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David and Goliath: comparative use of facilitation and competition studies in the plant ecology literature

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Competition and facilitation are extensively studied in plant ecology and are central to ecological theory. However, these processes do not occur in isolation from each other and should be studied concurrently and synthetically. Here, we compare the relative citation success of studies that focus on either side of the same interaction coin in terms of number of publications and citations per publication in six of the following major themes in plant ecology: biogeography, populations, communities, ecosystems, evolution and conservation. There were eight times more publications on plant competition than on facilitation but this is not surprising given its long history of comprehensive and relatively exclusive study in plant ecology. Although studies of facilitation comprised a smaller body of literature, the mean citation rate for each publication was equivalent to that of competition studies. Thus, facilitation studies are being used as much as competition. These patterns of use by the ecological community clearly indicate that both aspects of plant interactions address broad themes and that studies on plant interactions should now strive to either test both simultaneously or at the very minimum include interpretations and relevant literature from both sets of ideas. Importantly, these broad trends illustrate the old axiom that quality and not quantity of studies may be a consideration in the success of a sub-discipline.

Studying plant–plant interactions provides the capacity for both detailed and conceptually broad insights into community assembly. Generally, studies of plant interactions focus on either competition or facilitation, but the former has a much longer and extensive body of foundational literature (Fowler 1986, Welden and Slauson 1986, Mead 1979, Tilman 1990, Connolly et al. 2001, McPhee and Aarssen 2001) while the latter has only recently been integrated conceptually into community theory (Connolly et al. 2001, Stachowicz 2001, Bruno et al. 2003, Callaway 2007, Brooker et al. 2008). Despite the binary focus on

these two forms of interaction, competition and facilitation represent two sides of the same coin, occur at the same time within a given system, and combine to produce a net interaction effect (Callaway 2007). Yet, very different experimental approaches and assumptions are used for each (Gibson et al. 1999, Freckleton and Watkinson 2000, Brooker et al. 2005). Both sets of studies have substantially advanced our understanding of communities, but a polarized approach to analysis can lead to conclusions that either competition or facilitation dominates in a system and this is underscored by studies that only self-reference

the ideas most closely related to their side of the coin. These weaknesses are not unique to ecology, and perhaps progress is best served by testing one specific idea well and then switching to another idea and beginning anew. However, the time is ripe to broadly explore the use of literature to estimate how each focus is contributing to ecological progress.

At a recent special symposium of the British Ecological Society on facilitation in Aberdeen, Scotland, facilitation and its conceptual links to other ecological focal areas were thoroughly explored. It was evident that facilitation means different things even among plant ecologists but importantly that studies of positive interactions have influenced virtually every aspect of plant ecology (Pakeman et al. 2009). Here, we present a direct test of whether the contribution of facilitation studies to the major dominant themes in ecology are proportionally comparable to those made by studies of competition. The hypothesis is that mean citation per publication on facilitation is equal to competition if facilitation is impacting broad ecological themes and becoming incorporated into ecology at a rate comparable to competition. The null hypothesis is that competition studies accrue relatively higher citation rates per paper since this set of studies is more established, comprehensive, and likely more numerous. Furthermore, a larger body of scientists in that field using the literature increases the likelihood of citation (Kokko and Sutherland 1999). In other words, a more established field has had more time, opportunity, and participants in the literature able to attract citations and one would expect it to do better.

Competition vs facilitation

Citations are a useful metric of the success of a publication in reaching a desired audience and being used by others in subsequent publications. Admittedly, it is not a perfect tool and should be used judiciously (Kotiaho 1999, Adam 2002, Krell 2002, Leimu and Koricheva 2005, Monaster-sky 2005, Lawrence 2007). Nonetheless, we avoid many of these concerns here by using citations to determine only relative usage and not to infer quality of the publications. Importantly, we also calculate citations per publication to control for potential sampling effects, i.e. more publications in a given discipline generate the capacity *de facto* for more citations. In May 2009, we used the Web of Science (ISI Thomson Reuters) to complete sets of searches to compare the total number of publications and citations per publication for studies on plant competition and facilitation in six major themes we identified for ecology. The search terms were plant*competition*ecological theme and then again for facilitation. All years were used, and the same set of searches was repeated for the terms positive and negative plant interactions. To explore the potential contribution of studies that included both topic terms

conjunctly and to ensure that there was not significant overlap in the values associated with the two fields, the search was repeated for each theme with all four possible sets of terms, i.e. plant*competition*facilitation*ecological theme. The six ecological themes included biogeography, population, community, ecosystem, evolution, and conservation and were generated by inspecting most current editions of major textbooks on ecology. Each of the values associated with competition and facilitation were then treated as an independent replicate test of the success of those studies therefore $n = 12$, and general linear models were used to determine whether number of publications or citations per publication differed. The process tested or study type, competition or facilitation, was the main effect in the model and modeled as a fixed effect while the response variables, number of studies and citations per publication, were treated as linear responses. Statistics were done using Jmp 7.0.2 (SAS 2007).

