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Review

Can plant-pollinator network metrics indicate environmental quality?

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ABSTRACT

Plant-pollinator interaction networks may be more informative than the diversity of species in the evaluation of the effects of environmental change. Considering that networks vary with the integrity of ecosystems, their changes may help to predict the consequences of anthropogenic impacts on biodiversity and ecological processes. This characteristic highlights its use as environmental quality indicator. However, to employ interaction networks as ecological indicators it is necessary to identify the most sensitive metrics and understand how and why they vary with environmental changes. This review aimed to identify, in empirical studies, which network metrics have been evidenced as being more sensitive to changes in environmental quality. We analyzed published empirical studies, that applied the network approach on environmental quality gradients. In addition to the network metric behavior, we studied the interactions between them and possible causes of their variation. The available empirical data indicated that degree, nestedness and connectance did not have a simple, linear or unidirectional response to habitat degradation. Conversely, the metrics interaction asymmetry, d' (reciprocal specialization index of the species) showed the most consistent responses to environmental change. The role of the species changed, ranging between generalists and specialists under different conditions. In addition, specialist species with morphological and behavioral constraints were lost in worse environmental quality situations. The identity of interacting species and their role in the network, with a further specification of groups and interactions most affected, are the properties with greater potential to indicate changes in environmental quality. Most of the available studies focused on metrics at the network level, but several studies and this review indicate that the patterns at the network level can be better understood in the light of metrics analyzed at the species level. Our results provide information that enrich the network analysis, highlighting the need to consider important features that are often neglected. Discussions and information compiled here are important for deciding how to look at empirical data and what to look for, as well as to indicate some caveats when interpreting data on plant-pollinator interactions with a complex network approach. Network metrics can be good indicators of environmental quality if the underlying ecological causes of the numerical changes are carefully analyzed.

Contents

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1. Introduction

Complex network approaches on plant-pollinator interactions encompasses the characteristics of species, their interactions, and the evolutionary processes generating the complexity of ecological relationships (Bascompte, 2007). Therefore, plant-pollinator interaction networks may be more informative than species diversity in the evaluation of environmental change effects. The conservation of these interactions may be more important for maintaining biodiversity and ecological services than preservation of species that are isolated in degraded environments (Forup and Memmott, 2005; Aizen et al., 2012). Considering that networks vary with the integrity of ecosystems (Montoya, 2008; Ferreira et al., 2013; Weiner et al., 2014), their changes may help to predict the consequences of anthropogenic impacts on biodiversity and ecological processes (Weiner et al., 2014). For instance, it is expected that networks will be simplified even before the local extinction of pollinator species (Aizen et al., 2012) suggesting their potential as environmental quality indicators.

Ecological indicators are selected by their functional relevance, ease of quantification and predictability (Heink and Kowarik, 2010). They enable the identification of changes in complex ecosystem processes in a simple, fast, reliable and early way (Dale and Beyeler, 2002). However, there are several challenges to overcome in order to employ interaction networks as ecological indicators to predict anthropogenic impacts. An important task is identifying the most sensitive metrics and understanding how and why they vary with environmental changes. Metrics such as nestedness and connectance are expected to indicate redundancy in the network interactions (Tylianakis et al., 2010). So that an increase in nestedness values, for example, could be interpreted as a good trend because it would increase assembly resilience (Tylianakis et al., 2010) as the asymmetry typical of nested networks would prevent cascade extinctions. However, nestedness increases could also result in network simplification by losing specialist–specialist interactions and/or increasing the proportion of super generalist interactions, and forming a cohesive, resilient, yet smaller, network. In a similar way metrics that are expected to indicate redundancy in the network interactions such as nestedness and Connectance (Tylianakis et al., 2010) could be better understood, if analyzed in conjunction with metrics that indicate complementarity of interactions such as H_2' and d′ (Blüthgen et al., 2006)

The definition of conservation goals is another important topic which should be defined to support both the choice and the interpretation of network metrics. Conservation of the basic features of ecosystem functioning may not guarantee the conservation of native species diversity, and vice versa. Metrics that assess network stability and resilience, but disregard species composition, would not suffice if the goal is to conserve biodiversity. Therefore, understanding of what changes in the metrics indicate about biodiversity and ecological processes is important for their application in accordance with the conservation goals. This knowledge is also required to identify the desirable characteristics of a plant-pollinator network.

Empirical studies that investigate changes in plant-pollinator interaction networks under different conditions of environmental quality may bring with them important evidence regarding the application of interaction networks as ecological indicators. Such knowledge is essential for identifying which metrics should be analyzed under different environmental impacts and different conservation goals. This review aims to identify in empirical studies, which network metrics have been evidenced as being more sensitive to changes in environmental quality. We expect to identify candidate metrics that could be employed as indicators of network changes, with applications for biodiversity and ecological processes conservation.

2. Methods

We analyzed papers published up to December of 2016 that used plant-pollinator interaction network approaches on empirical data from gradients of environmental quality, impact or degradation. We searched on Web of Knowledge, Scielo and CAPES journal databases. The search was made with combinations of the key-words “environmental degradation”; “habitat loss”; “habitat fragmentation”; “interaction”; “mutualistic network”; “network”; “plant”; and “pollinator”. Papers supplementary material was also analyzed.

Metrics present in at least three of reviewed studies were selected. The metrics were classified as metrics based on unweighted links, which considered only the presence and absence of interactions, and metrics based on weighted links, which considered the frequency of interactions.

The behavior of each metrics along the studied gradients was analyzed to assess their suitability as an indicator of negative environmental impacts on the network. For this, in addition to changes in the values of the metrics in response to different impacts and conditions, we also investigated the causes of variation and ecological significance such as the discussions and interactions with other metrics in each study.

3. Results and discussion

We found 18 papers (Table S1 in Supplementary material), in five categories of impacts or environmental conditions: plant species invasion (5 studies), land use intensity (6), habitat patch area (2), habitat restoration (4) and landscape degradation (2) (Fig. 1). One study was reported in two categories, because it analyzed two types of impact.

3.1. Network metrics

Nine network metrics were included in the analysis because they were calculated in at least three empirical studies (Table 1). Theoretically, metrics based on weighted links would be more accurate than those based on unweighted links (Ings et al., 2009). Weights based on interaction frequency precludes that rare and frequent interactions are considered as the same. However, few studies have directly addressed this question. Despite the theoret-