Normalized Similarity Index: An adjusted index to prioritize article citations

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ARTICLE INFO

Article history:
Received 29 February 2012
Received in revised form 14 August 2012
Accepted 16 August 2012

Keywords:
Bibliographic coupling
Co-citation
Citation network
Similarity index
Weighted citation

ABSTRACT

One of the main applications of citation is to find articles that are relevant to a particular article. However, not all citations are equally relevant to the target article. This paper presents an approach to identify the most relevant citation(s). To this end, the Normalized Similarity Index (NSI) is proposed to quantify the similarity between the source and target of a citation base on the co-citations and references shared by them. To validate the method, NSI was calculated for five citation networks and was compared with the peer review grades for the relevancy between the source and the target articles. The results showed a significant correlation between the NSI ranks and those of peer review. Also, combined linkage (CL) and weighted direct citation (WDC) were calculated from the same data. According to the results of comparison between the NSI with other similarity measures, in most cases, NSI did better than others at reproducing the peer rankings. Our principal conclusion is that the NSI can be used to prioritize the citations of given highly cited article, and represent knowledge flow from the target article.

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1. Introduction

Citation/reference is a footnote in an article describing ideas or results in other (often older) articles. The citation networks between related articles are the classification systems for scholarly activities and research output. Article citation networks may be modeled as directed graphs often without cycles; however, cycles might exceptionally exist in such networks (Egghe & Rousseau, 2002). A citation network can also be considered as weighted directed graphs, where a weight is associated with each edge. These weights might represent some forms of similarity or dissimilarity between the articles which cite article A (source or citing articles) and article B (target or cited article) (Perissm, 2010). Co-citation is another measure used to establish subject similarity between two articles. If article A and B are both cited by article C, they may be related to one another, even though they do not directly reference each other. If A and B are both cited by many other items, they have a stronger relationship (Eto, 2007; Small, 1973; Van Eck & Waltman, 2008). Bibliographic coupling – the sharing of one or more references by two documents – have been used as a measure of subject similarity between two documents (Kessler, 1963). Co-citation and bibliographic coupling attempts to take advantage of the judge made by authors of the citing papers on how other articles closely relate to their paper. Other citation-based measures of similarity include combined linkage

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which considers direct citation link with indirect linkage counts such as co-citation and bibliographic coupling (Persson, 2010; Small, 1997).

In the field of information retrieval, weighting the citations is used for enhancing search performance in finding relevant documents (Elkiss et al., 2008). Similarly, co-citation linkage is used to identify related documents, through linking the judgment of later authors about the relevancy of two articles in their papers (Bichteler & Eaton lli, 1980; Elkiss et al., 2008; Yan et al., 2012). In general, one can categorize the approaches for deriving the similarities from cooccurrence documents into local and global methods (Ahlgren, Jarneving, & Rousseau, 2003; Van Eck & Waltman, 2009). The global approach relies on the profiles of cocitations of the documents (Van Eck & Waltman, 2008), while in local approach, the similarity is determined by adjusting the number of indirect citation linkages of the documents considering the total number of direct and indirect citation linkages (Van Eck & Waltman, 2009).

It frequently happens that one follows the citations of an article to find some relevant works. However, not all the source articles, to an extent, are relevant to the target one. Here we propose a Normalized Similarity Index (NSI) to find the most relevant articles citing a target article. In this study, relevancy of citations to the target article is the degree of pertinence to the main idea of target article (positive or negative), practical contribution (usage of introduced methods), and continuity (focus on same question or problem). We attempts to quantitatively measure the relevancy of citing and cited articles by using co-citation, bibliographic coupling, and longitudinal coupling as judgments made by later authors about what other articles closely relate to their paper (Bichteler & Eaton lli, 1980). Sometimes, target article is highly cited, and NSI enables scholars to choose the most relevant articles without going through citations one by one.

