Journal of Experimental Marine Biology and Ecology 377 (2009) 93–100

Contents lists available at ScienceDirect

Journal of Experimental Marine Biology and Ecology

journal homepage: www.elsevier.com/locate/jembe

Terrestrial ecologists ignore aquatic literature: Asymmetry in citation breadth in ecological publications and implications for generality and progress in ecology☆

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ARTICLE INFO

Article history:
Received 27 June 2009
Accepted 29 June 2009

Keywords:
Citation asymmetry
Freshwater
Generality in ecology
Literature survey
Marine
Terrestrial

ABSTRACT

The search for generality in ecology should include assessing the influence of studies done in one system on those done in other systems. Assuming generality is reflected in citation patterns, we analyzed frequencies of terrestrial, marine, and freshwater citations in papers categorized as terrestrial, marine and freshwater in high-impact "general" ecological journals. Citation frequencies were strikingly asymmetric. Aquatic researchers cited terrestrial papers ~10 times more often than the reverse, implying uneven cross-fertilization of information between aquatic and terrestrial ecologists. Comparisons between citation frequencies in the early 1980s and the early 2000s for two of the seven journals yielded similar results. Summing across all journals, 60% of all research papers ($n=5824$) published in these journals in 2002–2006 were terrestrial vs. 9% freshwater and 8% marine. Since total numbers of terrestrial and aquatic ecologists are more similar than these proportions suggest, the representation of publications by habitat in "general" ecological journals appears disproportional and unrepresentative of the ecological science community at large. Such asymmetries are a concern because (1) aquatic and terrestrial systems can be tightly integrated, (2) pressure for across-system understanding to meet the challenge of climate change is increasing, (3) citation asymmetry implies barriers to among-system flow of understanding, thus (4) impeding scientific and societal progress. Changing this imbalance likely depends on a bottom-up approach originating from the ecological community, through pressure on societies, journals, editors and reviewers.

1. Introduction

A prime motivation in research is to ask if one's results are applicable to systems beyond the one of focus. Given the immense diversity of ecological systems, answering this question is key to advancing our understanding of community and ecosystem functioning. In community and ecosystem ecology, however, the search for generality often seems hindered by a relative lack of awareness of progress in other systems. For example, several authors have commented on the gap in communication between scientists working in aquatic and terrestrial habitats (e.g., Steele, 1991; Chase, 2000; Stergiou and Browman, 2005a; Richardson and Poloczanska, 2008). In some respects, this terrestrial vs. aquatic "controversy" is based on real and important contrasts. Terrestrial and aquatic environments are inherently different, as reflected in several aspects of the ecology of the communities and organisms within them (Carr et al., 2003). However, most fundamental ecological processes are shared among systems. Further, contrary to the opinions of some (e.g., Richardson and Poloczanska, 2008), much of our conceptual framework applies across all systems with ideas flowing in both directions between aquatic and terrestrial arenas (e.g., Halley, 2005; Paine, 2005; Raffaelli et al., 2005).

But what is generality, exactly? As implied by the above-cited controversy, is it the extent to which results in one habitat apply to systems in other habitats? That is, do outcomes obtained in a study conducted in a terrestrial environment contribute to inductively reasoned inferences about the dynamics of systems occurring in the other major habitat types, marine or freshwater? We define this as "habitat" generality. Or is generality more theoretical, in which model results apply to a broad range of populations, communities or ecosystems? "Theoretical" generality was one of a triumvirate of

☆ Editor's Note: This paper represents the complete version of a manuscript that was shortened and published as a "peer-reviewed" letter to the editor in *Frontiers in Ecology and the Environment* (2009, Vol 7:182–183). Having read and commented upon the original version, this Editor noted that key pieces had been deleted in the shorter version and encouraged the authors to submit the manuscript in its original form to JEMBE. The issues discussed are important and pertinent to all ecological research, be it marine, aquatic or terrestrial. S.E. Shumway.

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doi:10.1016/j.jembe.2009.06.024

Table 1
Ranking of "impact factors" of top ecological journals, 2003–2007.

Journal	ISI CI Mean ± 1SEM	ISI CI range	AI	Category
Trends in Ecology & Evolution	13.85 ± 0.50	12.44–14.96	8.98	Broad
Ann. Rev. of Ecology, Evolution & Systematics	9.17 ± 0.76	6.18–10.34	8.39	Review
Ecological Monographs	5.98 ± 0.69	4.79–8.12	3.98	General
Ecology Letters	5.82 ± 0.88	3.91–8.20	3.69	General
Molecular Ecology	5.11 ± 0.71	3.87–5.17	2.01	Specialized
American Naturalist	4.44 ± 0.10	4.06–4.66	2.98	General
Ecology	4.38 ± 0.21	3.70–4.82	2.84	General
Frontiers in Ecology and Evolution[a]	4.30 ± 0.30	3.36–4.84	2.56	Broad
Journal of Applied Ecology	3.96 ± 0.30	3.21–4.59	1.76	Specialized
Journal of Ecology	3.83 ± 0.31	2.83–4.42	1.97	General
Ecological Applications	3.40 ± 0.16	2.85–3.80	2.29	Specialized
Journal of Animal Ecology	3.34 ± 0.14	2.84–3.75	1.94	General
Ecosystems	3.12 ± 0.14	2.68–3.46	2.16	General
Oecologia	3.07 ± 0.07	2.90–3.33	1.81	General
Oikos	2.97 ± 0.22	2.14–3.38	1.72	General
Functional Ecology	2.96 ± 0.19	2.35–3.42	1.59	General
Marine Ecology Progress Series	2.27 ± 0.08	2.05–2.55	1.15	Specialized
J. of North American Benthological Society	2.04 ± 0.15	1.58–2.37	1.20	Specialized
J. of Experimental Marine Biology & Ecology	1.70 ± 0.06	1.59–1.92	0.83	Specialized

Based on ISI citation index (Thomson Reuters Inc.), with Article Influence (AI) Index (http://www.eigenfactor.org) included for comparison. Categories: Broad = summaries of new developments and ideas; Review = reviews of current issues; General = primary research journals for all areas of ecology; Specialized = primary research journals for specific areas of ecology. Journals highlighted in bold italics are the seven surveyed in this study. Italicized journals had too few aquatic papers to allow statistical analysis. Table first appeared as Webtable 1 in supplementary material for article in *Frontiers in Ecology and the Environment* 7:182-183, 2009.
[a] Publication began in 2004.

characteristics (generality, precision, and realism) identified decades ago by Levins (1966) as a tradeoff that constrained the effects of model builders, with the asserted limitation that particular types of models (analytical, simulations) could satisfy two but not all three of these traits. Generality could also be "geographic," such that results obtained in a particular type of ecosystem in one geographic region apply to the same type of ecosystems located in different geographic regions. Another possible form of generality is conceptual, in which ecological concepts such as top-down, bottom-up, trophic cascade, positive interactions and intermediate disturbance provide a deductive framework for investigating patterns and processes that may operate across broad suites of individual systems (e.g., Chase, 2000).

