), University of Wyoming Museum of Geology (Laramie, Wyoming, USA), Wyoming Dinosaur Center (Thermopolis, Wyoming, USA), Yale Peabody Museum (New Haven, Connecticut, USA).

We thank Jordan Mallon for the editorial handling, and Kenneth Carpenter and Femke Holwerda for their thoughtful reviews.

Much of the work in preparing this spreadsheet was conducted by E. Tschopp during his PhD and Postdocs. Funding for these jobs were provided through fellowships and grants from the Fundaçao para a Ciência e a Tecnologia (Ministério da Ciência, Tecnologia e Ensino Superior, Portugal), a Volkswagen Foundation Postdoctoral Fellowship within the framework of the "*Europasaurus*-Projekt," and Theodore Roosevelt Memorial Fund and Division of Paleontology Postdoctoral Fellowships from the Richard Gilder Graduate School and the American Museum of Natural History, respectively.

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Figure

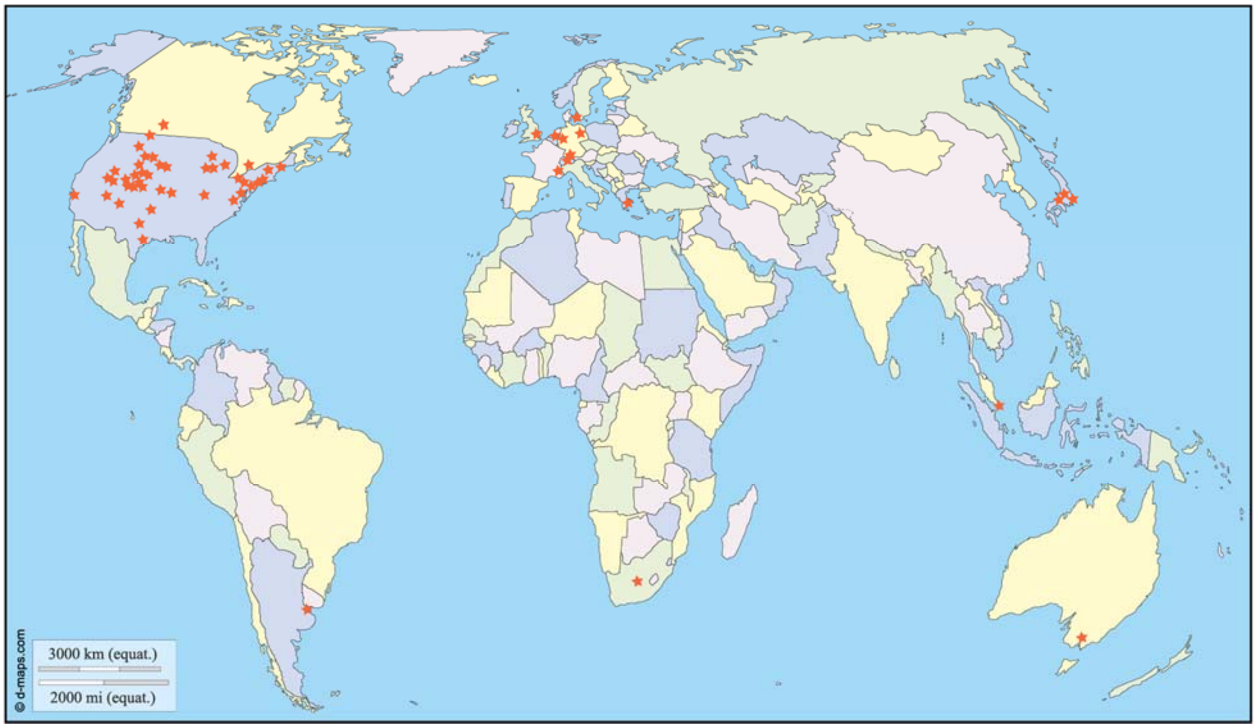

Fig. 1: Map showing the approximate locations of the museums and institutions housing sauropod specimens from the Morrison Formation. Map © d-maps.com, modified with permission. Original available here: https://d-maps.com/carte.php?num_car=126802&lang=en.