Citations and Citation Metrics in a Serial Assessment Using Master's Theses

We analyzed serial citations in 72 marine biology master's theses as well as the ranking data of aquatic science serials from six global serial citation metrics, to assess serial use by marine biology graduate students from two perspectives. From 1,035 unique serials, a core of 123 titles was identified and evaluated for access. Citation ages averaged 13.5 years, with 27% of serial citations dated prior to 1996. Students cited serials from disciplines beyond marine biology, demonstrating broad title dispersion compared to several other studies. Recommendations are offered for future investigation to develop a stronger understanding of graduate students' use of the library's serial collection.

KEYWORDS: citation analysis, graduate theses, marine biology, serial citation metrics, collection assessment

INTRODUCTION

Serial collection management often involves a cyclical process of evaluative decision making. This may occur annually, especially when budgetary challenges necessitate regular close scrutiny. A multi-year cycle may also be applied in the case of extended contracts with big package deals or when limited staff resources dictate other priorities. Subscription decisions may be based upon perceptions of value and need. These are often represented by quantitative assessment of data that demonstrate use and qualitative assessment from users, which adds context to the quantitative data. The detailed assessment of serial collections for a particular

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discipline, however, may be conducted less frequently. College of Charleston (CofC) Libraries subject liaisons average a five-year collection assessment cycle, frequently in alignment with academic department re-accreditation cycles. The most recent collection assessment for serials in the subject discipline of marine biology was undertaken in 2011, using core lists in *Magazines for Libraries* and *Journal Citation Reports* as a basis for evaluation. For the emerging discipline of marine genomics, citation analysis was undertaken for a selection of publications written by CofC marine biology faculty on the subject (Ivy 2011).

The Marine Resources Library (MRL), located at the South Carolina Marine Resources Center (SCMRC) on James Island, is a small branch library of the CofC serving the approximately 60 faculty and students of the Graduate Program in Marine Biology (GPMB). The MRL also serves and is supported by its other partners at the South Carolina Department of Natural Resources (SCDNR) Marine Resources Division (MRD), the National Centers for Coastal Ocean Science (NCCOS) Charleston Laboratories, and the National Institute of Standards and Technology (NIST) Charleston Laboratory, located at the SCMRC. Marine biology graduate students develop their thesis research under the guidance of an advisor who may be associated with one or more of the institutional partners. The student's research may be directly related to the research activity of the advisor.

The current study was undertaken to investigate the scholarly serials cited by GPMB master's students when conducting their thesis research, using two methods. Analyses of both serial citation data and the ranking data of aquatic science serials from six global serial citation metrics provided relevance- and metric-based perspectives of the adequacy of the CofC Libraries' marine biology serial collection. Graduate student theses were chosen as the basis for citation analysis because the specialized collection is primarily used by graduate students instead

of undergraduates. The thesis represents the pinnacle of graduate students' academic research activity. Additionally, theses are more readily accessible than term papers, comprehensive in depth and citation activity, and they demonstrate use of serial resources more pointedly than do vendor usage data. The techniques utilized in this investigation can be applied in various disciplines and contexts to better understand serial collection utilization and sufficiency. They may also assist with serial collection reduction or growth strategies.

Specifically, this study sought to determine which serials marine biology graduate students at our institution have cited the most frequently, and if the frequency of citation matches patterns observed by previous studies. We sought to identify the top serials in the aquatic sciences according to a variety of global citation indicators and to determine to what extent our students are citing them. We also aimed to evaluate the age of cited articles at the time of thesis publication to better understand the importance of maintaining serial back files. Lastly, we sought to evaluate the adequacy of our access to highly-cited and top-rated serials.

LITERATURE REVIEW

Citation analysis as a collection development tool is not a recent innovation. In identifying serials for an undergraduate library chemistry collection, Gross and Gross (1927) considered the significance of chemistry serials based upon citations obtained from a full recent volume of *Journal of the American Chemical Society*. The authors attributed importance to the careful interpretation of this global data for application in their specific context. Three decades later, Eugene Garfield pioneered the development of the *Science Citation Index* to transcend the definition of scholarly association imposed by subject classification systems. The basis of his index is the mapping of interrelated ideas using global citation data (Garfield 1955).

Commencing with 1974 *Science Citation Index* data, global serial ranking metrics such as Impact Factor and Immediacy Index have been published annually in *Journal Citation Reports* (JCR) to communicate the relative significance of serials (Garfield 1976). The resulting data have informed collection management for decades, while new metrics continue to be developed to account for perceived flaws in preceding metrics (Bradshaw and Brook 2016) or to harness different underlying datasets.

Global serial citation data and serial ranking metrics have long been employed to create discipline-specific core lists of serials to aid in collection management. Numerous studies, however, balance quantitative global citation data with subjective input. A proposed core list of marine biology serials was established from global citation data and Impact Factors but refined using country of publication data, to ensure representation of diverse international perspectives (Fuseler-McDowell 1989). A core of veterinary science serial titles was developed by tempering global serial ranking data with subjective input from librarians and professional reading lists, ensuring balanced representation of both research-based and clinical-based scholarship (Ugaz 2011). Sherwill-Navarro, Kennedy, and Allen (2014) utilized numerous criteria to develop a list of quality nursing serials and employed global citation analysis to account for interdisciplinary titles highly-cited within the nursing literature. Each of these studies was enhanced by the utilization of global citation data and metrics together with subjective input.

