RESEARCH

European Buckthorn (*Rhamnus cathartica*) and its Effects on Some Ecosystem Properties in an Urban Woodland

by Liam Heneghan, Carlton Rauschenberg, Farrah Fatemi and Margaret Workman

This research suggests that successful woodland restoration following buckthorn removal may require soil amelioration.

The proliferation of invasive species and their effects on local diversity has emerged as a priority issue in ecological conservation (Mooney and Hobbs 2000). Although the majority of invasive species remain minor components of the invaded assemblages, some species become dominant members and may, as a consequence, substantially modify both the composition and the function of ecosystems (Williamson 1996). Researchers have paid increasing attention to the potential of invasive species to alter aspects of ecosystem function (D'Antonio and Vitousek 1992, Lodge 1993, Williamson 1996), but only recently have quantitative data been available about the indirect effects of these species (Vitousek and others 1996, Ehrenfeld and Scott 2001, Heneghan and others 2002). Nonetheless, information about alterations to ecosystem processes is particularly useful when restoring the site following removal of the invasives.

European buckthorn is native to Eurasia and North Africa (Godwin 1943). It was introduced to North America in the late 1880s as an ornamental shrub and has become naturalized throughout much of the northeastern United States, the Great Plains, and throughout Canada. In Illinois, European buckthorn is widespread in the northern half of the state, and dominates many oak woodlands in the vicinity of Chicago (McPherson and others 1994). Surveys of European buckthorn populations reveal that it dominates the understory of some red oak (*Quercus rubra*) forests and can decimate populations of native herbaceous plants (Gourley and Howell 1984, Boudreau and Willson 1992).

Despite concern about the effects of European buckthorn on native flora, little is known about how it influences the soil processes in these woodlands. We do know that buckthorn produces considerable amounts of organic matter, mainly in the form of leaves and coarse woody debris. Buckthorn litter, with its high nitrogen (N) content (2.2 percent), decomposes faster than the litter of the dominant trees in an Illinois woodland (Heneghan and others 2002). If rates of decomposition are high, as these observations show, European buckthorn may enrich soils with rapidly mineralized nutrients. Moreover, since modification of site fertility is one of the fundamental drivers of plant community organization (Tilman 1988), a legacy effect of European buckthorn in the soil may have a dramatic effect on restoration sites cleared of buckthorn.

In this paper, we report on a study we conducted to characterize the effects on soil functions of rapidly decomposing,

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high N buckthorn litter. To do so, we examined the following characteristics: soil moisture, soil pH, forest floor litter accumulation in the summer and fall; carbon and nitrogen content of the organic horizon of the soil- and plant-available nitrogen; and soil microbial activity.

Methods

Study areas

Our study areas were located in Mary Mix McDonald Woods—a 100-acre (40-ha) site composed of a variety of different community types near Chicago. The upland forest at McDonald Woods is dominated by white oak (*Quercus alba*) with red oak and sugar maple (*Acer saccharum*) as sub-dominants. White oak dominates the dry-mesic woodland with red oak and ash (*Fraxinus* spp.) as sub-dominants. Red oak dominates the mesic woodland with white oak and sugar maple being sub-dominants. All sites have a degraded herbaceous flora. The lack of vegetation in the herbaceous layer appears to be due to a combination of fire suppression, dense shading from invasive woody species, a history of domestic livestock grazing, and an overabundant white-tailed deer population. European buckthorn is very common in highly degraded areas.

Measurement of Soil Properties

On September 29, 2001, we collected 15 soil samples from beneath well-established buckthorn shrubs and 15 soil samples from relatively buckthorn-free areas (designated for the purposes of this study as "open"), all within McDonald Woods. We measured the water content of the soil gravimetrically by drying a 100 g sample at 105° C to a constant dry weight (Jarrell and others 1999). We measured the soil pH in a soil slurry (30 mL deionized water in 15 g of fresh soil) using an IQ Scientific Instrument pH probe. Carbon and nitrogen content of the soil samples were measured using a Fison's CNS analyzer.