2. Related works

Weight for citations can be calculated at the author level (e.g. by self-citation or authorship), journal level (e.g. by prestige of citing journal), or paper level. Several studies have considered assigning weights to citation links at the paper level. Small (1997) proposed a combined linkage measure, which combines direct citation counts with co-citation, bibliographic coupling, and longitudinal coupling in a weighted average. Hummon and Dreian (1989) assigned the weights to citation links to identify the main citations paths through the citation graph. This has been integrated into HistCite software and used in other studies (Garfield, 2004; Lucio-Arias & Leydesdorff, 2008). In contrast to our method, citation weights were indications of information flows rather than similarity, and typically, a citation that was a bridge from one major cluster to another, gets high citation weights. Lin (2008) developed a method for analysis of citation network in the context of the WWW to cluster-based retrieval literature. This way of measuring was behind the PageRank algorithms to evaluate the status of web pages and explored the hypothesis that these networks can be exploited for text retrieval (Ding, Yan, Frazho, & Caverlee, 2009). He showed examples where the algorithm can help to literatures retrieval (Lin, 2008). Although this work is fundamentally different from ours in both aims and methods, it highlights that citation from all publications are not equally valuable, and this fact can have a considerable effect on the results of searches based on simple citation network. Boyack and Klavans (2010) used weighted direct citations to generate a large-scale map of science literature for portfolio analysis applications. Persson (2010) introduced Weighted Direct Citations (WDC) as a tool for decomposing a network of papers and obtaining significant sub-domains by removing links below a certain weight. In WDC, the direct citation link from paper A to paper B strengths by the fact that A and B cite C, and D cites A and B. Here WDC gets the value 3, which is the sum of one direct link and two shared links. For each additional shared reference or co-citation, the WDC will grow by 1 (Persson, 2010). WDC do not take into account the deviation cases by the discrepancy between the total degrees of under consideration nodes. Waltman and Van Eck (2012) proposed a methodology for constructing classification system of science. For this purpose, they used direct citations to determine the relatedness of publication, and normalized the relatedness scores for differences among different fields of science.

3. Materials and methods

3.1. Normalized Similarity Index

We assume that a direct citation becomes stronger if cited and citing articles are co-cited by other articles and if they share some references (Boyack & Klavans, 2010; Egghe & Rousseau, 2002). The main question of this study was how the indirect citation linkages can be used to distinct direct citations and explicates the similarity of the content in the two papers.

Similarity indices quantify the similarity between two connected nodes and are often based on the number of common neighbors shared by them (Leydesdorff, 2005; Van Eck & Waltman, 2008). We extended the pervious similarity indices such that the resulting framework simulates the degree of relevancy between the citing and cited articles (Pavloupolos et al., 2011). We denote this extension as the Normalized Similarity Index (NSI). NSI as a weight of citation is obtained as:

$$NSI_{ij} = \frac{\sum_{m \neq i,j} (A_{i,m}A_{j,m}, A_{i,m,A_{m,j}, A_{m,i,A_{m,j}}}) + C_{ij}}{k_i + k_j - \sum_{m \neq i,j} (A_{i,m}A_{j,m}, A_{i,m,A_{m,j}, A_{m,i,A_{m,j}}}) + C_{ij}}$$ (1)

Let us consider a directed citation network with adjacency matrix A where i and j represent two articles linked by a direct citation (C_{i,j}) and by indirect citation linkages with any other node m. Indirect citation linkages include: bibliographic
coupling \((A_{i\rightarrow m}A_{j\rightarrow m})\), longitudinal coupling \((A_{i\rightarrow m}A_{m\rightarrow j})\), and co-citation \((A_{m\rightarrow i}A_{m\rightarrow j})\) (Small, 1997). The weight of citation between articles \(i\) and \(j\) is computed as the number of indirect citation linkages of \(i\) and \(j\) to any other article \(m\) \((A_{i\rightarrow m}A_{j\rightarrow m}, A_{i\rightarrow m}A_{m\rightarrow j})\) and the number of citations between the articles \(i\) and \(j\) \((C_{ij})\), divide by the subtraction of numerator from summation of articles degree \((k = \text{number of citations} + \text{number of references})\). The article citation networks are binary graphs, and thus, \(C_{ij}\) equals to 1 if there is a direct citation between articles \(i\) and \(j\). In journal citation network, \(C_{ij}\) is the number of citations between journals \(i\) and \(j\), and can be equal to 1 or a larger value. The NSI can be assigned to each citation in the network and be used to identify the most relevant citations to the target article.