The synthesis of multiple global citation metrics potentially mitigates the shortcomings of a single metric, including the underlying assumptions, data, or formulation. Developing a core list of psychology serials, Paynter, Jackson, and Mullen (2010) utilized multiple global serial ranking metrics, synthesizing Journal Impact Factor, Eigenfactor Score, and Scopus Analyzer citation/publication data into a weighted serial rank. The presence of a given serial title in one or

more of several psychology Abstracting and Indexing (A&I) databases was also given a proportionately-weighted representation in the ranking calculation.

The practice of local citation analysis of scholarship produced within a specific institution offers a contextual perspective that can be invaluable for collection managers. Butler and Webster questioned the ongoing validity of a global core serial list for marine science. They compared a core list of 20 marine science serials, established in their previous paper (Webster and Butler 2002), with titles recently cited by faculty and student researchers and in which faculty published, at each of their institutions. The results demonstrated significant local differences from the core 20 titles, leading the authors to conclude that the ideal core collection is unique to a specific local context (Butler and Webster 2011). Furthermore, a recent study investigating the correlation between global ranking metrics (Journal Impact Factor and SCImago Journal Rank) and local data (usage and citations) aimed to support the assertion that, “...generic metrics cannot represent campus-level data to make informed collection decisions.” (Gao 2016, 121) While no significant correlation was observed between local citation data and the metrics’ serial rankings, a significant correlation did exist between local usage data and global ranking metrics.

Considering the impact of electronic serials on serial collection evaluation techniques, Thomas Nisonger predicted that, “Client-centered methods of measuring accessibility and availability will increase in importance; collection-centered methods focusing on ownership will decline.” (Nisonger and Guzi 2001, 399) It follows that gaining an understanding of patron information-seeking behavior and competency within the complex landscape of digital scholarship is key to evaluating the accessibility of a collection from students’ perspectives. Nisonger (2007) subsequently identified serial citation analysis as one element of a potential

suite of analyses that can help inform the definition of a core serial collection. Ugaz (2011) demonstrated that inherent bias may exist within an evaluation method, thereby lending credence to Nisonger's recognition of the value of using multiple facets of investigation in identifying a core of serials. It would seem prudent, therefore, to incorporate global citation metrics, local citation data, and the contextual wisdom of practitioners in the field to represent multiple perspectives.

Numerous local citation studies have been published in the disciplines of biology and marine biology. Four studies evaluating citations in biology Master's theses and doctoral dissertations demonstrate the unique characteristics of citation patterns within specific groups of researchers. The number of theses and dissertations analyzed in these studies ranged from 25 to 96, with the mean number of citations per thesis or dissertation ranging broadly from 44 to 133. Consistent mean serial citation ages of 10.6 and 11 years were observed by Miller (2011) and Barnett-Ellis and Tang respectively, while Ahmadiéh, Nalbandian, and Noubani reported a mean citation age of 14 years across all source types. Nabe and Imre (2008) reported mean serial citation ages of 16 and 18 years for zoology and plant biology dissertations respectively. They noted that 57% and 54% of citations were from articles published prior to 1996, an approximate retrospective limit for front file serial content. This challenged their assumption that biologists only prioritize citation of current research. Ahmadiéh, Nalbandian, and Noubani (2016) observed that 85% of serial citations occurred in the 1990s or later. Barnett-Ellis and Tang (2016) noted several general science titles among the most-cited serials.

Studies of faculty publications at Marine Sciences Research Center, Stony Brook and the Department of Atmospheric Sciences at Texas A&M University reported much smaller counts of unique serial titles than studies of graduate theses. Walcott (1994) determined that 80% of serial

citations came from 12.5% (52) of cited serials, while Kimball et al. (2013) discovered that 80% of citations came from the top 8% (24) of cited serials. The 80/20 Rule (Nisonger 2008) is used as a measure of citation dispersion. Several serial citation studies evaluated conformity to the rule (Miller 2011; Ahmadiéh, Nalbandian, and Noubani 2016; Keogh 2012; Kuruppu and Moore 2008). A more complex measure of serial title dispersion is Bradford's Law (Bradford 1985). Accordingly, a set of citations sorted in diminishing citation count order by serial title and divided into three zones representing approximately equal numbers of citations, will be represented by exponentially increasing numbers of serials. Two recent studies investigated adherence to Bradford's Law (Keogh 2012; Nagaraja and Prashanth 2015).

The value of citation analysis is overshadowed by the suggestion that not all citations in an article are legitimate. Todd et al. (2010) analyzed 198 randomly-chosen citations from recent issues of 33 marine biology serials, concluding that only 75.8% of citations clearly supported the assertion to which they were associated. Multiple studies noted challenges experienced in processing citations for analysis, due to incompleteness and inaccuracy (Barnett-Ellis and Tang 2016; Miller 2011). Citations with errant dates directly impact the validity of citation age-dispersion analysis (Ahmadiéh, Nalbandian, and Noubani 2016). The time required to evaluate and correct all citations in a large dataset is prohibitive. The analysis of a representative sample of citations, therefore, is a more realistic proposition if all citations are to be verified.

While data obtained from a local citation analysis is specific to that context, the strategy of the study itself can be of value to other researchers. Hoffmann and Doucette (2012) examined the objectives, design, techniques, and reporting clarity of 34 citation analysis studies, and developed a guide for future work. Particular emphasis is given not only to study design, but also to enabling replication of the study, according to its parameters, for potential comparison.