On September 23, 2002, we repeated the soil sampling using the same collection design. The soil was analyzed for available nitrogen ammonium-N (NH_4-N) using an ammonium cynaurate/ammonium salicylate method (Hach Company 1996-2000), and for nitrate-N (NO_3-N) concentrations using a cadmium reduction method (Reardon and others 1966).

Forest Floor Dynamics

To characterize the rates at which organic matter decomposes in areas under buckthorn and open areas in the woodland, we collected forest floor material in late September and early December 2001 within 30 0.1-m² quadrats (15 in buckthorn dominated plots and 15 in more open areas of the woodland). The forest floor material was air-dried and separated into leaf and coarse woody debris. Then we weighed each of the two components separately. Differences between buckthorn and open areas were analyzed using t-tests.

Microbial Communities

Using Ecolog plates (Biolog, Inc.), we investigated the level of microbial activity in the soil substrate. Ecoplates contain 31 common carbon substrates in three sets of replicated wells along the plate. The technique allows for a fairly rapid evaluation of microbial community functioning. Samples were prepared by adding 50 mL deionized water to 10 g of soil. These preparations were agitated for ten minutes on a reciprocal shaker and centrifuged for ten minutes. We next plated 150 µl of supernatant into each ecoplate's well. If the substrate is degraded it turns color, and the optical density may be read on a microbial plate reader at 590 nm. In all, we prepared 15 samples from buckthorn-dominated areas and 15 samples from open areas. After 48 hours we read the plates on a Biolog microstation (plate reader). The average well color development was then analyzed for differences using paired t-tests for each substrate. The data were also analyzed in a similarity matrix (Pearson's Coefficient) and plotted as a dendrogram (using the Multivariate Statistical program MVSP).

Statistical design

Buckthorn patches at McDonald Woods tend to be large in size but few in number. The nature of this clumped distribution posed some statistical difficulties. We took several measures to account for this distribution pattern. First, each sample we collected was at least 1 meter away from all other samples. Second, we chose to assume that samples were independent

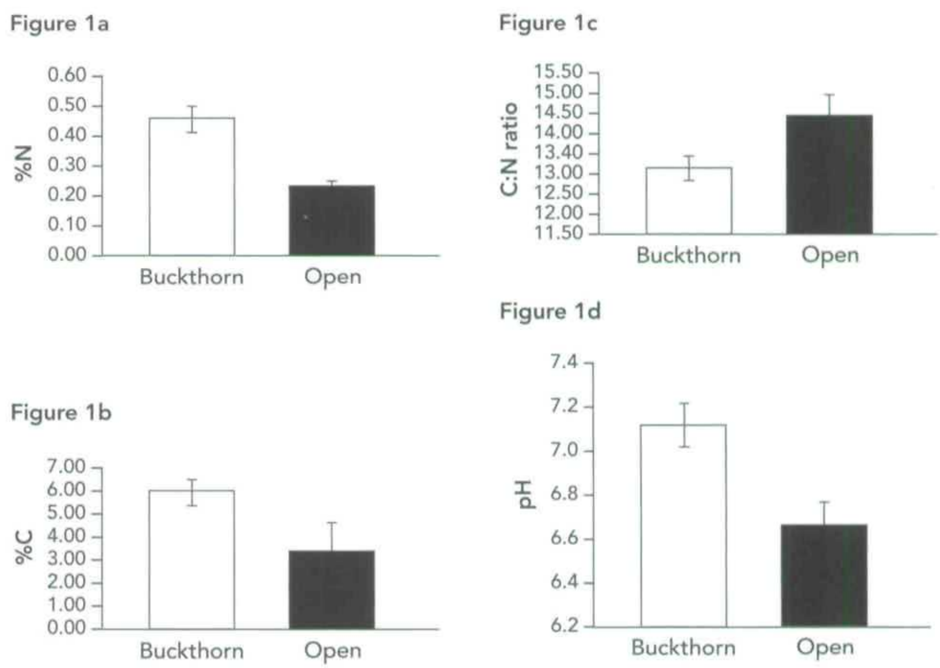

Figure 1. Soil properties (mean ± S.E.) under buckthorn and in buckthorn-free ("open") areas of McDonald Woods. a) percent Nitrogen , b) percent Carbon, c) C:N ratio, d) soil pH.

estimates of the measured characteristics, positing therefore that an individual plant and the local soil were largely functionally independent of one another. A more conservative approach would be to consider individual patches as a sampling unit and consequently sacrifice the variation among replicates within patches. However, this conservative approach would greatly restrict the power of the analysis and increase the likelihood of making a Type II error.