Here we focus on generality as reflected in citation patterns of terrestrial, marine and freshwater papers in publications categorized into these three groups. Our interest in examining habitat generality was prompted by personal experience and comments of colleagues (see e.g., Underwood, 2005) that reviewers often criticized submissions of marine ecological papers to general journals as not being of sufficiently broad interest; they were "too marine." The usual guidance was to demonstrate that results were of interest to a non-marine audience, usually understood as terrestrial.

Such comments made us wonder if non-marine authors received similar criticisms. In lieu of directly surveying authors, a difficult and relatively subjective method, we approached this question through a literature survey. Assuming that the extent of comparison of one's results would be reflected in the frequency of citations of papers from other systems, and using papers sampled from general ecological journals, we estimated the proportions of marine, freshwater, and terrestrial citations in marine, freshwater and terrestrial publications in community and ecosystem ecology. To assess the publication scenario against which these citation frequencies occur, we also summarized the frequencies of all terrestrial, marine, freshwater papers in each journal. Of course, one would expect that, correcting for citations that may largely be independent of habitat (methodological, conceptual/theoretical, reviews/books, and theses, collectively termed "other"), most citations in a terrestrial (or marine or freshwater) paper, for example, will be terrestrial (or marine or freshwater). But if all authors are being urged to emphasize generality or breadth independently of habitat, then the proportion of citations of papers from habitats other than the subject of the paper should be similar regardless of whether the paper was terrestrial, marine or freshwater.

2. Methods

We surveyed ten general ecological journals having the highest impact factors in which community and ecosystem ecology papers were frequently published. Our primary measure of impact was the ISI Impact factor index (http://www.isiwebofknowledge.com), averaged over 2003–2007 (Table 1). For comparison we also show a second measure, the eigenfactor index (Table 1; http://www.eigenfactor.org). Journals that specialize in reviews, applied papers, discussion, perspectives, ideas, and current events were excluded (e.g., *Trends in Ecology and Evolution*, *Frontiers in Ecology and Evolution*, *Advances in Ecological Research*, *Annual Review of Ecology*, *Evolution and Systematics*, *Ecological Applications*, *Journal of Applied Ecology*). On this basis, the top ten "general" journals were, in order, *Ecological Monographs*, *Ecology Letters*, *American Naturalist*, *Ecology*, *Journal of Ecology*, *Journal of Animal Ecology*, *Ecosystems*, *Oecologia*, *Oikos*, and *Functional Ecology* (Table 1).

Community and ecosystem papers were defined as those involving more than a single species, that examined species interactions or how species assemblages were influenced by the physical, chemical or biotic environment, and that dealt with at least one of the relevant conceptual topics (Table 2). When possible, the title and keywords of the papers

Table 2
Summary of literature survey.

Period	Habitat of source paper	Journal							
		American Naturalist	Ecology Letters	Ecological Monographs	Ecology	Ecosystems	Oecologia	Oikos	Total
Recent	Terrestrial	62 (28)	57 (7)	41 (35)	49 (0)	48 (0)	47 (0)	55 (2)	359 (72)
	Freshwater	15 (7)	21 (11)	6 (5)	24 (4)	14 (2)	23 (11)	24 (10)	127 (50)
	Marine	7 (4)	27 (11)	18 (14)	23 (5)	15 (10)	28 (16)	19 (12)	137 (72)
Past	Terrestrial	28 (6)	na	na	53 (0)	na	na	na	81 (6)
	Freshwater	6 (2)	na	na	32 (14)	na	na	na	38 (16)
	Marine	11 (6)	na	na	29 (19)	na	na	na	40 (25)
	Total	129 (53)	105 (29)	66 (54)	215 (42)	82 (12)	98 (27)	99 (24)	793 (241)

Data are number of papers in each category, with number of non-randomly selected papers shown in parentheses. Periods were 2002–2006 (recent) and 1980–85 (past). Conceptual categories included in survey: biodiversity, bottom-up, climate change, community assembly, community dynamics, competition, connectivity, dispersal, disturbance, disease, diversity, ecosystem engineers, environmental stress, facilitation, functional role of diversity, functional response, food web, herbivory, intermediate disturbance, indirect effects, island biogeography, interaction strength, interaction web, introductions, invasions, keystone species, keystone predation, meta-community, meta-ecosystem, numerical response, parasitism, predation, productivity, resilience, species richness, stability, source-sink, succession, top-down, tritrophic interactions, and trophic cascade. Table is modified from Webtable 5 in supplementary material for article in *Frontiers in Ecology and the Environment* 7:182-183, 2009.