Let us compare our framework with previous measures of linkage similarity based on co-citation and bibliographic coupling (Persson, 2010; Small, 1997). The Combined Linkage (CL) and Weighted Direct Citation (WDC) as measures of similarity are calculated as:

\[
\text{Combined linkage \ (CL)} = \frac{\sum_{m \neq i,j} (A_{i\rightarrow m}A_{j\rightarrow m}, A_{m\rightarrow i}A_{m\rightarrow j}) + (2 \times C_{ij})}{\sqrt{(k_i + 1)(k_j + 1)}}
\]  

(2)

\[
\text{Weighted direct citation \ (WDC)} = \sum_{m \neq i,j} (A_{i\rightarrow m}A_{j\rightarrow m}, A_{m\rightarrow i}A_{m\rightarrow j}) + 1
\]  

(3)

The NSI and CL take into account similar issues. Two similar papers (where the similarity is evaluated by the experts) that happen not to cite the same ancestor papers can develop a stronger linkage similarity to each other over time if subsequent authors recognize the same similarity. Two papers which are not similar will have a weakening linkage similarity to each other if subsequent authors recognize that they are dissimilar, and consequently, do not cite them together. The normalization step is indeed the main difference between these two approaches, where CL uses square roots while NSI uses Jaccard type measures (Small, 1997). The Jaccard family of similarity indices measure the similarity between sample sets and is defined as the size of the intersection divided by the size of the union of the sample sets (Isumo, 2009; Leydesdorff, 2008). The NSI formula also plainly shows the proportion of the common shared direct and indirect citation linkages among total references and citations of article \(i\) and article \(j\). NSI and other similarity measures can show relevancy between cited and citing articles, but cannot characterize between three parts of relevancy including degree of pertinence to the main idea, practical contribution, and continuity of citations to the target article. The NSI corresponds conceptually with many empirical networks, and can be generalized beyond the scopes of this study (Nassiri, Masoudi-Nejad, Jalili, & Moeini, 2012). For example, within a network of protein–protein interactions, two proteins that are involved in the regulation of two similar processes can be considered related (Liu, Wong, & Chua, 2009).

3.2. Overview of the tool

The Normalized Similarity Index Calculator (NSIC) program was written in C++, and is freely available at the web link of http://jlb.ut.ac.ir/Download/LJBsoft/NSIC. The inputs to NSIC is a text file specifying a directed graph in which each node represents a particular article and each directed edge models a citation. As output, the program provides a set of continuous values for weight of edges in the network according to the NSI formula. In addition, WDC, CL and the highest value of NSI for citations to selected article are specified.

3.3. Citation networks

To illustrate the functionality of the NSI algorithm to prioritize citations, we constructed and used five citation networks (Appendices A–E) (Carmeli, Knyazeva, Innocenti, & De Feo, 2005; Jalili, Rad, & Hasler, 2007; Masoudi-Nejad, Nasuda, Bihoreau, Waugh, & Endo, 2005; Raza et al., 2007; Saderi et al., 2002). Each network was included a cited article \(a_i\), citing articles \(a_j\), and those which \(a_j\) and \(a_k\) cites as references. Citation networks were extracted from journals covered by the Web of Science™ up to July 2011, and the records were converted to net format by WoS2Pajek program (Batagelj & Mrvar, 2002). For example, using title search with a query “An alternative to radiation hybrid mapping for large-scale genome analysis in barley” we got one hit with 11 citations (July 2011). To obtain the list of citing articles, we used “View Citing Articles” option.

We saved the target and source articles with their references on separate plain text files. At the end, we concatenated these files into a single file, and the records were converted to net format. The map of the components of one of citation network was showed in Fig. 1 (Saderi et al., 2002). Cytoscape 2.8 was used for drawing the network using the Spring Embedded layout (Michael, Keicher, Ruscheinski, & Wang, 2011).