METHODS

Citation data from 72 marine biology master's theses published between 2010 and 2015 were accessed, standardized, and ingested by a Python script into a PostgreSQL database for analysis. Bibliographic data for all theses were extracted from ProQuest Dissertations and Theses (PQDT) records and ingested into the database. Theses were downloaded as PDF documents from the PQDT database, if available, and the bibliographies were extracted. Bibliographies from theses not made available online were scanned with Optical Character Recognition from print copies held in the MRL. The PDF documents were converted to Microsoft Word documents for citation data standardization. Standardization could not be automated because multiple citation styles were used. CofC marine biology graduate students often write their theses with the goal of publishing them, or parts thereof, as journal articles, which necessitates adherence to the anticipated publishing journal's citation style. Publication year and serial title were manually extracted and separated by pipe delimiters, followed by remaining citation information retained for reference. The data were then imported into Microsoft Excel sheets for ingestion into the database. Theses with chapter-specific bibliographies often reflect the intention to publish the chapters independently and as a result, citation duplication occurs. In such cases, bibliographies were synthesized and de-duplicated.

For the purpose of this study serials are considered to be publications of an ongoing nature and published at least once a year, excluding independently-named monographs published annually in a series. Titles from the *Annual Reviews* series and conference proceedings are included with serials, while recurring government publications are excluded unless specifically marketed as a journal. In considering serial title changes, it was decided to treat each form of the

title as a different serial because many name changes and title splits appear to represent changes in focus or scope of the serial. For example, *Proceedings of the Royal Society* is currently published as *Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences* and *Proceedings of the Royal Society B: Biological Sciences*, representing distinct areas of focus. *Journal of the Malacological Society of Australia* changed to *Molluscan Research*, implying a shift in scope to include other geographic regions.

Before citation data ingestion could be completed, a citation title standardization process was developed to translate abbreviated serial titles into full title forms. This was accomplished using an extensive “translation” spreadsheet of serial titles and their various abbreviated forms. A Python script was written to read all thesis citation data and compare each serial title to the titles in the translation spreadsheet. All full or abbreviated titles not found in the comparison process were saved for review. Each of these titles was investigated to identify the correct serial title. The title or abbreviation used by the student was then added to the translation spreadsheet so that the citation would subsequently be correctly recognized. This process also served to eliminate non-serial titles, the analysis of which is beyond the scope of this study. Once all serial titles were correctly recognized by the script, the ingestion process was initiated.

A relational database structure was designed for efficient storage and cross-referencing of thesis and citation data (Figure 1). Four tables document unique data: Thesis advisors, citation sources, PQDT subject headings, and thesis metadata. Three relational tables document all associations between theses and advisors, sources, and subject headings.

To assess the adequacy of the CofC Libraries’ marine biology serial collection more completely than simply by student citation of serials in theses, rankings of the top aquatic science serials were also obtained. 2015 data was gathered from six global citation metrics: Journal

Impact Factor (JIF), Eigenfactor, SCImago Journal Rank (SJR), H-Index, CiteScore, and Source Normalized Impact per Paper (SNIP).

JIF and Eigenfactor are derived from Clarivate Analytics' JCR citation data, representing a highly-selective set of serials. The remaining global metrics are derived from Elsevier's Scopus citation data which includes a greater breadth of serials and serial document types than JCR. JIF was chosen for its long-established history, while Eigenfactor was selected for its improvement upon JIF. This includes accounting for self-citation and the use of five years of citation data rather than two ("Eigenfactor: About" n.d.). CiteScore was chosen for its functional similarity to JIF while using the broader Scopus dataset and a three-year data analysis. The SNIP metric was designed to compensate for subject-specific citation tendencies, while SJR adjusts for the esteem of serials citing a given serial title. Lastly, the H-Index represents a serial's most-cited articles and the extent to which they are cited ("Measuring a Journals Impact" n.d.).

The top 30 titles (Barnett-Ellis and Tang 2016) and data from each of six global serial-rating metrics were identified, synthesized, and rated by the number of occurrences across the six metrics. Serials were ranked according to these metrics and a weighted average was calculated using both the average rank (Bradshaw and Brook 2016; Paynter 2010) and the number of global metrics contributing to the average rank, in the formula:

$$\text{Average Rank} / (\text{Number of Contributing Metrics})^2$$

The top 30 titles were then sorted and ranked according to the weighted average values.

Citation currency was evaluated by establishing the approximate age of the citation at the time of thesis publication. This was calculated by subtracting the publication year of each article

from the publication year of the citing thesis, to establish an age in years. Citations pending publication were assigned an age of zero. Citations lacking publication years were researched to determine a publication date.

Access to each of the serials most cited by marine biology graduate students was determined by evaluating online serial coverage listed in Serials Solutions Core and print holdings listed in the Innovative Interfaces Millennium library catalog. For the purpose of this study, print serials located at both the main library and the branch library were considered as accessible to marine biology graduate students despite being located seven miles apart. Access was classified in descending order of access as Full Coverage, Extensive Coverage (nearly full coverage with current coverage and no more than five years archival gaps), Current Coverage (1997 through present), Partial Coverage, and No Coverage.