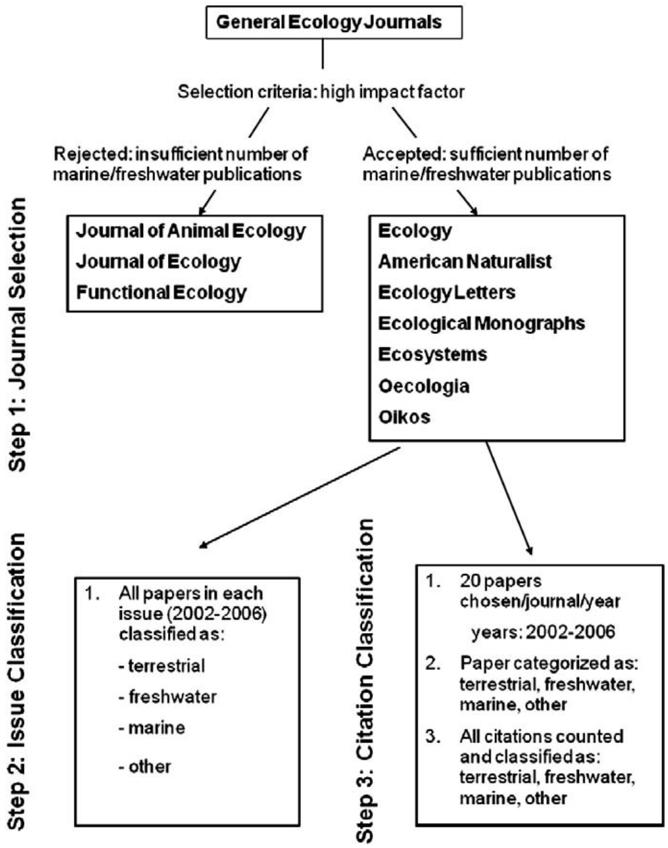

Fig. 1. Protocol used to select and classify papers used in survey. Modified from Webfigure 1 in supplementary material for article in *Frontiers in Ecology and the Environment 7*:182-183, 2009.

were used to determine suitability for inclusion. Sometimes these provided no clue as to the habitat, however, so we read the abstract or text to enable classification.

Our protocol is diagrammed in Fig. 1. Three top ten journals (*Journal of Ecology*, *Journal of Animal Ecology*, *Functional Ecology*) were dropped because they rarely publish marine and/or freshwater papers (e.g., Fig. 2). We analyzed articles from the five most recent years available, 2002–2006. To test if patterns had changed over time, we compared counts from 1980–1985 issues of *Ecology* and *American Naturalist* to counts for these journals from 2002–2006. We attempted to select 20 papers at random from each year in each journal, but in most journals random sampling failed to yield many aquatic papers. Thus, after ~12–15 randomly selected papers, we searched non-randomly in order to include three marine and three freshwater papers per year.

For each paper, we counted the total number of citations, and then categorized each as marine, freshwater, terrestrial, and "other." "Other" included citations of review and methods papers (often spanning multiple habitats or dealing with habitat-free topics), books (typically reviews, methods and/or conceptual), and theoretical or conceptual papers (usually independent of habitat). Special cases also categorized in "other," all rare, included theses, papers assessed as being focused on interactions between adjacent habitats ("transitional") or papers with studies from more than one habitat ("mixed"). Meta-analyses, often specifically examining across-system generality (e.g., Borer et al., 2005; Shurin et al., 2002), were also grouped as "other." Foreign language citations were excluded.

We also categorized all papers in all issues (Figs. 1, 2). We examined 5824 papers, of which 3516 were terrestrial, 1302 were "other," 542 were freshwater and 464 were marine (see Fig. 2 caption). For these issue statistics, "other" papers were on topics such as evolutionary biology, behavioral ecology, physiological ecology, and population ecology.

2.1. Data analysis

We tested two null hypotheses:

- H_{01}: the proportion of citations of papers in habitats other than the one which was the subject of the "source" paper was similar across all habitats.
- H_{02}: the proportion of citations reflected the frequency of papers published in each category.

To test H_{01}, we analyzed differences in citation frequency among journals using three-way analysis of variance followed by linear contrasts to detect differences among habitat of source reference, habitat of citations and journal. Similarly, to analyze citation pattern variation between different periods, we used three-way analysis of variance followed by linear contrasts to sort out the contributions of habitat of source reference, habitat of citations and period (past vs. recent papers). The variable used in the analysis was the proportion of references for each of the three habitat types in each paper. Thus each paper provided three data points. The proportions of citations for habitat type from each paper are independent data points because of the presence of the fourth category, "other." Proportional data were *ln*-transformed prior to analysis to normalize the data. Similar results were obtained using arcsine-transformed data, with similar distributions of residuals, normality and equal variances, so we used the *ln*-transformed analysis which explained about 5% more variance. To test H_{02}, we used log-likelihood methods. We compared the total number of citations of marine, terrestrial and freshwater paper by publications in each group to the total number of published papers sorted by habitat. For this analysis we used only papers or citations categorized by habitat since "other" papers were not comparable (see above). Analyses were done using JMP v 7.0.

3. Results

Overall we analyzed citation statistics for 793 papers, 55% (440) of which were terrestrial, 21% (165) freshwater and 22% (177) marine (Table 2). Similar proportions were sampled for the past vs. recent analysis (58%, 20%, and 22% from 2002–2006 vs. 51%, 24% and 25%, respectively, from 1980–1985). By journal, numbers ranged from 65

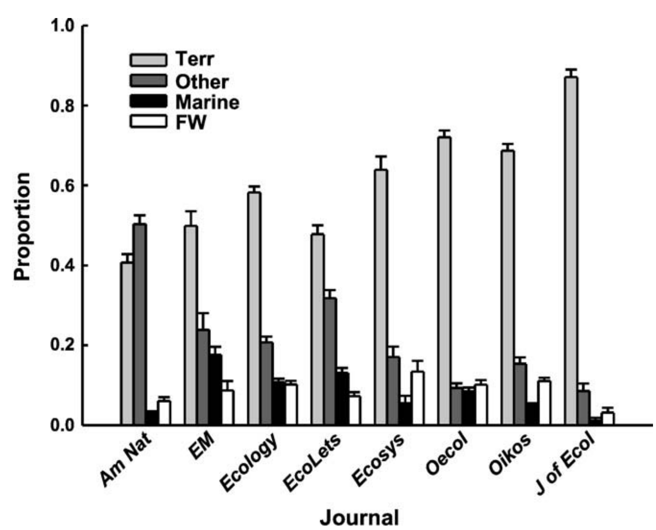

Fig. 2. Frequencies of publication of terrestrial, "other", marine and freshwater papers from 2002 to 2006 for seven general journals surveyed with three years (2002–2004) of data from Journal of Ecology for comparison. Based on a total of 5824 papers, with 3516 terrestrial, 1302 "other," 542 freshwater and 464 marine. Totals by journal were 766 in *American Naturalist* (= Am Nat), 151 in *Ecological Monographs* (= EM), 1617 in *Ecology*, 676 in *Ecology Letters* (= EcoLets), 322 in *Ecosystems* (= Ecosys), 912 in *Oecologia* (= Oecol), 1116 in *Oikos* and 264 in *Journal of Ecology*. Modified from Figure 2 in article in *Frontiers in Ecology and the Environment 7*: 182-183, 2009.

