Nicholas Boulanger

Grant Proposal

Introduction. (996/1000)

An important step in advancing the study of prehistoric life is increasing the reliability and precision with which scientists can locate fossil evidence; in the past, this process has been largely guesswork (Oheim 2007). Geographic information systems (GIS) have been used before in paleontology to map ranges of mammal fauna (Graham et al. 1996), and to determine the distribution of index fossils (Rayfield et al. 2005). My objective is to test whether transitional fossils of bats (order Chiroptera) in North America can be found by integrating paleontological and stratigraphic data. Modern bats are an incredibly diverse taxon, but discerning evolutionary relationships between bats and other mammals is difficult and unreliable without fossil evidence (Sears et al. 2005, Gunnell and Simmons 2005). I hypothesize that the presence of transitional fossil forms representing primitive bat lineages can be found in North American forest deposits from the early Paleocene or late Cretaceous.

Justification. (2082/2500)

Despite decades of research, the origin of Chiroptera remains unclear (Thewissen and Babcock 1992, Simmons et al. 2008). Morphological and genetic analyses support the conclusion that bats are monophyletic (Gunnell and Simmons 2005, Simmons et al. 2008), but their evolutionary relationship with other mammals is, as of yet, undetermined. The primary reason for this is simple: intermediate forms between bats and more primitive mammalian ancestors have not been found in the fossil record (Gunnell and Simmons 2005, Simmons et al. 2008). The first bats to appear as fossils already have the complex and derived traits associated with flight and, in many cases, echolocation as well (Gingerich 1987, Simmons et al. 2008, Hand et al. 2015), although echolocation apparently developed after flight (Simmons et al. 2008). In order to determine how these derived traits evolved, paleontologists must attempt to fill in gaps in the depauperate bat fossil record (Eiting 2009). Predicting fossil occurrences using taphonomic and paleobiological cues has been done before, most notably with the discovery of *Tiktaalik* in 2006. GIS modelling has also been used successfully by paleontologists in the past to assist in determining fossil distribution and taphonomy (Oheim 2007, Rayfield et al. 2005). However, these techniques have not yet been brought to bear in the search for transitional fossils. More sophisticated predictive modelling of sites where fossils are likely to be found should have substantial payoffs in the study of Chiroptera and other extinct taxa. This study offers significant benefits to science, because a refined approach to fossil hunting using stratigraphic paleobiology and geography is necessary to answer numerous unsolved questions in the study of extinct life. Thus, even if actual bat fossils are not recovered due to preservational or sampling limitations, development of these techniques will still be valuable. In particular, this study furthers exploration into uncommon terrestrial vertebrates, an underrepresented fauna in the current fossil record.

Research Plan. (2406/2500)

The Paleontology Database is a searchable index of fossil data, organized by the taxonomy of the organisms found, the sites at which fossils are found, and the age of the rock deposits at each site. The database also contains lithographic and environmental data about each fossil site, which will be crucial in determining where bats would most likely have been preserved. First, I will extract the spatial and temporal distribution of known bat fossil occurrences from the Paleontology Database to determine where the temporal gap in the origination of Chiroptera is most likely present. For example, because basically modern-looking bats are found in late

Paleocene and Eocene deposits, transitional forms ought to be found in early Paleocene or late Cretaceous strata. This data will be combined with additional information from the MacroStrat Database, a database of stratigraphic units, lithology, and environment, in order to find where rocks of the appropriate age and preservation environment are exposed. Because the ancestors of bats are hypothesized to have been arboreal insectivores and elementary gliders (Gunnel and Simmons 2005), I will look for deposits that contain terrestrial fauna characteristic of forest habitat during the Late Cretaceous-Early Paleocene. An especially important criterion will be the presence of mammals and other fossils that are frequently found alongside existing bat deposits (Simmons et al. 2008). Once sites have been identified that meet these criteria, GIS maps of those sites will be created. The GIS data will be used to create a frequently used predictive model called a suitability surface, in which different spatial variables are mathematically combined to produce suggested solutions (Oheim 2007). The suitability surface can then be used to rank potential sites by their likelihood of containing transitional fossils, and then to find locations within promising sites where fossils are likely to be found, based on key metrics such as terrain accessibility, vegetation coverage, and elevation. Fieldwork will be conducted in the summer of 2017. Teams of undergraduate volunteers and I will travel to each site for which transitional fossils are predicted by the above analyses, establish search images and prospect for fossils, if possible. Special emphasis will be placed on deposits and geographic areas that have already produced fossil bats.

References. (2288/2500)

Eiting, T.P, 2009. Global Completeness of the Bat Fossil Record: Journal of Mammalian Evolution, v.16, n.3, p.151-173.

Gingerich, P.D., 1987. Early Eocene bats (Mammalia, Chiroptera) and other vertebrates in freshwater limestones of the Willwood Formation, Clark's Fork Basin, Wyoming: Contributions from the Museum of Paleontology, University of Michigan, v.27, n.11, p. 275-320.

Graham, R.W., Lundelius, E. Jr., Graham, M.A., Schroeder, R., Toomy III, R, Anderson, E., Barnosky, A., Burns, J., Churcher, C., Grayson, D., Guthrie, R.D., Harington, C., Jefferson, G., Martin, L., McDonald, H.G., Morian, R., Semken, H. Jr., Webb, S.D., Werdelin, L., and Wilson, M, 1996. Spatial response of mammals to Late Quaternary environmental fluctuations: Science v.272, p.1601-1606.

Gunnell, G.F., and Simmons, N.B., 2005. Fossil Evidence and the Origin of Bats: Journal of Mammalian Evolution, v.12, n.1, p.209-246.

Hand, S.J., Sigé, B., Archer, M., Gunnell, G.F., and Simmons, N.B., 2015. A New Early Eocene (Ypresian) Bat from Pourcy, Paris Basin, France, with Comments on Patterns of Diversity in the Earliest Chiropterans: Journal of Mammalian Evolution, v.22, n.3, p.343-354.

Oheim, K.B., 2007. Fossil site prediction using geographic information systems (GIS) and suitability analysis: The Two Medicine Formation, MT, a test case: Palaeogeography, Palaeoclimatology, Palaeoecology, v.251, n.3-4, p.354-365.

Rayfield, E.J., Barret, P.M., McDonnell, R.A., and Willis, K.J., 2005. A Geographical Information System (GIS) study of Triassic vertebrate biochronology: Geological Magazine v.142, n.4, p.327-354.

Sears, K.E., Behringer, R.R., Rasweiler IV, J.J., and Niswander, L.A., 2005. Development of bat flight: Morphologic and molecular evolution of bat wing digits: PNAS, v.103, n.17, p. 6581-6586.

Simmons, N.B., Seymour, K.L., Habersetzer, J., and Gunnell, G.F., 2008. Primitive Early Eocene bat from Wyoming and the evolution of flight and echolocation: Nature, v.451, p. 818-821.

Teeling, E.C., Springer, M.S., Madsen, O., Bates, P., O'Brien, S.J., and Murphy, W.J., 2005. A Molecular Phylogeny for Bats Illuminates Biogeography and the Fossil Record: Science, v.307, p.580-583.

Thewissen, J.G.M., and Babcock, S.K., 1992. The Origin of Flight in Bats. Bioscience, v.42, n.5, p. 340-345.