Estimating the impacts of browsers on forest understories using a modified index of community composition

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ABSTRACT

Increases in deer densities throughout temperate regions are negatively affecting forest conservation, but approaches for estimating these impacts are labour intensive and thus prohibitive for many managers. Plant indicators provide a rapid and cost-effective approach for measuring the impacts of disturbances on forest communities, and may inform managers both about the need for conservation actions to mitigate deer disturbance and their outcomes. The Floristic Quality Index (FQI) is one metric that assesses plant community composition by assigning coefficients of conservatism (C) to individual species based on their life history traits, including responses to disturbances. FQI should therefore reflect the community-level impacts of browsing as a disturbance, but little information exists on its use within forests or along browsing gradients. Here, we improved the classical measure of FQI by generating a new Floristic Quality Abundance Index (FQAI) that better captures plant community responses to disturbance. We then tested whether it reflects local densities of white-tailed deer (*Odocoileus virginianus*) and their impacts on forest understories using ground cover data from twelve sites across south-eastern Ontario, Canada. By excluding deer at five sites, we found that they preferentially removed plant species with lower C values, thereby explaining positive relationships between deer densities and FQAI across our sites. We propose that FQAI is an assessment tool that may improve the effectiveness of limited conservation resources for monitoring deer impacts.

1. Introduction

Increasing deer (Cervidae) populations across temperate regions have raised concerns about the negative effects of browsing on the biodiversity and functioning of forests (Russell et al., 2001; Côté et al., 2004; Gordon et al., 2004; Mysterud, 2006; Tanentzap and Coomes, 2012). Predator removal, increased forestry and agriculture activities, and milder winters are among the many factors that have elevated densities of deer and expanded their ranges across temperate regions (Rooney, 2001; Russell et al., 2001; Côté et al., 2004). Deer have also been introduced widely beyond their native ranges (Dolman and Wäber, 2008), leading to rapid population growth and establishment in new areas (e.g. Forsyth et al., 2010). High deer densities increase levels of browsing, consequently altering community composition by reducing species abundance (Tremblay et al., 2007), and lead to local extirpation of preferred forage species (Barrios-Garcia et al., 2011). Although many plant species decrease under heavy deer browsing, others may dominate. For example, high levels of browsing by white-tailed deer (*Odocoileus virginianus*) in forest understories of North America shift communities towards less-palatable grasses, sedges and ferns, which increase at the expense of palatable woody seedlings (Rooney, 2009). Once established, these less-palatable plants can form thick, dense swards that prevent future recruitment of woody species (Royo and Carson, 2006), and such changes may be difficult to reverse (Hidding et al., 2013). Reductions in preferred species associated with browsing can also facilitate invasions by non-native plant species that subsequently displace native species, resulting in an additional loss of native biodiversity (e.g. Baiser et al., 2008).

Conservation managers need approaches to measure the impacts of herbivore browsing on native forest biodiversity and evaluate the success of interventions aimed at mitigating increasing deer populations. Since limited resources prevent managers from monitoring all of the biodiversity within forests, the development of cost-effective indicators that track important features of biodiversity are essential for evaluating conservation performance (Dale and Beyeler, 2001). Ideally, these indicators should respond rapidly to environmental changes and be easy to monitor (Carignan and Villard, 2002). For example, the heights and abundances of some plant species are widely used for monitoring the effects of herbivores on conservation values, such as forest biomass and habitat quality for threatened species (Anderson, 1994; LaPaix et al., 2009; Koh et al., 2010; Mysterud et al., 2010). Despite this

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potential, most phyto-indicators lack broad applications because they are restricted to the range of the focal plant species. Popular phyto-indicators for measuring deer densities, such as *Trillium grandiflorum, Hyacinthoides non-scipta*, and *Chelone glabra*, (Anderson, 1994; Cooke, 1997; Williams et al., 2000; Koh et al., 2010), also do not directly indicate how plant communities and overall biodiversity respond to browsing. Herbivore browsing influences key components of forest composition, such as species presence and abundance, and vegetation structure (Alverson et al., 1988; Barrios-Garcia et al., 2011). Therefore, an indicator that measures how deer affect overall community composition is clearly needed.