(*Ecological Monographs*) to 105 (*Ecology Letters*) (Table 2). Similar numbers of freshwater and marine papers were analyzed within each journal except for *American Naturalist* (only 7 marine papers) and *Ecological Monographs* (only 6 freshwater papers), dictated by availability in both cases.

3.1. General patterns

As expected, during 2002–2006 all groups cited papers from their habitat of focus most frequently (63.4% terrestrial citations by terrestrial authors, 46.4% freshwater citations by freshwater authors and 54.9% marine citations by marine authors; Fig. 3a). Citation frequencies of papers from other habitats were strikingly asymmetrical, however, rejecting H_{01}. Marine researchers cited terrestrial papers 10.4 times more often than terrestrial researchers cited marine researchers (8.4% vs. 0.81%; linear contrasts, $p<0.0001$) (Fig. 3a). Similarly, freshwater researchers cited terrestrial research 8.9 times more often than terrestrial researchers cited freshwater researchers (8.9% vs. 1.0%; linear contrasts, $p<0.0001$). Further, fully 77.2% (277 of 359) and 78.3% (281 of 359) of terrestrial papers cited no marine or freshwater papers, respectively, while only 22.6% (31 of 137) and 29.9% (38 of 127) of marine and freshwater papers, respectively, cited no terrestrial papers.

Alternatively, citation frequencies simply could reflect publication rates in the seven general journals (H_{02}). Log-likelihood analysis of frequencies does not support H_{02} (Table 3). Although terrestrial papers were published far more often than were marine and freshwater papers (Fig. 2, Table 3; 77.8% vs. 10.3% and 12.0%, respectively), citation frequencies of marine and freshwater papers by authors of terrestrial papers was even more strongly skewed from aquatic citations (97.3% terrestrial, 1.3% marine, 1.5% freshwater). Of course, citations in marine and freshwater were skewed in favor of aquatic citations (Table 3), but again, the citation frequency of terrestrial papers in aquatic papers was much greater (11.8% for marine citations of terrestrial papers, 15.1% for freshwater citations of terrestrial papers) than the reverse. The elevated citation rate of terrestrial papers by aquatic authors may be due to the sheer predominance of terrestrial papers, but clearly terrestrial authors do not cite in relation to the overall frequencies of each type of paper.

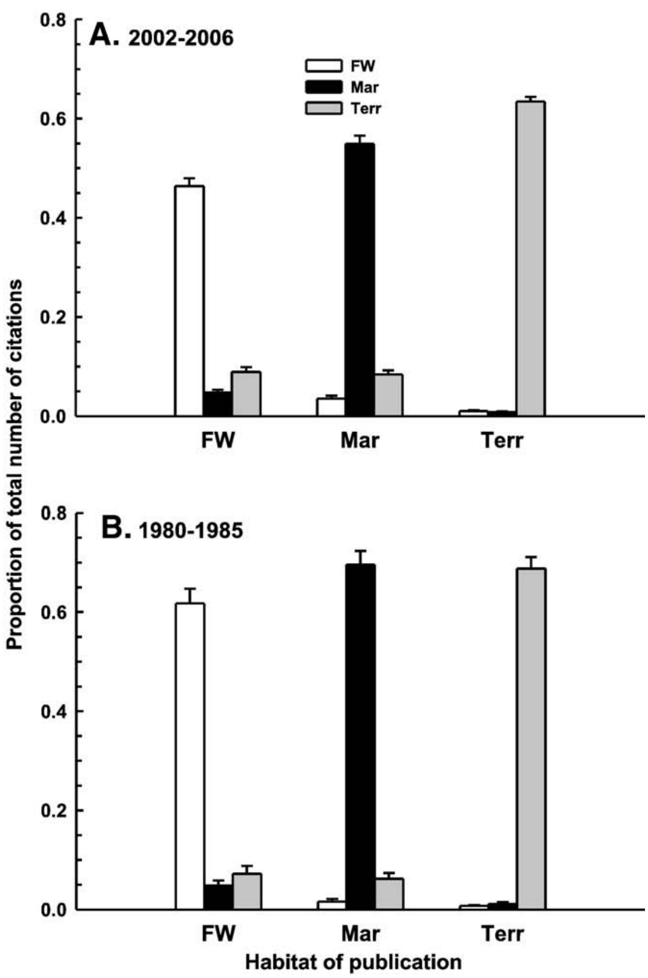

Fig. 3. Frequencies of citations of papers from freshwater, marine and terrestrial habitats in papers done in each of these three habitats in (A) 2002–2006 summed across all seven journals surveyed and (B) in papers published in *American Naturalist* and *Ecology* combined in 1980–84. Modified from Figure 1 in article in *Frontiers in Ecology and the Environment 7*:182-183, 2009.

3.2. Patterns by journal

Overall patterns of citation frequencies across the seven journals in both time periods appeared relatively similar (Fig. 4). In most journals the frequency of non-source citation habitats was greater in aquatic than in terrestrial papers (Fig. 4). Citation frequencies were context-dependent, however, and varied by journal, habitat of source and habitat of citation (Table 4; three-way interaction). With the exception of *Ecosystems*, citation frequencies of non-source references for studies done in aquatic habitats tended to be greater than non-source references for studies done in terrestrial habitats (Fig. 4, linear contrasts based on analysis in Table 4).

3.3. Temporal patterns

In *Ecology* and *American Naturalist*, citation patterns in the past (1980–85) were similar to those in 2002–06 (Fig. 3b). Freshwater authors cited terrestrial papers 9.7 times more often than the reverse, and marine authors cited terrestrial papers 5.2 times more often than the reverse, suggesting this trend has persisted for at least 20 yr.

