Academic Betadiversity and Future of Biological Collaboration

* Abstract
* Introduction:

Innovative discoveries often come from the mixing of academic fields. The importance of cross-disciplinary work is a key goal highlighted by the National Science Foundation and the National Institutes of Health. The cooperation of biological disciplines spurs theoretical and methodological progress. The melding of disparate fields of study has produced theoretical breakthroughs, like the mixing of quantitative genetics and evolutionary theory to form the modern synthesis (), as well as methodological advances such as the biochemistry underlying Polymerase Chain Reactions. Interdisciplinary work continues to drive innovation with the current omics age fueled by a tremendous expansion of bioinformatics. An ever-growing list of challenges, from the evolution of antibiotic resistance to producing robust climate models requires scientists to embrace a wider view of life sciences.

Despite the critical importance of interdisciplinary work, it is difficult to assess the relative specialization and connections of biological fields. While studies have focused on citation indexes as a proxy of academic collaboration, individual citations may be a poor indicator of the level of interdisciplinary work, and the relevance of a particular citation to the aim of the research may be limited(). In contrast, tracking publication of articles in research journals provides a new view into the depth and diversity of interdisciplinary research. The contribution of individual authors can be used to summarize the interdisciplinary nature of each biological field. By studying the emergent connections of life-science fields, we garner a new view of biology as an interconnected and complex system, and can highlight potential opportunities for future growth.

Networks provides powerful way for visualizing interdisciplinary research by harnessing graph theory to represent connections among group members. Graph theory is a branch of discrete mathematics that quantifies interactions among members of a set, called nodes, by measuring connections, called links, based on an interaction currency. To visualize the totality of life sciences, we must construct an adjacency matrix where each academic field is compared to every other field. This matrix consists of the degree of niche overlap between fields, as measured by the abundance of articles published by individual authors in field specific journals. The goal of this analysis was to determine, 1) Which fields act as bridges to connect other fields within life sciences? 2) Which fields have become more insular, and which more interdisciplinary? 3) Where is there potential growth among connections between fields?

To measure dissimilarity among life science fields, I queried all articles from 1995-2015 for 567 biologicals journals. Each of these journals were classified into one of thirty-nine biological fields (Table S1). Journals that did not belong to any field were discarded. From these 578 journals I tallied 1,353,142 publications by each of 327,381 authors in each of the biological fields. After computing dissimilarity among disciplines, I created a network to calculate the betweenness, degree, closeness and eigenvalue centrality of each field. These metrics all measure the centrality in graph networks. Fields with high betweenness are central members of the network and connect other members. Fields with high degree directly interaction with many other fields. Fields with high betweenness measures connective node to other parts of the network, acting as gatekeepers that connect academic fields. Finally, fields with high eigen value centrality are connected to many members that are well connected. These four measures provide complimentary ways of evaluating centrality and connectedness within the biological sciences. In addition, I calculated the change in link strength between disciplines over time to quantify the shifting connections and affinities for biological collaboration.

On average, fields were connected to 4.7 other fields, with an average dissimilarity of 0.86. **Overall, the life sciences network is highly modular, with distinct compartments**. These compartments include 4 to six biological fields. The strongest connection among fields is between Ecology and Biodiversity and Conservation Biology. Authors tend to publish frequently in both fields, and both are well connection evolutionary biology and zoology. This cluster of fields is connected by Insect and Arthopod journals which connect to a small cluster of crop related fields of Plant Patholoy, Pest Control and Pesticides and Agronomy.

These tight connections reflect the contribution of anthropogenic activity in connecting academic fields. Environmental sciences and Biotechnology act as strong bridges between compartments and represent well-connected fields within the life sciences. Authors that publish in environmental sciences also publish in environmental engineering, atmospheric sciences, marines sciences and sustainability.

Overall, temporal patterns among reasonably connected disciplines were fairly static. The ten largest increases in connectivity all included X,Y,Z while the ten largest decreases in connectivity included X,Y,Z. The patterns of temporal change were largely robust to x,y,z.

Visualizing life-sciences as a complex network gives rises to many questions and spurs the development of interdisciplinary connections. While, the strong connections between Biochemisty and Molcular Biology stem from the joint goal of understand the mechanistic underpinnings of cellular life, these fields are on the opposite side of biological network from Paleontology. The emergence of ancient DNA approaches, as well as increasing interest in comparative phylogenetic methods may see a greater niche overlap among authors publishing in these journals in the future. The current challenge of producing robust climate models highlights the observed connection between Oceanography, Athmospheric Sciences and Environmental Sciences. By comparing these link strengths over time, we can see that.