The Floristic Quality Index (FQI) is used by managers to assess the vulnerability of plant communities to disturbance by measuring forest composition from the presence of plant species (Swink and Wilhelm, 1994; Oldham et al., 1995). It was developed to quantify the extent to which communities contain rare species and allow for objective comparisons among sites in order to prioritize conservation interventions (Cretini et al., 2012). FQI is calculated by assigning a coefficient of conservatism (C) to native plants ranging between zero and ten, based on both species' fidelity to a region and resilience to disturbance (Table 1), and then summing these values across a community (Landi and Chiarucci, 2010). Common plant species usually have lower C values and are more resilient to disturbance than rarer species with higher C values (Swink and Wilhelm, 1994; Oldham et al., 1995). Although species with high C values are not as resilient to disturbances such as browsing, they often have traits that enable them to resist damage (Rosenthal and Kotanen, 1994). For example, in North America, the fast growing and non-native clover (*Trifolium*) genus has C values of 0 and resists herbivory poorly, while most members of the native milkweed (*Asclepias*) genus, with C values greater than 8 (Oldham et al., 1995), are browsing-resistant and toxic to vertebrates (Majak, 1992). This evolution of resistance comes at a cost to plant fitness and growth in carbon-limited species (Coley et al., 1985; Simms and Rausher, 1987; Fineblum and Rausher, 1995), so may explain why herbivore-resistant plants with higher C values are less common and retain a high degree of site fidelity. Given their relative rarity and greater vulnerability to loss, higher C value species are often of greater concern for conservation (Francis et al., 2000).

Tracking shifts in FQI provides a more informative measure of forest composition than simply change in species richness or cover. This is because FQI is sensitive to changes in species identity, which other measures neglect, and so provides information on the species' resilience to disturbance and their relative rarity. For example, in eastern North America, the replacement of the native red mulberry (*Morus rubra*) with the non-native congeneric white mulberry (*Morus alba*) reduces C by 10 and lowers FQI. Although standard measures of biodiversity would simply report an exchange in species abundance, and no net species loss for this replacement, the change in FQI informs managers of the sensitivity of potential biodiversity loss. Red mulberry is more vulnerable than white mulberry to hybridization and has a smaller geographical distribution, thereby increasing its susceptibility to future extinction from disturbance (Burgess and Husband, 2006). More generally, in situations where two species have overlapping

ecological niches with different breadths, disturbances can selectively remove the more widely-distributed species that has a lower C value. However, niche differentiation may prevent the recruitment of the species with the narrower niche (higher C value) into the recently disturbed region, and so only the abundance of the widely-distributed species will change. Thus, increased levels of deer browsing may not increase abundances of high C species per se, but can reduce the local abundance and/or presence of species with lower C values. These changes will then be reflected by FQI.

FQI may allow managers to monitor the impacts of browsers on plant communities and determine whether conservation interventions are required, but its ability to do so has never been tested. Here, we tested whether FQI reflected local browsing impacts using data from twelve sites in Ontario, Canada, distributed over ∼175 km and along a gradient of white-tailed deer densities. Our approach builds upon the classical measure of FQI to derive a more integrated measure of forest composition, the Floristic Quality Abundance Index (hereafter FQAI), which also considers the local abundance of species and their spatial distributions. Additionally, we compared plant composition inside and outside of deer exclosures at five sites to test deer preferences for species with different C values. We predicted that higher deer densities would result in a higher FQAI because resilient plant species with lower C values are preferentially browsed and so become less-abundant in the local environment, while browse-resistant species with higher C values persist better. In contrast, disturbance-resilient species should remain abundant where deer densities are lower, maintaining a lower FQAI.

2. Materials and methods

2.1. Study sites

We studied twelve sites in the Great Lakes-St. Lawrence Forest region of south-eastern Ontario, Canada (Fig. A.1). These sites were: Camelot Island (CAM), Hill Island (HLL), Gordon Island (GOR), Grenadier Island (GRE), and Jones' Creek (JCR), all located in St. Lawrence Islands National Park, Murphy's Point Provincial Park (MPP), Charleston Lake Provincial Park (CPP), two private woodlots Bentlage (BEN) and Linton (LIN), lands of the Otonabee Region Conservation Authority (ORC), and two sites in Frontenac Provincial Park (FRN and FRS). Four of the sites: CPP, FRN, FRS, and MPP, contained 4–5 year-old deer exclosures that were 5 m × 5 m in size (Table A.1). By the time of our study, mean height of the palatable spring ephemeral *T. grandiflorum* had begun to respond positively to deer exclusion (Table A.2). Deer densities were available for all sites from a combination of phyto-indicators, aerial and ground-based deer counts, and hunter returns (Koh et al., 2010). No other large herbivores occurred at these sites.

All sites were mixed coniferous/deciduous forest embedded in an agricultural matrix (Table 2). Canopy tree species included *Acer saccharum, Fraxinus americana, Pinus strobus* and *Quercus alba*. Native herbs, such as the spring ephemerals *T. grandiflorum* and

Table 1
Criteria for the coefficients of conservatism (C) for southern Ontario, adapted from the Ontario Ministry of Natural Resources Oldham et al. (1995).

Range of C	Resilience to disturbance	Site fidelity
0–3	Present in disturbed sites	Widely distributed
4–6	Resilient to moderate disturbance	Specific plant communities
7–8	Resilient to minor disturbance	Site-specific but associated with mature communities
9–10	No resilience	Very narrow range of ecological conditions, found in advanced succession