LIMITATIONS

In this study we evaluated work undertaken by master's students, a subset of one institution's marine biology research population. Additionally, we focused upon their thesis research which, while extensive and significant, does not represent their entire research output. It cannot, therefore, be considered representative of institution-wide use of serials for marine biology research. The research undertaken by undergraduate students and faculty, as well as non-thesis research of master's students, should be assessed to gain a broader perspective of institutional activity in this discipline. This could result in the evaluation of citations in a variety of additional scholarly products including assigned papers; published book chapters, books, and articles; white papers; and technical reports.

As in several studies cited, challenges were experienced with citation completeness and accuracy. A small number of citations lacked dates, necessitating investigation and addition of the absent data. Serial titles posed the greater problem. Some citation styles used serial title abbreviations while others used full forms of the title. Numerous instances of incorrect abbreviation of titles and expansion of abbreviated titles were observed. This suggests that some students are not aware either of the standards for serial title abbreviation (<http://www.issn.org/understanding-the-issn/standardization/>) or of tools, such as the Chemical Abstracts Service Source Index (<http://cassi.cas.org/>) and the International Standard Serial Number International Centre List of Title Word Abbreviations (<http://www.issn.org/services/online-services/access-to-the-ltwa/?lettre=#lettres>), that are available to assist with accuracy.

The varied citation styles observed in theses prevented us from determining the formats of the cited serials with any level of accuracy. Some bibliographies did not indicate article format, while others included Digital Object Identifiers or access dates and URLs. Many serial back files at CofC are available in both print and online formats. It would, therefore, require assumption to conclude that an article was actually accessed in the format implied by its citation.

RESULTS

From 72 marine biology master's theses 5,747 serial citations were obtained and analyzed. The number of serial citations per thesis ranged broadly from 19 to 245, with a mean of 79.7. From all citations 1,035 unique serial titles were identified. The number of unique serial titles per thesis ranged from 13 to 116, with a mean of 42.5 (Figure 2). Citations spanned the years 1852 to 2015 with a mean citation age of 13.5 years at the time of thesis publication (Figure 3).

Cited serial titles were ranked both by number of citing theses and total number of citations across all theses. These two rankings were combined into an average ranked list, of which the top 30 serials are presented in Table 1 (see Appendix 1 for alphabetical list). Of the 10 highest-ranked serial titles, six are specific to the aquatic sciences, while exhibiting a diverse emphasis within that discipline, and four are much broader in their coverage of science. *Marine Ecology Progress Series*, the top-rated serial cited 216 times by 50 theses, is the most popular serial of an aquatic emphasis. *Science*, the second highest-rated serial cited 116 times by 41 theses, is the most popular general scientific publication. The remaining 20 of the top 30 titles include a variety of general science or biology serials, including *PLoS One* and *Evolution*, and some more narrowly-focused aquatic science serials, including *Journal of Phycology* and *Journal of Shellfish Research*. Numerous interdisciplinary titles such as *Environmental Toxicology and Chemistry* and *Fish and Shellfish Immunology* occurred in the top 30-100 range of cited serials.

In anticipation of the data, sorted by times cited, adhering approximately to the 80/20 Rule, the proportion of serials comprising 80% of citations was evaluated. 80% of the citations came from 24.8% (257) of serial titles. The 80% margin centrally dissected the group of serials that received four citations. At the margin of five and four citations per title, the percentage of citations was 78.5% and at the margin of four and three citations per title, the percentage of citations was 81.6%. In this study, then, the citation dispersion tends towards 80/25.

Bradford's Law of Scattering was also tested using the data sorted by times cited. Division of the citations into three approximately equal-sized groups (without splitting a group of serials with equal citation rates) resulted in three zones of 23, 100, and 912 serials representing 1,858, 1,931, and 1,958 citations respectively (Table 2). If Bradford's Law were

closely approximated, an almost constant multiplier n would be obtained by dividing the serial count in Zone 1 by Zone 0 and Zone 2 by Zone 1. The resulting n values of 4.35 and 9.12 respectively, demonstrate that the cited title dispersion in the third zone does not closely model Bradford's Law, as it contains a disproportionately high count of serials. Interestingly, the multiplier for the first two zones is less than, but similar to, that of Bradford (1985). This demonstrates a relatively narrow dispersion in the Core (Zones 0 and 1). For this reason, the 123 titles of the Core were used as the basis upon which to evaluate access.

The analysis of the top 30 serials from the aquatic science category of each of the six global metrics, identified 63 unique titles. Of these, just five occurred in all six metrics and 22 occurred in just one. When the 63 titles were ranked according to the previously-described formula, the top 10 serials by weighted rank most closely matched the top 10 serials by CiteScore metric ranking, with eight of the 10 titles present. The top 30 serials by weighted rank most closely matched the top 30 serials by CiteScore and SCImago Journal Rank ranking, with 26 of the 30 titles present.

Of the 63 unique titles obtained from the six global metrics, 36 serials (57.1%) were cited at least 10 times or by at least five theses. Comparing the top 30 cited serials in theses with the 63 top titles from the six global metrics, 11 serial titles (36.7%) were common to both datasets. Of these *Limnology and Oceanography* and *Marine Pollution Bulletin* were present in all six global metrics, while *Canadian Journal of Fisheries and Aquatic Sciences*, *Coral Reefs*, *Journal of Phycology*, *Marine Biology*, and *Marine Ecology Progress Series* occurred in five. *Aquaculture* and *Journal of Experimental Biology* were present in four of the global metrics and *Journal of Experimental Marine Biology and Ecology* and *Journal of Fish Biology* occurred in just two.