From out data, we can view the budding of new academic fields and their eventual separation from their predescesors. of fields and their eventual separation from their

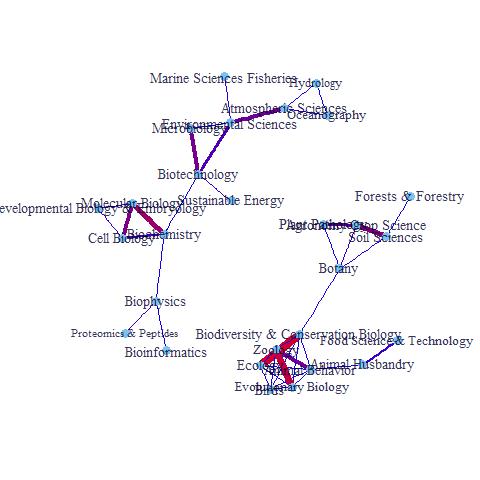


Figure 1

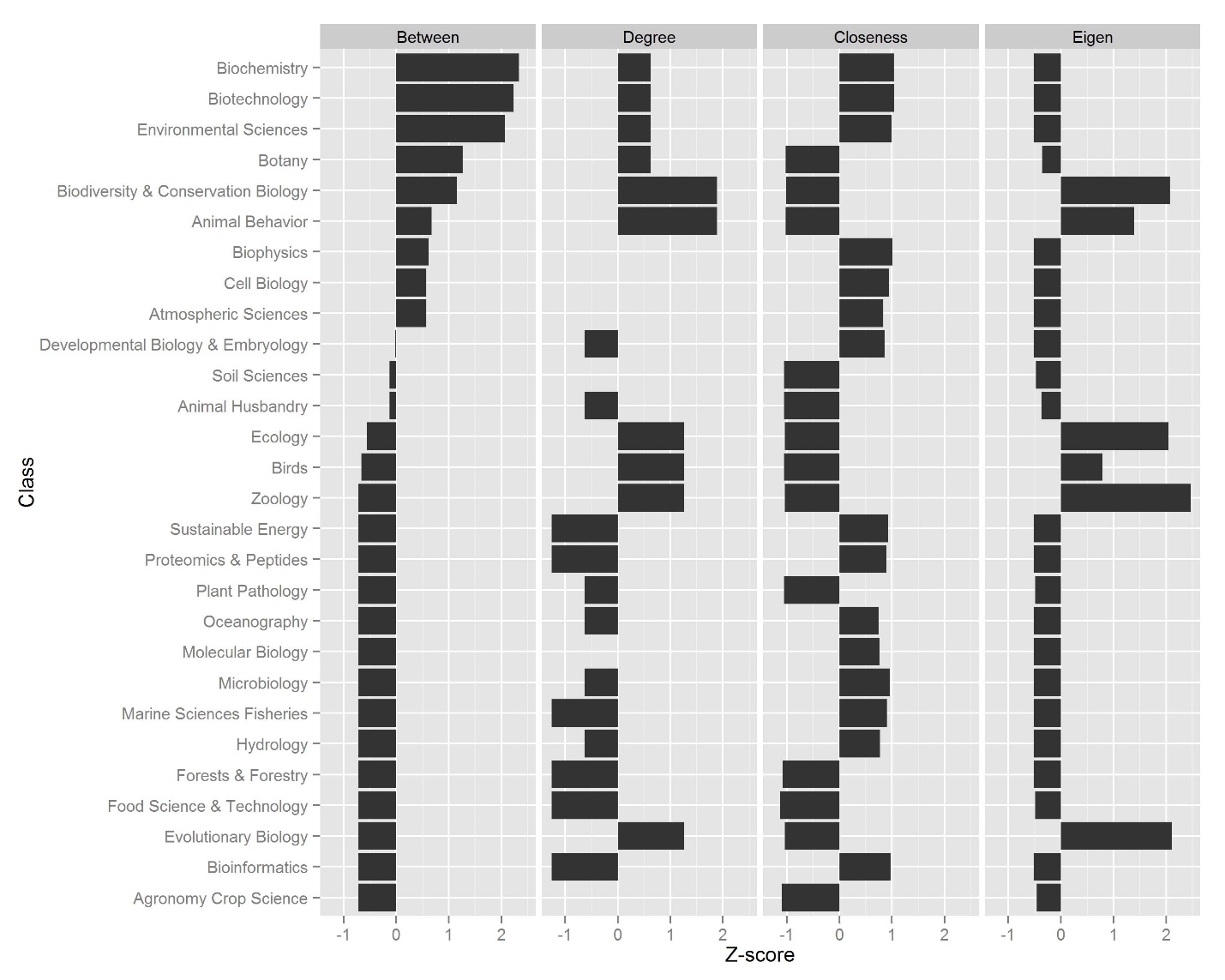
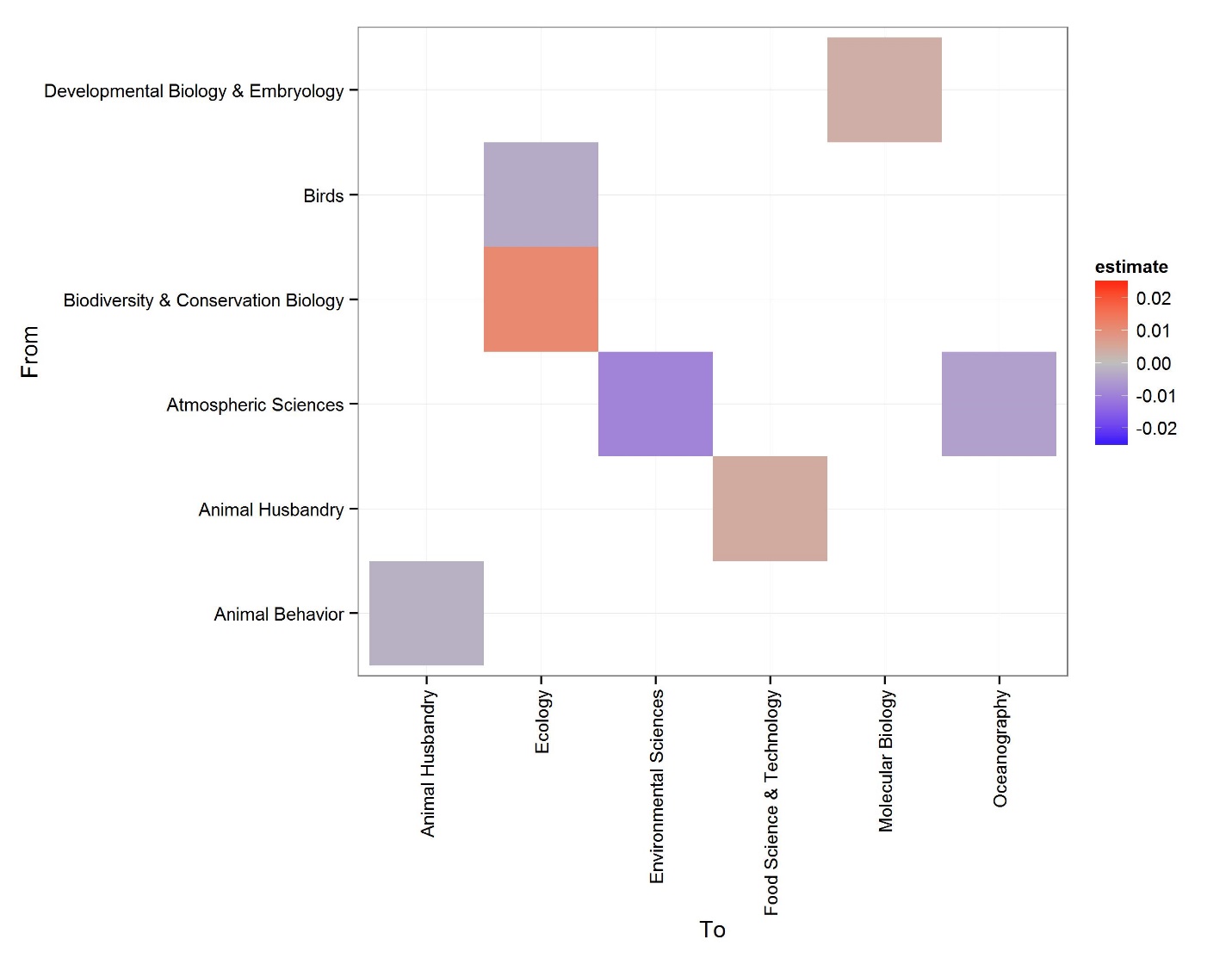


Figure 2



* Methods
  + Scopus archives
  + Each classification consisted of twenty journals. While the boundaries of discrete classifications will always be difficult to define, the vast majority of journals can be placed between one or two categories.
  + Journal Classification
  + Defining Niche overlap
  + Search Terms
    - Temporal Search
  + Network statistics
  + Change through time
* Results
* Discussion
  + Academic networks and future for evaluation
  + Promoting collaboration and indexes through citation sharing (cites)
  + On why we see strong interaction among certain fields
  + Caveats
  + The potential for future growth

**Appendix**