Results

Soil properties

We found dramatic differences in soils taken from under buckthorn trees compared to samples from more open areas. The gravimetric water content in buckthorn plots (mean 0.54 g) was 59 percent higher than in open areas (mean 0.34 g) (t-value 4.1, d.f. 19.2, $p < 0.001$) from samples taken in September 2001. There was also twice the amount of nitrogen in soils under buckthorn than in open areas of the woodland (Figure 1a, t-value 5.07, d.f. 17.8, $p < 0.001$). Total carbon increased under buckthorn by 78 percent compared with open areas (Figure 1b, t-value 4.37, d.f. 28, $p < 0.001$), while the carbon:nitrogen ratio of the soil was lower in buckthorn plots by 9 percent, (Figure 1c, t-value 2.06, d.f. 20.6, $p = 0.05$). The pH was significantly higher under buckthorn than in adjacent open areas (Figure 1d, t-value, d.f. 21.6 2.46, $p < 0.02$).

In September 2002, there was lower NH_4-N availability in soil samples taken under buckthorn (mean 0.69 mg/L) compared to open areas (0.86 mg/L) (Figure 2, t-value 2.27, d.f. 20, $p = 0.02$). Nitrate levels did not differ. Total N (NH_4-N + NO_3-N) was also significantly greater in open areas than under buckthorn (Figure 2, t-value 1.94, d.f. 21, $p = 0.03$).

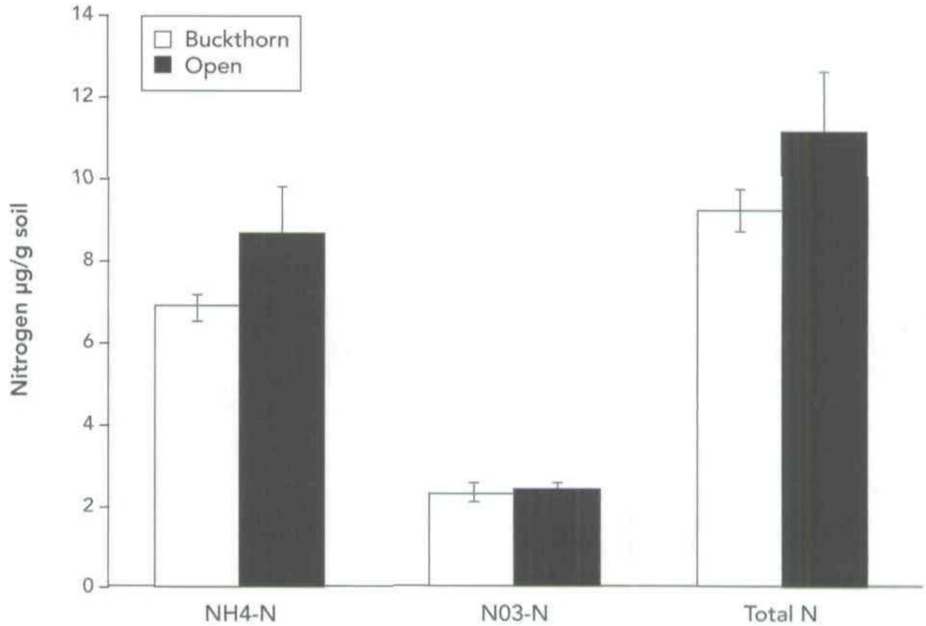

Figure 2. Nitrogen availability (mean ± S.E.) under buckthorn and in buckthorn-free ("open") areas of McDonald Woods. Total N is calculated as NH_4-N plus NO_3-N.