Certain citation trends have shifted since the 1980s (Table 4, period × habitat of source references × habitat of citation interaction), but linear contrasts indicates this primarily reflects changes in citation patterns of aquatic researchers, not terrestrial ones. That is, no changes in citation frequencies from past to present have occurred for terrestrial citations of terrestrial, freshwater or marine papers (mean percent ± 1 standard error, 68.7 ± 2.3% vs. 63.5 ± 0.9%, 0.7 ± 0.2% vs. 1.0 ± 0.2% and 1.2 ± 0.3% vs. 0.8 ± 0.1%, linear contrasts: $p=0.10$, 0.98 and 0.81, respectively). No changes occurred for freshwater citations of marine or terrestrial papers (linear contrasts: $p=0.71$ and 0.36) or for marine citations of freshwater or terrestrial papers (linear contrasts: $p=0.45$ and 0.59). What have changed are reduced frequencies from past to recent in freshwater citations of freshwater papers (61.8 ± 3.0% to 46.4 ± 1.6%) and marine citations of marine

Table 3
Numbers and proportions of published papers and citations of published papers sorted by habitat of study and totaled across all seven journals.

Source	Metric	Marine	Terrestrial	Freshwater	Total	χ^2	p
Published	*Number*	464	3516	542	4522		
	Proportion	10.3	77.8	12.0			
Citations — marine	*Number*	4439	625	247	5311	6002.5	<0.0001
	Proportion	83.6	11.8	4.7			
Citations — terrestrial	*Number*	167	13,013	197	13,377	1538.7	<0.0001
	Proportion	1.3	97.3	1.5			
Citations — freshwater	*Number*	296	608	3127	4031	4290.4	<0.0001
	Proportion	7.3	15.1	77.6			

Statistics are for likelihood ratio tests comparing the frequencies within each citation category to the frequencies of published papers in each category. First appeared as Webtable 3 in supplementary material for article in *Frontiers in Ecology and the Environment 7*:182-183, 2009.

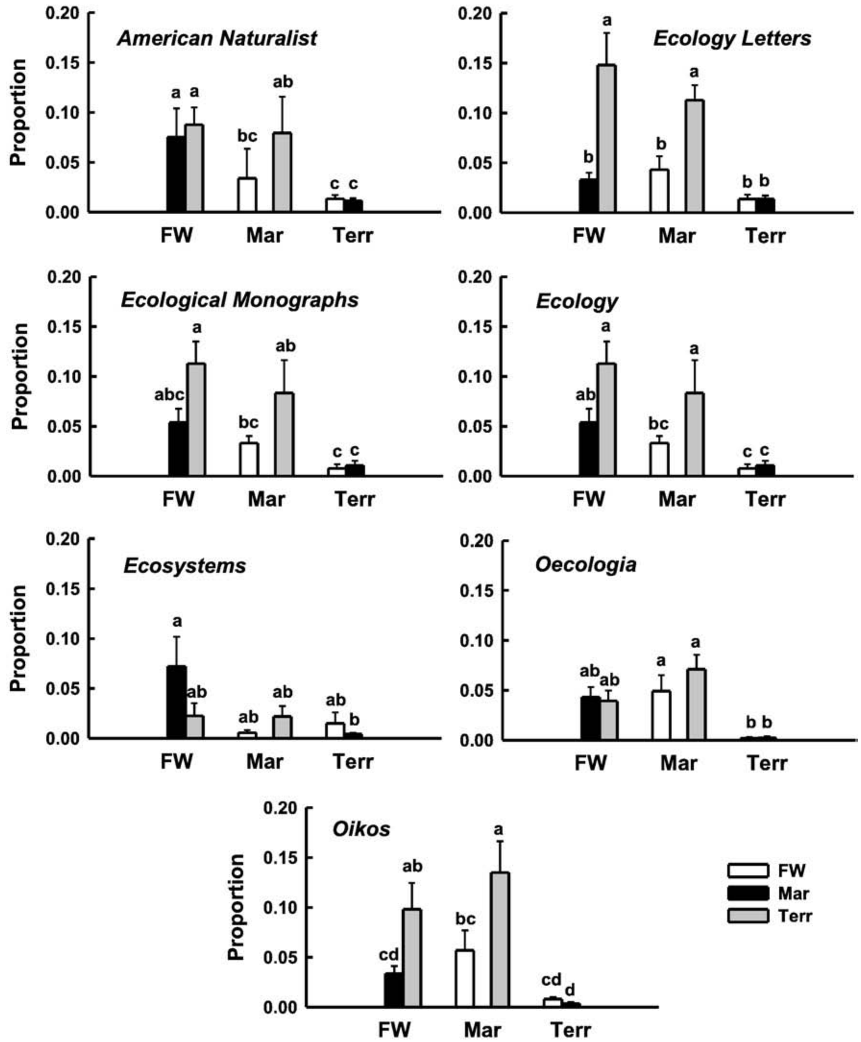

Fig. 4. Citation frequencies partitioned by journal for seven "general" ecological journals, 2002–2006. For clarity, we omit the citation frequencies of papers from the habitat of the source paper (i.e., removing freshwater citations of freshwater papers, marine citations of marine papers, and terrestrial citations of terrestrial papers; see Fig. 3 for overall averages). Modified from Webfigure 2 in supplementary material in article in *Frontiers in Ecology and the Environment* 7:182-183, 2009.

papers (69.6 ± 2.8% to 54.9 ± 1.7%) (linear contrasts: $p = 0.0001$ and <0.0001, respectively). These changes are explained primarily by increased citation frequencies in the "other" category, which includes books, reviews, theoretical and conceptual references. Freshwater and marine researchers have increased their citation frequencies of these "other" papers by about 10–13% (past vs. recent — freshwater: 26.1 ± 2.1 vs. 40.0 ± 1.3%, marine: 22.5 ± 2.3 vs. 33.0 ± 1.3%) while terrestrial researchers have increased citation frequencies of "other" papers by only about 5% (29.3 ± 2.2 vs. 34.7 ± 0.9%). This differential shift may reflect increased attention paid by aquatic ecologists to theoretical/conceptual literature.