3.4. Validation

Presumably, author of an article is the best attributer to prioritize citations according to the relevancy to the cited article. To this end, questionnaire survey was administered to examine the relevancy of citations to the five selected articles by their authors. The survey instrument included explanations about the purpose of the study, selected article and its citations. The respondents were presented with the citing articles title and abstract in random order, and were not shown any indication of distinction. Respondents were asked to score a series of citations to their article with the value 0–10, which represent the degree of pertinence to the main idea and continuity (focus on same question or problem) of citing and cited articles.
Questionnaires were distributed by email among a group of researchers in July 2011. A sample of questionnaire that we used is presented in Appendix F. Frequently, authors of target articles assigned equal weights to several citations. In order to prioritize article citations according to the authors’ grades, equal values were assigned a rank equal to the average of their positions in the descending order of the grades (Corder & Foreman, 2009).

4. Results

First, citations to the selected articles were weighted by the NSIC tool. For each direct citation to the target article, number of citations to citing papers and weights of citations (NSI, WDC, CL and author’s grade of relevancy) were specified (Appendices A–E). Then, the performance of the similarity measures for reproducing peer rankings of citing papers was compared.

4.1. Performance of the similarity measures

In this section, we investigate the performance of NSI in prioritizing citations according to the relevancy with the target article. To this end, the relevancy of citations to the five selected articles, including the degree of pertinence to the main idea and continuity (focus on the same question or problem) was examined by the authors of articles, and compared with the results of ranking citations by using similarity measures.

According to the results, the NSI and peer rankings were in agreement, with Spearman’s correlation $R$ of 0.560 ($P < 10^{-9}$) (Fig. 2A–F). We also computed the correlation of rankings according to the NSI value and the title of citing articles (random ranking), and the correlation between them were not significant ($R = -0.010$; $P = 0.926$). As we can see in Table 1, the peer review’s grades to the relevancy between the cited and citing articles decreases synchronously in line with the value of NSI, and thus, the NSI can help to filter out less relevant citations. Finally, the performance of NSI in reproducing peer rankings of citing papers was compared with other similarity measures including number of citations to citing papers, CL and WDC (Table 2). Most relevant citing article according to the NSI and peer ranking were adapted in three networks (Table 3).
Table 1
Ranking the citations of (Jalili et al., 2007) article according to the author’s grades and NSI values. The columns are sorted according to the author’s grades for the degree of relevancy between cited and citing articles.

<table>
<thead>
<tr>
<th>Title of citing article</th>
<th>NSI values</th>
<th>Peer review grades</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rewirings Based on the Eigenvectors of the Laplacian Matrix for Enhancing Synchronizability of Dynamical Networks</td>
<td>0.1687</td>
<td>10</td>
</tr>
<tr>
<td>Building synchronizable and robust network</td>
<td>0.0471</td>
<td>9</td>
</tr>
<tr>
<td>Enhancing synchronizability of weighted dynamical networks using betweenness centrality</td>
<td>0.1279</td>
<td>9</td>
</tr>
<tr>
<td>Synchronizability of dynamical networks: different measures and coincidence</td>
<td>0.125</td>
<td>9</td>
</tr>
<tr>
<td>Efficient rewirings for enhancing synchronizability of dynamical networks</td>
<td>0.1685</td>
<td>8</td>
</tr>
<tr>
<td>On Enhancing Synchronization Properties of Dynamical Networks Using Node and Edge Centrality Measure</td>
<td>0.1447</td>
<td>8</td>
</tr>
<tr>
<td>Reducing synchronization cost in weighted dynamical networks using betweenness centrality measures</td>
<td>0.1081</td>
<td>8</td>
</tr>
<tr>
<td>Enhancing synchronizability by rewiring networks</td>
<td>0.1</td>
<td>8</td>
</tr>
<tr>
<td>Weighted coupling for geographical networks: Application to reducing consensus time in sensor network</td>
<td>0.0667</td>
<td>8</td>
</tr>
<tr>
<td>Synchronization Behavior Analysis for Coupled Lorenz Chaos Dynamic Systems via Complex Networks</td>
<td>0.0667</td>
<td>5</td>
</tr>
<tr>
<td>Numerical versus Analytic Synchronization in Small-World Networks of Hindmarsh-Rose Neurons</td>
<td>0.0625</td>
<td>5</td>
</tr>
<tr>
<td>Synchronization of identical neural networks and other systems with an adaptive coupling strength</td>
<td>0.0495</td>
<td>5</td>
</tr>
<tr>
<td>Weighted Small World Complex Networks: Smart Sliding Mode Control</td>
<td>0.0353</td>
<td>5</td>
</tr>
<tr>
<td>Estimating weight distribution in coupled oscillator networks</td>
<td>0.0326</td>
<td>4</td>
</tr>
<tr>
<td>Synchronization Criteria and Synchronization Orbits Analysis of Coupled Two Lorenz System</td>
<td>0.061</td>
<td>4</td>
</tr>
<tr>
<td>Neuronal Synchronization over Networks with Small-world Property</td>
<td>0.1013</td>
<td>3</td>
</tr>
<tr>
<td>Synchronizing Hindmarsh-Rose neurons over Newman-Watts networks</td>
<td>0.0561</td>
<td>3</td>
</tr>
<tr>
<td>Community Detection Enhancement in Networks using Proper Weighting and Partial Synchronization</td>
<td>0.0127</td>
<td>3</td>
</tr>
<tr>
<td>Global robust stability of interval delayed neural networks: Modified approach</td>
<td>0.011</td>
<td>2</td>
</tr>
<tr>
<td>Inferring networks from multivariate symbolic time series to unravel behavioural interactions among animals</td>
<td>0.0088</td>
<td>1</td>
</tr>
<tr>
<td>Stimulus dependent interaction between the visual areas of the two hemispheres</td>
<td>0.0125</td>
<td>0</td>
</tr>
</tbody>
</table>