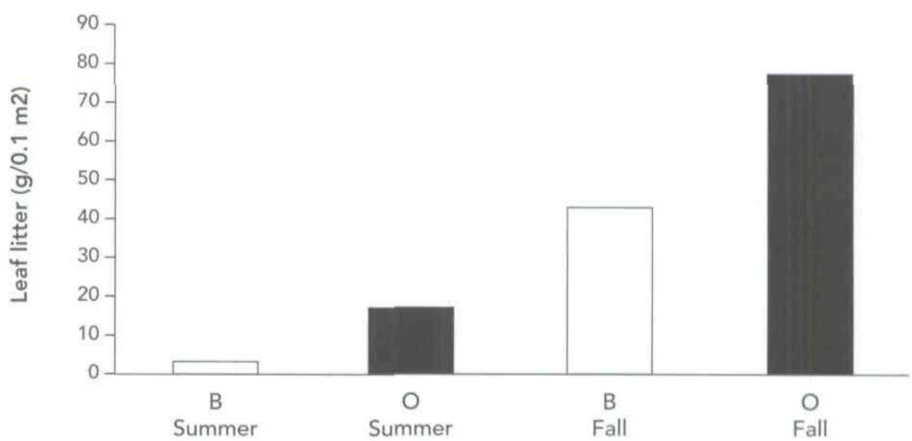

Figure 3. Leaf litter accumulation under buckthorn and in buckthorn-free ("open") areas of McDonald Woods in summer and fall samples.

Forest floor dynamics

In late summer of 2001, we found that there was more than six times more litter in open areas than under buckthorn (t-value 3.19, d.f. 13.2, $p < 0.01$). Coarse woody debris was similar in both areas. In the late autumn of that year, the total amount of litter increased six-fold in all plots (t-value 6.62, d.f. 10, $p < 0.001$). Coarse woody debris mass remained relatively constant between seasons. Differences in litter mass between open and buckthorn areas persisted (t-value 4.27, d.f. 28, $p < 0.001$) though the differences were only two-fold (Figure 3).

Microbial Communities

Differences in substrate use by microbial communities under buckthorn and open areas was greater and differed significantly for 14 of the 31 ecoplates substrate we analyzed (Table 1). When the results of this analysis are presented in a percent similarity matrix, they reveal that overall responses correlated very strongly with plant cover (Figure 4). That is, in the manner in which carbon substrates were degraded, the similarity between samples taken from under buckthorn were greater than their similarity to samples taken from open areas.

Table 1. **Substrates on Ecolog plates where significant differences were found between samples extracted from buckthorn plots and open plots.**

	Substrate	Chemical composition
Utilization higher in buckthorn samples		
1	ß-Methyl-D-glycoside	Carbohydrate with non-carbohydrate residue
2	*2-hydroxy benzoic acid*	*Carboxylic acid (salicylic acid)*
3	α-Cyclodextrin	Carbohydrate
4	N-Acetyl-D-Glucosamine	Amino sugar
5	Glycogen	Carbohydrate
6	D-cellobiose	Carbohydrate
7	Phenylethylamine	Amine
Utilization lower in buckthorn samples		
8	L-Asparagine	Amino acid
9	Tween 40	Detergent
10	Phenylalanine	Amino acid
11	Tween 80	Detergent
12	L-Threonine	Amino acid
13	D-Glucosaminic Acid	Amino acid
14	D, L-αGlycerol Phosphate	Trihydric alcohol