Considering all of the serial titles included across the six global metrics for aquatic science, the top 30 cited serials accounted for 19 (Appendix 1). Analyzing these more closely for each global metric (Table 3), the majority of top 30 cited titles fell in the upper 50th percentile of the metric ranking for all global metrics. For five of the six global metrics, 50% or more of top-cited titles represented in the metric fell into the first quartile.

Citation ages varied substantially with the oldest citation being 162 years at the time of thesis publication and the newest being published or made available as a preprint in the same year as thesis publication. 1,571 or 27.3% of citations were for material prior to 1996 compared to the 54% and 57% observed in Nabe and Imre's (2008) study. This contrast was anticipated due to the elapsed time between their study and the current investigation. Citation ages also varied somewhat by serial title (Table 4). Of the 30 most-cited serials, mean citation ages ranged from two years to 25 years at the time of thesis publication.

Access to serials was assessed for the Bradford dispersion Nucleus (Zone 0, containing 23 titles representing 1,858 citations), Zone 1 (containing 100 titles representing 1,931 citations), and Core (Zones 0 and 1, containing 123 titles representing 3,789 citations). Access was also assessed for the 30 most-cited titles and for the 63 top-rated titles from the six global metrics. The data in Table 5 demonstrate complete current coverage (Subtotal) of all cited serials in the Bradford Nucleus and Top 30 Cited groups. This is supported by strong archival coverage (Full and Extensive Coverage). Strong current coverage is demonstrated in the Bradford Core group (Subtotal, 90.2%) with over half of that portion being Full Coverage (52.0% of total). Strong current coverage of 82.5% (Subtotal) of the 63 top-rated serials of the six global metrics, is satisfactory. Almost half of those serials have Full Coverage (47.6%). While title-by-title

coverage has not been analyzed for the 912 titles in the Bradford Zone 2, it is anticipated that coverage of these titles would be primarily categorized as Current or Partial.

DISCUSSION

Most-Cited Serials

It was anticipated that marine biology graduate students would extensively use marine biology-specific serials, supported by general biology and science titles. We expected the specificity of marine biology serials to result in students discovering higher numbers of potentially-relevant articles therein, compared to serials of much broader scope. We also anticipated serials with broader scope to be cited by more theses than the most specialized serials. The results demonstrate that general science, biology, and ecology titles are of greater relevance than anticipated, as determined by citation counts. The broader subject content of leading general science serials like *Science*, *Nature*, and *Proceedings of the National Academy of Sciences of the United States of America* may be mitigated by their higher publication frequencies compared to many marine biology serials. This increases the probability of relevant marine biology articles being found within these serials in a given publication year. Furthermore, the broad subject content found in general science titles increases the likelihood of multiple master's students with diverse marine biology thesis specialties locating relevant articles.

Marine biology incorporates multiple biology sub-disciplines as well as interdisciplinary links with other fields such as fisheries and aquaculture, environmental science, biomedicine, bioengineering, and genomics. Many serials focus on such sub-disciplines and inter-disciplinary research areas, independently of specific research contexts. Yet they are valid publication outlets for marine biology articles. For example, a number of theses cited serials in the interdisciplinary

fields of environmental toxicology and biochemistry. Additionally, and important to the context of this study, numerous students conducted their theses with an emphasis on fisheries in collaboration with SCDNR. Fisheries and aquaculture fall under the Library of Congress Classification of Agriculture. Several serials devoted to this sub-discipline were also cited, with five in the top 30 titles. We observed that students cited broadly from biology sub-disciplines that transcend the marine context, with 12 (40%) of the 30 most-cited serials being independent of the aquatic, fisheries/aquaculture, and marine biology fields.

Such diversity of cited serial sources has implications for collection management where subscribed serials may be assigned to a single fund code or subject area, potentially compartmentalizing decision making. To mitigate this, the CofC Libraries Collection Development Committee includes two representatives from the public services librarians to increase perspective in decision making. A number of serials that were highly cited in the current study are assigned to other subject fund codes like environmental science and chemistry. The relevance of these serials to marine biology research will be documented for future reference, to ensure adequate representation of marine biology researchers in future renewal decisions.

Citation of Top-Rated Aquatic Science Serials

With current access available to 82.5% of the 63 top-rated aquatic science serials in global serial metrics, ample opportunity exists to cite scholarship published therein. Of these 63 titles, 57.1% were cited 10 or more times or by at least five theses, and 36.7% were in the top 30 cited serials. We do not know why students chose to cite top-rated aquatic science serials. They may have selectively searched them based upon reputation. Alternatively, scholarship from such titles may have featured particularly prominently in online search results. We acknowledge that

the aquatic science category includes both freshwater and marine sub-disciplines. Some serials in this category, therefore, are not of significant interest in a marine biology context.

We observed that several highly-rated titles with a general science classification including *Nature*, *Science*, *Proceedings of the National Academy of Sciences of the United States of America*, *Proceedings of the Royal Society of London: B*, and *PLoS One* were also frequently cited by students. Additional prominent titles assigned to biology, ecology, and other subject categories on the global citation metric platforms were also highly cited. These did not occur in the aquatic science metrics by virtue of their broader scope or alternative emphasis with regards to subject matter.