Target of citation: Jalili et al. (2007).

Table 2
The comparison of rankings according to the NSI, CL, WDC and number of citations to citing papers with peer review grades by Spearman’s correlation (Networks 1–5 are based on Appendices A–E, respectively).

<table>
<thead>
<tr>
<th>SM</th>
<th>PR</th>
<th>Network 1</th>
<th>Network 2</th>
<th>Network 3</th>
<th>Network 4</th>
<th>Network 5</th>
<th>All</th>
</tr>
</thead>
<tbody>
<tr>
<td>NSI</td>
<td></td>
<td>0.763</td>
<td>0.579</td>
<td>0.220</td>
<td>0.821</td>
<td>0.408</td>
<td>0.560</td>
</tr>
<tr>
<td>CL</td>
<td></td>
<td>0.747</td>
<td>0.602</td>
<td>0.043</td>
<td>0.821</td>
<td>0.408</td>
<td>0.504</td>
</tr>
<tr>
<td>WDC</td>
<td></td>
<td>0.068</td>
<td>0.020</td>
<td>0.083</td>
<td>0.302</td>
<td>−0.212</td>
<td>−0.349</td>
</tr>
<tr>
<td>Citations</td>
<td></td>
<td>0.339</td>
<td>0.113</td>
<td>0.406</td>
<td>−0.327</td>
<td>−0.307</td>
<td>0.421</td>
</tr>
</tbody>
</table>

Abbreviations: WDC, weighted direct citation; CL, combined linkage; citations, number of citations to citing papers; SM, similarity measure; PR, peer ranking; \(P\), \(P\)-value.
Fig. 2. The plots of rankings according to the NSI values and peer review grades with correlations values and confidence intervals (based on Appendices A–E).