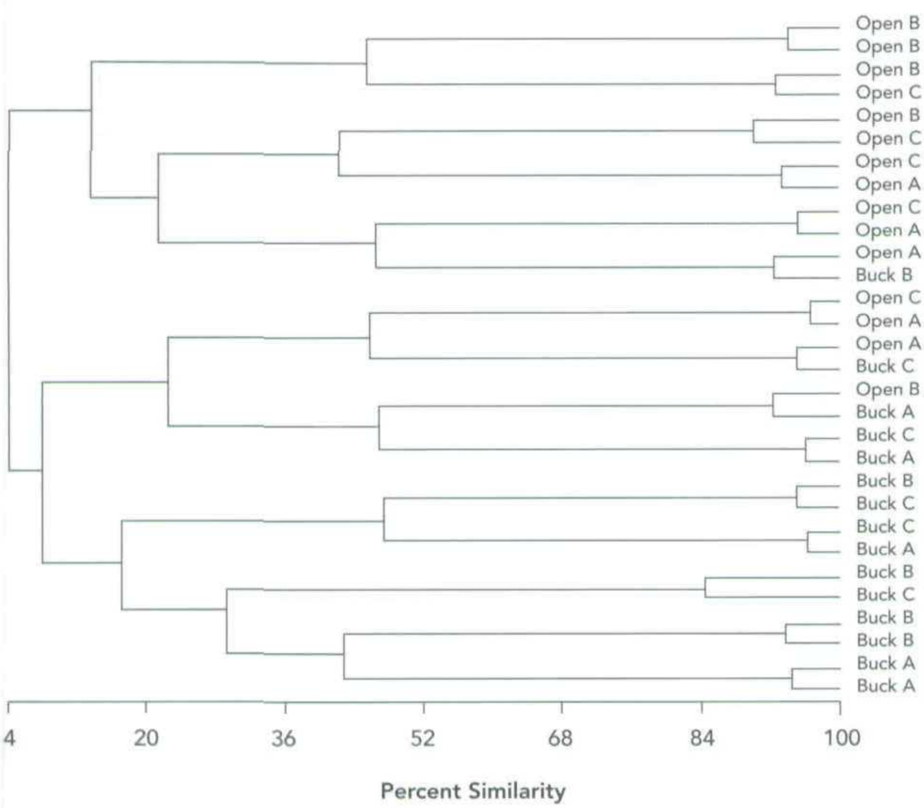

Figure 4. Dendrograph showing percent similarity in the average utilization of 31 carbon substrates by microbial communities isolated from 15 buckthorn-infested and 15 buckthorn-free ("open") areas in McDonald Woods.

Discussion

Removal of buckthorn and other woody shrub invasives is often a prelude to the ecological restoration of woodlands. It is important to consider the possibility that buckthorn infestations may impose a persistent effect on the soil through the modification of soil food webs and nutrient dynamics. If this is the case, the modified ecosystem properties may have implications for the success of subsequent restoration and management.

The results reported here demonstrate that buckthorn is associated with significant modification to a variety of ecosystem properties in an urban woodland. Previous observations that buckthorn litter, which is high in nitrogen, decomposes very rapidly (Heneghan and others 2002), led to two predictions: First, there would be an alteration in organic matter dynamics in areas of woodland dominated by buckthorn. Therefore, we would expect a greater reduction of the litter layer in those areas than in areas without buckthorn at the end of the growing season and before a redeposition of fresh litter in autumn. Second, the upper layers of soils beneath buckthorn trees would be enriched with nitrogen. This latter prediction is, however, a consequence of higher leaf N rather than the rapid decomposition rate.

In McDonald Woods we found these predictions confirmed. Differences between the accumulation of litter under buckthorn and open areas were significant in both autumn and in late summer. As expected, the differences were very much greater in late summer. This may be a reflection of differences in annual litter decomposition rates between the two areas, but other factors may contribute. Earthworm biomass appears to be greater in areas dominated by buckthorn (James Steffen unpublished data). Furthermore, dissimilarity between the two areas in litter biomass measured in December may reflect differences in leaf input to these areas. Dead organic matter inputs into the different areas have not been quantified for this site.

The water content of soil under buckthorn was greater than in adjacent areas.

This could be a result of lower evaporative loss under dense growth. Of course, this could be alternatively interpreted as being the result of buckthorn selectively growing in the wetter parts of the site.