3.4. Publication frequencies

The frequencies of publications in the four categories (terrestrial, marine, freshwater, and other) varied substantially among the seven journals, but marine and freshwater papers were in all cases the least frequent categories (Fig. 2). Terrestrial papers were most frequent in all but *American Naturalist*, in which "other" papers were more frequent. Across all journals, 53.5 ± 1.0% of published papers were terrestrial, 29.8 ± 1.1% were "other," 9.2 ± 0.4% were freshwater, and 7.5 ± 0.4% were marine. Dropping "other" papers yields the frequencies shown in Table 3.

Comparison of past to recent publication trends indicates an increase in publication rate of terrestrial and a decrease in publication rate of "other" papers in *American Naturalist,* and a decrease in publication rate of freshwater papers in *Ecology* (Fig. 5). Publication rates of marine (both journals), terrestrial (*Ecology*), freshwater (*American Naturalist*) and "other" (*Ecology*) papers have otherwise not changed.

4. Discussion

Both null hypotheses were rejected. Terrestrial ecologists do not cite aquatic papers as often as aquatic ecologists cite terrestrial papers. Citation patterns were highly asymmetric, with aquatic community

Table 4
Three-way analysis of variance testing effect of journal, habitat of source paper, habitat of citation, and their interactions for entire data set.

Source	SS	df	MS	F	p	R^2
Journal	0.03239	6	0.00540	2.61	**0.016**	0.86
Habitat of source (HOS)	0.01425	2	0.00713	3.45	**0.032**	
Habitat of citation (HOC)	0.44012	2	0.22006	106.5	<**0.0001**	
Journal × HOS	0.01237	12	0.00103	0.50	0.92	
Journal × HOC	0.10139	12	0.00845	4.09	<**0.0001**	
HOS × HOC	15.2480	4	3.81199	1845.3	<**0.0001**	
Journal × HOS × HOC	0.22604	24	0.00942	4.56	<**0.0001**	
Error	3.73079	1806	0.00207			

Boldface: $p < 0.05$.
Data were *ln*-transformed prior to analysis. Similar results were obtained using arcsine-transformed data, but the *ln*-transformed analysis explained about 5% more variance. First appeared as Webtable 2 in supplementary material in article in *Frontiers in Ecology and the Environment* 7:182-183, 2009.

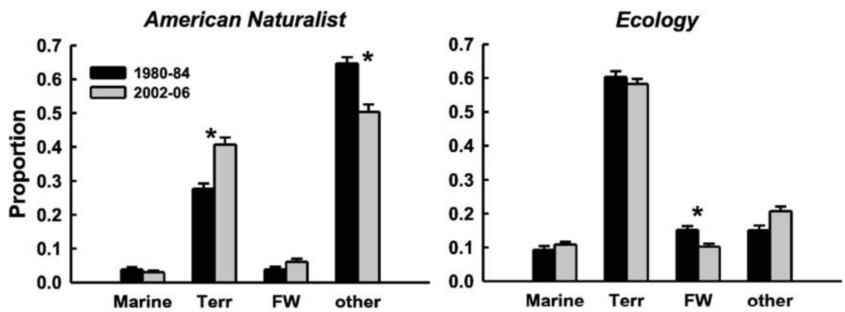

Fig. 5. Changes between 1980–84 and 2002–06 in proportions of marine, terrestrial, freshwater and other papers published in *American Naturalist* and *Ecology*. Asterisks indicate changes within a group that were significant at $p<0.05$ (Bonferroni-corrected $p=0.0125$).

ecologists citing terrestrial papers almost an order of magnitude more often than terrestrial ecologists cited aquatic papers. Citation frequencies by habitat varied somewhat among the seven general ecological journals, but the general patterns of citation frequencies were similar among the journals. Citation patterns appear to have changed minimally through time as well. In *American Naturalist* and *Ecological Monographs*, citation of non-source habitat papers remained basically unchanged from 1980–85 to 2002–06. The primary temporal change was a reduction by all community ecologists in the frequency of citations of papers from within their habitat of work and an apparent increased focus on more general ("other") papers, although these changes were greater for aquatic ecologists. Finally, publication frequencies of each type do not explain the infrequent citation of aquatic papers by terrestrial authors. The patterns of citation frequencies were generally similar among the journals.

What are the impacts of such asymmetrical citation patterns? We suggest that such imbalance should be a cause for concern among aquatic and terrestrial ecologists alike. If progress in ecology can be gauged by the depth of system-specific understanding and success in unraveling general mechanisms of ecological organization, impediments to a vigorous cross-fertilization of advances between terrestrial and aquatic ecologists can hinder progress for the field as a whole. Terrestrial ecology would be different today if conceptual advances such as keystone predation (Paine, 1966), ecological stoichiometry (Redfield, 1934; Sterner and Elser, 2002), and trophic cascades (Paine, 1980; Carpenter et al., 1985), all developed in aquatic systems, had not diffused to terrestrial research. Likewise, aquatic ecology has been enriched by advances such as meta-population dynamics (Hanski, 1989), island biogeography (MacArthur and Wilson, 1967), and watershed biogeochemistry (Bormann and Likens, 1967). Together, these hallmarks highlight the fact that both aquatic and terrestrial systems have been fruitful in generating broad ecological concepts. Clearly, the diversity of life-history strategies, divergent scales of processes, range of abiotic settings and suite of methodological approaches across the aquatic–terrestrial continuum mean that new, broad conceptual advances will continue to start where research is most tractable and productive, irrespective of water content. Should citation asymmetry persist, an even larger fraction of aquatic research may be marginalized to not only more specialized, lower-impact journals (e.g., Table 1) but also viewed as work that is intellectually parochial in nature. For ecologists in general, we suspect that the pace of new conceptual and technical discoveries will suffer if the full benefits of intellectual exchanges continue to be hampered by asymmetrical diffusion.

4.1. Publication frequencies

As independently demonstrated by Stergiou and Browman (2005b), the "general" journals are really largely "terrestrial" ecology journals. The overall rate of publication of terrestrial papers in these seven journals was 6 to 7 times higher than that of freshwater or marine papers, respectively.