Serial Citation Dispersion

The dispersion of cited serials observed in this study is greater than that described by the 80/20 Rule and Bradford's Law. We observed that 25% of cited serials are needed to account for 80% of citations. Similarly, we observed that a disproportionately high number of serial titles was represented in the third Bradford zone, at 912 titles or 88.1%. These observations may be a result of the great diversity of serials in which marine biology-related articles can now be published. This is surely a much greater number than when the 80/20 Rule and Bradford's Law were first used in citation analysis. Such diversity includes serials that are broadly-scoped, field or context-specific, and from other disciplines that now interface with marine biology research.

Furthermore, the ability of students to search thousands of serials using online A&I databases, discovery platforms, and the internet, facilitates the discovery of scholarship in unexpected places. The search and discovery process is decreasingly linear and increasingly serendipitous as subject boundaries are seamlessly traversed. Nisonger (2008) suggested that

online research resources would result in an increased number of serials required to satisfy a given percentage of total citations. This poses a logistical challenge for libraries. How can we best fund and deliver the diverse content that researchers are discovering, especially if they expect immediate access?

Serial Citation Ages

The age distribution of articles cited was anticipated to be biased towards current content. Older content was also expected to be cited, particularly related to species-specific classifications and descriptions that have been published historically. Additionally, the three most relevant A&I databases available to CofC marine biology students do not provide extensive retrospective coverage (Web of Science, 1980-present; Aquatic Sciences and Fisheries Abstracts, 1971-present; and Zoological Record Plus, 1978-present). Access to JSTOR at CofC provides strong archival coverage in biology, although it is promoted to marine biology graduate students as a source of full text content rather than as a search tool. Google Scholar and EBSCO Discovery Service are popular search interfaces that provide exposure to the greatest breadth of scholarship, including older content. JSTOR and numerous mainstream publishers, such as Elsevier, Springer, and Wiley, are indexed by Google Scholar. Nearly all CofC serial and database subscriptions are searchable by EBSCO Discovery Service.

Overall citation age distribution was of the pattern expected. Results demonstrated that during the six-year period evaluated, 50% of serial citations were aged 10 years or less, 75% 18 years or less, and 90% 29 years or less. 72.7% of cited materials were published in 1996 or later. This is very similar to Keogh's (2012) analysis with pharmacy serial citations, concluding serial retention requirements for 50% of citations to be nine years, 80% to be 18 years, and 90% to be

27 years. Citation age distribution by serial title is directly dependent upon the length of time a serial has been published. For example, *PLoS One* exhibited the lowest mean citation age of two years and a median year of 2011 in this study, but it was first published in 2006. It is beyond the scope of this study to try to explain why this pattern exists or to interpret the varying citation age distributions observed among individual titles. It would be interesting, however, to attempt to determine if, or to what extent, a title's online accessibility over print had any significant effect on the total number of citations.

Serial Access

Access to serials is provided by several acquisition methods. These include individual serial and package subscriptions, subscription to/ownership of current or archival content in databases, current print subscriptions (where online is not available), and ownership of print archives. The extent of access possible is dependent upon budgets. Archival access has been supported in recent years by acquisition of JSTOR collections with end-of-year funds. Strong current access to the existing breadth of cited titles is made possible by serial package contracts with some of the largest scientific and multidisciplinary publishers.

Access to articles in non-subscribed serials is achieved using the library's Interlibrary Loan (ILL) service. Integrated with the library's link resolver, the process of requesting an ILL article is simple. The link resolver is represented by a button which appears in databases and Google Scholar (when configured for our institution). Upon accessing the link resolver and logging into their ILL account, users submit a pre-populated form to request the article. Processing normally occurs within one business day and articles are received electronically,

often within two or three days. This speed is facilitated by the careful selection of libraries from which articles are requested.

We acknowledge that some graduate students never use ILL. When students restrict themselves to resources immediately available at their library, or even limit themselves further to online resources only, their citation patterns become increasingly defined by access rather than by their endeavors to discover scholarship. This is unfortunate and can perhaps be mitigated by timely reinforcement of library skills, including use of ILL, as graduate students begin their thesis research. We also recognize that we are unable to track informal methods used to access articles, such as the provision thereof by advisors or friends and colleagues at other institutions.

The observed citation patterns in this study demonstrate that access to current content should be given the highest priority. Herein lies the problem: Current access to serials necessitates recurring expenditure, while archival access can sometimes be achieved as purchases utilizing one-time funds at the end of fiscal cycles without ongoing commitment.

CONCLUSION

The analysis of serial citations in marine biology graduate theses has enhanced our understanding of the recent use of the serial collection by marine biology master's students at our institution. The most-cited serials and the diversity of serials utilized beyond the immediate marine science discipline has raised our awareness of the importance of interdisciplinary consideration during collection management decision making. As research increasingly traverses traditional subject boundaries, it is essential to ensure that all stakeholders are appropriately represented during collection management decisions.

The adequacy of the collection is demonstrated by strong current coverage of a core of 123 titles, which is fiscally attainable, in part, by big deal package subscriptions. If the budget situation were to necessitate the reevaluation of these subscriptions, their significance for marine biology graduate students may be presented as evidence. Archival coverage of highly-cited titles with high mean citation ages should be further explored, with investment in back files of Zoological Record made to enhance the discovery of older research, if opportunity arises. We must also better engage students to ensure sufficient understanding and use of ILL services, so that their research is freely shaped by inquiry rather than restrained by access.