5. Discussion

Citation analysis aims at obtaining indications of the history of scholarly documents and determining which contributions are valuable and enduring to scholarly knowledge (Margolis, 1967). At present, in the computational resources for article citation analysis such as Scopus, Web of Science, and HubMed, citations are unweighted, which means that all citations are given equal weight (Eaton, 2006; Falagas, 2008). However, in practice, for a given highly cited article, citations from all publications are not equally credible, and one might be interested in considering and following the more relevant ones. In this study, for each citation to the target article, NSI was computed according to the number of indirect citation linkages and references shared by source article. We provided several examples to illustrate how the citations that are the most relevant to the target article may be specified by NSI. The results showed a significant correlation between the normalized similarity scores and those given in the peer review for the relevancy between source and target articles. We then compared the efficiency of ranking through different similarity measures. According to the results, NSI and CL ranking were correlated with peer ranking in many networks with close values, indicating that these measures captured similar concepts. Whereas, WDC and citations to citing papers were not suitable for predicting peer ranking, and even, their correlation in some cases were negative. These results are promising for application of NSI to discriminate between the citations of highly cited papers and extracting main knowledge flow path from citation networks. For extracting the main knowledge flow path from the citation network, the search can start from the target node, and at each step, select citation with highest NSI weight, until newest article is reached (Lucio-Arias & Leydesdorff, 2008). Finally, NSI and other similar studies are examples for the application of weighted direct citation as an alternative to the direct citation approach that has dominated so far.
Table 3
The first three most relevant citing articles according to the peer review’s grades, NSI, CL, number of citations to citing papers, and WDC (Networks 1–5 are based on Appendices A–E, respectively).

<table>
<thead>
<tr>
<th>Network of citations</th>
<th>Title of citing article</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Peer review’s grades</td>
</tr>
<tr>
<td>Network 1</td>
<td>Rewirings based on the Eigenvectors of the Laplacian matrix for enhancing synchronizability of dynamical networks</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Building synchronizable and robust network</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Enhancing synchronizability of weighted dynamical networks using betweenness centrality</td>
<td>3</td>
</tr>
<tr>
<td>Network 2</td>
<td>Changes in intracellular calcium in brain cells of aged rats</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Impaired calcium homeostasis in aged hippocampal neurons</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td>Impaired mitochondrial bioenergetics determines glutamate-induced delayed calcium deregulation in neurons</td>
<td>2.5</td>
</tr>
<tr>
<td>Network 3</td>
<td>Constructing brain functional networks from EEG: partial and unpartial correlation</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td>Psychogenic seizures and frontal disconnection: EEG synchronization study</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td>Topography of EEG multivariate phase synchronization in early Alzheimer’s disease</td>
<td>2.5</td>
</tr>
<tr>
<td>Network 4</td>
<td>Dissection of barley chromosome 3H in common wheat and a comparison of 3H physical and genetic maps</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td>Dissection of barley chromosome 4H in common wheat by the gametocidal system and cytological mapping of chromosome 4H with EST markers</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td>Cytological dissection and molecular characterization of chromosome 1R derived from ‘Burgas 2’ common wheat</td>
<td>2.5</td>
</tr>
<tr>
<td>Network 5</td>
<td>Adenoviruses associated with acute gastroenteritis in hospitalized and community children up to 5 years old in Rio de Janeiro and Salvador, Brazil</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Detection of Rotavirus and Enteric Adenovirus antigens in outpatients with gastroenteritis</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Circulation of a novel pattern of infections by enteric adenovirus serotype 41 among children below 5 years of age in Kolkata, India</td>
<td>3</td>
</tr>
</tbody>
</table>

Abbreviations. WDC, weighted direct citation; CL, combined linkage; citations, number of citations to citing papers.

6. Conclusions

For a given highly cited article, one may be interested to consider and follow the more relevant citations. In this study, we proposed a measure (NSI) as a grade for the relevancy between target and source of citation. The weighted citations given by NSI allow us to choose most relevance citing articles for next steps of study. NSI is therefore a complementary method to citation analysis, which allows us to identify most relevant articles citing to highly cited articles. Nowadays, we have the comprehensive computational resources for citation analysis, and implementation of NSI can be performed on these scientific literature collections.

Acknowledgments

The authors are thankful to Maria G. Knyazeva (Centre Hospitalier Universitaire Vaudois, Lausanne, Switzerland), Mohsin Raza (Department of Physiology, School of Medical Sciences, Tarbiat Modares University, Tehran, Iran), and Parviz Owlia (Department of Microbiology, Faculty of Medicine, Shahed University, Tehran, Iran) for their help in grading the citations to their selected articles. We would like to thank all three anonymous reviewers of this manuscript for their very constructive comments, which made this article more informative and easy to understand.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.joi.2012.08.006.
References