There were significantly more publications on plant competition relative to facilitation (Fig. 1, GLM, chi-square = 5.4, $p = 0.02$, $n = 12$). All major themes in ecology were also dominated by studies on competition (Table 1). These findings support our assumptions that the study of competition is a more established field of study relative to facilitation (Callaway 2007), that plant competition has a long history, and that it has furthered all major themes of ecology (Connolly et al. 2001, Vandermeer and Goldberg 2003) excepting perhaps plant biogeography (Table 1).

The alternative hypothesis that the study of facilitation has at least caught up with the usage of competition by ecologists was supported. Citations per publication were not significantly different between studies of competition and facilitation (Fig. 1, GLM, chi-square = 0.14, $p = 0.7$,

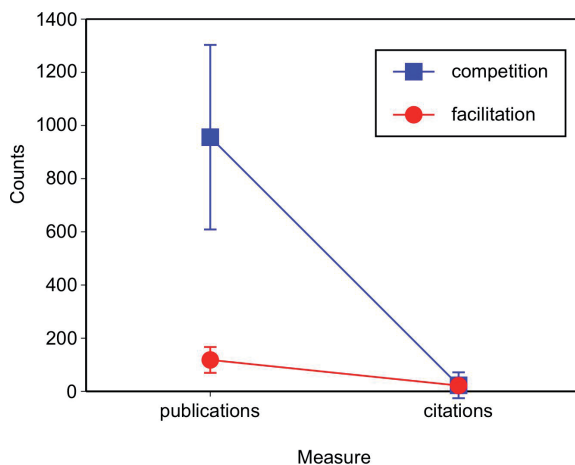


Figure 1. The total number of publications and citations per publication for studies on plant competition and facilitation. These data were generated using the Web of Science in May 2009 with appropriate search terms for the major themes generally explored in ecology as a discipline. The mean ± 1 SE is plotted.

Table 1. A summary of the major topics studied in plant ecology using competition and those using facilitation. Data were collected from the Web of Science in May 2009 using the appropriate set of search terms. The values reported in the final row are the totals associated with number of studies and citations and the mean is listed for the cites per paper.

Topic	Competition			Facilitation		
	studies	citations	cites per paper	studies	citations	cites per paper
Biogeography	34	548	16.1	6	133	22.2
Population	1979	37996	19.2	139	2355	16.9
Community	2041	52251	25.6	333	8569	25.7
Ecosystem	733	23583	32.2	143	4096	28.7
Evolution	598	13564	22.7	36	656	18.2
Conservation	350	7623	21.8	53	1046	19.7
Total	5735	135565	22.9	710	16855	21.9

n = 12). In fact, we view the proportional equivalence in use by the ecological community of fewer available studies as evidence that facilitation is outperforming competition in explaining virtually every one of the broad themes typically studied. This contradicts the assumptions discussed at the BES symposium that facilitation has been poorly incorporated into the study of evolution in particular (but see Kikvidze and Callaway 2009). Competitive and facilitative interactions are not only two faces of the same coin but in reality a continuum of interactions (Lortie et al. 2004) from positive to negative varying in both intensity and importance (Brooker et al. 2005) and citation use supports this view. The citation success of both in ecosystems and conservation is a profoundly interesting finding since the humble roots of plant interaction studies began with the study of processes at the individual level yet now significantly contribute to use by authors at much higher levels of ecological organization.

Nonetheless, it is worthwhile to consider whether a more balanced or expansive approach to plant interactions and general ecology is now necessary. A small proportion of the total publications testing competition included the term facilitation (the mean of all themes was 6.5% ± 1%), however facilitation studies commonly included both concepts (mean of all themes = 53% ± 8%). While it is possible that these proportions are underestimates, i.e. additional publications that either tested competition or facilitation did reference the other, it seems unlikely since the topic term search for both *within* publications is broad in the Web of Science. These findings support the position that plant ecologists to date focus or at least discuss in a given paper either competition or facilitation but not both. It does appear that facilitation studies are less guilty, but this field and term is more recent, and the interpretation of the term competition is also likely evolving over time. Importantly however, studies that did focus on both forms of interactions accrued far more citations per publication than either independently (mean relative increase of all themes was 43% ± 2.5%). Clearly, there is a significant citation or recognition benefit in using, and hopefully

testing, both concurrently. The ecological community in general has clearly embraced the findings associated with the study of facilitation and is moving, or at least reading and citing, more synthetically.

Conclusions

Competition studies comprise the majority of publications and citations in the plant ecology literature. Most major themes in ecology use competition studies extensively and always more so than facilitation. While facilitation studies account for less of the published literature, the mean citations per publication are equivalent to those of competition studies. Facilitation is arguably a biblical David in plant ecology in that its relative usage is much greater given fewer total participants in the publication process. However, the time has come for David and Goliath to reconcile since there are clear citation benefits to incorporating both concepts into publications. Both sets of studies have the capacity to speak larger themes in ecology such as the community and ecosystem yet to date are not heavily used nor contributing to the theme of biogeography.

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