The techniques described in this study to document and analyze the tangible evidence of serial use, namely citations in works produced by an institution's scholars, may be applied in other contexts to gain further insight into serial collection use. Important or underutilized serial titles may be identified, and awareness of the use of older articles may be developed. For institutions where budgets remain challenging and where deselection of the least-utilized serials has already been completed, the application of the methodology utilized at the MRL will generate data to support difficult collection management decisions. For institutions seeking to expand serial access, the application of these techniques may identify opportunities to enlarge back files or to add highly-rated or interdisciplinary serials.

This study has identified the serials most cited by marine biology graduate students in their master's theses but has not explored some aspects of user behavior. Further investigation is recommended to identify the influence of serial format and availability upon citation likelihood. Investigation of the subject classifications of cited serials is suggested to model the interdisciplinary nature of marine biology research. Research into correlations between advisor

and advisee citation patterns could reveal indicators of influence. Lastly, subjective evaluation should be developed to assess non-citing use of serials, such as reading for scholarly awareness.

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Figure 1. PostgreSQL database structure.

Figure 2. Serial citations per thesis and unique serials per thesis.

Figure 3. Citation ages at time of thesis publication.

Table 1. Ranking of most-cited serials by citation count and number of citing theses

Title	Combined Rank	Average Rank	No. of Citing Theses	Rank by Thesis Count	No. of Citations	Rank by Citation Count
Marine Ecology Progress Series	1	1	50	1	216	1
Science*	2	2.5	41	3	116	2
Journal of Experimental Marine Biology and Ecology	3	3.5	39	4	114	3
Marine Biology	4	4.5	42	2	98	7
Bulletin of Marine Science	5	5.5	28	7	107	4
Proceedings of the National Academy of Sciences of the United States of America*	5	5.5	33	6	106	5
Limnology and Oceanography	7	6.5	28	7	99	6
Nature*	8	7	35	5	83	9
Ecology*	9	7.5	28	7	89	8
Transactions of the American Fisheries Society†	10	11.5	23	11	70	12
Fishery Bulletin†	11	12	22	13	71	11
PLoS One*	11	12	24	10	62	14
Journal of Fish Biology	13	14	22	13	59	15
Aquaculture†	14	15	19	17	65	13
Canadian Journal of Fisheries and Aquatic Sciences†	14	15	22	13	58	17
Journal of Phycology	16	17.5	15	25	74	10
Environmental Biology of Fishes	17	18	17	21	59	15
Journal of Experimental Biology*	17	18	19	17	55	19
Estuaries	19	20.5	22	13	41	28
Evolution*	20	21.5	17	21	48	22
Molecular Ecology*	21	22	16	23	49	21
Proceedings of the Royal Society of London, Series B: Biological Sciences*	21	22	23	11	34	33
Journal of Shellfish Research	23	24.5	16	23	42	26

Marine Pollution Bulletin	24	25	18	19	36	31
Coral Reefs	25	25.5	15	25	42	26
Biological Bulletin*	26	27	15	25	40	29
Journal of Biological Chemistry*	27	28.5	15	25	35	32
Environmental Health Perspectives*	28	29.5	13	35	46	24
North American Journal of Fisheries Management†	29	30.5	15	25	33	36
Copeia	30	32.5	15	25	30	40

* Serial scope is broader than aquatic science, fisheries, aquaculture, and marine biology.

† Serial is focused on aquaculture or fisheries.

Table 2. Bradford dispersion grouping

Zone	Citation Count	Serial Count	Multiplier <i>n</i>
0	1,858	23	-
1	1,931	100	4.35
2	1,958	912	9.12
Totals	5,747	1,035	

Table 3. Most-cited serials found in the aquatic science category of one or more global serial ranking metrics

Title	No. of Metrics	No. of Q1	Impact Factor		Eigenfactor		SCImago Journal Rank		H-Index		CiteScore		SNIP	
			Rank	Quartile	Rank	Quartile	Rank	Quartile	Rank	Quartile	Rank	Quartile	Rank	Quartile
Aquaculture	6	5	42	Q2	5	Q1	30	Q1	6	Q1	36	Q1	13	Q1
Biological Bulletin	2	0	56	Q2	53	Q2								
Bulletin of Marine Science	6	1	45	Q2	49	Q2	50	Q2	48	Q1	64	Q2	84	Q2
Canadian Journal of Fisheries and Aquatic Sciences	6	6	19	Q1	17	Q1	21	Q1	5	Q1	29	Q1	40	Q1
Copeia	2	0					96	Q2	61	Q2				
Coral Reefs	6	5	11	Q1	18	Q1	6	Q1	22	Q1	18	Q1	63	Q2
Environmental Biology of Fishes	6	1	62	Q3	33	Q2	74	Q2	34	Q1	87	Q2	73	Q2
Fishery Bulletin	4	2					33	Q1	59	Q2	59	Q2	31	Q1
Journal of Experimental Biology	4	4					4	Q1	4	Q1	25	Q1	22	Q1
Journal of Experimental Marine Biology and Ecology	6	3	48	Q2	11	Q1	41	Q1	16	Q1	52	Q2	80	Q2
Journal of Fish Biology	6	2	67	Q3	16	Q1	54	Q2	19	Q1	66	Q2	64	Q2
Journal of Phycology	6	5	18	Q1	20	Q1	17	Q1	12	Q1	17	Q1	53	Q2
Journal of Shellfish Research	6	0	85	Q3	54	Q2	107	Q3	65	Q2	105	Q3	94	Q2
Limnology and Oceanography	6	6	4	Q1	4	Q1	2	Q1	2	Q1	2	Q1	7	Q1
Marine Biology	6	5	23	Q1	10	Q1	19	Q1	15	Q1	30	Q1	67	Q2
Marine Ecology Progress Series	6	5	25	Q1	2	Q1	13	Q1	3	Q1	20	Q1	48	Q2
Marine Pollution Bulletin	6	6	8	Q1	3	Q1	22	Q1	8	Q1	8	Q1	16	Q1
North American Journal of Fisheries Management	4	0					85	Q2	57	Q2	101	Q3	79	Q2
Transactions of the American Fisheries Society	4	1					61	Q2	35	Q1	75	Q2	65	Q2