These trends led us to examine if terrestrial and aquatic workers had access to similar numbers of more specialized journals focused on specific habitats. We examined the ISI Web of Science Journal Citation Reports data base (http://www.isiwebofscience.com) to determine the frequencies of general, terrestrial and aquatic journals that publish ecological papers. We searched all categories of journals that might publish ecological research (Biodiversity Conservation, Ecology, Entomology, Environmental Science, Fisheries, Forestry, Limnology, Marine and Freshwater Biology, Oceanography, Ornithology, Plant Sciences, Soil Science). We sorted the 693 journals retrieved to exclude journals unlikely to publish ecological research (e.g., Journal of Apicultural Research). The result was 135 journals which we categorized (general, aquatic, terrestrial) based on personal knowledge, title of journal and/or journal information listed on the website of each. This analysis yielded 11.1% (15) terrestrial, 42% (57) marine or freshwater, and 47% (63) general journals.

The greater number of aquatic journals than terrestrial journals is contrary to the idea that publication frequencies are a simple consequence of different sizes of the marine, freshwater and terrestrial communities of ecologists. Importantly, however, most of the journals with the highest impact factors are general and terrestrial (e.g., Table 1). In the larger ISI analysis above, 0 of the top 20, and only 6 of the top 40 journals were aquatic. Average impact factor for general/terrestrial journals was almost double that for aquatic journals (mean ± 1SE: 2.9 ± 0.3 vs. 1.7 ± 0.1, respectively; one-way ANOVA $F=13.3$, $p=0.0004$). Thus aquatic ecologists evidently have more limited opportunities than do terrestrial ecologists to publish in the "general," higher impact ecological journals with possible consequences for the influence and dissemination of their work.

4.2. Possible reasons for asymmetry

Why do aquatic ecologists cite terrestrial literature so much more often? Higher citations of terrestrial papers by aquatic ecologists may result from

(1) there being more terrestrial papers to cite,
(2) aquatic ecologists independently tend to focus more on seeking across habitat comparisons than do terrestrial ecologists,
(3) editors and/or reviewers of aquatic papers are more likely to demand greater citation breadth of their authors than are editors and/or reviewers of terrestrial papers, or
(4) authors go out of their way to include terrestrial citations to improve chances of acceptance by editors.

Examining (1), it is possible that the higher frequency of publication of terrestrial papers (Fig. 1) leads to higher citation frequencies in aquatic papers (see also Stergiou and Browman, 2005b). This difference might simply reflect the predominance of terrestrial ecologists. But are there really more terrestrial than aquatic ecologists? This seems likely, but the relative numbers may not be as disproportional as the distribution of publications might suggest (i.e., 78% terrestrial, 12% freshwater and 10% marine or a 3:1 terrestrial to aquatic ratio). The 2007 ISI data cited above, for example, suggest that 57% of 15,517 articles published and 64% of 617,701 citations were general/terrestrial. Independent analysis (Stergiou and Browman, 2005b) reached similar estimates. Assuming that 22% of articles and citations in general journals are aquatic, we separated numbers of terrestrial vs. aquatic articles and citations in the ISI data. An estimated 46.4% (53.6%) of articles and 52% (48%) of citations are terrestrial (aquatic), very different from the 78% (22%) frequencies of published articles in the top journals. In a survey of scientific societies, Stergiou and Browman (2005b) estimated the proportions of terrestrial vs. aquatic ecologists as 57% vs. 43% (total $n = 14{,}814$), or approximately a 3:2 terrestrial to aquatic ratio. Stergiou and Browman (2005b) acknowledged that this analysis was limited (many societies did not respond to their request for membership numbers, many ecologists belong to multiple societies). Nonetheless, their data plus the ISI data do not support the hypothesis that the high frequency of terrestrial papers in general journals reflects a comparable difference in number of types of ecologists.

Stergiou and Browman (2005b) extended their analysis to consider citation frequencies of aquatic and terrestrial papers. They surveyed four general ecological journals (*Ecology*, *Oecologia*, *Ecology Letters* and *Oikos*) and four aquatic journals (*Marine Ecology Progress Series*, *Journal of Experimental Marine Biology and Ecology*, *Canadian Journal of Fisheries and Aquatic Sciences*, and *Limnology and Oceanography*). Their analysis suggested that from 1981 to 2004, the cumulative number of citations of aquatic papers did not differ from cumulative citations of terrestrial papers (Stergiou and Browman, 2005b). Further, between 2000 and 2004, the general journals considered published 4745 articles and the aquatic journals published 5449 articles. Number of citations to these articles were 31,734 (general journals) and 26,734 (aquatic journals) or a ratio of 54:46. Thus, numbers of ecologists, articles, and citations do not differ greatly between terrestrial and aquatic groupings, suggesting that the differences in citation frequency are not a simple consequence of dramatically higher numbers of terrestrial ecologists and their publications.

We suggest that both author (2 and 4 above) and editor/reviewer behavior (3 above) in part may underlie the pattern of higher citations of terrestrial papers by aquatic ecologists. First, because they are a minority in "general" journals, aquatic authors submitting to these journals may relate their results to those from terrestrial literature more often than the reverse, perhaps attempting to reach more readers. More cynically, some may cite terrestrial papers simply to improve their chances of acceptance. Second, as suggested by comments from aquatic-habitat colleagues, editors and reviewers may be an important source of the skewed citation frequencies. Ironically, assuming that journals mostly assign aquatic editors and reviewers to aquatic submissions, editorial and reviewer demands for greater citation breadth likely come mostly from individuals who themselves are marine or freshwater ecologists. Thus, aquatic community ecologists may be more critical of their aquatic colleagues in at least this aspect of reviewing papers than terrestrial ecologists are of their terrestrial colleagues.