Soil pH was higher under buckthorn. The hydrogen concentration of the soil can be reflective of various aspects of nitrogen cycling. Hydrogen concentrations can be elevated when nitrate is rapidly taken up by vegetation (Imas and others 1991). It is possible that nitrogen uptake is elevated under buckthorn, as was shown here, although differences were found for NH_4-N and not for NO_3-N. Alternatively, pH increases can also result for redistribution of soil cations (Finzi and others 1998). The likelihood of such redistribution has not been investigated here.

Total nitrogen and carbon, measured by combustion, were greater in soil under buckthorn. The elevation of total nitrogen is not necessarily in conflict with the lowered nitrogen availability in the buckthorn-influenced soil measured as KCl extractable NO_3-N. That is, a proportion (at least) of the nitrogen enrichment detected through combustion occurs in a form that is potentially available to plants. The lower KCl-extractable nitrogen in buckthorn-dominated areas suggests that in later months of the year continued physiological activity of buckthorn reduces availability, even though the total accumulation of nitrogen, not all of which is in a plant-available state, increases over the years. Alternatively, it is possible that mineralization may be suppressed under buckthorn. Some of the nitrogen enrichment evidenced by combustion may be a reflection of "new" nitrogen in the system. Two possibilities suggest themselves. First, buckthorn growth may result in more nitrogen being drawn from deeper in the soil and redistributed to the upper soil horizon. Alternatively, there may be greater nitrogen fixation under buckthorn plots. Neither of these possibilities has been explored, though there is considerable need to do so.

The elevation of nitrogen cycling in the soil can be expected to have implications for a variety of processes, including plant diversity and the growth of individual plants (Huston 1994).

Does the modification of nitrogen content have implications for soil biota? Results from the substrate utilization tests (using ecoplates) revealed clear differences when microbial communities isolated from under buckthorn are compared to those from more open areas. This may indicate that there has been either a shift in the community composition or an induced change in the types of substrates used. Since we have not characterized the species in the samples, we cannot decide between these two alternatives.

There are some clear limitations to extrapolating these findings to a landscape scale. We report here on a single woodland stand, though we have some data that appear to confirm the general observations for another nearby woodland (Heneghan, Fatemi and Fagen unpublished). More extensive multi-site studies are required. Our observations that buckthorn growth is associated with elevated nitrogen could be interpreted as either evidence for buckthorn having a preference for soil with high nitrogen or as buckthorn driving those changes in nitrogen over time, or that both occur. We think that there is evidence that the growth of buckthorn is driving some of the changes in soil properties. This conclusion is consistent with the hypothesis that a shrub with a rapid growth rate and profligate use of nitrogen will modify the fertility of soil. We stress that these observations should form the basis for an extensive experimental study.

The results reported here are strikingly similar to results reported by Ehrenfeld and her colleagues (2001) on the effects of Japanese barberry (*Berberis thunbergii*) on deciduous forests in the eastern part of the United States. They report that this shrub can form very dense thickets, has leaves that are high in nitrogen, and that these leaves rapidly decompose and resulted in modified nitrogen dynamics in soils of the invaded sites.

The objectives of this paper are primarily phenomenological, attempting to verify the existence of a pattern that we consider to have important implications for the potential success of costly and time-consuming management efforts. If the striking pattern that we provide evidence for is apparent at grander landscape scales, and can be experimentally induced, this may well direct restoration to an ecosystem approach that may have a greater probability of success.

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Liam Heneghan is an associate professor in the Environmental Science Program, 2325 North Clifton Avenue, DePaul University, Chicago, IL 60614; 773/325-2779, lhenegha@depaul.edu.

Carlton Rauchenberg is a research assistant in the Environmental Science Program, 2325 North Clifton Avenue, DePaul University, Chicago, IL 60614.

Farrah Fatemi is a research assistant in the Environmental Science Program, 2325 North Clifton Avenue, DePaul University, Chicago, IL 60614.

Margaret Workman is a Research Associate in the Environmental Science Program, 2325 North Clifton Avenue, DePaul University, Chicago, IL 60614.