Table 4. Citation ages of most-cited serials

Title	Mean Citation Age (Years)	Std. Dev.	Median Year	Median Citation Age (Years)
Marine Ecology Progress Series	12	7.66	2002	11
Science	15	11.92	2002	11
Journal of Experimental Marine Biology and Ecology	15	10.05	1998	14
Marine Biology	15	10.16	2000	13
Bulletin of Marine Science	19	10.04	1994	20
Proceedings of the National Academy of Sciences of the United States of America	12	8.86	2002	11
Limnology and Oceanography	17	11.78	1998	15
Nature	15	12.39	2000	12
Ecology	21	18.82	1996	16
Transactions of the American Fisheries Society	19	13.4	1996	16
Fishery Bulletin	23	16.99	1992	21
PLoS One	2	1.72	2011	2
Journal of Fish Biology	13	11.44	2004	9
Aquaculture	12	7.68	2002	12
Canadian Journal of Fisheries and Aquatic Sciences	14	8.95	2000	13
Journal of Phycology	12	7.72	2001	11
Environmental Biology of Fishes	11	9.4	2003	8
Journal of Experimental Biology	18	11.8	1998	16
Estuaries	18	8.71	2000	15
Evolution	18	9.12	1996	16
Molecular Ecology	7	3.72	2006	6
Proceedings of the Royal Society of London, Series B: Biological Sciences	10	9.12	2003	9
Journal of Shellfish Research	9	6.61	2005	7

Marine Pollution Bulletin	9	6.39	2005	7
Coral Reefs	9	7.17	2005	8
Biological Bulletin	19	15.89	1997	16
Journal of Biological Chemistry	19	18.67	2001	12
Environmental Health Perspectives	11	7.41	2001	10
North American Journal of Fisheries Management	11	8.3	2002	10
Copeia	25	14.78	1992	20

Table 5. Access to most-cited and top-rated serials at College of Charleston

Group	Full Coverage ¹		Extensive Coverage ²		Current Coverage ³		SUBTOTAL		Partial Coverage ⁴		No Coverage		TOTAL	
	No. Titles	% Titles	No. Titles	% Titles	No. Titles	% Titles	No. Titles	% Titles	No. Titles	% Titles	No. Titles	% Titles	No. Titles	% Titles
Bradford Nucleus (Zone 0)	18	78.3	1	4.3	4	17.4	23	100	0	0.0	0	0.0	23	100
Bradford Zone 1	46	46.0	6	6.0	36	36.0	88	88.0	11	11.0	1	1.0	100	100
Bradford Core (Zones 0+1)	64	52.0	7	5.7	40	32.5	111	90.2	11	9.0	1	0.8	123	100
Top 30 Cited	25	83.3	2	6.7	3	10.0	30	100	0	0.0	0	0.0	30	100
Top Rated (independent of citation)	30	47.6	3	4.8	19	30.1	52	82.5	3	4.8	8	12.7	63	100

¹ Complete coverage from the first volume through the last published volume.

² Nearly full coverage with both current coverage (as defined below) and no more than five years of archival gaps.

³ Coverage of 1997 through present.

⁴ Less than current coverage.

Appendix 1: 30 Most-Cited Serials by Citation Count and Number of Citing Theses

Aquaculture†
Biological Bulletin*†
Bulletin of Marine Science†
Canadian Journal of Fisheries and Aquatic Sciences†
Copeia†
Coral Reefs†
Ecology*
Environmental Biology of Fishes†
Environmental Health Perspectives*
Estuaries
Evolution*
Fishery Bulletin†
Journal of Biological Chemistry*
Journal of Experimental Biology*†
Journal of Experimental Marine Biology and Ecology†
Journal of Fish Biology†
Journal of Phycology†
Journal of Shellfish Research†
Limnology and Oceanography†
Marine Biology†
Marine Ecology Progress Series†
Marine Pollution Bulletin†
Molecular Ecology*
Nature*
North American Journal of Fisheries Management†
PLOS One*
Proceedings of the National Academy of Sciences of the United States of America*
Proceedings of the Royal Society of London, Series B: Biological Sciences*
Science*
Transactions of the American Fisheries Society†

* Serial scope is broader than aquatic science, fisheries, aquaculture, and marine biology.

† Serial found in the upper 50th percentile in the aquatic science category of one or more global serial ranking metrics