Why do terrestrial ecologists cite aquatic papers so infrequently? We do not believe this is deliberate, but more likely is a form of benign neglect. Historical influences may be at play. The emergence of terrestrial ecology as a major subdiscipline of biology preceded that of aquatic ecology, and especially marine ecology, by several decades. During the rise of ecology, plant succession was a major focus (Clements, 1916; Cowles, 1900; Gleason, 1917). This emphasis likely shaped the interests of following generations of terrestrial community ecologists. Since freshwater environments are surrounded by terrestrial ones, freshwater ecologists were probably also influenced by developments in terrestrial ecology and were next in line to make important conceptual advances (e.g., Lindeman, 1942; Hutchinson, 1959). In contrast, modern marine community ecology did not really get underway until the mid 20th century (e.g., Connell, 1961a,b; Lewis, 1964; Paine, 1966). Thus it could be argued that modern journals and their publication practices simply reflect legacy influences. Nonetheless, a disproportional terrestrial bias persists.

Other possibilities are that some aquatic ecologists

(1) avoid the general journals, instead seeking a more targeted audience in the more specialized aquatic journals,
(2) do not see it worth even trying for the general journals, or
(3) are not doing the caliber of work necessary for the general journals.

Given the possible historical effects suggested above, behaviors (1) and (2), if they exist, could be an artifact arising from ingrained habits within terrestrial and aquatic ecologists. In the case of (3), it seems unlikely that the distribution of quality of aquatic research is substantially different from that in terrestrial research. Ultimately the root causes of many of these differences remain open to speculation and may be refractory to more rigorous analysis. Further research seems warranted, however, with investigations focusing on surveys of numbers of investigators working in different habitats, submission and acceptance rates of terrestrial and aquatic papers by journals, editorial and reviewer practices, histories of and reasons for journal startups, reasons for author decisions on where to submit, and fates of submissions by authors. Such a study would be a major undertaking.

4.3. Possible solutions

What, if anything, should be done? Clearly there is marked inequality in the standards for cross-system generality in high-impact journals. The two obvious alternative actions are either to ease pressure on aquatic authors to cite non-aquatic literature or to increase pressure on terrestrial authors to cite aquatic literature. We fervently believe that community and ecosystem ecologists should seek synthesis by relating their results to those from other major habitats, and thus, as is appropriate, to seek habitat, theoretical, geographic, and conceptual generality in their work. Further, as research programs "scale up" from local to global scales, shift towards interdisciplinary approaches, and increasingly examine the magnitude and importance of connections between adjacent ecosystems (e.g., Polis et al., 1997, Loreau et al., 2003), the need for cross-system communication grows, and indeed, becomes a necessity. Thus, we favor the second alternative. We therefore echo recommendations made by most authors in a recent theme section in *Marine Ecology Progress Series* (Stergiou and Browman 2005a): we urge editors and reviewers of terrestrial papers to exert the same level of pressure on their authors to address the broader implications of their results with respect to results from other habitats.

Are changes possible? As noted by Raffaelli et al. (2005), hindrances to greater cross-habitat awareness exist. These include:

- institutional structure commonly places aquatic and terrestrial ecologists in separate units, inhibiting cross-communication.
- Funding agencies tend to have strongly compartmentalized structures that are typically separated by habitat, and thus have separate groups of reviewers, ultimately hindering efforts within the ecological community to cross-fertilize through collaborative efforts. And
- terrestrial and aquatic scientists tend to have different societies and meet separately, and the "general" societies tend to be dominated by terrestrial ecologists (e.g., Ecological Society of America, British Ecological Society).

These and related factors suggest to us that the only means of causing a "sea change," so to speak, is through bottom-up pressure on top-down control. Institutions and funding agencies tend to be conservative and thus seem unlikely to change on their own. Hence, we suggest that the scientific community itself, with a little nudging through its own editorial boards and through service as reviewers, can trigger change in institutions, funders, and societies by pushing for change in the publication process.

A final caveat: the search for generality will inevitably unearth non-general results, and these can sharpen our insights and understanding of ecosystems. Hence, papers deemed "not sufficiently broad in application to other ecosystems" should not be discriminated against by general journals. Thus, for example, reviewer comments that (e.g.) a paper is "too marine" or "relevant only to lakes" are inappropriate. In our view, the primary criterion for acceptance of manuscripts in general journals should be the excellence of the research, and not a subjective assessment of its likely appeal to terrestrial readers. This recommendation does not contradict our recommendation for all authors to seek generality. Papers found to not have broad application to other systems or habitats would presumably discuss this fact, and in the process, cite publications from these other systems to exemplify their conclusion.

4.4. Summary

We find that aquatic ecologists seek to compare results and potentially achieve broader generality across habitats far more than do terrestrial ecologists. These citation patterns are remarkably consistent across seven "general" ecological journals with high citation impact factors. Further, these differences appear to have persisted since at least the early 1980s based on our examination of *Ecology* and *American Naturalist*. It seems more likely that these differences result from pressure to generalize from aquatic editors and reviewers than from a bias of terrestrial editors and reviewers against aquatic manuscripts. We suggest that change is needed, and the most likely source of change will be from us, the practitioners of ecology, through pressure on our societies, editors, and through our own efforts as reviewers. To more strongly encourage efforts to bridge the gap between terrestrial and aquatic ecologists, and to foster greater fertilization of concepts, approaches and technology among scientists working in different systems, the goal should be a level playing field amongst ecologists of all stripes, at least when having papers evaluated by the "general" journals. The numbers suggest that ultimately, equivalency in the proportions of terrestrial, aquatic and marine papers appearing in the general journals is a realistic expectation. Achieving equivalency will not be easy and will take concerted effort on all sides, not least of which is the aquatic community itself.

Acknowledgements

We thank many colleagues for helpful comments, including Carol Blanchette, Elizabeth Borer, Jennifer Burnaford, Heather Leslie, David Lytle, Duncan Menge, Sergio Navarrete, Laura Petes, Pete Raimondi, Eric Sanford, David Schiel, and Sandra Shumway. Communications with John Bruno, Emmett Duffy, Steve Gaines, Pete Raimondi and Jay Stachowicz were influential in spurring our pursuit of the question of citation asymmetry. This is publication number 325 from PISCO, the Partnership for Interdisciplinary Studies of Coastal Oceans, a large-scale, long-term consortium funded primarily by the David and Lucile Packard and Gordon and Betty Moore Foundations. **[SS]**

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